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# An investigation on the quantitative correlation between urban morphology parameters and outdoor ventilation efficiency indices

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**ABSTRACT**
Urban outdoor ventilation and pollutant dispersion have important implications for the urban planning and design of urban morphology. In this paper, two urban morphology parameters including Floor area ratio (FAR) and Building site coverage (BSC) are attempted to investigate the quantitative correlation with urban ventilation indices. Firstly, we present an idealized model including nine basic units. The FAR of model is constant 5.0, and the BSC increases from 11% to 77%, which in consequence generates 101 non-repetitive asymmetric forms. Next, the Computational Fluid Dynamics (CFD) is employed to evaluate the ventilation efficiency of pedestrian level within each model's central area. Six indicators including air flow rate (Q), mean age of air ($\tau_p$), net escape velocity (NEV), purging flow rate (PFR), visitation frequency (VF) and resident time (TP) are used to assess the local ventilation performance. Results clearly show that when the FAR of the plot is specified, the local ventilation performance does not present an obvious linear relationship. As the BSC increases, the ventilation in the central area does not keep reducing. On the contrary, some forms with low BSC have poor ventilation and some particular forms with high BSC have better ventilation performance. This shows that for an urban, it not always exists poor local ventilation under the high-density conditions. The local ventilation performance can be effectively improved by rationally arranging the architectural arrangement within the plot. These findings suggest a preliminary way to build up the correlation between urban morphology parameters and ventilation efficiency. Even though the application of these results to the real cities require further research, but for this paper, it presents a feasible framework to the urban designers.

**KEYWORDS**
correlation research, urban morphology, ventilation indicators

## INTRODUCTION

Past few decades the urbanization has become a global phenomenon. The urbanization process has accelerated the increase of urban density, which leads to significant differences between urban morphology and original form in natural conditions (such as the number of streets, height of buildings, void spaces, etc.). Due to the compact urban spaces, air pollutant cannot be diluted and dispersed in time and it probably causes a series of health problems.

Flow rate (Q) was used to assess the effective flow which passes through the urban canopy layer (Hang et al., 2009). The concept of mean age of air ($\tau_p$) is a statistical measure of the time it takes for a parcel of air to reach a given point in the flow field after entering this flow field, and large mean age of air implies a poorly ventilated region. Purging flow rate (PFR), was introduced to predict the net rate of removing pollutant in the urban domain by (Bady et al., 2008), The visitation frequency (VF) is the number of times a pollutant enters the domain and passes through it. The residence time (TP) is the time a pollutant takes from once entering or being generated in the domain until leaving the domain. The feasibility of PFR, VF and TP using to evaluate the urban ventilation has been verified by (Kato and Huang, 2009). The concept of net escape velocity (NEV) proposed by (Lim et al., 2014) represents the effective velocity at which the contaminant is transported/diluted from a target point, and a high NEV indicates fine removal efficiency of the pollutants.

Ventilation indicators abovementioned have been validated by wind tunnel measurement and numerical simulations. Nevertheless, morphological parameters associated with most of them are purely geometric parameters such as urban street aspect ratio (*H/W*), building height (*H*), building packing density ($\lambda_p$) (Cheng et al., 2007),etc. However, with the increase of urban density, the floor area ratio (FAR) within urban plots is the first key factor considered by urban designers and planners, which involves economics, policy and urban development strategies, etc. In the early planning stage, the FAR of urban plot has been determined first, so it may be of great significance to investigate the relationship between building site coverage (BSC) and ventilation performance in a specific area when the FAR is constant. Previous research(Peng et al., 2017) has preliminary explored the relationship between FAR, BSC and ventilation performance, but only the average wind ratio was employed. In this paper, more comprehensive ventilation assessment indicators and substantial forms will be adopted for comprehensive research.

## METHODS

### Morphology characteristics of idealized models

During the early stage for urban planning and designing, the floor area ratio (FAR) within urban plots has been formulated, which is closely related to the cost, benefit, development strategies etc. Once the FAR of plots has been specified, it will not be easily changed. The main factors affecting the morphology of plots include the building site coverage (BSC) and the architectural arrangement within the plots. The idealized model is consisted of 9 basic units, and each unit size is a 30-meter square. The central square is the interested area which does not to be covered by building. The other eight units around the central may be covered with buildings. The FAR of all possible forms are constant 5.0, and the initial BSC is 11%, meaning that there is only one high-rise building. Meanwhile, there are five possibilities for the position of building in the plot (excluding symmetry conditions).

In order to explore the correlation between morphology and performance, all possible forms should be classified. As shown in Figure 1. according to the architectural layout around the central area, the model is divided into Form C and Form B. The Form C configuration means that the front and back directions of the central area are not blocked and there have a channelling effect. The Form B1~B3 means the number of building along the windward projection. The Form B(F1~F3) means the number of building front (in the first two rows) along the windward projection. In this study, there only one incoming wind direction ($\theta$=90°) is considered. As a consequence, the symmetrical configurations along the east-west direction are exclude. When the BSC increases from 11% to 77%, a total of 101 asymmetrical forms are generated.

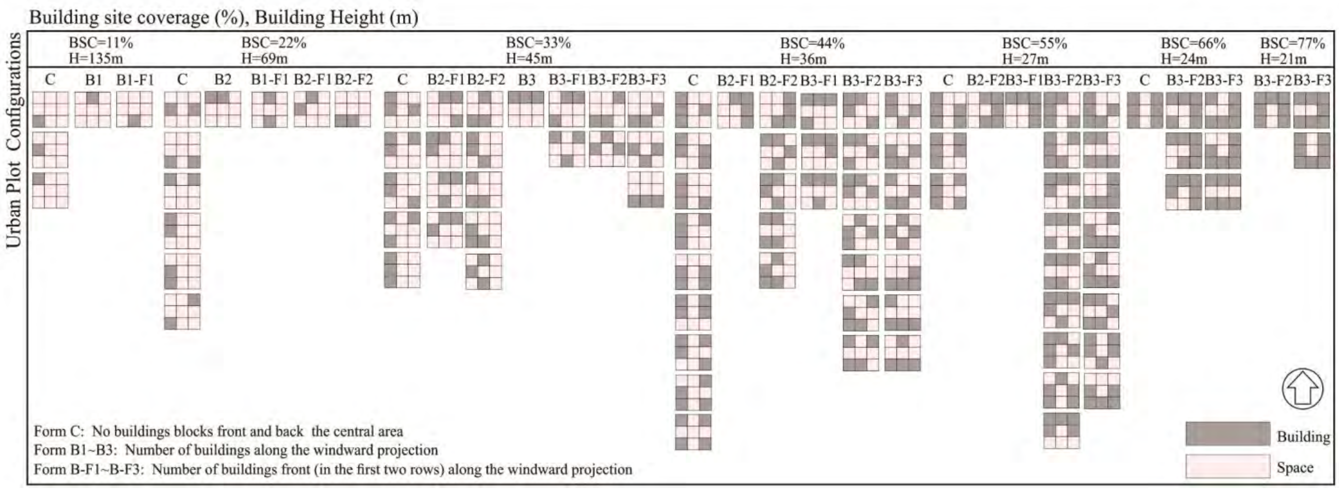


Figure 1. Idealized models with BSC increasing from 11% to 77%

**CFD simulation setup**

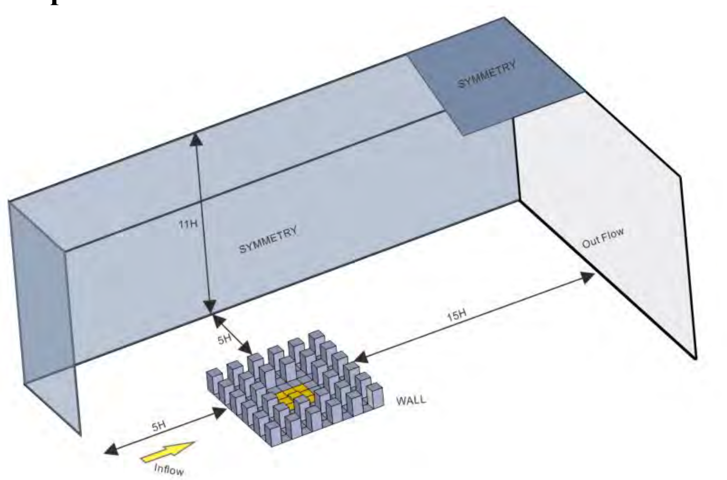


Figure 2. Schematic sketch of geometry and boundary conditions used in CFD simulations

The computational domain size is shown in Figure 2, the inflow and lateral boundaries are set 5H and away from the buildings. The outflow and the top boundaries are respectively 15H and 6H. Mesh resolution fulfils the major simulation requirements as recently recommended by (Franke et al., 2007) and by the Working Group of the Architectural Institute of Japan (AIJ). The comparison showed that the k-ε model can be used for such configurations and that there is a good agreement in terms of the essential features of the mean flow. The inlet profiles of mean wind speed $U$, turbulent kinetic energy $k$ and turbulence dissipation rate $\varepsilon$ were identical for all simulations. A logarithmic mean speed profile was fitted to the measured profile using Eq. (1) where $z_0$ is the aerodynamic roughness length taken as 0.2m, $\boldsymbol{k}$ the von Karman constant equal to 0.42 and $z$ the height coordinate. Turbulent kinetic energy profile was calculated as in Eq. (2), where $I_u$ is the measured longitudinal turbulence intensity, and the turbulence dissipation rate ε was calculated as in Eq. (3).

$$U(z) = \frac{u^*_{ABL}}{\kappa} \ln\left(\frac{z + z_0}{z_0}\right) \quad (1)$$

$$k(z) = \frac{{u_{ABL}^{*}}^{2}}{\sqrt{C_{\mu}}} \tag{2}$$

$$\varepsilon(z) = \frac{{u_{ABL}^{*}}^{3}}{\kappa(z + z_0)} \tag{3}$$

The indicators used for correlation studies with morphological parameters in this study include flow rate (Q), local mean age of air ($\tau_p$), net escape velocity (NEV), purging flow rate (PFR). visitation frequency (VF) and residential time (TP). Due to the limitation of pages, the calculation equations for these indicators are not listed here. Uniform release method is applied in this study(Hang et al., 2009). In this paper we used uniform tracer gas source from ground up to 2 m for ventilation analysis. The tracer gas emission rate $S_c = 10^{-7}$ kg/m$^3$ s to ensure the source release produced little disturbance to the flow.

**RESULTS**

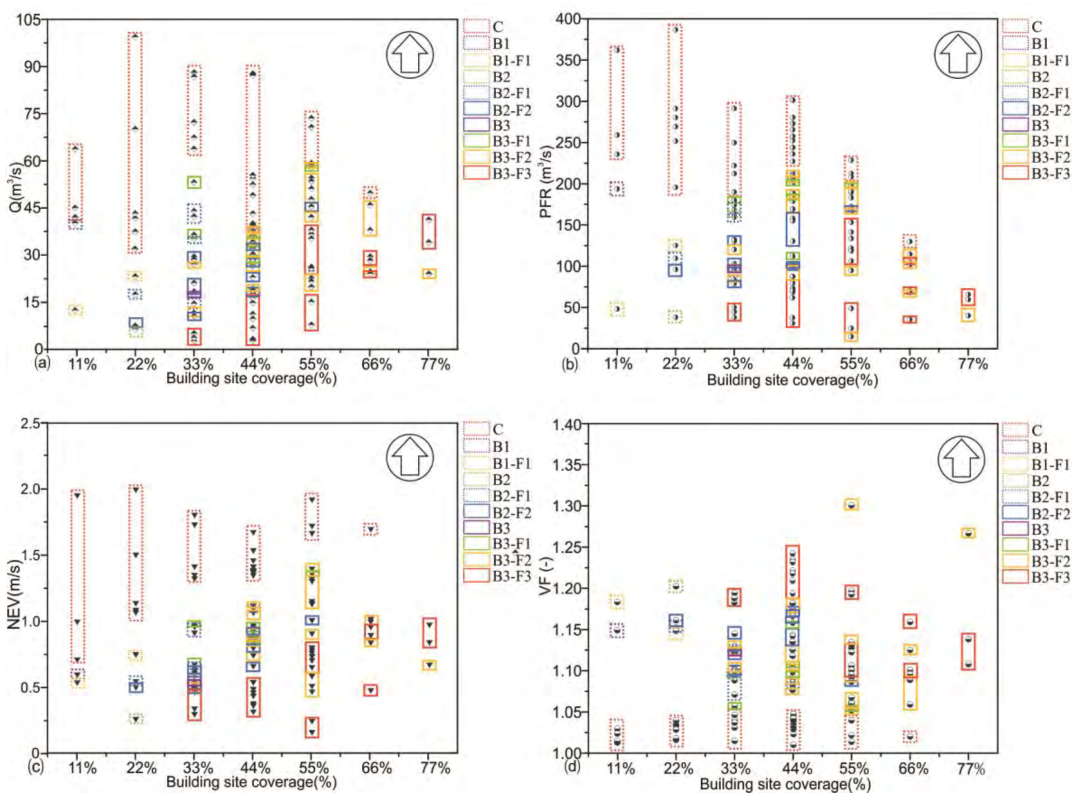


Figure 3. The value of ventilation indices within each configuration of BSC increasing from 11% to 77% (a) Q, (b) PFR, (c) NEV, (d) VF

Figure 3 shows the results within the study domain at pedestrian level for the BSC increasing from 11% to 77%. Results clear show that the level of ventilation efficiency within the central area decreased as the BSC increased in general, due to the increase of buildings within the plot. However, it is not absolutely that with the gradual increase of the BSC, the ventilation performance of the central area is declining in particular in the calculation result of NEV and VF (Fig. 3c,3d). When the BSC continues to increase from 44% to 77%, the NEV and VF become slightly better. However, the result of each model in Figure 3 does not intuitively reflect the relationship between ventilation indicators and morphological parameters. Also, the number of configurations corresponding to various BSC is also different and it is difficult to make comparisons. Therefore, the average value and the error are calculated for each configuration, which can reflect the intuitive relationship between the indicators and the morphology as the BSC changes.

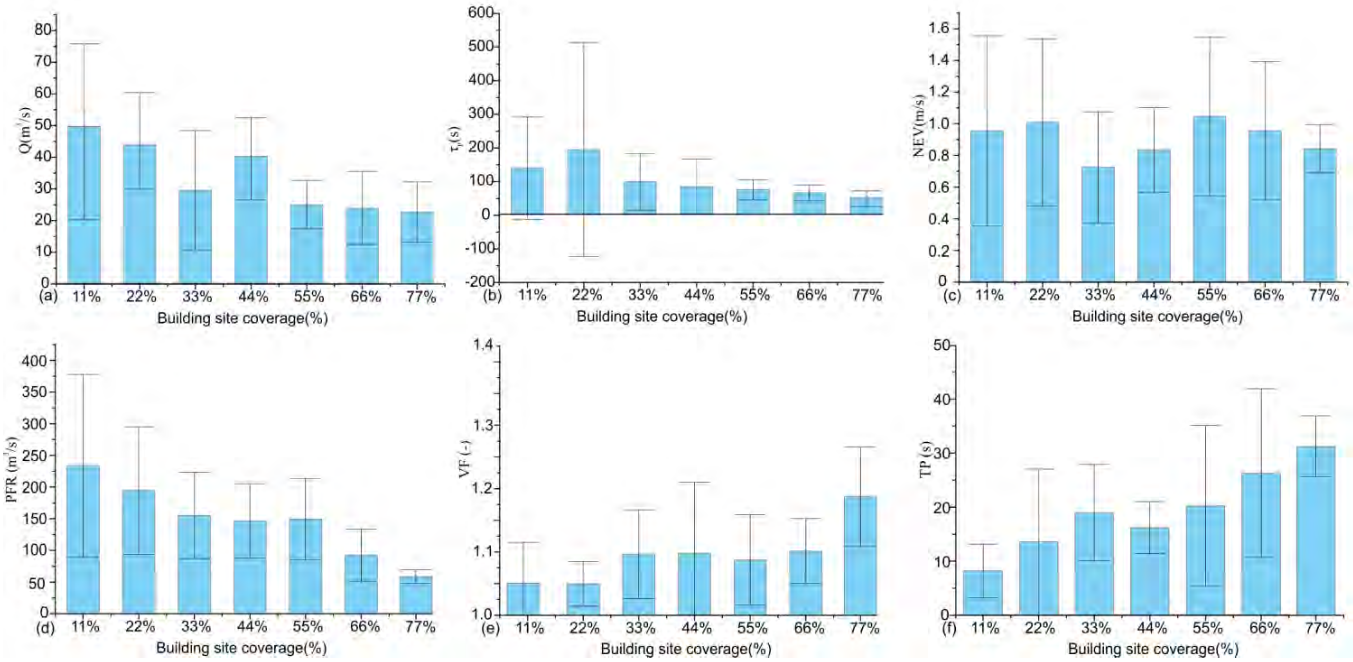


Figure 4. The average value and variance of each index corresponding to BSC increasing from 11% to 77% (a) Q, (b) $\tau_p$, (c) NEV, (d) PFR, (e) VF, (f) TP

In Figure. 4, results of different indicators show that the ventilation performance at the pedestrian level in the central area is slightly lower as the BSC increases. In particular, when the BSC is 44%, values of six indices show that the capacity of removal pollutant obvious enhances. With the BSC ranges from 44% to 77%, although the buildings density in the plot is gradually raise, meanwhile the channeling effect is interrupted and weak. Due to the constant of FAR, the building height gradually decreases with the BSC increasing. The air flow flush the central area is mainly mean flow when the BSC is at a low level. As the BSC increases, and the building height reduces, especially the BSC is 55%, the fresh air entering the domain through the turbulent flow from the roof of building enhances obviously, which is consistent with the research results of (Hang et al., 2015), the fresh air flow flush and remove the concentration of pollutants in the central area and plays a role in improving ventilation performance.

**DISCUSSIONS**

It can be explained that for an urban area where the density is at a high level, the wind channeling effect is not the only and effective way to dilute or remove air pollutants. When the average building height is relatively low, the effect of turbulence flow can effectively remove the pollutants at the pedestrian level and improve the local ventilation performance. At the same time, the results also yield that the BSC is not the only factor that determines the ventilation performance within the urban plot, and the building patterns within the plot also plays a significant role on the pollutant dispersion.

## CONCLUSIONS

First of all, to make constant the FAR to 5.0, the BSC gradually increases from 11% to 77%, resulting in a total of 101 asymmetrical idealized plot configurations. Second, we propose six indicators for correlation with morphological indicators. Simulation, and statistical results show that when the BSC is 11%, 22%, and 33%, the ventilation performance at pedestrian level within the domain decreased significantly, which illustrates when the BSC is below 33%, the building height is at a high level. With the increase of BSC, the fresh airflow flushes into the center area is interrupted by isolate building, resulting in an increase in the concentration of pollutants. When the BSC increased to 44%, 55%, 66%, and 77%, though the ventilation performance was slightly lower than before, due to the lower average building height, the fresh air flows into the center area which is mean flow to turbulent flow through building roof. The results in this study show that BSC and FAR are effective morphological parameters for establishing correlation studies. For high-density cities, the ventilation performance of void spaces can be effectively improved by reducing the average height of buildings.

Moreover, this study is still an idealized configuration. Subsequent research will add secondary roads within the central area, and discuss which indicators are most sensitive to morphological changes and more suitable for in-depth correlation research with BSC and FAR.


## ACKNOWLEDGEMENT

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## REFERENCES


Bady, M., Kato, S., Huang, H., 2008. Towards the application of indoor ventilation efficiency indices to evaluate the air quality of urban areas. *Building & Environment* 43, 1991-2004.

Cheng, H., Hayden, P., Robins, A.G., Castro, I.P., 2007. Flow over cube arrays of different packing densities. *Journal of Wind Engineering & Industrial Aerodynamics* 95, 715-740.

Franke, J., Hellsten, A., Schlünzen, H., Carissimo, B., 2007. Best practice guideline for the CFD simulation of flows in the urban environment. *Cost Office Brussels 732*.

Hang, J., Sandberg, M., Li, Y., 2009. Age of air and air exchange efficiency in idealized city models. *Building & Environment* 44, 1714-1723.

Hang, J., Wang, Q., Chen, X., Sandberg, M., Zhu, W., Buccolieri, R., Sabatino, S.D., 2015. City breathability in medium density urban-like geometries evaluated through the pollutant transport rate and the net escape velocity. *Building & Environment* 94, 166-182.

Kato, S., Huang, H., 2009. Ventilation efficiency of void space surrounded by buildings with wind blowing over built-up urban area. *Journal of Wind Engineering & Industrial Aerodynamics* 97, 358-367.

Lim, E., Ito, K., Sandberg, M., 2014. Performance evaluation of contaminant removal and air quality control for local ventilation systems using the ventilation index Net Escape Velocity. *Building & Environment* 79, 78-89.

Peng, Y., Gao, Z., Ding, W., 2017. An Approach on the Correlation between Urban Morphological Parameters and Ventilation Performance. *Energy Procedia* 142, 2884-2891.