Wind Engineering Joint Usage/Research Center FY2022 Research Result Report

Research Field: Outdoor Environment
Research Year: FY2022
Research Number: 22223003
Research Theme: PIV measurement of flow within vertically stratified isolated building with various floor opening locations

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Budget [FY2021]: 280000 Yen

*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
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1. Research Aim

It is well known that natural ventilation can provide a comfortable atmosphere in a building by exchanging fresher outside air. Furthermore, the use of natural ventilation is not limited to creating a pleasant climate but can also help reduce the infection of respiratory diseases such as COVID19 that can spread easily when occupants are in an enclosed space with air conditioning. Natural ventilation is one of the sustainable strategies that help reduce dependence on non-renewable energy. However, the application of natural ventilation remains a difficult task due to many factors that influence its effectiveness. These factors can be divided into so-called environmental factors and design factors. Environmental factors include wind strength, wind direction and the type of terrain, while design factors include the location and design of the external openings, the configuration of the internal openings, the building design itself and the topography of surrounding buildings. Many studies have been conducted to further investigate natural ventilation using a generic building design in an isolated or group of buildings conditions. Due to the complexity of airflow and limitations in terms of on-site and wind tunnel measurement techniques, most of the buildings used for the study are simplified buildings with only one zone for the interior of the building. While some studies have considered the effects of different interior room designs and internal opening positions, most are limited to horizontally arranged room configurations. Given the limitations of on-site and wind tunnel measurements, **this study aims to conduct a series of wind tunnel experiments on generic isolated buildings with vertically arranged interiors, i.e. first and second floors with different internal opening positions connecting both floors to evaluate the distributions of the flow fields.**

2. Research Method

2.1 Building geometries

Figure 1 shows the schematic diagram of the target buildings adopted in this study. The dimensions of the model building are 320 mm x 150 mm x 200 mm, corresponding to the length (x-axis), the width (y-axis) and the height (z-axis). Each model consists of transparent acrylic plates with a thickness of 2 mm, divided into two layers, i.e., a first layer and a second layer with a total height of 200 mm. There is also an opening of 70 mm x 70 mm in the middle of the bottom of the second layer, which corresponds to 10% of the floor area. The inlet and outlet openings (75 mm x 40 mm) are located on the windward and leeward walls respectively.

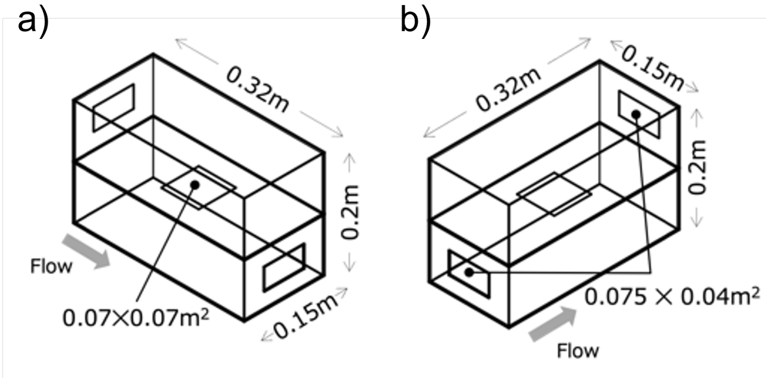

Fig. 1 Schematic representation of the target buildings a) inlet on the windward façade of the second layer and outlet on the leeward façade of the first layer (Case1) b) inlet on the windward façade of the first layer and outlet on the leeward façade of the second layer (Case2) with internal opening in the middle.

2.2 Wind tunnel experiments

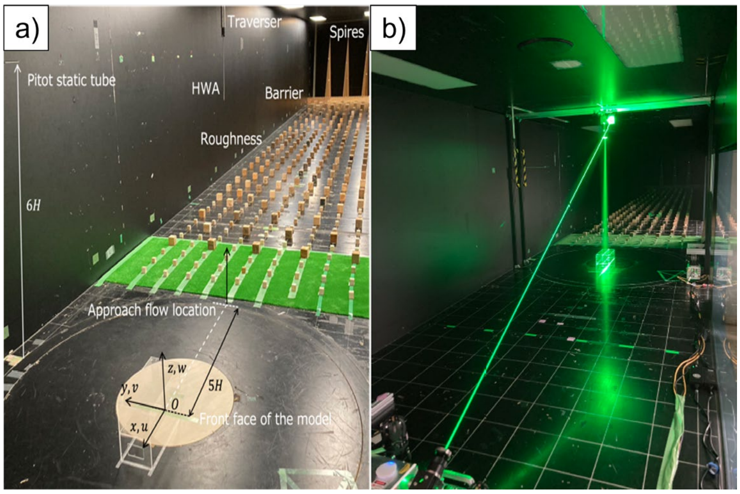

Fig.2 Position of the target building during wind tunnel experiments a) hot wire anemometer (HWA) measurement b) particle image velocimetry (PIV) measurement.

The experimental measurements were carried out in a wind tunnel at Tokyo Polytechnic University. The cross-section of the test section of the wind tunnel has a dimension of 19 m length x 2.2 m width. The model building is mounted on a turntable with a diameter of 2 m. 3 sets of spires were used, each with a height of 150 cm and a width of 20 cm and a barrier. To generate turbulent atmospheric boundary layer wind profile, spires and roughness elements made of wooden blocks cubes with dimensions of 3 mm, 6 mm and 9 mm were placed in the upstream zone in staggered manner. Figure 2 shows the two measurement methods that were conducted namely hot wire anemometer (HWA) (Fig.2(a)) and particle image velocimetry (PIV) (Fig.2(b)).

The profile of the averaged streamwise velocity $\bar{u}$ and $\bar{w}$, and turbulent kinetic energy (TKE), k of the approaching flow was measured at the x-z plane of the target model building before it was placed on the measurement area in the wind tunnel. The instantaneous velocity was measured by x-type hot wires probe. The x-type hot wire was mounted parallel to the direction of the incoming flow. The measured velocity and TKE profiles can be expressed by Eq. (1) and Eq. (2), respectively.

$$\frac{\overline{u}}{u_H} = \left(\frac{z}{H}\right)^{0.25} \tag{1}$$

$$\frac{k}{u_H^2} = 0.033\, exp\left(-0.32\left(\frac{z}{H}\right)\right) \tag{2}$$

where z represents the vertical position in z-axis from the ground, and H is the height of the model building which is 200 mm.

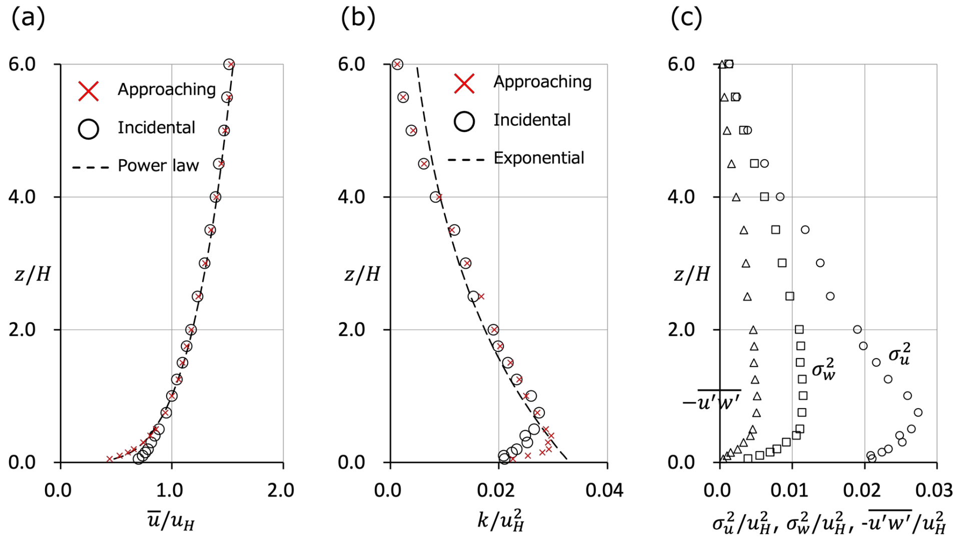

Fig.3 Vertical profiles of (a) streamwise velocity component, (b) approximated turbulent kinetic energy (TKE) and (c) streamwise, vertical variances and Reynolds stress.

Figure 3 (a, b) shows the vertical profiles of the streamwise velocity component and TKE for the approaching (*red cross*) and incidental (*empty circle*) flow. The vertical profiles both of $\overline{u}$ and k are well expressed by Eqs. (1) and (2). Although the incidental flow slightly recovered only near the surface due to the smooth surface condition, the profile above $0.5H$ agrees well with the approaching flow. Fig. 3 (c) shows the comparison of the variances and the vertical Reynolds stress, σ_u^2, σ_w^2 and $-\overline{u'w'}$ normalized by ${u_H}^2$.

3. Research Result

3.1 Mean velocity distributions

Figure 4 shows the color map of the mean velocity components, $\overline{u}$ and $\overline{w}$ with their vector distributions for Case1 and Case2 configurations. Obviously, the external flow fields over the models are identical regardless of the opening conditions. In contrast, the velocity fields in the interiors differ drastically between Case1 and Case2. For Case1 (Fig. 4 (a, b)), the flow is introduced horizontally into the model, almost in the streamwise center of the model. Since there is no cross-ventilation window on the opposite side, the floor opening on the second floor changes the flow direction from the horizontal velocity component to the vertical component, as can be clearly seen in Fig. 4 (b). The airflow introduced into the 1st floor flows towards the opening on the downwind side of the model, although the streamwise velocity component towards the outlet is weaker than that near the inlet opening. In contrast, Case2 shows distinctly different flow patterns in the interior. Due to the opening being at the lower height at the front of the model, the flow is introduced diagonally into the 1st floor, goes along the lower wall and creates the room-sized circulation for the Case2 model. This flow pattern is completely different from that of the Case1, which highlights the importance of the opening location. More interestingly, the flow pattern in the 2nd floor of Case2 seemingly resembles to that of the 1st floor of the Case1 model, although the vertical flow direction is opposite. The streamwise velocity component near the outlet position is also weaker than that of the inlet.

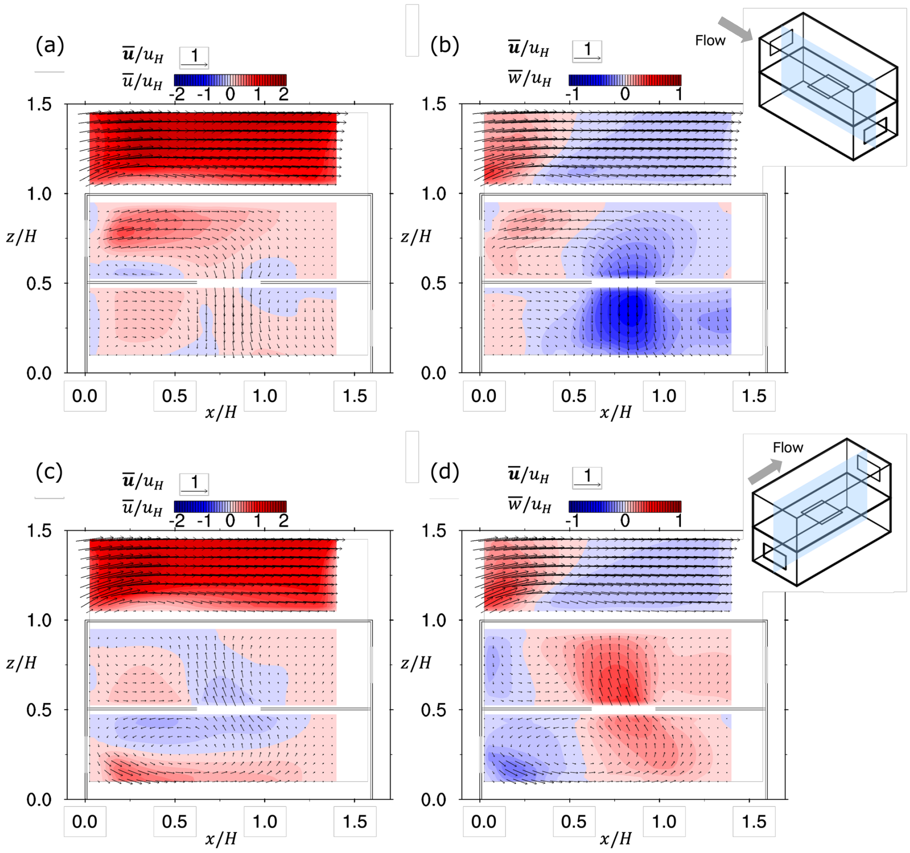

Fig.4 Mean velocity distributions in a vertical x-z plane at y/H = 0 for (a, b) Case1 and (c, d) Case2 configurations. Color contours show the magnitude of the streamwise and vertical velocity components, respectively and arrow shows the velocity vectors.

3.2 Turbulence characteristics

The turbulent effect on the indoor flow patterns is another concern to evaluate the indoor ventilation. To understand the relationship between the flow pattern and the turbulent transport, the spatial distributions of σ_u^2 and σ_w^2 are shown in Fig. 5 with the streamlines of $\overline{u}$ and $\overline{w}$.

Above the model, there are no significant difference in the distribution of σ_u^2 and σ_w^2, showing the large values of variances in $0.25<x/H<0.75$ due to the formation of the strong shear layer. As for the indoor turbulence in general, the strengths of the variances gradually reduce along with the streamlines toward the second layer. In the second layer, the magnitude of the variances is smaller than those of the approaching flow except for the location near the mid-floor opening. According to the observation of the instantaneous flow patterns, the airflow from the upstream opening of Case1 model flips between upward and downward. Therefore, the variances of both u and w are greater than those of the approaching flow. However, the generated turbulence near the inlet position attenuates soon probably due to the restriction by the wall of the indoor space. Case2 also shows similar increase of the variances near the inlet opening, although the regions are narrower than Case1. Like the mean flow patterns, σ_u^2 and σ_w^2 in the second layer shows very similar spatial distributions, implying the universality of the flow and turbulence patterns in the second layer for the multi-layer cross-ventilation models.

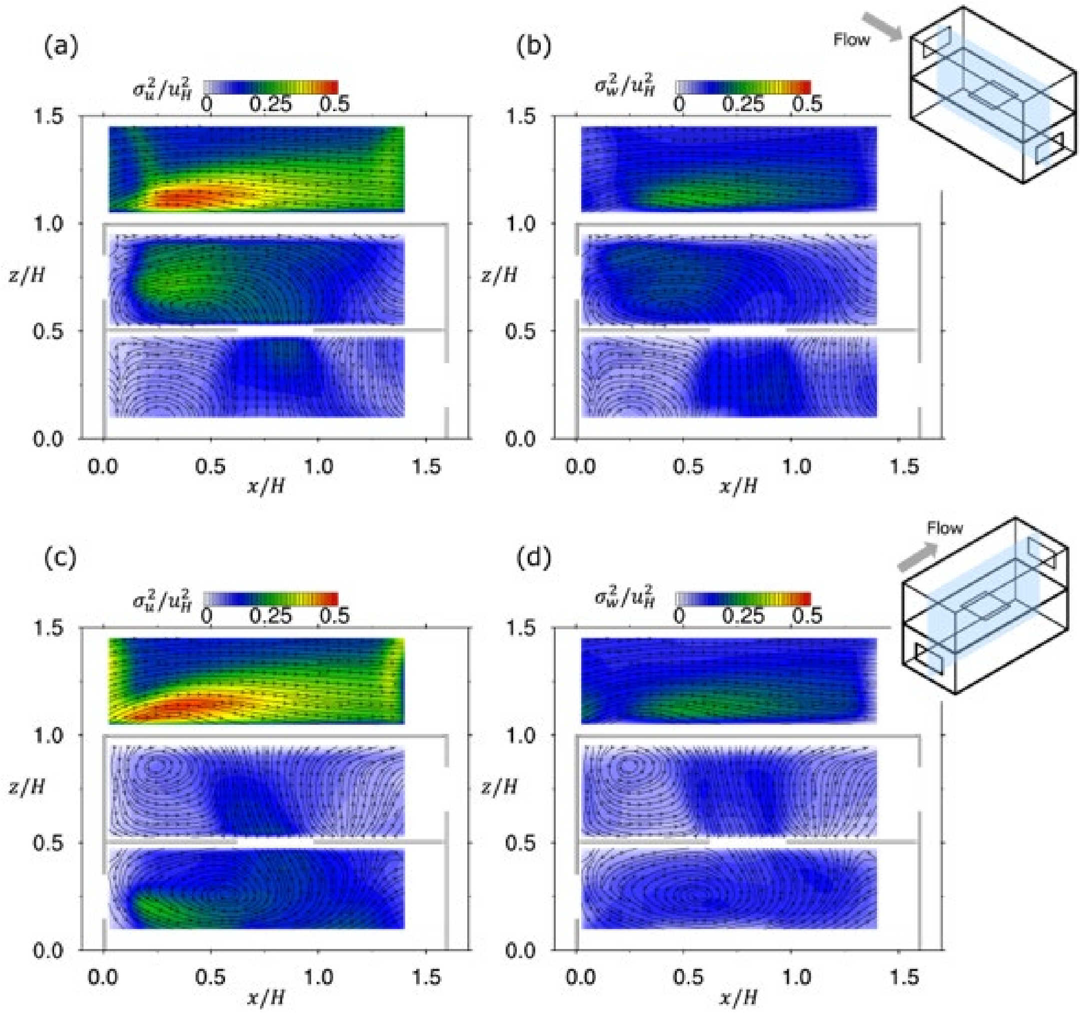

Fig.5 Variance distributions in a vertical x-z plane at y/H = 0 for (a, b) Case1 and (c, d) Case2 configurations. Color contours show the magnitude of the streamwise and vertical velocity components, respectively. The lines are the streamlines of ($\overline{u}$, $\overline{w}$).

4. Published Paper etc.

[Underline the representative researcher and collaborate researchers]

[Published papers]

1. Not available
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[Presentations at academic societies]

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5. Research Group

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6. Abstract (half page)

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Summary・Figures

In this study, high quality data was obtained through the experimental study in the wind tunnel using HWA and PIV to investigate the velocity profile and flow patterns of a simple two-layer building with two different configurations of inlet-outlet arrangements. The major findings on the study can be summarized as follows:

- Comparing the two different configurations of inlet and outlet positions (Case1 and Case2) for a two-layer building, the external flow fields above the building are less sensitive to the opening positions. However, the internal flow depends to a considerable extent on the position of the inlet, as the two cases have completely different flow field distributions.
- Large values of variances are observed just above the building as the evidence of the formation of strong shear layer. However, in the building envelope, the variances attenuate due to the restriction introduced by the internal wall.