Effect of Street Canyon Configurations and Orientations on Urban Wind Velocity in Bangkok Suburb Areas

D Jareemit¹ and M Srivanit²
¹,²Faculty of Architecture and Planning, Thammasat University, Pathumthani, Thailand.
Email: jdaranee@gmail.com

Abstract. Urban ventilation is considered as one parameter, which impacts on building energy consumption and outdoor living condition. This study primarily investigates the effect of street canyon characteristics as well as its orientations on wind pattern and velocity in street canyon via using urban microclimate simulation model, ENVI-met. The wind simulations are performed with four aspect ratios or height-to-width ratio (H/W), three canyon lengths, and four canyon orientations. Calculated wind velocity measured at 1.5 m height of the centre of the street and pedestrian on both sides of the street ranges from 0.2 to 0.97 m/s. N-S and NW-SE canyons, which oriented parallel to the prevailing wind has greater wind velocity than those oriented perpendicular to the wind. The wind velocity is sensitive to aspect ratio and canyon length. The wind velocity in shallow canyon is mostly higher than those in the deep canyon. However, increasing the canyon length considerably improves the low wind speed in the deep canyon up to twice.

1. Introduction
Bangkok and suburb provinces is affected by urban heat effect and traffic congestion results in air pollution problem. Breathable city is a concept to bring more ventilation in the city. Pedestrian wind velocity is importance that the wind can remove heat and also dilute pollutant concentration from the traffic, which those make better environment for outdoor living. Previous studies have shown that urban configurations have a significant effect on airflow patterns and wind speed in street canyon [1,2,3]. High density cities typically have poor air ventilation since the buildings obstruct the wind flows. Lower site coverage ratio could increase the pedestrian ventilation performance [1]. In addition, wider street canyon also provides better ventilation potential than those in shorter one [2,3]. Rahman et al. [4] and Kitous and Adolphe [5] investigated the effect of aspect ratio of the length to width (L/W) on wind velocity and found that the short canyon contributed to low wind speeds when compared to that of the long canyon. Their findings agree well with Kitous et al.’s results [6].

The study of the effects of canyon configurations on wind velocity have been widely studied in several countries. Based on the literature reviews on design achieving urban ventilation, most focused on aspect ratios of building height to street width in relation to canyon orientations. One study considered building length to street width. Such the design combinations of street width, building height and its length have not been investigated yet. In addition, previous investigations were conducted with limitations by local land use and regulations, which such conditions might differ and not properly implement in Thailand’s context.

The aim of this study firstly investigates an effect of street canyon configurations regarding a proportion of street width, building height and its length on pedestrian wind velocity. Lastly, the urban wind velocities influenced by different urban typologies are compared and discussed. The results of
this finding will be extended for further evaluation the design configurations that promote cooling and thermal conditions for outdoor living. Regarding the case studies used in this investigation, the urban typologies are constructed based on local regulation and those forms are typically found in Bangkok suburb areas. This research results could benefit for urban planners and architects to determine characteristics of buildings and planning, which can create Bangkok suburb areas a breathable city.

2. Research methodology

The street canyon is usually expressed by aspect ratio (ratio of building height to street width, H/W) and the length (L) of the canyon. In this study, urban wind simulations of forty-eight street canyon characteristics classified by four aspect ratios of 0.5, 0.7, 0.9, and 1.1, three canyon lengths represented by building block size of 4, 5, and 10 units per block, and four canyon orientations of N-S, NS-EW, E-W, and NW-SE (shown in figure 1) are performed using urban microclimate simulation model, ENVI-met model. Those classifications of urban forms and its geometries generally represent the typical characteristics of residential cluster developments in Bangkok neighbourhood areas.

The ENVI-met model [7] has been accepted in evaluating thermal environment and outdoor thermal comfort. In addition, this simulation model is widely used for a measure of airflow and wind velocity in urban scale. Average 10-years local meteorological data for the Rangsit region obtained from a nearest weather station of the Thai Meteorological Department (TMD) at Pathumthani Station (14.116°N, 100.621°E), such as wind direction, air temperature, wind velocity, long and short wave radiation is used as an input in ENVI-met modelling. From the simulation results, the wind speeds are measured across the street canyon at 1.5 m. height of both pedestrian paths and centre of the street as presented in figure 2. The simulation results are validated by comparing field measurements. The correlation between measured data and simulation shows a strongly correlation with $R^2 = 0.91$ ($p < 0.001$).

![Figure 1. Design parameters and input variables used to perform in ENVI-met simulation.](image1)

![Figure 2. Section of street canyon and measurement locations.](image2)

3. Results and discussion

Wind simulations through ENVI-met modelling are used for examining and comparing level of wind speeds in street canyon for different street orientations, aspect ratios, and the canyon lengths. The results are presented and discussed as the three following topics.
3.1. Effect of street canyon orientations on wind velocities

Figure 3 (left) presents distribution of colour shades visualizing wind speeds in street canyon at 1.5 m. height of the 1.1 canyon with 4-units length as an example. Average wind velocity along forty-eight canyon typologies is calculated. It is found that wind velocities are typically high at the front of canyon and the velocities gradually reduce at the end of the canyon. The street canyon orientations parallel to local wind mainly from the south, specifically the canyon oriented N-S and NW-SE, have the highest wind velocities (ranging from 0.7-1 m/s) while the NE-SW and E-W canyons which oriented perpendicular to the wind have the lowest velocities, which ranges from 0.2-0.4 m/s.

Considering airflow pattern in these four canyon orientations, the wind mostly flows narrow to the street since characteristic of the street acts as a tunnel. However, at street intersection, the airflow does not deflect the direction to perpendicular streets since the proportion of street width to the canyon length might be insufficient to allow the wind changes that direction [8]. For all street canyon arrangements, the distribution of wind velocities across the canyon vertically increases with building height while the velocities in the horizontal plane are almost the same. The wind velocities near the ground level are lowest, which are less than 0.58 m/s and the wind speeds at the rooftop are above 1.00 m/s.

Figure 4 (right) compares the box plots of the wind velocities of four different aspect ratios classified by four different street canyon orientations. The wind velocity in the street canyon is sensitive to the canyon aspect ratio. The distribution range of wind velocities in aspect ratio of 1.1 is wider than others (standard deviation = 0.05) while the wind velocities in the canyon with aspect ratio of 0.5 has small distribution range with standard deviation = 0.1. The distribution of wind velocities in N-S and NW-SE oriented canyons is larger than those of NE-SW and E-W canyons since orienting canyon parallel to the local wind could allow more wind to access into the canyon.

3.2. Effect of canyon aspect ratios and canyon lengths on wind velocities

The study compares calculated wind velocities at 1.5 m height for four different aspect ratios of 0.5, 0.7, 0.9, and 1.1 with three canyon lengths of 4, 5, and 10 units per block. As mentioned above, the wind velocity profile across the canyon section increases in line with the building height. Overall, design of 10-units block length provides the highest pedestrian wind velocities to both deep and shallow canyons ranging from 0.9-1 m/s for N-S and NW-SE orientations and 0.3-0.4 m/s for E-W and NE-SW orientations (shown in figure 5). However, the wind velocities in the shallow canyons (H/W = 0.5 and 0.7) are slightly lower than those of the deep canyons. Such increment has similar
results as found in Kitous et al. [6] and Rahman et al. [4] that street length significantly influenced more airflow velocity than in those of the shorter one.

Regarding wind performance in 4 and 5 units block lengths, the wind velocities at pedestrian level in the aspect ratio of 1.1 are lowest when compared to those of the shallow canyons. The pedestrian wind velocities in the canyon with H/W=1.1 range from 0.2-0.3 m/s for E-W and NE-SW orientations and 0.7-0.8 m/s for N-S and NW-SE orientations. Decreasing the canyon height significantly improves the velocity performance in E-W and NE-SW orientations up to 45 percent and 19 percent for N-S and NW-SE oriented canyons. High aspect ratios with long canyon length considerably increases the wind velocity than those of lower aspect ratios with the short length since the canyon shape might act like the small opening channel. This small hole accelerates the wind speed as called Venturi effect, which is related to proportion of canyon’s width, length, and its height [8].

![Figure 5. Calculation of wind velocities associated to street canyon length and aspect ratios distribution by canyon orientations.](image)

3.3. Design strategies for urban ventilation

Increasing ventilation performance in pedestrian level for the street oriented parallel to prevailing wind, design the canyon with either 10-units length with H/W =1.1 and 4 units length with H/W=0.5 is recommended since it allows better wind to access into the street canyon than other design scenarios. The wind velocities in the canyon with 4-units length with H/W=0.5 are slightly lower. In contrast, for the street situated perpendicular to the wind direction, long canyon length (10 units per block) with H/W = 0.5 provides the highest wind velocities; however, the pedestrian wind velocities are much lower than those in the canyons parallel to the wind. To improve the wind speed in the street oriented perpendicular to the wind direction, other techniques such as providing more open space, step the building back, or increasing more opening between the canyon block might increase the wind velocity. The influence of such design combinations should be investigated in future study.
4. Conclusion
The study assesses wind velocities in street canyon, which influenced by various urban design configurations typically found in Bangkok suburb areas. The urban microclimate simulation model, ENVI-met is used to perform wind velocity as well as airflow pattern. The design of aspect ratio associated to canyon length considerably impact on the pedestrian wind. Most shallow canyons present high wind velocities than those of the deep canyons, which the maximum velocity for those parallel and perpendicular to the wind is 1.1 m/s and 0.38 m/s, respectively. The street canyon with aspect ratio of 1.1 and length of 4 units per block has the lowest velocity performance. Increasing the canyon length to 10 units per block effectively improves the wind velocity in the canyon by twice. Alternative design techniques for improving ventilation potential in street canyon oriented perpendicular to the wind should be investigated for further work. The limitation of this study is to assess wind velocity in canyon, which has the same building height. Such urban form is typically found in suburb areas, but building height in the big city varies. Consequently, future studies should account the influence of different building height, which might contribute different wind velocities and airflow patterns in street canyon.

5. References
[1] C Yuan and E Ng 2012 Building porosity for better urban ventilation in high-density cities – A computational parametric study Building and Environment 50 176–189
[2] N Shishegar 2013 Street Design and Urban Microclimate: Analyzing the Effects of Street Geometry and Orientation on Air flow and Solar Access in Urban Canyons Journal of Clean Energy Technologies 52–56
[3] J A Akubue 2019 Effects of Street Geometry on Airflow Regimes for Natural Ventilation in Three Different Street Configurations in Enugu City Different Strategies of Housing Design
[4] W B Rahman, A Dinapradipta and I Defiana 2018 The impact of long canyon design and waterfront barrier buildings on wind velocity in a coastal area of Selatpanhang city ARSITEKTURA 6(2), 231–238
[5] S Kitous, R Bensalem and L Adolphe 2012 Airflow patterns within a complex urban topography under hot and dry climate in the Algerian Sahara Building and Environment 56 162–175
[6] C A Arkon and Ü Özkol 2014 Effect of urban geometry on pedestrian-level wind velocity Architectural Science Review 57(1) 4–19
[7] M Bruse 1999 The influences of local environmental design on microclimate- development of a prognostic numerical Model ENVI-met for the simulation of Wind, temperature and humidity distribution in urban structures. Ph.D. thesis, University of Bochum, Germany (in German)
[8] A W Spirn 1986 Air quality at street-level: Strategies for Urban Design Boston, Prepared for: Boston Redevelopment Authority

Acknowledgment
The authors wish to thank Pichamon Leethongin. This work was supported in part by a grant from the National Research Council of Thailand under the NRCT 2014 Grant No. P-15-50076.