Wind pressure coefficient distribution of detached houses in a dense residential block

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Abstract
In a dense residential block, external airflow patterns around a site should be analyzed initially in the design stage to improve cross ventilation, thereby improving the comfort of an occupant and saving energy. After surveying the block density in Tokyo’s main residential zones, we concluded that the height and distance of neighboring buildings contribute significantly to external airflow patterns. Next, using a wind tunnel, we tested the effect of altering the height and distance of a neighboring building based on the wind pressure coefficient regarding two different scenarios: a typical residential model and a model with ventilation-enhancing strategies.

Keywords
courtyard, cross ventilation, height and distance of neighboring buildings, roof monitor, wind tunnel test

1. Introduction
Residents have high expectations in terms of their health and energy conservation when it comes to improving comfort by providing natural ventilation during summers and mid-seasons, instead of relying on air conditioning. However, in recent years, when houses have become highly insulated and airtight, natural ventilation is not expected to be fully realized unless the characteristics of outside airflow around a site are gathered from the design phase onward, and openings are installed at appropriate locations. In a dense residential block, it is important to accurately identify the wall or roof surface where the wind pressure acts effectively and to propose the creation of an opening or to use a ventilation promotion device. To do so, it is necessary to build a database of wind pressure coefficients that is easy for designers to use. Maruta et al. conducted wind tunnel (WT) tests on individual buildings to understand the basic characteristics of the wind pressure on the outer skin to create a database of outer skin wind pressure coefficients for detached houses. There are many other studies that have investigated the distribution of wind pressure coefficients and ventilation rates using wind tunnel tests.2–6 Many studies have been performed on the effectiveness of ventilation promotion devices in dense residential areas. Using an experimental model house and WT tests, Murakami et al. showed that skylights help boost ventilation. Akabayashi et al. suggested a comprehensive airflow performance index for detached homes using computational fluid dynamics (CFD) to demonstrate the relationship between the building coverage ratio (BCR) and the average airflow ratio, as well as to verify the effect of skylights on stimulating airflow. Nishizawa et al. carried out WT tests on a two-story detached house in a dense residential zone to investigate the locale’s ventilation features, as well as to establish the impact of wind catchers, ventilation towers, and roof openings on ventilation. Kobayashi et al. focused on roof monitors on sloped roofs, and clarified the wind ventilation traits of buildings using WT tests, thereby measuring wind ventilation volumes of homes with roof monitors. In addition, Takizawa et al. established a model to quantitatively assess the performance of ventilation towers described in preliminary studies using CFD analysis and suggested that ventilation towers have the advantage of utilizing natural ventilation, especially in dense residential blocks.

On the other hand, in dense residential blocks, actual measurements have indicated that in many cases, the prevailing wind direction of the actual site differs from that of the nearest meteorological data obtained from Japan’s automated meteorological data acquisition system (AMeDAS) available to the
designer owing to the influence of adjacent buildings.\textsuperscript{12} Using a WT test, Sato et al.\textsuperscript{13} shed light on the influence of reducing wind pressure on planned buildings owing to the size and distance of the adjacent buildings. However, the database of wind pressure coefficients, regarding the walls or roofs of the target buildings (owing to differences in the height and distance of nearby buildings), is not yet sufficient for analysis.

Therefore, in Section 2, we detail how we surveyed the density of major residential areas in Tokyo to understand the actual ratio of the building coverage (defined as the “gross BCR”) in dense residential zones. Section 3 discusses the effects of the density and shape of city blocks on wind pressure, which affects the walls and roofs of buildings. Section 4 examines the influence of modifying the height and distance of neighboring buildings on the short and long sides of the building. Section 5 delves into the impact of ventilation promotion devices (e.g., courtyards and roof monitors) on the modified height and distance of the neighboring buildings, as addressed in the previous section.

2. Survey on the density of city blocks

Among 23 wards in Tokyo, we surveyed the density of the relatively large residential wards of Setagaya and Suginami for Class 1 and Class 2 low-rise residential areas. As displayed in Figure 1, we first used the survey method to identify Class 1 and Class 2 low-rise residential zones, based on the urban planning map of each ward. Next, we divided Setagaya into 74 blocks and Suginami into 78 blocks. After that, we used data of the geographic information system for each block to determine the status of the building coverage of the block. The building coverage status is defined as the total built-up area (square meters) of each house in the block relative to its total area (square meters). Hereinafter, we will refer to it as the gross BCR (%).

\[
\text{Gross BCR (\%)} = \frac{\text{Total building area of each house in the lock (m}^2\text{)}}{\text{Total area of the block (m}^2\text{)}} \times 100
\]

The gross BCR, defined here, is calculated based on the overall size of the area (including all roads, parks, and vacant land) and differs from the commonly used building-to-land ratio.

Figure 2 presents the frequency distribution and cumulative frequency for each gross building coverage area in Setagaya.  

![Figure 1. Survey method of block density](image1)

![Figure 2. Status of block density](image2)
and Suginami. Figure 3 shows actual residential blocks with gross BCRs of 28%, 33%, and 43%. Based on the gross building coverage of 33%, the densities of the city block to be reproduced in the WT tests at 5% increments are 23%, 28%, 33%, 38%, and 43%.

3. Relationship between the distribution of wind pressure coefficients and the circumstances of a city block based on the WT tests

3.1 Overview of the WT tests
We conducted the tests using a WT apparatus at the University of Tokyo. The measuring tunnel has a square cross section of 1.8 m on one side and a total length of 15.6 m. The wind angle can be set by a 1.6 m diameter turntable located 12.5 m from the entrance of the measuring tunnel. We used the wind speed at the model eave height ($H = 59$ mm) as a reference ($7$ m/s), and we employed the vertical wind velocity profile of roughness (category III; residential area: 0.2 index) from Recommendations for Loads on Buildings\textsuperscript{14} for WT airflow (Figure 4).

As shown in Figure 5, we placed five different kinds of models with distinct planes and roof shapes at the center of the turntable to gauge wind pressure. We set up wind pressure conditions for each model and measured the wind pressure coefficients.
Figure 7. Average wind pressure coefficient on each wall surface for all wind directions (distributed in a simplified dense manner)

Figure 8. Correlation of wind pressure coefficients based on block density (rectangular building, gabled roof, wind direction = 45°)
Table 1. Inclination of the trend line based on a gross BCR of 33% (rectangular building, gabled roof)

<table>
<thead>
<tr>
<th>Wind direction (°)</th>
<th>Gross BCR (building coverage ratio)</th>
<th>Inclination</th>
<th>R2</th>
<th>Inclination</th>
<th>R2</th>
<th>Inclination</th>
<th>R2</th>
<th>Inclination</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23%</td>
<td>1.52</td>
<td>0.91</td>
<td>1.18</td>
<td>0.93</td>
<td>0.74</td>
<td>0.84</td>
<td>0.63</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>28%</td>
<td>1.33</td>
<td>0.93</td>
<td>1.07</td>
<td>0.98</td>
<td>0.77</td>
<td>0.93</td>
<td>0.72</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>33%</td>
<td>1.36</td>
<td>0.94</td>
<td>1.22</td>
<td>0.97</td>
<td>0.85</td>
<td>0.94</td>
<td>0.84</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>38%</td>
<td>1.03</td>
<td>0.94</td>
<td>1.00</td>
<td>0.99</td>
<td>0.82</td>
<td>0.96</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>43%</td>
<td>1.19</td>
<td>0.95</td>
<td>1.05</td>
<td>0.98</td>
<td>0.95</td>
<td>0.97</td>
<td>0.90</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Table 2. Inclination of the trend line based on a gross BCR of 33% (wind direction = 0°)

<table>
<thead>
<tr>
<th>Type of measurement model</th>
<th>Gross BCR (building coverage ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23%</td>
</tr>
<tr>
<td>Rectangular building, flat roof</td>
<td>1.56</td>
</tr>
<tr>
<td>Rectangular building, gabled roof</td>
<td>1.52</td>
</tr>
<tr>
<td>L-shaped building, flat roof</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Figure 9. Layout of models (located at the center/corners of the block)

Table 3. Distances to neighboring buildings

<table>
<thead>
<tr>
<th>Gross BCR</th>
<th>Simplified dense manner</th>
<th>Center/ Corner of blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1</td>
<td>L2</td>
</tr>
<tr>
<td>23%</td>
<td>1.4H</td>
<td></td>
</tr>
<tr>
<td>28%</td>
<td>1.2H</td>
<td>1.5H</td>
</tr>
<tr>
<td>33%</td>
<td>1.0H</td>
<td>1.4H</td>
</tr>
<tr>
<td>38%</td>
<td>0.8H</td>
<td>1.2H</td>
</tr>
<tr>
<td>43%</td>
<td>0.7H</td>
<td></td>
</tr>
</tbody>
</table>

H: Eaves height (59 mm).
measurement points on the walls and roofs of each type of model to determine the pressure difference from the static pressure of the pitot tube in the WT.

### 3.2 Evaluating the impact of city block density

Figure 6 outlines the distribution of the surrounding models in a simplified dense manner. Figure 7 shows the changes in the wind direction of the average wind pressure coefficients, which affect the walls and roofs of the model with a rectangular plane and a gabled roof, when the gross BCR is changed from 23% to 43% (at 5% increments).

Figure 8 shows the correlation between the wind pressure coefficients of the model for wind pressure measurement, with a rectangular plane and a gabled roof at a wind angle of 45°, and the wind pressure coefficients of all measurement points at a gross BCR of 33% along the horizontal axis, and at a gross BCR of 23%, 28%, 38%, and 43% on the vertical axis, with a gross BCR of 33% as the reference. The inclination of the trend line shows that the absolute value of the wind pressure coefficient decreases along with an increase in the gross BCR. However, as there is minimal change in the inclination between 38% and 43%, the lower limit of the change in the wind pressure coefficient is expected to be ~40%. The results were similar for other wind angles of the model with a rectangular plane and a gabled roof, as listed in Table 1, as well as for models that measure the wind pressure of other shapes, as listed in Table 2.

![Figure 10. Average wind pressure coefficient on each surface for all wind directions (when studying building location within the block)](image)

![Figure 11. Average wind pressure coefficient on each roof surface for all wind directions (when studying roof types)](image)
Figure 12. Plan/Elevation of the model house

Figure 13. Overview of the WT tests (changing the conditions of neighboring buildings on the side of wall surface B)

Table 4. WT test cases (changing the conditions of neighboring buildings on the side of wall surface B)

<table>
<thead>
<tr>
<th>Heights of an adjacent building (an adjacent building on the side of wall surface B)</th>
<th>Distances to neighboring buildings (neighboring buildings on the side of wall surface B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (none)</td>
<td>0.5H</td>
</tr>
<tr>
<td>0.5H</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>1.5H</td>
<td></td>
</tr>
<tr>
<td>2H</td>
<td></td>
</tr>
</tbody>
</table>

Comparison 3

Comparison 4
The above explanation indicates that if we can determine the wind pressure coefficients for each surface at a particular gross BCR, we can also predict the wind pressure coefficients for other gross BCRs. In this study, we considered a gross BCR of 33% as the basic city block density.

3.3 Evaluating the impact of the shape and location of city blocks

Within the block, we must consider the relationship between buildings and roads for the effective use of cross ventilation. In addition to the simplified dense manner, based on the findings of the city block density survey, we created a city block model with a gross BCR of 28%–38% (at 5% increments). We compared the average wind pressure coefficients on each wall and roof according to the city block’s shape and location.

Figure 9 outlines the shape of the city block and its location (its center and corner), and Table 3 lists the distances to neighboring buildings. We performed the experiment using a model with a rectangular plane and a gabled roof (Figure 5).

Figure 10 depicts the changes in wind direction of the average wind pressure coefficients that affect each wall and roof surface in a simplified dense manner, the center of the block, and the corner of the block, with a gross BCR of 33%. The pressure is positive on wall surface A along the long side, in terms of the wind angle is 247.5°–337.5° toward the upwind side, at the corner of the block and with a road in front. Although, it is negative in a simplified dense manner and at the center of the block (toward which wall surface A is not facing the road). On the other hand, there is no noticeable difference in the wind direction of the average wind pressure.
coefficients that affect wall surface B on the gabled side and roof surface Ra, depending on the shape of the block. In general, the corner of the block is considered to be an advantageous site for cross ventilation. Hence, during the WT tests, we distributed the models in a simplified dense manner, demonstrating a change in the average wind pressure coefficients with wind direction, as occurred at the center of the block (which is less favorable for ventilation).

3.4 Evaluating the impact of roof geometry
To understand the effects of the shape of the roof on the wind pressure coefficients that affect each roof surface, we placed a wind pressure measurement model with a rectangular plane in a simplified dense manner at a gross BCR of 33%. We altered the roof shapes, so that they were flat, gabled, and hipped. Figure 11 displays the changes in the average roof surface wind pressure coefficients caused by the wind direction as per the roof shape. The negative pressure on the flat roof was always approx. −0.05, regardless of the wind direction. In contrast, for gabled and hipped roofs, negative pressure was relatively high at downwind angles of 0°–180°. This outcome indicates that in dense residential blocks, a roof opening with a certain slope is more beneficial for cross ventilation. The changes in the average wind pressure coefficients on gabled roof Ra and hipped roof Ra caused by the wind direction show similar trends with different wind angles. In addition, we confirmed that for the hipped roof, it is possible to ensure a relatively large difference in the wind pressure coefficients between roof surface Ra and roof surface Rb, which averaged ~0.11.

Figure 15. $\Delta C_p$ (Southern window – Western window) in the child’s room [1] for all wind directions (changing the conditions of neighboring buildings on the side of wall surface B)
4. Evaluating the impact of the height and distance of adjacent buildings using the WT tests

In the previous section, we underscored the strong correlation between the gross BCR and the average wind pressure coefficients for each surface. Hence, if we can understand the wind pressure coefficients at a particular gross BCR, then we can predict the wind pressure coefficients at other gross BCRs. In addition, we examined the effects of the shape of a city block’s shape, the location on the city block, and roof shape on the wind pressure (which affects the wall and the roof). In this section, based on the results of the previous analysis, we explore the model for wind pressure measurement with a rectangular plane and a gabled roof, as well as the effects on wind pressure, which affects each surface when the height and distance of neighboring buildings are altered at a gross BCR of 33% (distributed in a simplified dense manner). In addition, we assumed the housing plan shown in Figure 12 for the measurement model. Furthermore, when the conditions of the surrounding buildings are modified, we consider the change in the differences in the wind pressure coefficients between the windows in the wall of each room (the living/dining room, the tatami room, the master bedroom, and the child’s room [1]).

4.1 Evaluating the impact of the height and distance of adjacent buildings on the short wall side

We conducted the experiments by varying the heights and distances of neighboring buildings on the side of wall surface B.

Figure 13 displays an overview of the WT tests, and Table 4 lists the test cases.

For each comparison, Figure 14 outlines the change in the average wind pressure coefficients on wall surface B. When the distances to neighboring buildings are fixed at H, the average wind pressure coefficient is -0.1 to 0.2 greater if the height is between 0 (none) and 0.5H, within wind angles of 45° to 45°. Changing the height of an adjacent building does not affect the average wind pressure coefficients for the other wind angles on wall surface B (or other surfaces). When the distances to neighboring buildings are fixed at 2H, there is a slight difference even when a neighboring building’s height is changed, within the wind direction angles of -45° to 45° on wall surface B. However, the effect of altering the height of an adjacent building is not significant compared to when the distance to it is H. When the height is fixed at H and 2H, the average wind pressure coefficient on wall surface B varies with the distance to neighboring buildings, within wind angles of -67.5° to 67.5°. The average wind pressure coefficient is negative, even if wall surface B is on the upwind side, when the distance to neighboring buildings is 0.5H.

For each comparison, Figure 15 exhibits the differences in the wind pressure coefficients between the windows on the wall of the child’s room [1] (= southern window – western window). Particularly when the wind direction angle is such that wall surface B is on the upwind side, the change in the differences in the wind pressure coefficients owing to the condition of the neighboring buildings is greater than that in the average wind pressure coefficients of wall surface B. Hence, it is necessary to accurately analyze the circumstances of neighboring buildings to ensure a difference in the wind pressure coefficients in each room and provide effective cross ventilation in a dense residential block. Moreover, in the fourth comparison analysis, when an adjacent building with a height of 2H is built on the upwind side, the differences in the wind pressure coefficients are maintained when the distances to the neighboring buildings are not H. Therefore, that even if there is a tall building on the upwind side, this does not mean a general disadvantage for cross ventilation.

4.2 Evaluating the impact of the heights and distances of adjacent buildings on the long wall side

We performed tests by varying the height and distance of neighboring buildings on the side of wall surface C. Figure 16 shows an overview of the WT tests, and Table 5 lists the test cases.

For each comparison, Figure 17 illustrates the change in the average wind pressure coefficients on wall surface C. When the distances to neighboring buildings are fixed at H, we can see the differences in the average wind pressure coefficients.

### Table 5. WT test cases (changing the conditions of neighboring buildings on the side of wall surface C)

<table>
<thead>
<tr>
<th>Heights of an adjacent building (an adjacent building on the side of wall surface C)</th>
<th>Distances to neighboring buildings (neighboring buildings on the side of wall surface C)</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>H</em>: Standard eaves height (59 mm)</td>
<td>0.5H</td>
<td>1.5H</td>
</tr>
<tr>
<td>0 (none)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2H</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 16. Overview of the WT tests (changing the conditions of neighboring buildings on the side of wall surface C)
caused by the height of an adjacent building at most wind angles. In particular, when the height is 0 (none), 0.5H, and 2H, the average wind pressure coefficients are greater at 0 (none) and 0.5H when wall surface C is on the upwind side and greater at 2H when wall surface C is on the downwind side. On the other hand, when the distance to neighboring buildings is 2H, there is not much difference in the average wind pressure coefficients, depending on the height of the neighboring building, as compared with the height of H. When a neighboring building’s height is fixed at H, there is no effect regarding the distances to neighboring buildings at any wind direction angle. However, when the height of the neighboring building is set at 2H—especially when the distance to neighboring buildings is set at 0.5H or H—the average wind pressure coefficients vary significantly, depending on the wind direction angle. Moreover, we observed the above trends at roof surface Rc.

For each comparison, Figure 18 displays the differences in the wind pressure coefficients between the windows on the wall of the master bedroom (= southern window – eastern window). In all cases, the effect of the neighboring building is greater compared to the change in the average wind pressure coefficients at the wind angle of 90°, where wall surface C is on the upwind side. In cases where the difference in the wind pressure coefficients can hardly be guaranteed (depending on the conditions of the neighboring buildings), initially in the design phase, it is essential to carefully plan for windows that consider the surrounding situations.
In the previous section, we clarified the effects of altering the height and distance of neighboring buildings on the average wind pressure coefficients for each surface. The change in the maximum differences in the wind pressure coefficients between the windows of each room (which we studied using a model building) highlights the importance of accurately grasping the conditions of nearby buildings. In this section, we continue to examine the impact of modifying the height and distance of neighboring buildings on ventilation facilitators (e.g., courtyards and roof monitors).

5.1 Verifying the effects of a courtyard on ventilation
Hoshino et al. confirmed that even in a dense residential block, a middle court surrounded by walls on all four sides is always kept under negative pressure, and the window facing the middle court provides a stable outlet. However, it is difficult to set up a middle court in a narrow house owing to the limited space available.
to the limitations of the layout. On the other hand, actual measurements suggest that it is possible to devise a stable ventilation path—even in a small home—if the airflow characteristics of a courtyard (which is surrounded by walls on three sides and external space on the other), as seen in a townhouse in Kyoto, are clarified. Thus, we determined the distribution of wind pressure coefficients in the courtyard using the WT tests. The measurement target is a two-story home with a rectangular plane and a flat roof (Figure 19). The surrounding buildings are distributed in a simplified dense manner at a gross BCR of 33%. The height and distance of the neighboring buildings facing the courtyard are diverse (Figure 20).

For each measurement, Figure 21 depicts the average wind pressure coefficients in the courtyard, as well as the maximum differences (absolute value) of the wind pressure coefficients between the courtyard and the wall surface facing the outside. The negative pressure inside the courtyard is greater when the height of an adjacent building is lower than the measurement model, but when the height is 2H, the pressure inside the

Figure 20. Overview of the WT tests (the courtyard)

Figure 21. Average wind pressure coefficients on the courtyard surface and maximum ΔCp between the courtyard and another wall for all wind directions

Figure 22. Measurement model of shed roof/roof monitor
The distances to neighboring buildings are fixed (H)

270°
(Surface D)

Changing the height of an adjacent building (surface B) 01, 2H

0°
(Surface A)

Changing the height of an adjacent building (surface A) 01, 2H

180°
(Surface C)

Changing the height of an adjacent building (surface C) 01, 2H

The distances to neighboring buildings are fixed (H)

Figure 23. Overview of the WT tests (shed roof/roof monitor)

Table 6. Test cases of the WT tests (shed roof/roof monitor)

<table>
<thead>
<tr>
<th>Equal height</th>
<th>Neighboring building’s height on surface A side: 2H</th>
<th>Neighboring building’s height on surface B side: 2H</th>
<th>Neighboring building’s height on surface C side: 2H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shed roof (without roof monitor)</td>
<td>○○○○</td>
<td>○○○○</td>
<td>○○○○</td>
</tr>
<tr>
<td>Shed roof (with roof monitor)</td>
<td>○○○○</td>
<td>○○○○</td>
<td>○○○○</td>
</tr>
</tbody>
</table>

courtyard is positive owing to the reverse flow. However, even when the inside of the courtyard contains positive pressure, a relatively large difference in the wind pressure coefficients occurs between the wall surface facing outside and the wall facing the courtyard. This suggests that the ventilation route can be designed with the window facing the courtyard as a stable outlet. On the other hand, when the height of an adjacent building on the upwind side is modified, the negative pressure inside the courtyard will be greater if a neighboring building is taller. When the wind angle is 45° and an adjacent building has a height of 2H, the greatest amount of negative pressure is applied, and a large difference in the wind pressure coefficients occurs between the walls facing the outside of the building and the courtyard.

Therefore, an effective ventilation route through the courtyard can be arranged if the dominant wind is correctly grasped owing to the neighboring buildings’ conditions.

5.2 Verifying the effects of a shed roof and a roof monitor on ventilation

To maximize the use of sunlight or solar heat, many houses adopt a shed roof. In contrast, owing to the azimuthal nature of a shed roof compared to a flat or gabled one, it is necessary to grasp the dominant wind direction at the site owing to the condition of the neighboring buildings. Moreover, it is vital to understand the airflow characteristics of a roof monitor (an airflow and lighting device often found in traditional Japanese homes) on the shed roof for successful cross ventilation. Figure 22 shows the model that measures wind pressure. We gauged the wind pressure coefficients at each wind direction angle when we altered the height of a neighboring building (H or 2H). We determined the airflow characteristics of the shed roof and the roof monitor by placing the surrounding buildings in a simplified dense manner around the model at a gross BCR of 33%. Figure 23 shows the WT tests, and Table 6 lists the test cases.

Figures 24 and 25 portray the effects of modifying a neighboring building’s height on the roof surface for each case of measurement, with and without the roof monitor. As shown in Figure 24, the roof surface (R) is relatively stable and negative in all cases when there is no roof monitor. The fluctuation in the average wind pressure coefficients of the roof surface, caused by the change in the wind angle, is the smallest when a neighboring building on the side of wall surface A is higher (represented by ● in the figure). On the other hand, when a neighboring building on the side of wall surface C is higher (represented by ■ in the figure), the average wind pressure coefficient acting on the roof (surface R) is positive when the wind direction angle is −22.5° to 22.5°. As depicted in Figure 25, even with a roof monitor, the average wind pressure coefficient on the roof surface (R) is almost the same as that

![Surface R (without roof monitor)](image-url)
Figure 25. Average wind pressure coefficients on each surface for all wind directions (shed roof with roof monitor)
without a roof monitor. However, the sides of the roof monitor (Ra–Rd) are different from the building walls and are subject to substantial positive pressure when they are on the upwind side. In addition, the average wind pressure coefficients on Rd are almost the same when the neighboring building on the side of wall surfaces A–C side is taller. This implies that if a window on the side-wall of the roof monitor is provided, it would be necessary to consider the condition of an adjacent building facing the window of the roof monitor, as well as the dominant wind direction. In contrast, surface Rt has the most stable negative pressure, although there is some variability in the wind direction. As demonstrated in Section 4, in a dense residential block, it is difficult to maintain an effective difference in the air pressure coefficients between the walls. Meanwhile, it is easy to sustain an effective difference in the air pressure coefficients between the walls and the roof monitor. Thus, a roof monitor is helpful for cross ventilation in a dense residential block. Although, as shown by Kobayashi et al., it is important to understand the ventilation features of the roof monitor by considering the effects of ventilation resistance, as well as the difference in the wind pressure coefficients (the ventilation’s driving force), this study aims to go further by creating a database of wind pressure coefficients that is meaningful for the designer. Hence, the primary purpose is to shed light on the impact of the wind pressure coefficients, which affect the sides and tops of the roof monitors, depending on the conditions of the neighboring buildings.

6. Conclusions

In this study, to achieve efficient use of cross ventilation in dense residential blocks, we derived the following findings from WT experiments using the average gross BCR in a dense residential block, as determined using a density survey of actual residential blocks.

1. As there is a strong correlation between the gross BCR and the average wind pressure coefficients affect each surface, it is possible to predict the average wind pressure coefficients at other gross BCRs based on a specific gross BCR.

2. If the target building is located at the corner of the city block, it has an advantage of cross ventilation owing to the positive pressure on the wall surface, if the roadside surface is on the upwind side, as opposed to the other shapes and locations in the city block. In a dense residential block, there is no significant difference in the mean wind pressure coefficients for each surface when the surrounding models are distributed in a simplified dense manner and the building is located at the center of the model block.

3. Relatively greater negative pressure acts on a shed roof (vs a flat roof). For a hipped roof, a large difference in the wind pressure coefficients between the gabled and long sides of the roof can be guaranteed.

4. The average wind pressure coefficient acting on the wall on the upwind side is significantly affected by the condition of the neighboring buildings when the circumstances of the adjacent buildings along the short side are altered. Likewise, modifying the situation of the neighboring buildings along the long side affects the average wind pressure coefficient on the upwind side-wall, but the impact is somewhat mitigated owing to the shape of the gabled roof. However, when we verified the maximum difference in the wind pressure coefficients between the windows of each room in a model building, the change caused by the effect of the conditions of the nearby buildings is greater than that of the average air pressure coefficients acting on each surface. Hence, initially in the design phase, it is vital to prepare the windows carefully, considering the circumstances of the surrounding buildings.

5. If the dominant wind direction of sites and the conditions of neighboring buildings can be correctly apprehended, an effective difference in wind pressure coefficients occurs between the windows facing the courtyard and the windows facing the outside in a narrow house. Moreover, a ventilating route through the courtyard can be planned.

6. The surface of a shed roof is stable and subject to negative pressure, regardless of whether or not it has a roof monitor. On the other hand, the side of the roof monitor differs from the building wall, and there is a large positive pressure on the upwind side. In addition, the upper surface of the roof monitor is subject to considerable negative pressure. Therefore, even in dense residential blocks where it is difficult to maintain a beneficial difference in the wind pressure coefficients between the walls and the roof monitor, an effective difference in wind pressure coefficients can be sustained, between the walls and the roof monitor.

We will continue to improve the database of wind pressure coefficients for dense residential blocks to provide meaningful information for designers in future studies.

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