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Computational Analysis of Cross Ventilation for Spaces with Operable Transom Windows in Hot and Humid Climate

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ABSTRACT

Natural ventilation is an important free cooling strategy for public building in hot or warm climates by providing fresh air and increasing room air flow without using mechanical cooling/ventilation systems when the exterior condition is suitable. While single-sided natural ventilation has been widely studied, the applications of double-sided natural ventilation (cross ventilation) require more attention especially in hot climate and might provide some extra potential for achieving net-zero public buildings. This study aims to analyze cross ventilation in a public space with two transom windows on opposite sides by using 3D steady Computational Fluid Dynamics (CFD) simulations with the SST k-ω turbulence model. Three different transom windows types with three different combinations commonly used in Taiwan's public buildings were analyzed and compared. Parametric study regarding size and position were conducted to provide design recommendations.

1. INTRODUCTION

Mechanical ventilation is a common and convenient strategy for keeping the indoor environment in a comfortable condition for hot or warm climates, but it usually associates with considerable energy consumption [1]. Furthermore, using mechanical ventilation in enclosed space for a long time may cause the concentration of toxic chemicals released by the furniture or electrical products increasing, so providing fresh air and increasing room air flow is also an important aspect. Effective natural ventilation in buildings received increasing attention from architects and researcher and was identified as possible solutions [2]. It can potentially save energy consumptions and improve thermal comfort conditions by harnessing the cooling potential of the ambient environment [3]. Therefore, how to efficiently use natural ventilation and design buildings for providing more natural ventilation is worth further investigation for hot and humid climates.

Natural ventilation can be caused by the pressure differences across space's openings due to the wind. Differences in wind pressure along the façade and differences between leeward and windward create a natural air exchange between indoor and outdoor air [4]. Consequently, cross-ventilation is usually more effective than the single-sided opening(s). While single-sided natural ventilation has been widely studied, the applications of double-sided natural ventilation (cross ventilation) require more attention especially in hot climate and might provide some extra potential for achieving net-zero buildings.

In hot climates, operable transom windows are widely used for natural ventilation as shown in Figure1. However, for public buildings' cross ventilation design, the details were seldom thoroughly studied. How to properly design efficient operable transom windows is a challenging task. Moreover, how to evaluate its efficiency is also challenging, because the physical phenomena of air flow have lots of factors involved. As many studies have shown, computational fluid dynamics (CFD) can be a valuable tool for analyzing natural ventilation [5]. In this paper, we use CFD to facilitate the analysis.

This study aims to analyze nature ventilation in public buildings induced by two transom windows on opposite side (cross ventilation) for combinations of designed locations and different configurations (types). We picked Taipei, Taiwan as the target location which has average temperature between 28 to 30°C in the summer. Three different combinations were analyzed as shown in Figure 4. Combination I is double-sided windows with the inlet located lower than the outlet. Combination II is double-sided open windows with the inlet higher than the outlet. Combination III is double-sided windows at the same height. Then, we chose three different types of transom windows that are commonly used in Taiwan's public buildings. Figure 2 shows the three types of transom windows studied in this paper including:

horizontal slide window which is slidable horizontally in a window frame, vertical turn window whereat the window is tiltable about a vertical axis adjacent the right or left edge, and vertical pivot window whereat the window is tiltable about a vertical middle axis.

Figure 1: Transom windows.

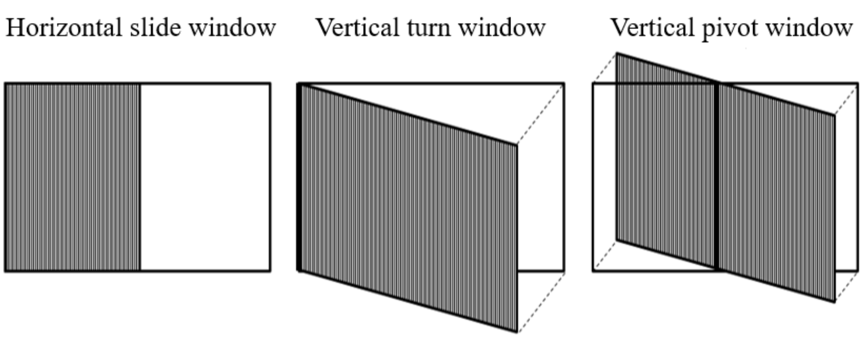

Figure 2: Three types of transom windows that are commonly used in Taiwan's public buildings.

2. METHODOLOGY

The simulations are performed using ANSYS Fluent (Version 15.0). To make sure the numerical model is appropriate for this analysis, we first compared our simulation with the results of wind tunnel experiments and CFD simulations of Peren et al. [6] under the same settings and conditions. After we get an agreement with Peren's study, we conducted simulations for comparing different combinations.

The SST k-ω turbulence model was chosen in this simulation by recommendations from previous studies [7]. Figure 3 shows the perspective view of simulation combinations – the domain and the referenced building and the respective grid size. The height of the simulation domain was height (H) is 10 m, length (L) is 20 m, and width (W) is 20 m. The height of the referenced building (H_b) is 4 m, the length of the building (L_b) is 4 m, the width of the building (W_b) is 4 m, the wall thickness (T_b) is 0.2 m, and the window thickness (T_w) is 0.1 m. The height of the window (H_w) is = 1 m and the width of the window (W_w) is 2 m. Table 1 organizes the distance between the top edge of inlet window and the ground (H_1) and the distance between the top edge of outlet window and the ground (H_2). The inlet wind velocity is 10 m/s, and the air density is 1.22 kg/m3.

The tetrahedron grid was used in present CFD simulations. The smallest grid used in the indoor area is 0.02 m. Then the grids increased from the wall of the building to the simulation domain gradually. The largest grid is 0.2m. The type of inlet boundary condition was velocity-inlet, the type of outlet boundary condition was pressure-outlet, and the type of others boundary conditions was set as "wall".

The dynamic pressure coefficient is used to compare different combinations of windows, and can be calculated by Eq. (1) [8] :

$$C_p = \frac{(P - P_0)}{(0.5\rho U_{ref}{}^2)} \tag{1}$$

where P is the average of the pressure of the transom windows area, Pascal, P_0 is the static pressure in the undisturbed flow, pascal, ρis the air density, kg/m3, and U_{ref} is the velocity of inlet wind, m/s.
We also calculated the air exchange per hour N:

$$\mathrm{N} = \frac{\mathrm{Q}}{\mathrm{V}_b} \tag{2}$$

where Q is the air volume per hour, m^3/h, and V_b is the volume of the building m^3.

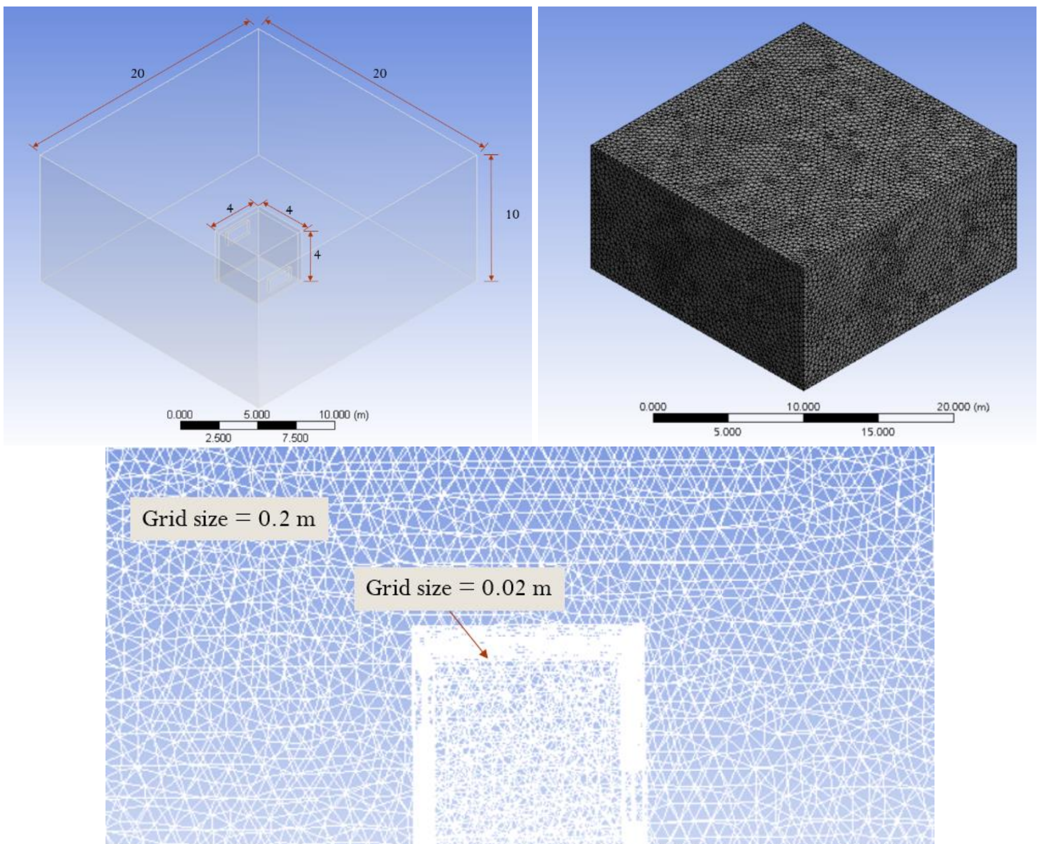

Figure 3: Perspective view with dimensions.

Table 1: The distance between the edge of the window and the ground for different combinations.

Combination	**H_1 (m)**	**H_2 (m)**
I	0.6	2.4
II	2.4	0.6
III	2.4	2.4

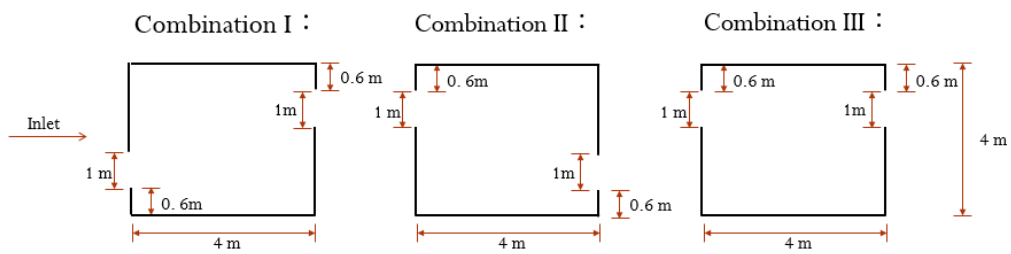

Figure 4: Side view for different combinations of windows.

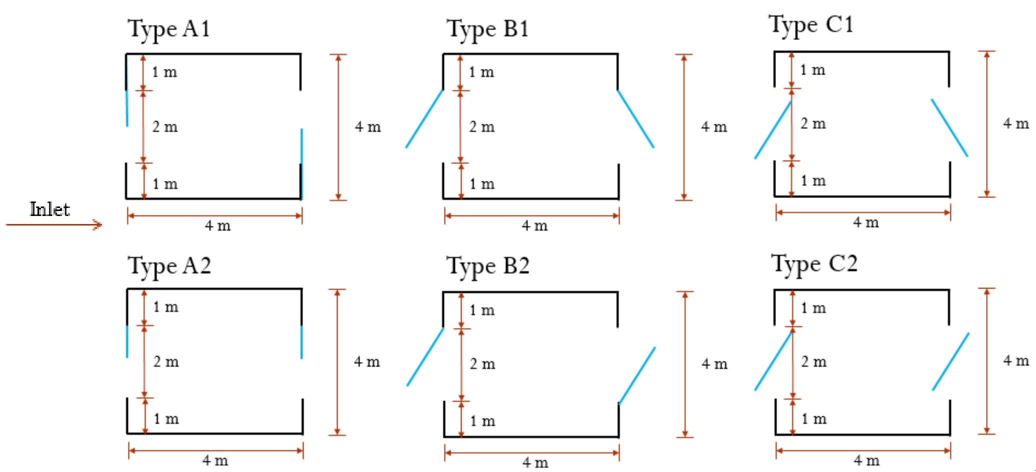

Figure 5: Top view for different types of windows. Type A shows horizontal slide window, Type B shows vertical turn window, and Type C shows vertical pivot window.

3. Results

3.1 Comparison between the three different window height combinations

The primary purpose of the present study is to investigate the effect of the different combinations of the transom windows when modeling wind-driven natural ventilation in the building. For this reason, the comparison between three different combinations has been limited to the zone of the computational domain closer to the building. Table 2 shows the dynamic pressure C_D, relative velocity and the air exchange per hour N. The inlet wind velocity is 10 m/s. The C_D values are larger when the Combination I and the Combination II were used. Combination III which the two transom windows are at the same height has the highest relative velocity 0.87 and the air exchange per hour is the largest one (N = 1272).

Figure 6 and figure 7 show the distributions of the pressure and the vector of the velocity closer the building. The different combinations cause the different distribution of indoor pressure. For Combination I and II, the windward pressure is larger than Combination III, and the velocity around the windward transom windows is smaller than the Combination III. In other words, the effect of cross ventilation is less effective for combination I and II. It can be observed that Combination III has the highest air velocity around the inlet, outlet, and the entire space compared to other combinations.

Table 2: The dynamic pressure C_D and relative velocity for three different combinations

Combination	$C_{D\text{-}in}$	$C_{D\text{-}out}$	U/U_{ref}	N
I	0.55	-0.23	0.64	936
II	0.41	-0.33	0.68	994
III	0.22	-0.36	0.87	1272

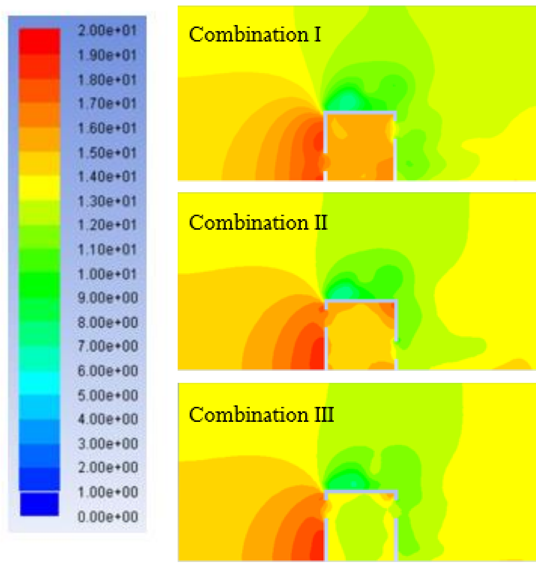

Figure 6: CFD results for three different combinations: pressure (pascal).

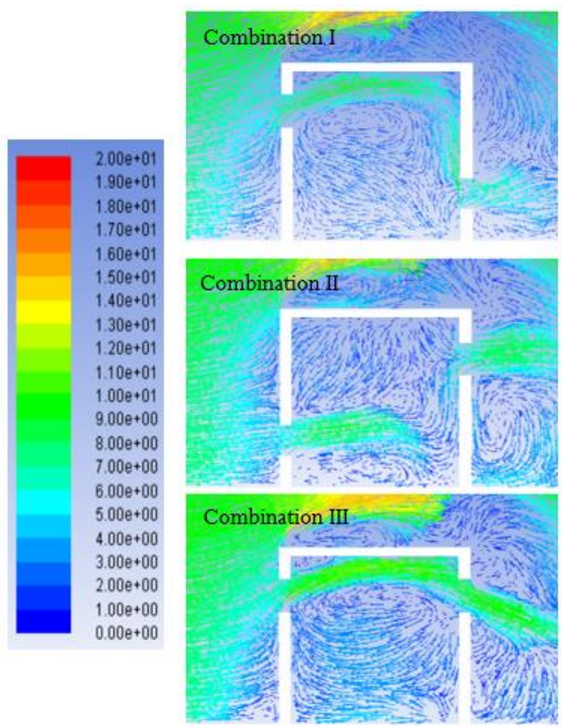

Figure 7: CFD results for three different combinations: velocity (m/s).

3.2 Comparison between the three different window types

Table 3 shows the result of the building with the three different types transom windows and combination III. It can be seen that the highest velocity around the two transom windows and the air exchange per hour are combination III. Concerning the same type transom windows with different combinations, the fact that the pressure coefficient, the relative velocity and air exchange per hour for Type A1 and A2 are nearly the same. For vertical turn windows, the Type B2's value of the pressure coefficient is larger than Type B1's. Furthermore, the relative velocity and air exchange per hour for Type B2 are also larger than Type B1. As the result, two transom windows set in the same direction is the better combination. On the other hand, the vertical pivot window type transom window is not a suitable combination of natural ventilation. The value of the dynamic pressure, relative velocity and air exchange per hour for Type C are the largest of all Types.

Figure 8 and figure 9 present the distributions of the pressure and the vector of the velocity closer the building. The indoor pressure for Type B is the smallest one. The value of indoor velocity for Type B is the largest one.

Table 3: The dynamic pressure, relative velocity and air exchange per hour for three different types.

Type	$C_{D\text{-in}}$	$C_{D\text{-out}}$	U/U_{ref}	N
Combination III	0.22	-0.36	0.87	1272
A1	0.27	-0.32	0.71	1038
A2	0.24	-0.33	0.66	965
B1	0.19	-0.32	0.46	673
B2	0.28	-0.35	0.65	950
C1	0.45	-0.21	0.35	512
C2	0.45	-0.15	0.48	702

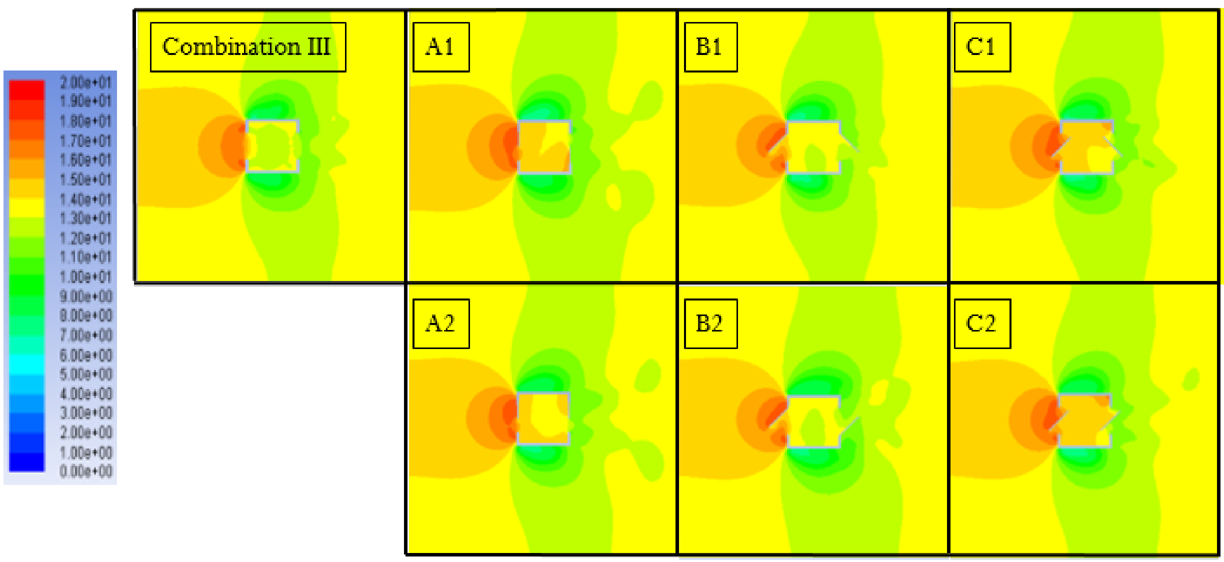

Figure 8: CFD results for three types windows: pressure (pascal).

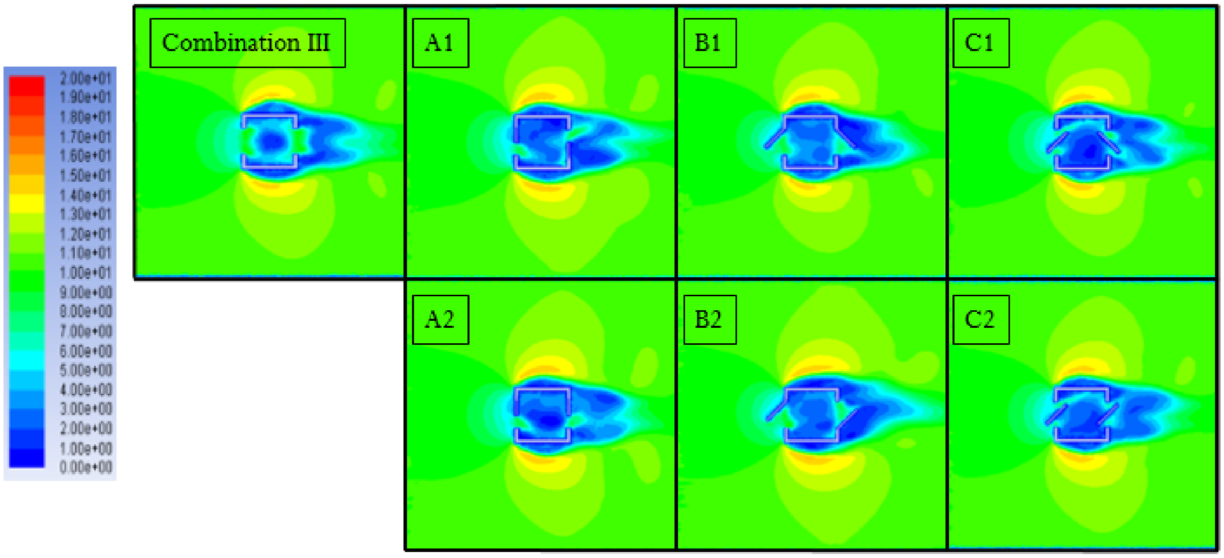

Figure 9: CFD results for three types windows: velocity (m/s).

4. Conclusions

In the present study, CFD simulations have been applied to wind-driven natural ventilation in buildings; three different combinations and three types transom windows were considered. The following conclusions were obtained through the analysis:

- For the three combinations of the transom windows, Combination III (the double side transom windows at the same height) achieves the highest air exchange rate per hour.
- For horizontal slide window or vertical turn window type transom windows, to increase the natural ventilation, the two transom windows should be aligned to each other.
- The vertical pivot window type transom window is not a suitable combination for natural ventilation.

5. Future Work

In the present, We only discussed the pressure and velocity distribution for different types transom windows and different combinations. In the future, we will continued some investigations as follow:

- We will add the analysis of tempetature and energy exchange by CFD simulation. As a result, the distribution of tempetature can be analyzed and compared.
- Furthermore, the buoyancy effect and mass flow rate should be measured and analyzed in the future study.
- The more different types tran windows can be simulated in the furture CFD simulation like vertical slide window or horizontal turn window.

REFERENCES

1. Wang, J., et al., *Assessment of single-sided natural ventilation driven by buoyancy forces through variable window configurations.* Energy and Buildings, 2017. **139**: p. 762-779.
2. Gilani, S., H. Montazeri, and B. Blocken, *CFD simulation of stratified indoor environment in displacement ventilation: Validation and sensitivity analysis.* Building and Environment, 2016. **95**: p. 299-313.
3. Artmann, N., H. Manz, and P. Heiselberg, *Climatic potential for passive cooling of buildings by night-time ventilation in Europe.* Applied Energy, 2007. **84**(2): p. 187-201.
4. Rodrigues, A.M., et al., *Modelling natural convection in a heated vertical channel for room ventilation.* Building and Environment, 2000. **35**(5): p. 455-469.
5. Ramponi, R. and B. Blocken, *CFD simulation of cross-ventilation for a generic isolated building: Impact of computational parameters.* Building and Environment, 2012. **53**: p. 34-48.
6. Perén, J.I., et al., *CFD simulation of wind-driven upward cross ventilation and its enhancement in long buildings: Impact of single-span versus double-span leeward sawtooth roof and opening ratio.* Building and Environment, 2016. **96**: p. 142-156.
7. Montazeri, H. and F. Montazeri, *CFD simulation of cross-ventilation in buildings using rooftop wind-catchers: Impact of outlet openings.* Renewable Energy, 2018. **118**: p. 502-520.
8. Evola, G. and V. Popov, *Computational analysis of wind driven natural ventilation in buildings.* Energy and Buildings, 2006. **38**(5): p. 491-501.

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