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Impact of surroundings on the local peak pressure in high-rise building clusters

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SUMMARY:

This study contributes to the field of wind engineering by evaluating the local peak pressure coefficients in a generic high-rise building cluster. Unlike previous studies that have focused on isolated buildings or buildings in tandem arrangements, this research considers the impact of four buildings when surrounding the principal one. Both experimental and numerical techniques are applied, demonstrating the capabilities of the LES method in predicting the local peak pressure. The obtained results offer new insights into the complex interplay between buildings and the wind environment in high-rise building clusters, especially in the roof zone. The experiments reveal higher peak suctions for the building in the group than the isolated at all wind angles. The minimum negative peak pressure coefficient of 5.8 is recorded at a 45° wind angle. Validation of the obtained numerical results shows the promising potential of the LES as a design tool in wind engineering, providing higher resolution of the quantities of interest.

Keywords: Wind tunnel measurements, LES, Peak pressure

1. INTRODUCTION

High-rise building clusters appear as a response to the contemporary planning challenges provoked by urban development. These configurations trigger relatively complex wind flow behaviour, which is reflected in the surface pressure distribution. Many researchers investigated the impact of the surroundings through the interference effects, focusing mainly on the pressure statistics on the building facade, while the roof zone stayed less explored. The vast majority of these studies were experimental, while in the past few years, the use of numerical methods was in increase. The Large Eddy Simulation (LES) method was marked as the leader in its capacity to predict the wind flow and underlying physics (Blocken, 2015).

This study evaluates the impact of surrounding buildings on local peak pressure in densely populated urban areas with high-rise building clusters. It compares two building configurations: an isolated high-rise building - the principal one and a group configuration consisting of four buildings surrounding the principal one. The values of the local peak pressure coefficients are analyzed from the available wind tunnel experiments for two configurations at four wind angles (0°, 15°, 30° and 45°), with special attention to the roof zone. Besides, LES simulations at two extreme wind angles (0° and 45°) are conducted as well. Thus, the study explores the potential in predicting peak pressure by the LES method throughout validation. Moreover, by using the main numerical advantage (higher resolution of all quantities of interest), the study aims to sheds some light to the complex flow behaviour that surrounding buildings create in the roof zone above the principal building.

2. METHODOLOGY

2.1. Building model and configurations

The high-rise building model and configurations used in both the experimental and numerical parts of the study are shown in Fig. 1. The square-base building model with a height (H) to width (B) ratio of 1:3 corresponds to a 120 m high-rise building at full-scale. Two configurations are included in the study: one with the isolated building model (marked as $Conf.1$ in Fig. 1(a)) and one group configuration with four geometrically identical buildings surrounding the principal one (marked as $Conf.2$ in Fig. 1(a) and Fig. 1(b,c)). Four angles of the approaching wind (α) are included in the experimental analyses (0°, 15°, 30° and 45°), while only two are investigated numerically (0° and 45°).

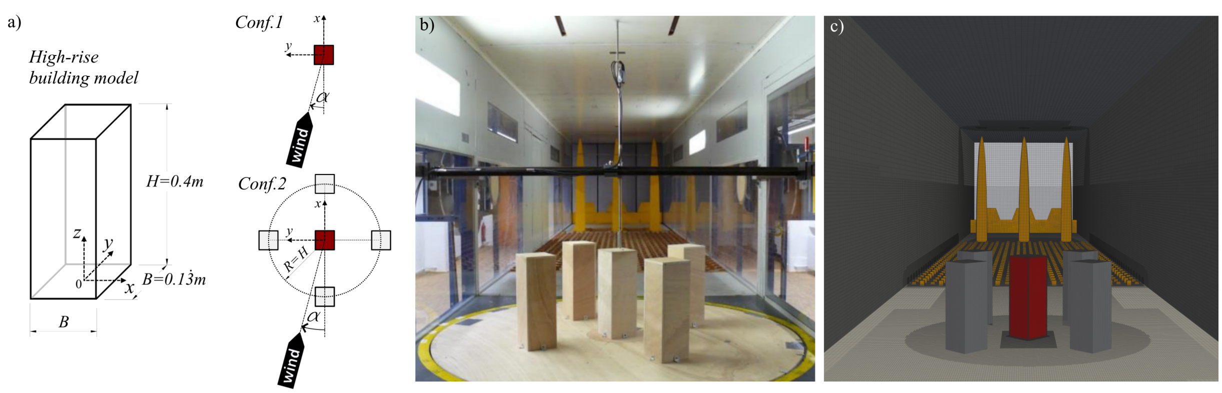

Figure 1. The geometry of the high-rise building model and configurations (a); group configuration: experimental setup (b) and computational domain (c).

2.2. Wind tunnel measurements

Experimental measurements have been conducted in the atmospheric boundary layer wind tunnel at Ruhr University, Bochum, Germany. The spire-roughness technique is applied, and the incident mean velocity profile matches a power law with an exponent of 0.2 and reference velocity of U_{ref} = 16 m/s at $(0,0,H)$. Surface pressure has been recorded using piezoresistive pressure sensors, installed in 64 taps on the top (marked in Fig. 2 and 3 with black dots) and 26 taps on the facade. More information on the experimental procedure can be found in (Hemida and Šarkić, 2014).

2.3. Numerical simulations

Numerical simulations are performed with the OpenFoam©Finite Volume open-source code applying the LES method. The sub-grid scale turbulence is modelled using The Wall-Adapting Local Eddy-viscosity (WALE) model. All schemes used for the discretisation of LES equations are second-order accurate. The computational domain represents a replica of the wind tunnel test section, with the extension of the computational region behind the building to a distance of $10H$. The domain is discretised with a hex-dominant grid, as shown in Fig. 1(c). An additional, body-fitted structured grid of 10 boundary layers at the principal building surface entails the max dimensionless wall distance y^+ below 5. The applied boundary conditions mimic the conditions in the wind tunnel, and the validation of the incident wind profile has already been published in the previous work of the authors (Vranešević et al., 2022).

3. RESULTS

The peak values of the surface pressure coefficient C_p defined by $C_p = (p - p_\infty)/(0.5\rho U_{ref}^2)$ (where p_∞ is the free-stream pressure, ρ air density and U_{ref} reference velocity) are calculated using the Cook and Mayne method (Cook and Mayne, 1980). The study reports the peak values relative to a 22% probability of exceedance, obtained by dividing the Cp signals in 10 minutes full-scale time windows, finding the most positive ($\hat{C}_p$) or negative ($\check{C}_p$) peak from each window, and fitting them to Gumbel distribution to the extreme values.

Fig. 2 gives the distribution of the $\check{C}_p$ on the roof from the experimental measurements. The highest suction peaks are recorded close to the windward edges at all wind angles. Furthermore, higher values are obtained for the group configuration ($Conf.2$) than the isolated building configuration ($Conf.1$). Fig. 3 provides an insight into the mean ($\bar{C}_p$), fluctuating (C'_p), and peak pressure coefficient over the upstream line on the roof at 0° and 45° wind angles. The effect of the surrounding buildings is evident in all three cases. Namely, lower mean suction $\bar{C}_p$ is observed in group configuration at 0°, as the upstream building produces the "sheltering" effect on principal one. Nevertheless, at both wind angles, an increase in the fluctuating pressure coefficient (C'_p) in the group configuration is recorded. It is interesting to observe a similar trend in C'_p and $\check{C}_p$, which suggests that the C'_p has a more dominant influence on the local peak pressure.

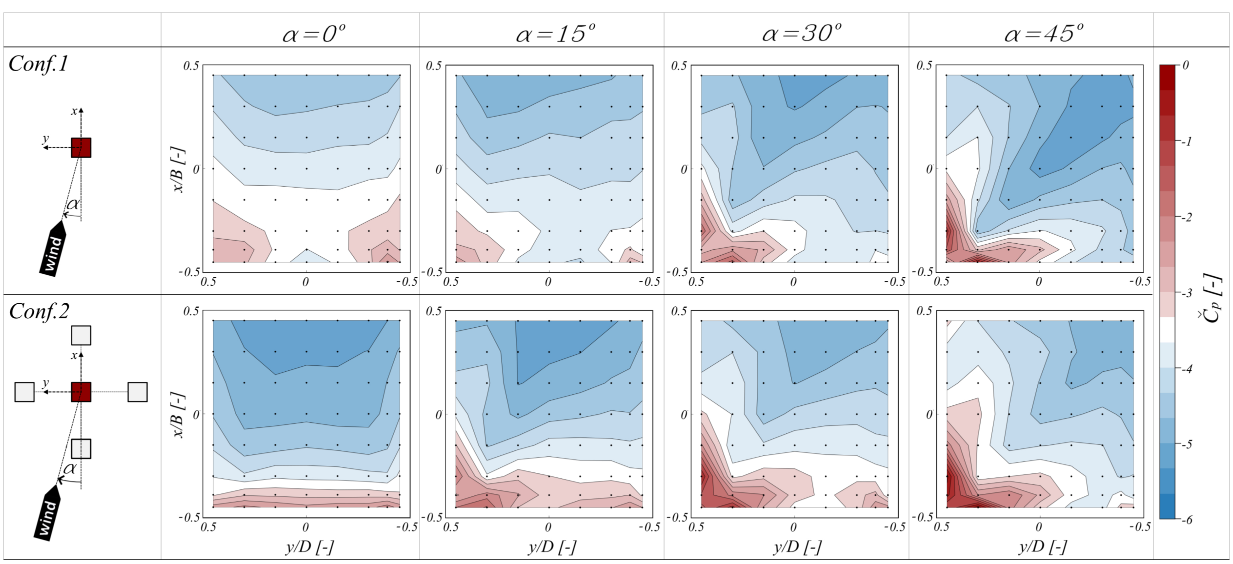

Figure 2. Experimental results of the minimum peak pressure coefficient over the roof for various wind directions in the single ($Conf.1$) and group ($Conf.2$) configurations

The surface pressure statistics from the experiments are compared with the results from the LES simulations at 90 measuring locations and presented in Table 1 for 0° wind angle. A suitable

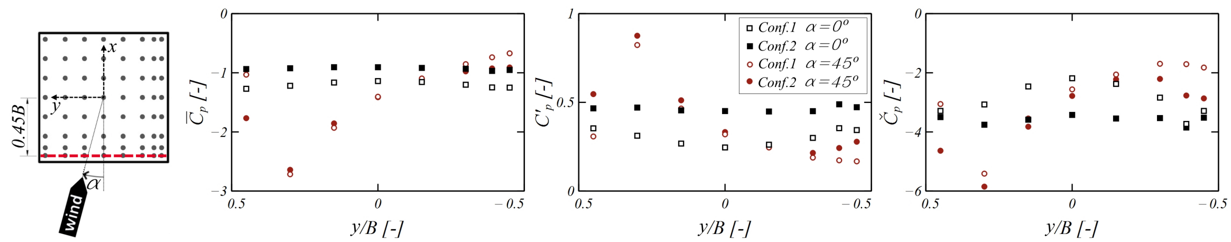

Figure 3. Mean, instantaneous and minimum peak pressure coefficient distribution along the roof's upstream line at 0° and 45° wind angles, and both single ($Conf.1$) and group ($Conf.2$) configurations.

level of accuracy is reached, showing the high potential of the LES. The presentation will provide numerical results of the peak coefficients at more locations on the roof and facade for both wind angles to identify the locations of the highest peak suctions. Future work will consider the use of other methods to obtain the incoming wind conditions to save computational time.

Table 1. Performance metrics for the pressure coefficient for two configurations at 0°.

Performance metrics	Configuration 1			Configuration 2		
[%]	$\bar{C}_p$	C'_p	$\check{C}_p$	$\bar{C}_p$	C'_p	$\check{C}_p$
10% tolerance	77.33	46.67	24.49	47.95	24.66	26.53
20% tolerance	97.33	90.67	67.35	91.78	67.12	59.18
30% tolerance	100.00	100.00	89.80	91.78	97.26	83.67

4. CONCLUSIONS

The study of the impact of surrounding buildings and approaching wing angle on the local peak pressure coefficients is conducted, with a focus on the roof area. Both experimental and numerical methods are employed for two analysed configurations: the isolated high-rise building and the group configuration of five buildings in a generic cluster arrangement. The results highlight the importance of local surrounding in the evaluation of the peak pressure coefficients since higher peak suction on the roof is recorded in group configuration at all wind directions compared to the isolated one. The validation process shows the promising prediction capabilities of the LES.

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