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Ventilation Potential Assessments for Residential Building Arrangements Based on Exceedance Probability Analysis

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ABSTRACT

In this study, the building ventilation potentials were assessed at building group level. Exceedance probability analysis was applied to estimate the uncertainties associated with the influence of climate on wind environment. The criterion was proposed based on building facade pressures. Two typical residential building arrangements were investigated. Simulation results show that facade pressure based exceedance probability are efficient in assessing the natural ventilation potentials of building groups and building height variations are important for improving building natural ventilation potentials.

KEYWORDS

Residential buildings, Ventilation potential, Exceedance probability, Facade wind pressure.

INTRODUCTION

Natural ventilation is a common adopted passive building design strategy. It can improve indoor thermal comfort and air quality by removing excess heat and airborne contaminants. Optimizing building natural ventilation design is not only related to building façade opening size and location, but also refers to the arrangements of buildings. Thus, the assessments of natural ventilation potentials require an investigation at building group level.

For building natural ventilation, wind pressure distribution of building facade is an important boundary condition, as wind is the driving force. Many studies had investigated the indoor natural ventilation in terms of wind pressures for building groups. Tsutsumi et al. (1992) experimentally studied the wind pressure on a building surrounded by a group of buildings. The relations between average wind pressure coefficients and various layouts of buildings are discussed under different wind conditions. Similar studies were also carried out by Kim et al. (2012) and Shirzadi et al. (2018). In addition, Asfour (2010) investigated the effect of building layout patterns on ventilation potential of these buildings. Six hypothetical arrangements of buildings were assessed by calculating wind pressure difference. Bady et al. (2011) carried out wind tunnel experiments to study wind pressure characteristics on groups of buildings located within high density building arrays. The results all show that buildings configuration and wind direction are important factors in determining urban ventilation. However, most studies had investigated single building under typical wind directions.

For wind environment evaluation considering the uncertain upper wind parameters, some researches introduced the probability analysis into wind performance studies. This method estimates the probability of ventilation performance satisfying certain criteria. In past researches, probability analysis had most been applied in investigation of pedestrian-level wind environment, generally focusing on wind comfort/safety issues (Blocken and Persoon, 2009; Du et al. 2017). Recently, several researchers had introduced the probability concept into other wind performance area. Pietrzyk (2008) developed a probabilistic model and

studied the problem of air infiltration in low-rise buildings. Bu et al. (2009) analyzed the exceedance probability of local air change rate and local kinetic energy for investigating the ventilation performance and thermal comfort within urban street canyons.

This study attempted to introduce probability concept into wind-driven natural ventilation area for valuating natural ventilation potentials of building groups. Exceedance probability was calculated in terms of wind pressure on building facades. Two typical residential building arrangements, namely multi-story buildings and high-rise buildings, were adopted as the evaluation objects. The cases were located at a typical southeast monsoon wind city - Nanjing. And residential building units were investigated for natural ventilation potentials. To calculate building facade pressures, computational fluid dynamics (CFD) method with ANSYS-Fluent was adopted. The exceedance probabilities were post-processed by MATLAB and ArcGIS.

RESIDENTIAL BUILDING GROUP CONFIGURATION

A 3 x 3 building group were built for building arrangement analysis. The central group (CG) was the analysis unit, and surrounding units (SG) were arranged around the studied area as environmental conditions, as shown by Figure 1a. Road widths (Sr1, Sr2) were determined as 30m according to design code. Two residential building types were established for case comparison (Figure 1b-c). Case A was multi-storey building group (building height H=18m), and Case B was high-rise building group (H=36m). Building widths L and depth D were determined as 72 and 12m, respectively. Lateral spacing S were 12m, and north-south spacing was 24m and 48m for multi-storey and high-rise building group. Figure 1d shows the data extracted zones for probability calculation and comparison. W1-W6 numbered the south and north facade of living units. W0 and W7 numbered the east and west facade of living units. For vertical partition, multi-storey building was divide into three part, which represent the living unit at low, middle and high levels, and high-rise building was divide into six levels.
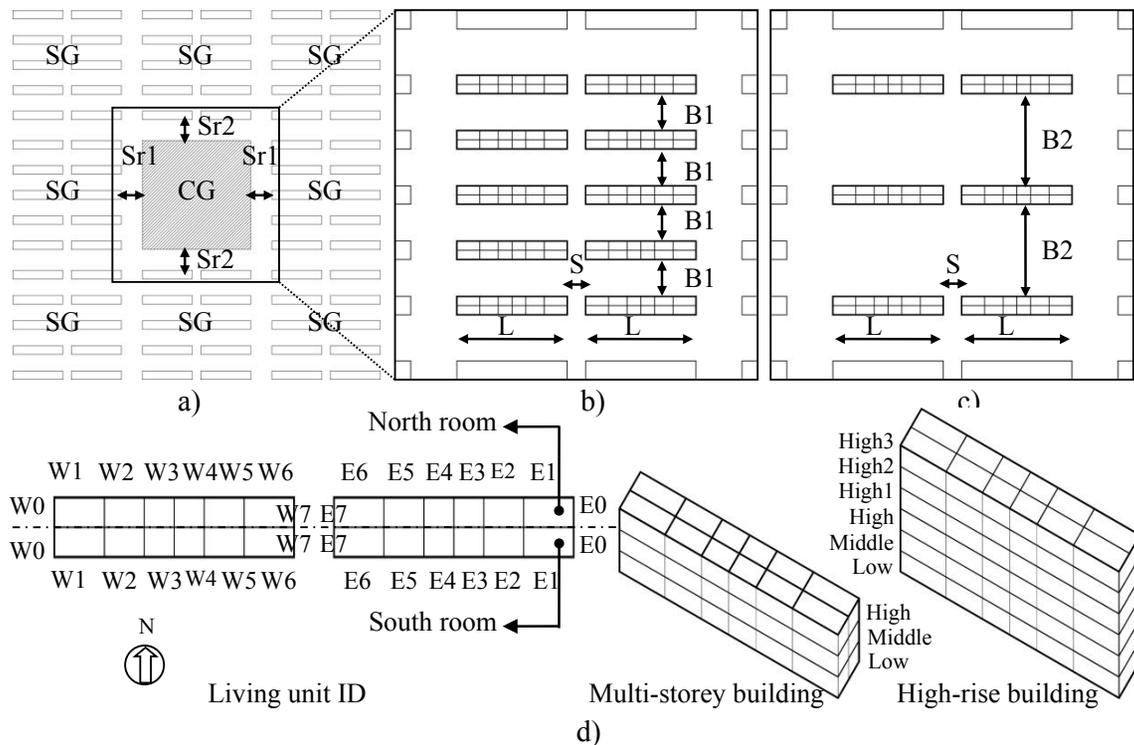

Figure 1. a) Building groups setting, b) Case A, c) Case B, d) Data extracted zones

EXCEEDANCE PROBABILITY CALCULATION FOR VENTIALION POTENTIALS
The exceedance probability based building ventilation assessment consisted of three parts, as shown in Figure 2. The first part was the base data collection, which include weather data, building geometry data and wind flow data. The second part was MATLAB based data processing. In this step, wind data and façade pressure data were extract from the weather file and simulation results. Exceedance probability for each building façade were calculated by processing façade pressure data. At last, building façade geometry and the corresponding probability data were linked and by ArcGIS's spatial join tool for further ventilation potential analysis. The probability distributions were also visualized for each studied surface.
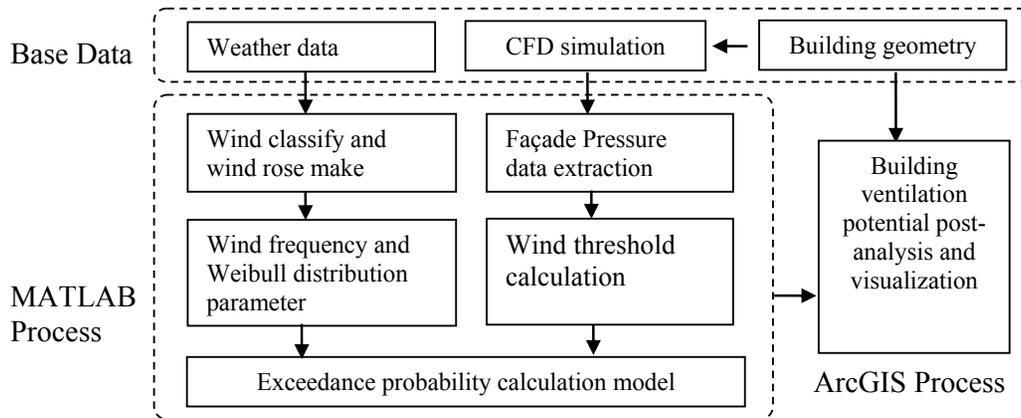

Figure 2. Flow chart of exceedance probability calculation

Base data obtaining
The wind climate of Nanjing was obtained from calibrating the hourly wind data of the solar and Wind Energy Resource Assessment (SWERA) weather file, which were download from EnergyPlus Weather Data (EPW) website. Building façade pressure data were obtained from CFD simulation results. The study referred to the AIJ (Architectural Institute of Japan) guidelines (Tominaga et al. 2008). For turbulence model selection, the Reynolds-Averaged Navier-Stokes (RANS) approach with standard k-ε model was adopted in this study due to its less time consumption and less complexity in boundary condition setting.

Exceedance probability calculation
The pressure based exceedance probability (P_g-EP) at each point above building facade was assumed to follow a two-parameter Weibull distribution in this study. And the P_g-EP for 12 azimuths was calculated as follow:

$$P(P_g > P_g^*) = \sum_{i=1}^{12} A(i) \exp\left[-\left(\frac{\sqrt{P_g^*}}{R \cdot C(i)} \cdot \left(\frac{H_{met}}{\delta_{met}}\right)^{\alpha_{met}} \right)^{k(i)} \right] \tag{3}$$

$$R = \frac{\sqrt{abs(P_g)}}{V_{ref}} \cdot \left(\frac{H}{\delta}\right)^{\alpha} \tag{2}$$

Where $P(P_g > P_g^*)$ is the probability of exceeding the specified P_g^*. i is the wind direction number, and $A(i)$ is the occurrence frequency, and $K(i)$, $C(i)$ are two parameters of Weibull distribution. P_g is the façade pressure extracted from CFD simulation results. V_{ref} is the

reference up wind speed at the height H. α, α_{met}, δ and δ_{met} are the wind speed profile exponent and boundary layer thickness of the studied building located terrain and the weather station located terrain. H_{met} is the wind measured height at the the weather station.

RESULTS AND DISCUSSION
Figure 3 showed the distributions of exceedance probability percentage (P_g-EP) on building facade for multi-story and high-rise buildings. In subplot (a)-(b), the facade P_g-EP distribution were viewed from southeast and in subplot (c)-(d), the P_g-EP distribution were viewed from northeast. The natural ventilation potentials of the building groups were clearly revealed by the P_g-EP distribution on each building facades. High-rise buildings obviously improved the building natural ventilation potentials, comparing with that of multi-story buildings. The variation range of P_g-EP was between 30% and 70% for high-rise buildings, while between 20% and 60% for multi-story buildings. For high-rise building group, the more ventilation living units were located at the first (south) and third (north) row, which the P_g-EPs of first row building's south facade (Figure 3b) and the third row building's north facade (Figure 3d) were almost above 60%. It was because the surrounding buildings were multi-story buildings, which wind can directly reach the up part of the high-rise building facades. For the multi-story building group (Figure 3a) and the middle row high-rise buildings (Figure 3b), the more ventilation living units were located at the building's eastside. It was due to effect of southeast monsoon in summer. Due to the recirculation flow phenomenon, the middle level P_g-EPs of the multi-story buildings' north facade increase (Figure 3c). It revealed the ventilation potentials of north living units at the third and fourth storey building are improved.
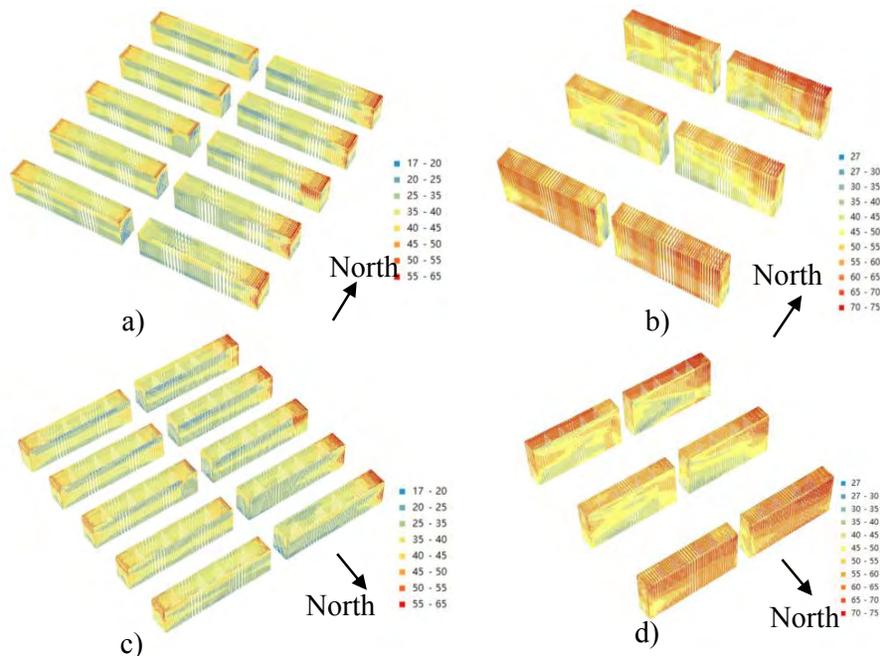

Figure 3. Distributions of the exceedance probability percentage on building facades.

More detailed quantitative analysis of natural ventilation potentials of the building groups was shown in Figure 4 and Figure 5. Figure 4 were the P_g-EP compassion of different height level residential units for multi-story and high-rise buildings. From the figure, it can be found that for the multi-story building group, the P_g-EPs were all below 50% (Figure 4a). And the natural ventilation potentials of low, middle and high levels of high-rise building units all increased, with P_g-EP around 50% (Figure 4b). It was due to the strengthen of air flow by the

upper facade of the high-rise building. The natural ventilation potentials of higher levels (high1 high2 and high3) of high-rise buildings were improved greatly due to the less effect of surrounding buildings. The P_g-EPs of these areas were all generally above 50% (Figure 4c). In terms of the positions of residential units at one storey, ventilation potentials of side units are better than that of middle units, and ventilation potentials of east side units are better than that of west side units. It is more obviously reflected within the multi-story building group. Figure 5 shows the P_g-EPs of south and north units for multi-story and high-rise buildings. The simulation results showed that P_g-EPs of north units were slightly better than that of south room for multi-story building. It was due to the turbulence flow, which acted on the north facade of the multi-story residential building, which discussed above.
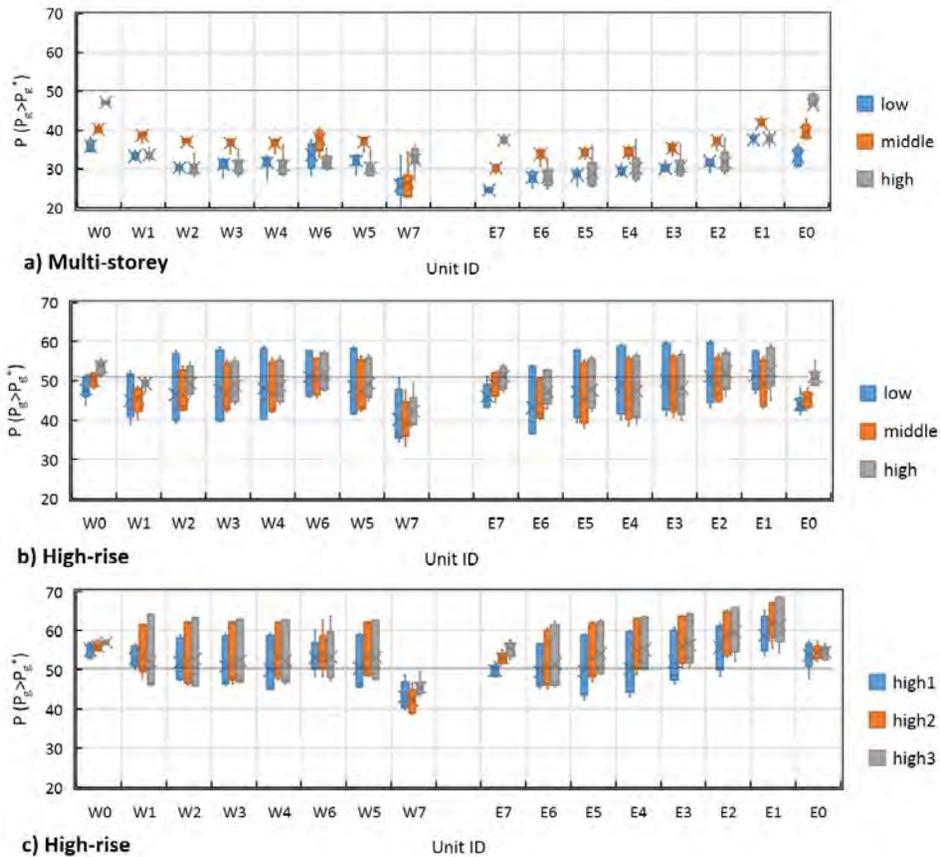

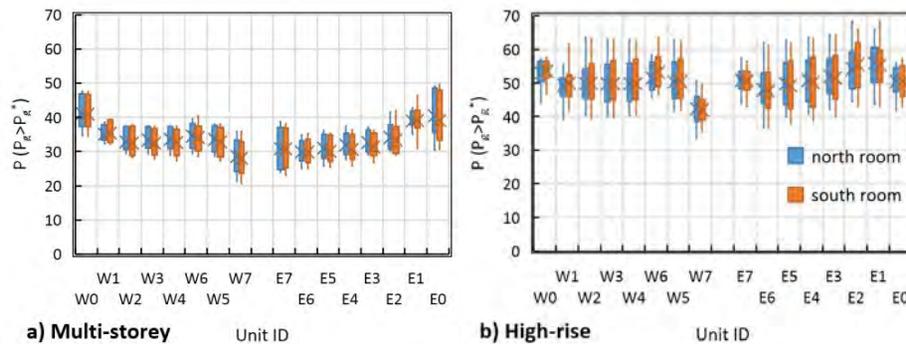Figure 4. Comparison of different living-unit levels for multi-story and high-rise buildings.

Figure 5. Comparison of living-unit facade directions for multi-story and high-rise buildings.

CONCLUSIONS
This paper provided a simple method to assess building group's natural ventilation potentials considering the effect of local wind climate. The cases studies show that, by calculation the exceedance probability of wind pressure on building facades, the natural ventilation potentials of building group can be revealed for each living units. Two typical residential building arrangements were investigated using the façade pressure based exceedance probability. Simulation results show that high-rise buildings could obviously improve the building's natural ventilation potentials by increasing P_g-Eps of around 20%, comparing to that of the same levels (1-6 storey) of multi-story buildings. In southeast monsoon regions, the ventilation potentials of eastside living units is indeed improved especially for multi-story buildings. The P_g-Eps could increase by about 10%. And the ventilation of north façade living units could also be beneficial by the turbulence flows.

This study is a preliminary test of using façade pressure based exceedance probability as an indicator for assessing of building natural ventilation potentials. Only two typical residential building groups were investigated. In the following study, more building arrangement cases will be evaluated to provide design strategies for architects.

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