15th World Congress on Computational Mechanics (WCCM-XV)
8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII)
Virtual Congress: 31 July – 5 August 2022
S. Koshizuka (Ed.)

# LES ANALYSIS OF VENTILATION PERFORMANCE AND WIND GUST OCCURRENCE FOR STRATEGIC URBAN TRANSFORMATION

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**Key words:** LES, Urban Transformation, Ventilation, Wind Resilience

**Abstract.** *In order to achieve desirable urban redevelopment in the near future, various transformation strategies were investigated using LES, focusing on their impact on ventilation performance and wind gust generation. This study evaluated the replacement of city blocks with high-rise buildings, replacement with mid-rise buildings lower than the surrounding area, and simple multi-building arrangements utilizing the prevailing wind direction.*

## 1 INTRODUCTION

Ventilation performance is a critical environmental factor in urban spaces that has been gaining importance in recent years in the context of reducing heat stress on human bodies and exposure to chemical substances or pathogens, as well as improving the efficiency of urban energy consumption. Cities will gradually change their form and function over time, reflecting social needs, and in near-future urban designing, it is most likely that achieving compatibility between ventilation performance and disaster resistance against extreme weather such as violent typhoons become essential. Therefore, it is desired to systematically examine possible transformation strategies for actual, complex city areas and accumulate knowledge on the effect on ventilation performance and disaster risk of various urban configurations including shape, arrangement, and density of buildings.

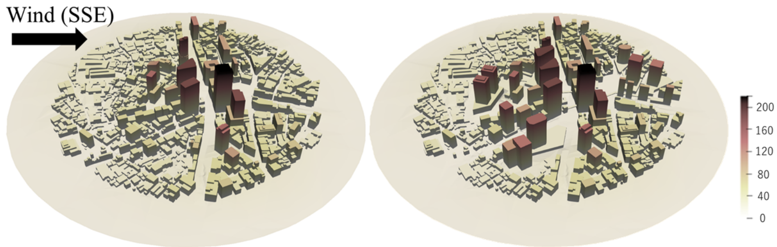
In this study, we performed high-resolution large eddy simulations (LES) focusing on an actual densely built-up urban area of Shibuya district in Tokyo, Japan, with various possible transformation of urban spaces and investigated near-ground ventilation performance improvement and occurrence of strong wind gusts.

## 2 METHOD

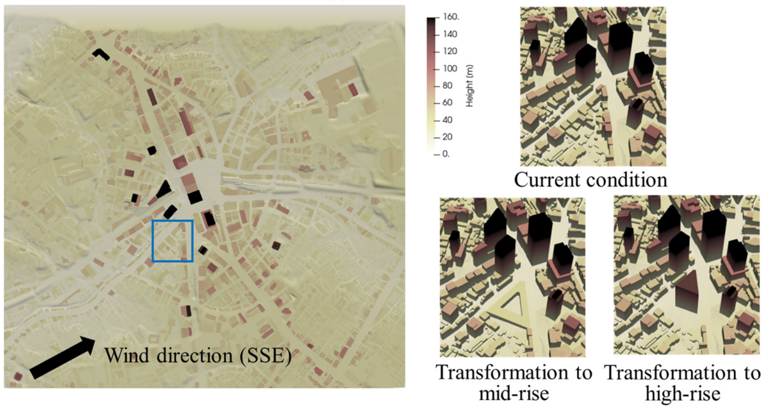
### 2.1 Overview of the cases

Three different series of numerical analyses were performed. In Series 1, we analyzed the effect of a conventional redevelopment approach of urban area, that is, mid-rise building blocks are converted into a small number of high-rise buildings. The approach was applied to the entire urban area (Figure 1 (a)). In Series 2, one mid-rise urban block in the city center was selected for study and tested a new urban transformation strategy, in which the urban area is replaced by a single mid-rise building of equivalent volume with a lower height than surrounding buildings (Figure 1 (b)). A courtyard-type open space is provided to the building from architectural planning considerations. Comparisons were made with the current situation and the conventional high-rise redevelopment scenario, focusing on the flow patterns. In Series 3, another densely built-up mid-rise urban block adjacent to the city center was selected and transformed into 2 types of simple low- to mid-rise building blocks (Figure 1 (c)). A comparison was made between the case in which the taller buildings are aligned parallel to the prevailing wind direction and the orthogonal case.

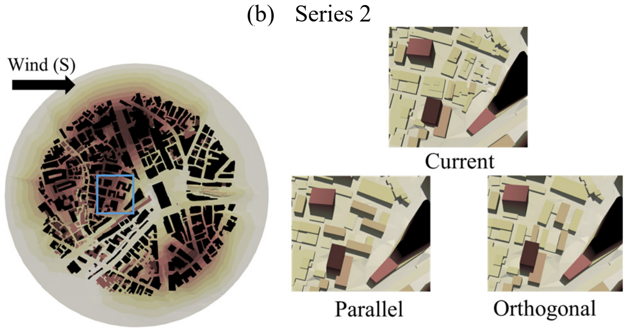
The ground surface models for those cases were created by combining building shape data obtained from high-resolution satellite imagery and topographic data in 5-meter resolution provided by the Geospatial Information Authority of Japan (GSI).




(a) Series 1




(b) Series 2




(c) Series 3

**Figure 1:** Ground surface model

## 2.2 Numerical simulation

LES of the urban area was performed with the flow solver CUBE[1] developed by RIKEN R-CCS, which has an outstanding load balancing performance in large-scale parallel calculations owing to multi-block hierarchical cartesian grid system and is capable to calculate flows around complex geometries with implimentation of immersed boundary method.

The inflow conditions for Series 1 and Series 3 were created by LES in a driver region using quasi-periodic boundary condition based on the method of Nozawa and Tamura[2]. Turbulence profile over an urban area (power-law index $\alpha = 0.20$) was reproduced.

Series 2 was calculated using inflow turbulence that includes structures of an actual meteorological disturbance. Detail structure of Typhoon Hagibis (2019) was firstly simulated using Japan Meteorological Agency non-hydrostatic model (JMA-NHM)[3] with three domains at the resolutions of 1 km, 250 m, and 50 m. Subsequently, High-frequency components were regenerated to the meteorological field of the actual typhoon using the method of Kawaguchi, Tamura et al[4]. Then, the obtained result was introduced to the preliminary LES of the urban area at 1.5-m resolution, where the domain of 6km*3km around the target was replicated with the ground surface model. The inflow data for the west, south, and east boundaries of the final urban area LES were prepared.

Due to the difference in the preparation method of inflow turbulence, the cases were performed with models of different scales, but the results are shown in the actual scale in this paper. In all cases, the final LES was executed with a minimum resolution of approximately 90 cm, and the total number of grids was in the range of 300 to 400 million. An example of grid distribution is shown in Figure 2. As for the numerical schemes, the second-order central difference was used for spatial discretization. (5% first-order upwind difference was added for the advection term.) The Crank-Nicolson method was used for time integration. The time increments were set so that the Courant number would not exceed 1.

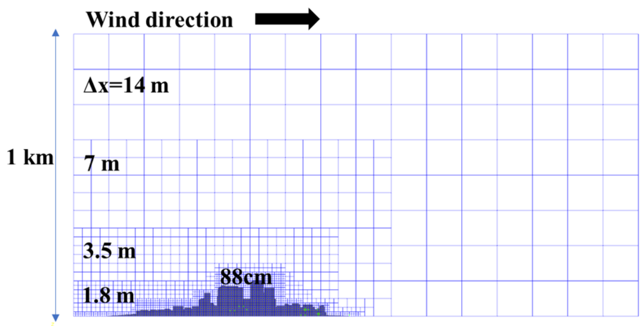



**Figure2:** Example of grid resolution distribution (Series 3, orthogonal)

## 3 RESULT OF SERIES 1 (HIGH-RISE REDEVELOPMENT STRATEGY)

Figure 3 shows the distribution of mean wind speed and maximum wind gust at about 50 m above ground level (AGL) over the evaluation time (466.5 s) in Series 1.

As a qualitative change due to replacing mid-rise building blocks with fewer high-rise buildings, mean wind speed increased significantly at locations where high-rise buildings line up in the stream-wise direction as shown by white arrows due to the effects of the contracted flow and successive downwash. In such locations, ventilation performance increases, but wind risk is also likely to increase. In contrast, both ventilation performance and wind risk were deteriorated in downstream of the buildings aligned orthogonal to the wind direction (white circles), by decreased wind speed and intensified maximum gust. In the area indicated by red circle, maximum gust speed was drastically decreased, as location of prominent downwash was moved to upstream high-rise buildings.

Figure 4 shows the comparison of the spatial distributions and the histgrams of average wind speed at 20 m AGL (in the vicinity of the ground). Replacement of the mid-rise buildings with a small number of high-rise buildings allowed more space on the ground, increasing the mean wind speed from 7.7 m/s to 9.2 m/s by 21% over the entire inspection area (the region within a radius of 400 m from the center of the ground surface model). This result suggests that conventional approach of high-rise redevelopment can improve ventilation performance in the near-ground region.

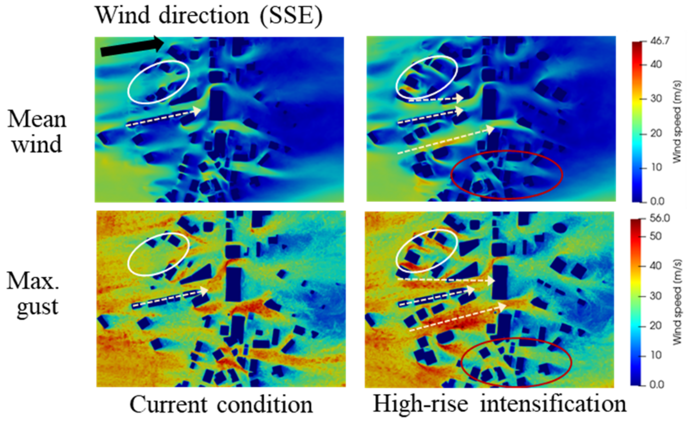



**Figure 3:** Mean wind speed and maximum wind gust at about 50 m AGL in Series 1

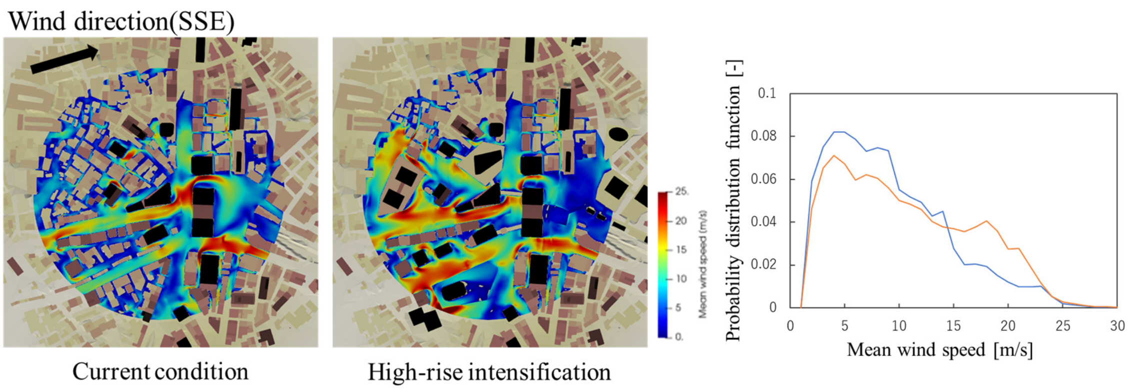


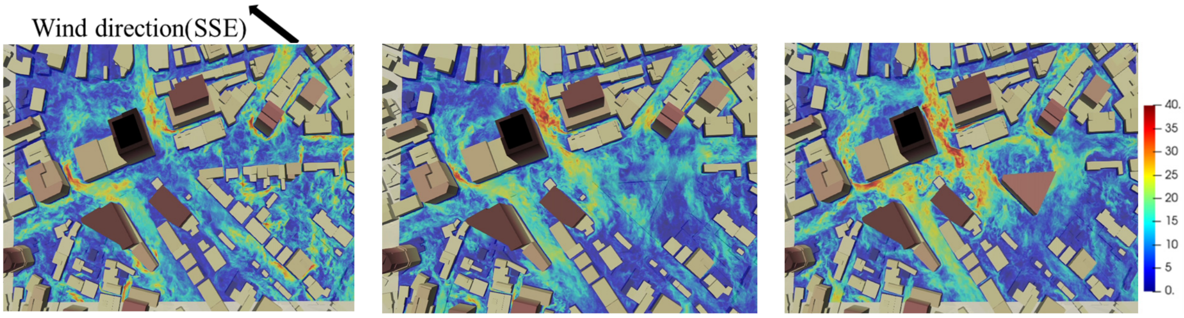

**Figure 4:** Spatial distribution and histogram of mean wind speed at about 20 m AGL in Series 1

## 4 RESULT O SERIES 2 (MID-RISE REDEVELOPMENT STRATEGY)

Figure 5 shows visualizations of typical instantaneous wind field of each case in Series 2. In the current condition, small vortices were randomly generated due to the inhomogeneous geometry of the mid-rise buildings, and no organized flow pattern was observed in the street behind the buildings, which suggests relatively poor ventilation performance.

In the case of the replacement with mid-rise, larger-scale wind fluctuation coming from the upstream was smoothly transported inside the urban area. It is expected that by limiting the building height lower than the surrounding buildings, large-scale wind velocity fluctuations and air of upper canopy layer is introduced inside the urban area and wind speed is recovered to some extent.

In the case of the replacement with high-rise, the vortices induced by the high-rise buildings periodically change wind speeds and promote ventilation of the space around the buildings.




(a) Current condition (b) Transformation to mid-rise (c) Transformation to high-rise

**Figure 5:** Typical instantaneous flow fields at about 20 m AGL in Series 2

Figure 6 shows the distribution of mean wind speed and maximum wind gust at approximately 20 m above ground level over the evaluation time (300 s) in Series 2. By replacing the urban block with a mid-rise building, wind speed moderately increased behind the building, while downwash around high-rise buildings moved downwind. In case of the transformation to the high-rise building, a significant increase of both mean wind and maximum gust speeds were observed locally around the building.

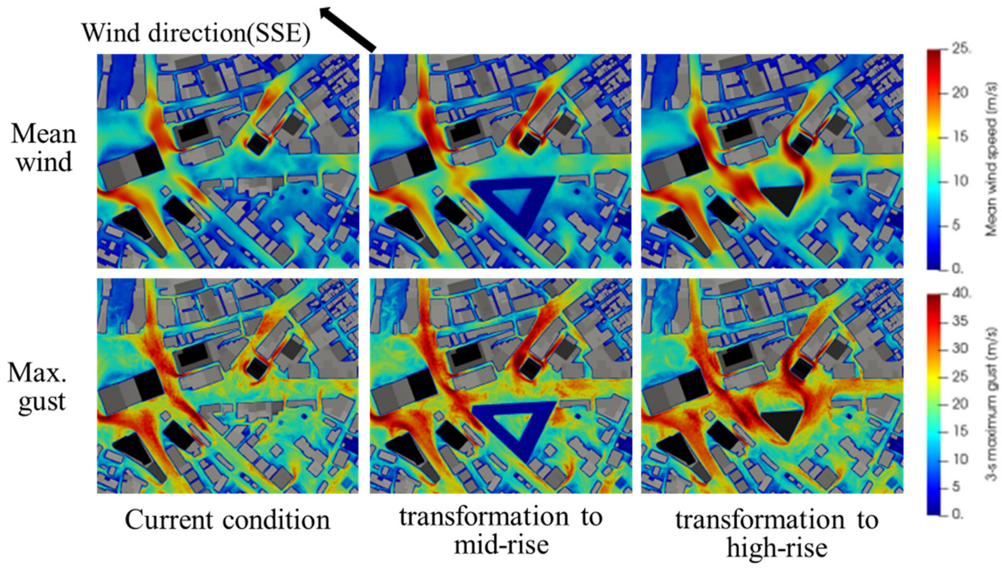



**Figure 6:** Mean wind speed and maximum wind gust at about 20 m AGL in Series 2

## 5 RESULT OF SERIES 3 (BUILDING ORIENTATION RELATIVE TO THE WIND DIRECTION)

Figure 7 shows the stream lines colored by height in the target area of Series 3. In the current situation, the flow in the upper canopy layar hardly interacted with near-ground flow. Its height was nearly constant. In the case where taller buildings are parallel to the wind direction, stronger flows were made between the buildings due to flow contraction and they change height along the stream line due to the layout of the lower buildings. In the orthogonal case, downwash and swirling flow around the taller building was distinctly observed.

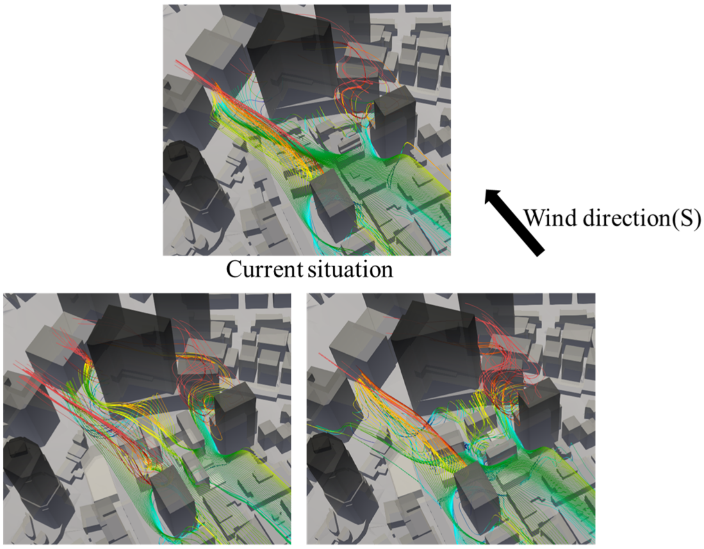



**Figure 7:** Stream lines of each case in Series 3

Figure 8 shows the distribution of mean wind and maximum gust at 20 m AGL in the target area over the evaluation time (600 s). In orthogonal case, both of mean and maximum gust wind speeds were higher in the street at near-ground level due to occurrences of strong downwash, while the parallell case showed fair ventilation across the area including small spaces between buildings, possibly because the wind speed in the upper canopy layer is maintained by flow contraction and small and local height difference along the stream direction sufficiently promoted vertical circulating flow.

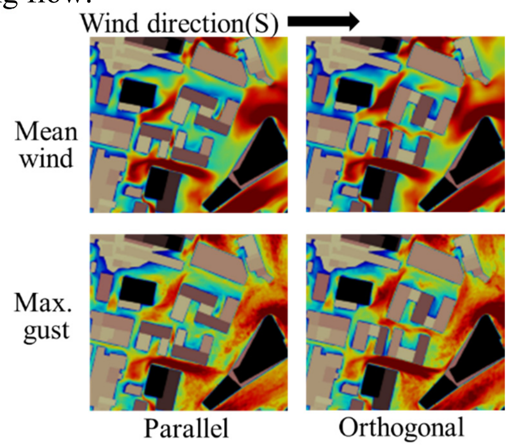



**Figure 8:** Mean wind speed and maximum wind gust at about 20 m AGL in Series 3

## 6 CONCLUSIONS

This study evaluated ventilation performance and wind gust generation in various cases of transformation of urban area. Replacement of city blocks with high-rise buildings, replacement with mid-rise buildings lower than the surroundings, and simple multi-building arrangements utilizing the prevailing wind direction were examined.

From Series 1, it is concluded that ventilation performance and gust generation near the ground are significantly affected by high-rise building arrangement with respect to inflow direction. Conventional high-rise redevelopment approach generally increases near-ground wind speed. These results suggest that consideration of prevailing winds may be effective for controlling ventilation performance and gust occurrence and they can be optimized by the building arrangement in the urban area.

In Series 2, mid-rise transformation strategy was examined, focusing on the flow patterns in the target area. This strategy moderately improved ventilation, avoiding occurrence of intense unsteady wind as is the case of high-rise redevelopment. However, it can intensify downwash of the high-rise buildings in the downwind area, so careful consideration is required for selecting the location of implementation.

In Series 3, the effect of building orientation relative to the prevailing wind direction was investigated in low- to mid-rise multi-building arrangements. In the case where taller buildings are orthogonal to the wind direction, ventilation and gust occurence in the street were promoted, while the parallell case presented fair ventilation performance generally in the target area, even in small spaces surrounded by buildings.

## ACKNOWLEDGMENTS

This work used computational resources of the supercomputer Fugaku provided by RIKEN through the HPCI System Research Projects (Project ID: hp210158, hp210262).

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