연구논문

Effect of the Changes in Neighboring Building Layout onto Natural Ventilation Force in Buildings

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주변건물군의 변화가 건물 자연환기력에 미치는 영향에 관한 연구*

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Abstract

도시의 일상생활에서는 시가지의 바람이 나무, 집 등 낮은 건축물 군에 의해 방해되어 보통은 전원의 바람보다 풍속이 저감되는 경우가 많다. 이러한 기존의 바람 흐름이 있는 곳에 건축물이 세워지게 되면 기존의 풍환경은 크게 변화되어 풍속이 약한 곳과 강한 곳이 조성되어 이와 같은 바람이 지표부근의 구조물에 의해 받는 영향은 도시지역에서 강하게 나타나게 된다. 이는 교외나 시골지역은 상대적으로 도시지역에 비해 영향을 적게 받게 된다. 임의의 지역, 특히 도시지역의 경우 기존의 건물이 증축되거나 혹은 새로운 건물이 신축되면 이로 인하여 기존의 바람흐름이 달라지며 이는 인접건물들의 확보하고 있던 자연 환기력의 변화를 야기 시키는 원인이 되기도 한다. 이러한 현상은 건축물에 의해 자연 환기력이 바뀌게 되는 일종의 기존 환경으로 부터의 변화를 의미한다.

본 연구에서는 수치해석을 이용하여 이와 같이 건물의 주변 환경변화, 즉 신축, 증축 등과 같은 변화를 고려하여 그 영향을 예측/분석하였다. 그 결과로 건물의 자연환기력을 전면에서 바람에 의한 압력증가와 후면에서 바람의 흡입에 의한 압력감소로 인해 전면의 풍속에 의해 발생하는 동압보다 큰 압력차가 발생하고, 그로 인해 환기량이 발생하는 것을 알수 있다. 주변 변화에 의해서는 동일한 규모의 건물이 추가되는 경우에 기존의 경우에 비해 35~45%의 자연환기격이 감소되는 것으로 나타났다.

주요어 : Environmental dispute, ventilation obstruction, building layout, CFD modeling

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1. Introduction

The wind environment surrounding buildings is influenced by small-scale factors as well as large-scale factors including monsoon. When the concept of natural ventilation through building openings is adopted in design practice, the impact of external changes becomes significant (Kashiyama *et al*., 2008). These changes in wind environment can be formed by various reasons that could distort existing wind field. Recently the lawsuit cases related to the changes in wind environment are easily encountered in environmental disputes which require the clear definition of wind blockage and the evaluation method.

In this study, it is aimed to study the distortion of wind environment by the changes in building layout and to evaluate its impact onto the natural ventilation force in buildings concerned. Primarily the parameters affecting external wind field (i.e. natural ventilation) are find out and the wind field is numerically simulated based on the conditions. The variation in natural ventilation, caused by the change in building surroundings, is then analyzed to quantify.

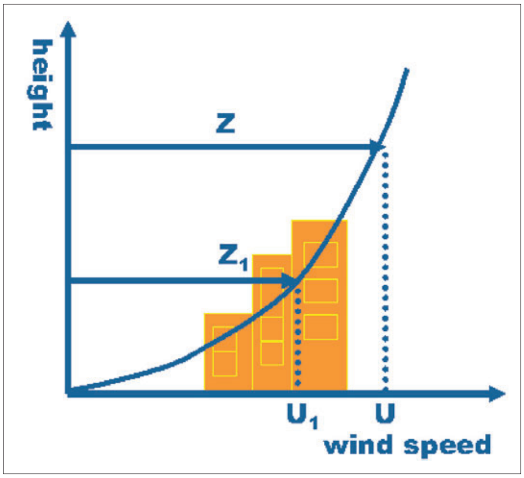


Figure 1. Vertical wind profile in the atmospheric boundary layer

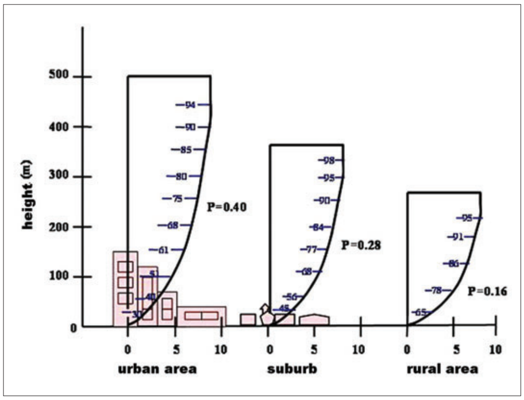


Figure 2. Vertical wind profiles under different surface conditions

2. Review of the Micro-Scale Wind

When wind blows near the ground level, it experiences the friction between airflow and ground surface and creates boundary layer of the atmosphere (Arya, 1999). It is called the atmospheric boundary layer and covers up to 1~2 km/high. As shown in Figure 1, the vertical profile of wind velocity in this boundary layer is expressed by the exponential formula in equation 1.

$$U = U_0 \left(\frac{Z}{Z_0} \right)^p \tag{1}$$

Where U is the wind velocity (m/s) at corresponding height Z (m) and U_0 is the wind velocity at the reference height Z_0 (=10m). p is the constant representing the roughness of the ground surface.

Figure 2 displays different vertical wind profiles due to various roughnesses of the ground conditions such as urban, suburb, or rural area. As shown, the constant p of urban area is bigger than other conditions, which indicates that the wind in urban area is further influenced by the ground condition than rural area. It is also strongly correlated to the dispersion of air pollution (Kato *et al*., 2009).

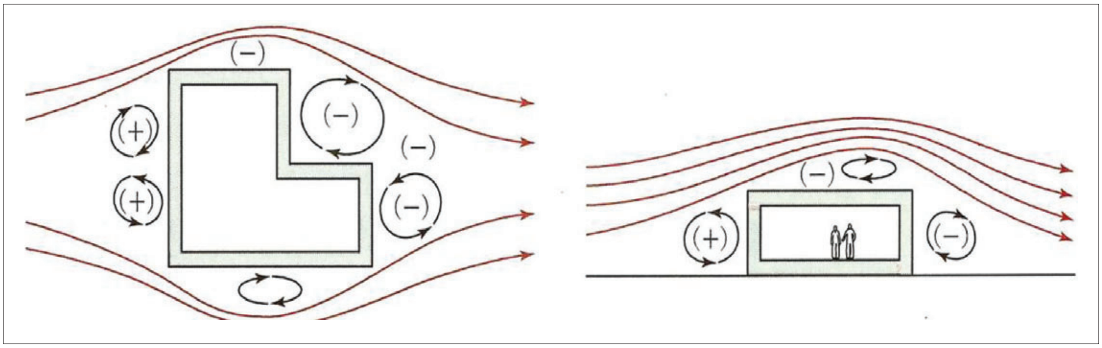


Figure 3. Pressure field around a building in wind field

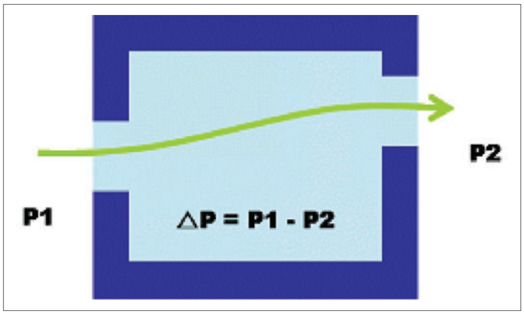


Figure 4. Air flow created by the pressure difference between leeward and windward sides

When wind flows around a building structure, the air flow field is blocked and distorted. Subsequently it creates a calm zone or vortex zone, which turns out into pressure difference. The relatively high pressure is formed on the front side of the building (i.e. leeward side) and the low pressure is formed on the back side of the building (i.e. windward side, as shown in Figure 3) (Park *et al*., 2005). When Figures 3 and 4 are combined, the indoor airflow generated by the pressure differences becomes higher than the external airflow.

$$\Delta P = P1 - P2 \qquad (2)$$

Where,
ΔP = differential wind pressure [Pa],
$P1$ = leeward side pressure [Pa],
$P2$= windward side pressure [Pa]

In the atmosphere, the atmospheric pressure consists of static pressure and dynamic pressure generated by the air movement. When a building is located in the middle of a wind field, it experiences pressure changes by the interaction between wind and buildings. On the leeward side of the building, the wind is blocked and generated a high pressure. On the windward side, a low pressure is generated. Subsequently the air flow through the building is created as shown in Figure 4. As depicted, the pressure difference (ΔP) is the driving force of natural ventilation in building practice. To evaluate the ventilation effect, equation 3 is introduced. Where, v is the wind velocity that can be derived from the dynamic pressure using equation 4.

$$Q = \alpha \cdot A \cdot v \qquad (3)$$

$$\Delta P = \frac{1}{2}\rho v^2 \qquad (4)$$

$$Q = \alpha \cdot A \cdot \frac{2 \cdot \Delta P}{\rho} \qquad (5)$$

Where,
Q : ventilation [m^3/s],
α : flow constant [0.65~0.7 for simple opening],
A : opening dimension [m^2],
v : wind velocity [m/s],
ΔP : wind pressure[Pa],
ρ : air density [1.3kg/m^3 at 25℃]

The airflow field near buildings is varied depending on building shapes, the interval between neighboring buildings, building density, etc. As shown in Figure 5, various types of air flows are observed such as vortex flow, corner stream, and through flow. Figure 6 depicts the air flows in crowded buildings. Consecutive buildings form a path for the wind field, e.g. street canyon, the variation of sections for wind flow is easily varied by building layouts, which produces venturi effect. It in turn creates the wind velocity change and causes uncomfortable conditions to the residence as well as pedestrians (Taseiko *et al*., 2009).

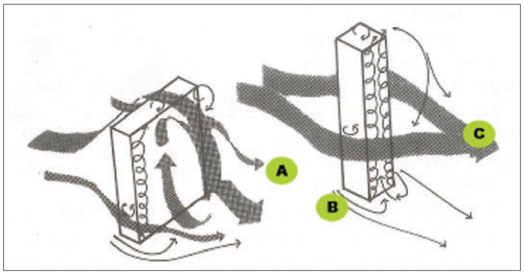


Figure 5. Wind flow pattern around low and high-rise (multi story) buildings

(A : Vortex flow, B : Corner stream, C : Through flow)

3. Numerical Modeling of Small-Scale Wind

In this study, the phenomenon of obstructed ventilation is evaluated. Initially a basic case including a single building is investigated to study the natural ventilation effect as the reference case for further study. Then the study cases are setup with an additional building construction as summarized in Table 2. Case 2 represents the case for new building construction next to an existing building. Cases 2 and 3 represent the cases for the crosswise and length wise building extension respectively.

In modeling analysis, a commercial CFD (computational fluid dynamics) code, named CFX (v.10, Ansys Inc.) is utilized and Table 1 summarizes the modeling conditions. A few steps are carried to construct CFD modeling domain and Figure 7 shows the modeling domain for CFD analysis. Both bottom sides were cut to simulate 45°-oriented winds and Figure 8 displays the mesh generated in CFD modeling. (The Case 2 for new building construction)

To define the boundary conditions, different

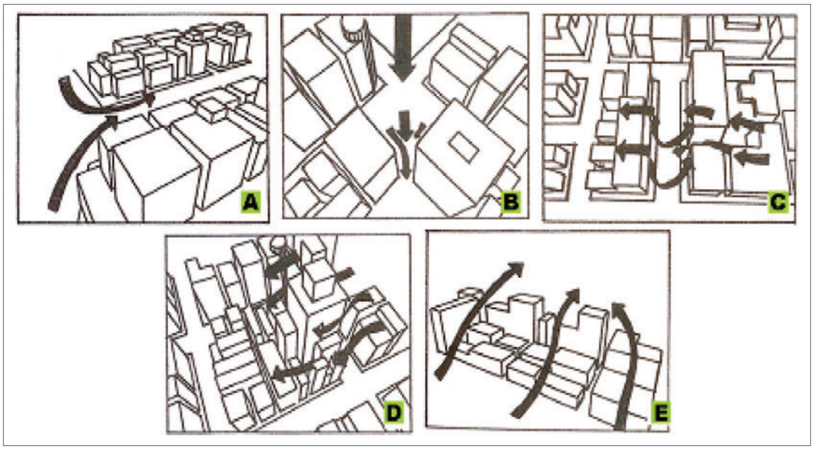
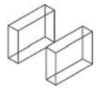
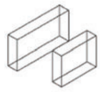
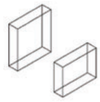


Figure 6. Wind flow pattern around congested buildings (A : Channel effect, B : Venturi effect, C : Pressure connection effect, D : Pyramid effect, E : Shelter effect)

Table 1. Test conditions for modeling

Variable	Conditions	Shape
Study Cases	CASE 1: Existing building - H: 35.5m, L: 46m, W: 12m	
	CASE 2: New construction - H: 35.5m, L: 46m, W: 12m - H: 35.5m, L: 46m, W: 12m	
	CASE 3: Crosswise extension - H: 35.5m, L: 68m, W: 12m - H: 35.5m, L: 46m, W: 12m	
	CASE 4: Lengthwise extension - H: 50m, L: 46m, W: 12m - H: 35.5m, L: 46m, W: 12m	

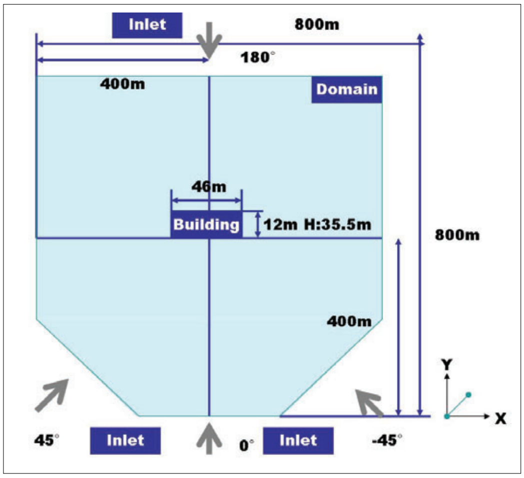


Figure 7. Domain for CFD modeling

types of boundary conditions are applied. Especially for the inlet boundary condition, equation (1) is used to express the vertical wind profile generated by the concerned ground roughness. The prototype of building tested in Case 1 has the dimension of 46m (H) × 12m (W) that is the common shape of 12-story apartment building in Korea. In Case 2 of new building construction, the same size of the building in Case 1 is added near the location. The distance between two buildings is equal to the height of the original building, which is based on Korean Building code.

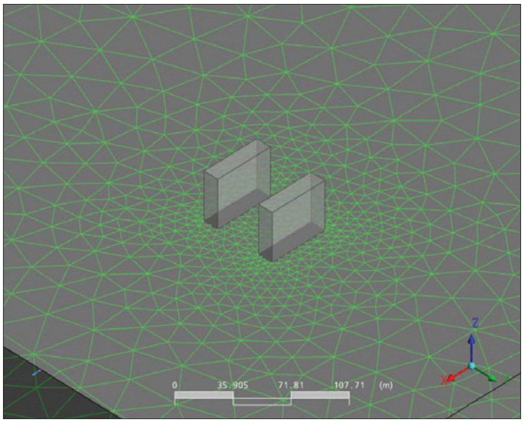


Figure 8. Mesh generation in CFD modeling

4. Results and Discussion

Figures 9 and 10 display the numerically simulated air flow and pressure fields respectively. As shown in Figure 9(a), the wind flow is blocked by the building and creates a vortex in the windward side of the building. On the leeward side of the building, the wind flow is blocked and creates the high pressure zone as shown in Figure 10(a). The low pressure force is also observed in the corner face in the Case 1 of Figure 9 (a).

When the same – size building is added, the air flow pattern in the windward of the original building has no significant difference. The air flow structure in the leeward side (i.e. the space

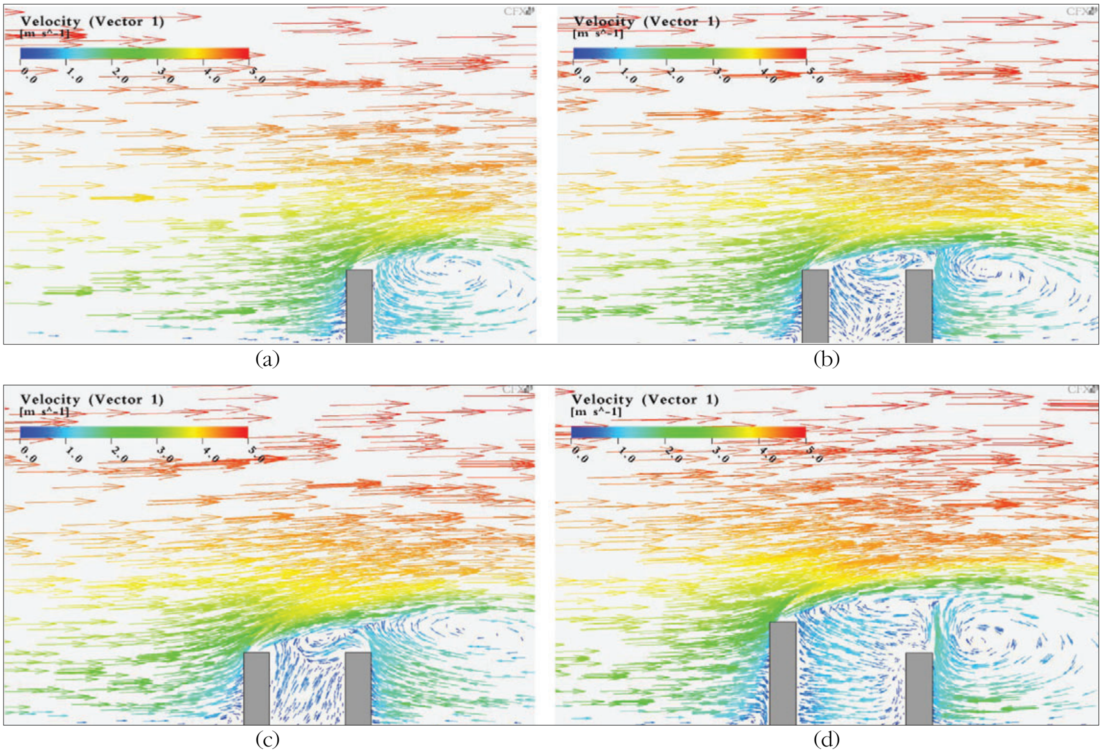


Figure 9. Wind flow patterns in section view (a: Existing building, b: New construction, c: Crosswise extension, d: Lengthwise extension)

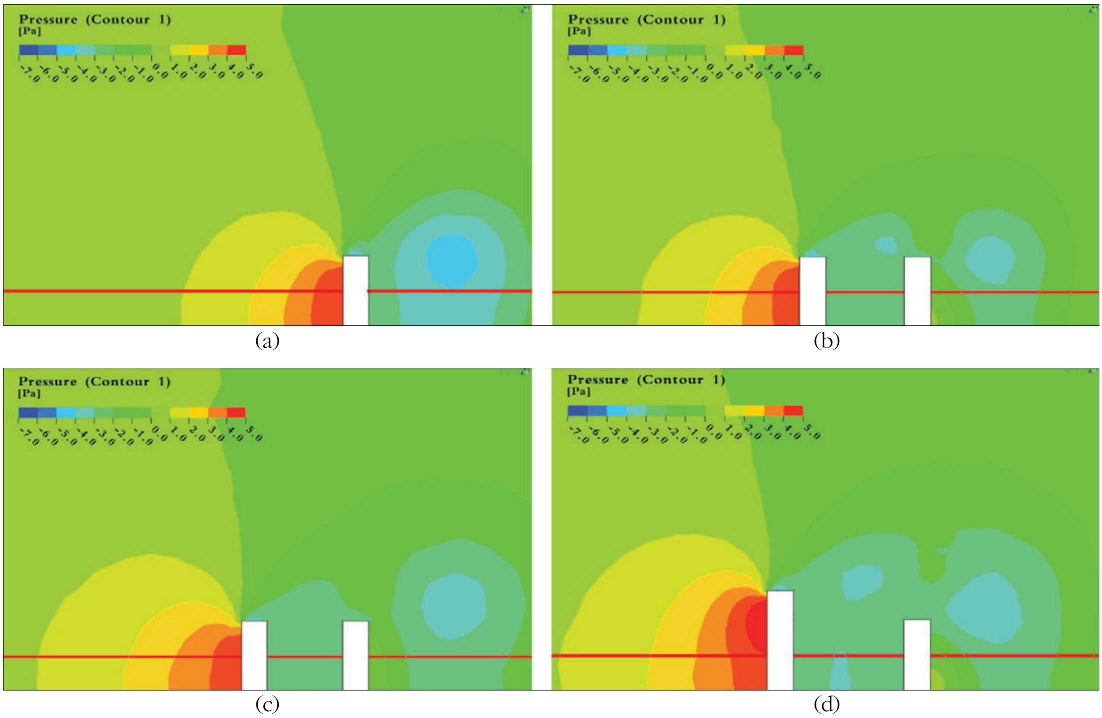


Figure 10. Pressure fields in section view (a: Existing building, b: New construction, c: Crosswise extension, d: Lengthwise extension)

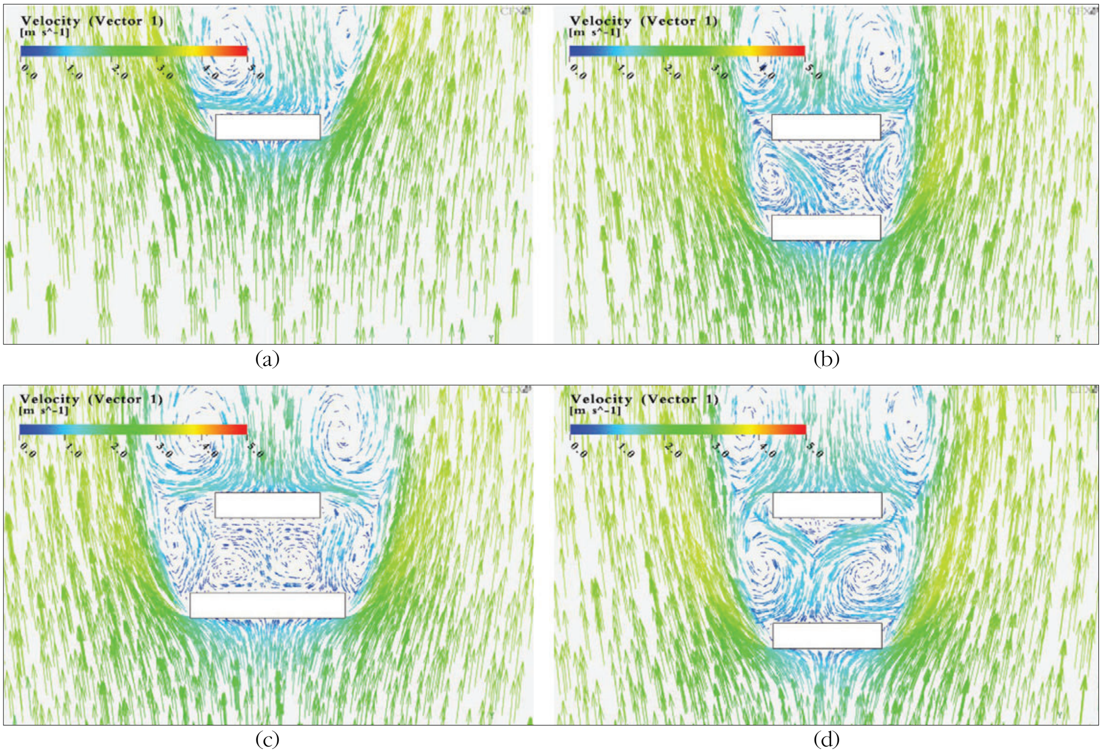


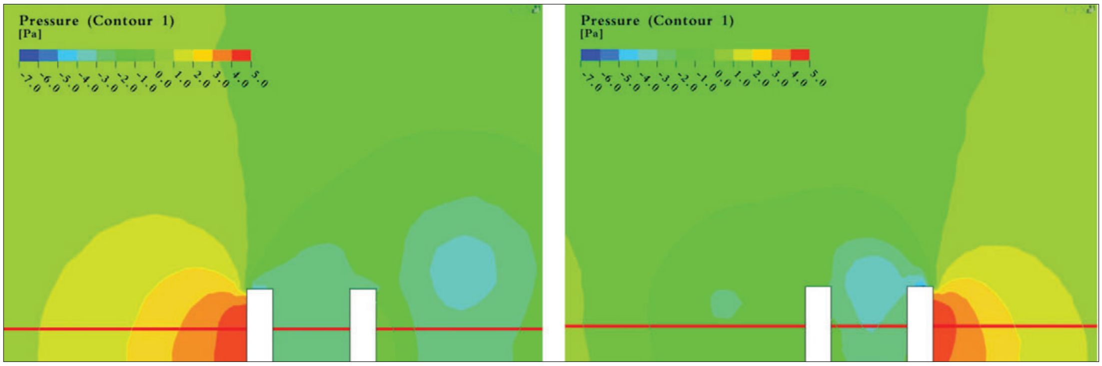
Figure 11. Wind flow patterns in plan view (a: Existing building, b: New construction, c: Crosswise extension, d: Lengthwise extension)

between the two building), however, has completely different air flow pattern. It produces the remarkable difference in the leeward side of the building, which causes the variation of the driving force of natural ventilation ultimately. The Case 3 for crosswise extension, however, does not produce a noticeable change in the air flow pattern. The case of lengthwise extension creates even bigger vortex force in the windward of the extended building.

Figure 11 shows the wind flow fields in the plan view. As described previously, the case for new building construction in the subplot (b) creates another vortex between two buildings, which reshuffles the air flow pattern in the leeward side of the original building (see Figure 11(a)). While the lengthwise extension in the subplot (d) has a big change compared to the Case 2, the crosswise extension create even wider vortex region in the windward side of the extended building.

Furthermore, the opposite wind direction was tested and visualized in Figure 12. As displayed, the pressure gradient around the original building is completely changed to produce adverse effect on the ventilation effect. Table 2 summarizes the pressure gradients monitored in CFD modeling. It is found that the change in neighboring buildings reduces the pressure gradient in the original building and appears in the variation of natural vortex. For the wind direction, the perpendicular wind to the building has more impacts compared to 45° oriented winds.

To evaluate the change in the driving force of natural ventilation, the estimated air velocity from the pressure gradient in Table 2 is convert-



(a) (b)

Figure 12. Wind effect on the case of new construction by opposite wind direction (a: Left-hand-side wind, b: Right-hand-side wind, Note: The original building is located in the right-hand-side.)

Table 2. Summary of pressure distribution in CFD modeling and estimated velocity

CASE		45°	0°	-45°
Existing building [CASE 1]	P1	2.6	4.8	2.6
	P2	-3.2	-2.3	-3.2
	△P	5.8	7.1	5.8
	v[m/s]	3.57	3.95	3.57
New construction [CASE 2]	P1	-1	0.5	-1
	P2	-3.5	-2.5	-3.4
	△P	2.5	3	2.4
	v[m/s]	2.34	2.57	2.3
Crosswise extension [CASE 3]	P1	-2.3	-0.4	-2.4
	P2	-4.2	-2.5	-4.3
	△P	1.9	2.1	1.9
	v[m/s]	2.04	2.15	2.04
Lengthwise extension [CASE 4]	P1	0.2	0.4	0
	P2	-2.9	-2.5	3
	△P	3.1	2.9	3
	v[m/s]	2.61	2.52	2.57

ed into air flow after applying the unit ($1m^2$) of opening area as the reference. Then the effect of building change is assessed by equation (6). As summarized for the case of the perpendicular wind, after adding the new building construction the driving force of natural ventilation in the original building was reduced by 45%. And the 45° skewed wind has less reduction by approximately 35%.

Table 3. Summary of estimated ventilation rate for the $1m^2$ opening assumed (for the perpendicular wind)

	Case 1	Case 2	Case 3	Case 4
P leeward [Pa]	4.8	0.5	-0.4	0.4
P windward [Pa]	-2.3	-2.5	-2.5	-2.5
l△Pl	7.1	3	2.1	2.9
Q [m^3/s]	3.95	2.57	2.15	2.52
	-	34.93(%)	45.57(%)	36.2(%)

Note:

$$\varepsilon = \frac{Q_{case1} - Q_{case2,3,4}}{Q_{case1}} \times 100[\%] \qquad (6)$$

5. Conclusion

As described, the external wind environment has influence on to the internal air flow inside concerned buildings. Several test conditions are made and numerically simulated to investigate the degree of influence.

Some typical cases of building changes are subjected with the application of CFD simulation. It is also confirmed that a single building in a wind field experiences pressure gradients which are the driving force of natural ventilation in some cases. By the new building construction, the natural ventilation force of the original building is reduced by 35~45% depending on wind condition. Finally, the evaluation procedure in this study has a potential to assess the changes in the driving force of natural ventilation technically. Subsequently, it would be beneficial to ease the environmental disputes related to natural ventilation force between neighboring buildings.

Acknowledgements

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