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# Numerical prediction of wind pressure around a high-rise residential building in urban area by means of LES based on lattice Boltzmann method

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## SUMMARY

We carried out large eddy simulation of fluid flow around the high-rise residential building with double corner recessions and chamfered corners in city blocks. As the numerical method of LES we adopted D3Q27 cumulant lattice Boltzmann method in Cartesian mesh combined with an octree-based grid refinement with Smagorinsky model and wall model. We successfully reproduced the rough-wall turbulent boundary layer with power index of 0.2. The mean, standard deviation, maximum and minimum peak wind pressure coefficients obtained by LBM for the target building in case of wind angle of 90 degrees were confirmed to fall within approximately ±20% of the experimental results.

***Keywords:*** *large eddy simulation, lattice Boltzmann method, peak wind pressure, chamfered corner, corner recession*

## 1. INTRODUCTION

In recent years, the Lattice Boltzmann Method (LBM) has begun to be used in wind environment and automotive aerodynamics because LBM is an explicit numerical method, which is suitable for large-scale parallel computers, such as GPU computers. However, there is a few previous studies evaluating peak wind pressure coefficients for assessing wind load for cladding of buildings in turbulent boundary layers using LBM. Therefore, this study aims to clarify computational accuracy by performing LES based on Lattice Boltzmann Method on wind pressure of high-rise residential buildings in city blocks.

## 2. MODEL

The entire measurement section of the boundary layer wind tunnel in Kajima Technical Research Institute was reproduced as the computational domain as shown in Figure 1. In order to generate the inflow turbulence approaching to buildings with power index of 0.2, a saw, spires and roughness blocks with the same shape and arrangement as the actual wind tunnel test apparatus were used. The target building was a high-rise residential building featuring a height $H$ of 128m and a reference width $B$ of 43m surrounded by low-to-mid-rise urban area within a 400m radius (T. Tamura et al., 2019). The high-rise residential building has varying plan shapes at different heights. The target building has double corner recession, chamfered corner and external balcony. These building models were created at a scale of 1:400. The wind direction angle was set to 90 degrees (east wind), directly facing the east wall of the target building. A uniform flow of 12.1 m/s was applied to the inflow boundary condition of the computational domain in order to set the wind speed ($U_{\mathrm{H}}$) at the building height (0.32m) of the target building model to 10 m/s.

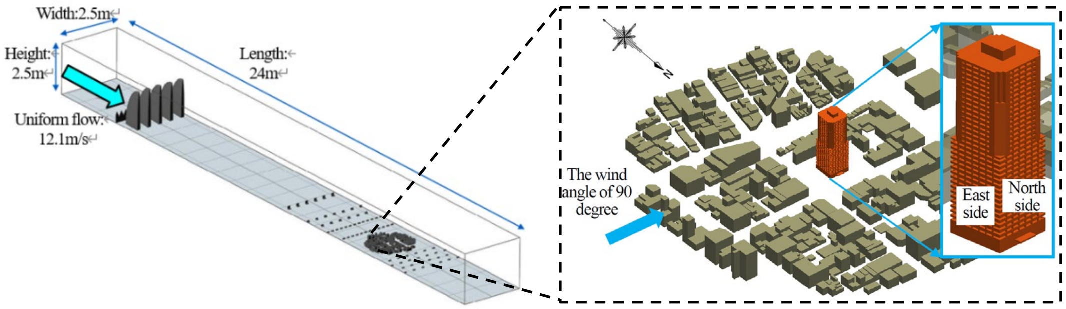


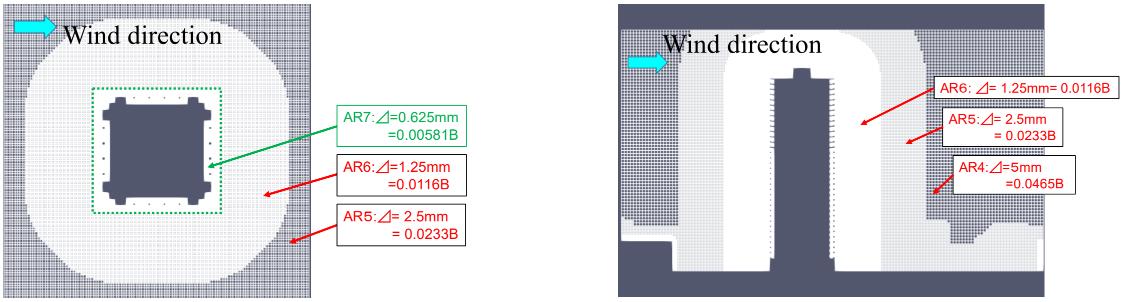
Figure 1: Computational model of wind tunnel and the target building surrounded by low-to-mid-rise urban areas

## 3. COMPUTAIONAL METHODS

In order to carry out LES based on the Lattice Boltzmann Method, we used the software named ultraFluidX (Christoph A. Niedermeier et al., 2018). The D3Q27 model was used for discretizing the three-dimensional velocity distribution function. It obtains the LBM collision operator based on Cumulants with an LBM-consistent Smagorinsky model and a wall modeling technique. The Cartesian LBM base mesh is combined with an octree-based grid refinement. Based on a relatively coarse Cartesian background grid, the mesh is consecutively refined towards the obstacle surface. The computations were conducted on a single Linux workstation equipped with eight Tesla V100-SXM2-16GB GPUs interconnected via NVLink.

## 4. COMPUTATIONAL CONDITIONS

The computational grid around the target building is shown in Figure 2. The maximum grid width within the analysis domain is 80 mm (0.744*B*’). The surface grid width for the turbulence generator is 2.5 mm, and the grid width on the target building surface is 0.625 mm (0.00581*B*’). The time integration interval is set to 0.000611 seconds (1637 Hz), matching the finest grid.



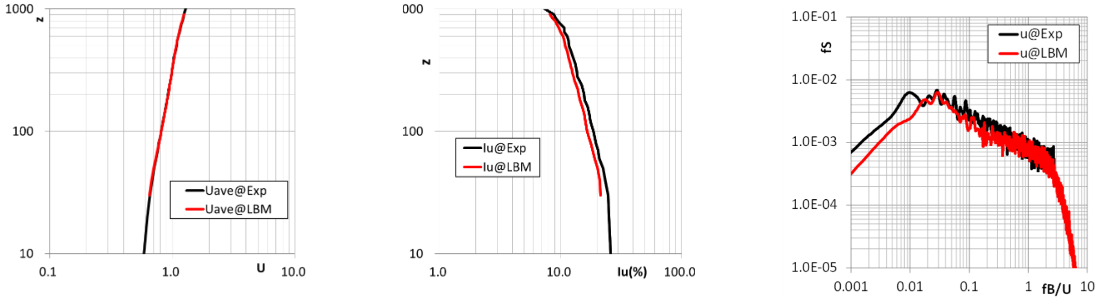
(a) Horizontal view at the height of 270mm (0.84*H*‘) with double corner recession

(b) Side view of the target building in central cross section of computational domain

Figure 2: Grid distribution around the high-rise residential building in the wind angle of 90 degree

## 5. REPRODUCIBILITY OF APPROACHING FLOW IN LBM

In this section, it is confirmed that the reproducibility on statistics of the rough-wall turbulent boundary layer with power index of 0.2, which approaches to the target buildings. We measured the vertical profile of the mean streamwise wind speed $U(z)$, streamwise turbulence intensity (the ratio of standard deviation of $u(z, t)$ to $U(z)$ and the power spectrum density function of $u(H, t)$ at 1m upwind from the center of the target building's position (the upwind edge of the surrounding the city blocks) without the target building and the city blocks as shown in Figure 3. The sampling ratio of hot-wire anemometer is 1000Hz. The mean wind speed in LBM agrees well with the experimental results. The streamwise turbulence intensity of LBM is a little smaller than that of the experiment. The LBM underestimated the power spectrum density function of streamwise fluctuating wind speed compared to experimental results in the frequency range below 0.02 of the dimensionless frequency ($fB/U_H$). This caused the underestimation of the streamwise turbulence intensity in Figure 3(b).



(a)Streamwise mean velocity (b) Streamwise turbulence intensity (c)Power spectrum density function of streamwise velocity at the height of 0.32m

Figure 3: Statistics of approaching flow at 1m upwind from the center of the turn table

## 6. NUMERICAL ACCURACY OF WIND PRESSURE OF HIGH-RISE RESIDENTIAL BUILDING

The wind pressure coefficient on the target building is normalized by $U_H$. Figure 4 shows the correlation diagram for the mean, standard deviation, maximum peak and minimum peak values of the wind pressure coefficients between LBM and experiment. Regarding the maximum positive mean wind pressure coefficient, the LBM results reproduced the experimental results well. It indicates that the mean wind pressure at stagnation points was nearly identical. Considering that the LBM's negative mean, standard deviation, maximum peak and minimum peak value generally fall within ±20% of the experimental results (inside the dashed area in Figure 4), we confirm the validity of numerical accuracy on the wind pressure by means of LBM. However, for some measurement points, the LBM underestimated the maximum peak wind pressure coefficient, which experimentally ranges from 0.5 to 1.2 as shown in red dashed line of Figure 4(c). These measurement points are located on the wall parallel to the windward wall (east wall) in corner recesses and on the windward corners of walls inside balcony of a lower floor.

## 7. CHARACERISTICS OF WIND PRESSURE OF HIGH-RISE RESIDENTIAL BUILDING

We examine the reproducibility of the circumferential spatial distribution of wind pressure coefficients at representative measurement levels as shown in Figure 5. The characteristic variation in the mean, standard deviation, maximum, and minimum peak wind pressure coefficients computed by LBM show good agreement with experimental results, except for below some areas near the windward corner.

Regarding the double corner recession at the windward corner of the 30th floor (east wall) in Figure 5(a), the LBM underestimated the maximum peak pressure on the wall parallel to the east wall near the north or south wall, because it is considered that the velocity of the separated flow reattaching to the east wall in case of LBM is smaller than that of experiment due to the coarse mesh around the double corner recession. On the other hand, focusing on the chamfered corner in the windward corner of the 26th floor in Figure 5(b), the variation characteristics of the maximum peak pressure and mean value from LBM matched the experimental results. LBM underestimated the standard deviation and the absolute value of the minimum peak pressure, because the local vortical flow on the chamfered corners could not be resolved computationally due to the coarse mesh.

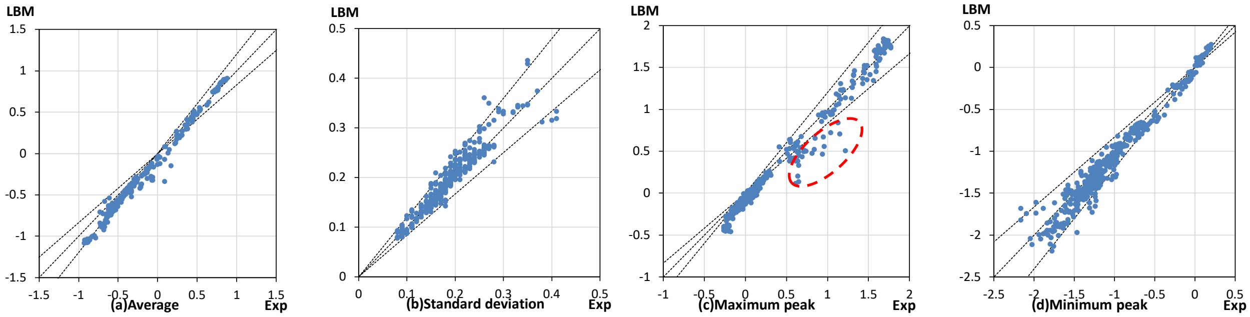
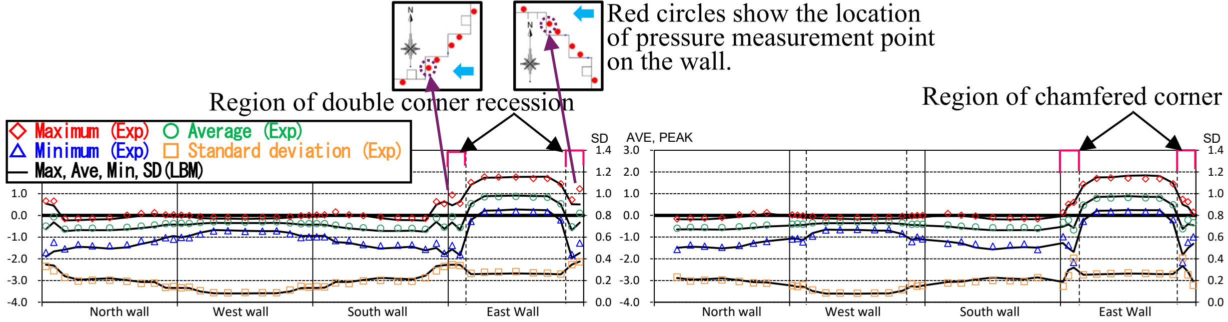


Figure 4: Comparison between statistics of surface pressure coefficients of LBM and experiment (EXP) in the wind angle of 90 degree



Red circles show the location of pressure measurement point on the wall.

Region of double corner recession

Region of chamfered corner

(a) 30th floor (z =108.2m) with double corner recession

(b) 26th floor (z =94.2m) with chamfered corner

Figure 5: Comparison of surface pressure distribution between LBM and Experiments in the wind angle of 90 degree (color circle : experiment, black line : LBM)

## 8. CONCLUSIONS

The reproducibility of LES based on lattice Boltzmann method on statistics of the rough-wall turbulent boundary layer approaching to the target buildings with power index of 0.2 was good by using a saw, spires and roughness blocks with the same shape and arrangement as the actual wind tunnel test apparatus. Numerical wind pressures of the high-rise residential building in the city blocks by LBM were good agreement with experimental values except for part of maximum peak pressure on the windward corner recessions and part of minimum peak pressure and standard deviation of pressure on the windward chamfered corner.

## REFERENCES

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