Urban Geometry and Wind Simulation Studies for Comfort in Bangkok Street Canyon

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ABSTRACT

The increase of densely built-up areas in Bangkok aggravates Urban Heat Island phenomenon. Urban geometry as formed by the relationship of building height and street width or height-to-width ratio is a contributing factor to UHI. While the street canyon can provide self-shading during the day which is good for hot-humid regions, the deep street canyon influences heat absorption and airflow in the city, resulting in trapping air pollutants especially at the pedestrian level. Therefore, it is important to find optimum urban geometry for thermal comfort and enhancing airflow for public health. Wind studies were conducted using CFD simulation for uniform urban block arrays. Height-to-width ratios were varied for 95 cases. Results show that height-to-width ratios ranging from 1 to 2 can generate turbulence for heat mitigation and air pollution dispersion. The minimum height-to-width ratio recommended is 0.5 while the minimum building height is 9 meters. The minimum road width recommended is 12 m. However, the width of 34 m is preferable for heat mitigation and promoting air circulation.

Keywords: *urban geometry, wind simulation, street canyon*

1. INTRODUCTION

Urbanization has a significant impact on shaping the city. The densely built-up areas trap the heat within urban canopy causing urban environments to be warmer than their surroundings especially during the night time. This phenomenon is known as Urban Heat Island (UHI). There are many factors contributing to UHI including canyon geometry, thermal properties of materials, anthropogenic heat released from combustion and metabolism, and lack of green spaces. Among these factors, the canyon geometry has an impact on the type and magnitude of urban airflow as well as the short and long wave radiation balance in the canyon. It is also suggested that the urban geometry is much more important at the microscale than the thermal behaviour of materials and the albedo effect.

The urban canyon is considered very critical for UHI investigation since the canyon is formed with buildings along roadsides. The geometrical characteristics of the urban canyon are defined by height-to-width ratio, (H/W ratio) or aspect ratio which has been found to correlate significantly and directly with the UHI effect. It influences urban shading and ventilation for passive cooling and air pollution dispersion, thus affecting people's thermal comfort and health.

The temperature distribution in the canyon is influenced by the canyon surface temperatures and energy transfer depends on convective process. A study in Athens concluded that air temperature in the canyon is not greatly influenced by street orientation either during the day or during the night but is mainly controlled by the airflow process.

Whilst UHI has been studied extensively in many countries especially in temperate climates, there is still a need for more research in the tropics. It is also the case of Bangkok where only a few studies were found. At macro-scale level, urban heat island intensity of Bangkok was studied based on meteorological data. Nonetheless, at micro-scale level, there is still a big gap of knowledge on urban geometry in relation to UHI effect. Even though airflow is crucial for heat mitigation, the overheating conditions in urban areas of Bangkok are affected by the lack of airflow to enhance outdoor thermal comfort and air pollution dispersion. Therefore, the study is an attempt to investigate effect of height-to-width (H/W) ratio on airflow at pedestrian level in the street canyon. The research is supported by the National Research Council of Thailand and results from the study will be taken into consideration for establishing urban geometry design guidelines to promote wind for heat and air pollution mitigation in urban area of Bangkok.

2. LITERATURE REVIEW

2.1 Air movement and thermal comfort in hot-humid climate

Environmental factors of thermal comfort include air temperature, humidity, mean radiant temperature, and air velocity. The air movement produces physiological cooling effect by increasing evaporation from the skin. For hot-humid climate, the desirable wind speed at body's skin is 1-1.5 m/s or within the limit of 2 m/s. This is in accordance with results from field studies in the sub-tropical climate of Hong Kong as under summer condition, air velocity of 1.0-1.5 m/s would likely satisfy 80% of building occupants thermally. The studies in India and Iran show a reduction in thermal discomfort at 32-40˚C with air velocity greater than 0.25 m/s. Field studies in the warm and humid climate of Bangladesh also present an increase in comfort temperature with air velocities greater than 0.3 m/s.

Providing channels for airflow distribution is a way to promote thermal comfort in the city. Urban design requires Air Ventilation Assessment (AVA). The assessment height for pedestrian level is 1.5-2 meter above ground. To evaluate the effect of wind speed on outdoor thermal comfort, wind speed classification is derived based on Physiological Equivalent Temperature (PET).

2.2 H/W Ratio and urban airflow

Densely built-up areas tend to have street canyons with high aspect ratios. In general, the canyon has ratio approximately equal to 1 without major openings on the walls. An aspect ratio below 0.5 defines shallow canyon while a value of 2 represents the deep one.

Urban wind flow conditions can be improved by providing ventilation paths, mixing building heights, and increasing building height while decreasing land coverage. The latter strategy was found most efficient as it can increase wind velocities by up to 2.4 times of the real case.

An investigation in Singapore shows that placing a few high-rise towers will enhance the airflow inside the canyon thereby reducing the air temperature. An optimum H/W ratio for the canyons can increase the velocity by up to 35% and reduce the corresponding PET by up to 0.7oC.

2.3 CFD numerical simulation

Wind flow in the city is commonly studied using field measurement and numerical simulation methods known as Computational Fluid Dynamics (CFD). Even though the measurement method gives quantitative information about ambient air temperatures and velocities at specified locations and times, it cannot identify causes of the problem. Air modeling is, on the other hand, widely used for parametric studies in order to determine cause and effect from individual and combined parameters influencing airflow conditions.

In order to verify results from field measurement and CFD simulation, most models created are non-uniform to simulate real situation. Nevertheless, uniform modeling is generally used to study effect of individual parameter as it is more controllable. Two-dimensional and three-dimensional models are commonly produced for the studies.

3. BANGKOK'S CHARACTERISTICS

Bangkok is situated at 13.44oN latitude. It is in the central region of Thailand covering total area of 1,568.74 sq.km. The city has approximately registered population of 5.7 million and a hidden population of 2.6 million (in 2010). It has a diurnal temperature range of minimum 22.5oC to 26.9 oC and maximum 32.1 oC to 36.3 oC. A mean annual temperature is 27.8 oC and a mean annual RH is 79.9%. The minimum RH is 74% in January and the maximum RH is 85% in September. Bangkok experiences only moderate wind speed. The average wind velocity at 10 meters above ground is 1.7 m/s. The street canyons in densely built areas of Bangkok are blocked by tall buildings, therefore calm periods and stagnant conditions possibly occur.

4. STUDY METHODS

The research adopts CFD method to study urban airflow conditions influenced by H/W ratios or aspect ratios ranging from 0.1 to 2 as the maximum permitted by Thai regulation. Road widths are 12, 18, 24, 34, 64, and 94 meters, respectively. These widths include the actual road width and possible 6-meter setback distance. Building heights are then calculated according to the relationship between H/W ratios and road widths. There are 95 simulation cases possible for the specified range of H/W ratios as shown in Table 1. The simple geometry with aspect ratios above 1 are expected to produce a skimming flow regime in the street canyon.

The commercial CFD simulation program, DesignBuilder is employed for calculation. The numerical models are uniform regardless of the effect of building's length and width. Domain size is 1000 m × 1000 m. All buildings are square shape and areas considered are at intersection providing identical street canyons on the direction parallel and perpendicular to prevailing wind. In the studies, the wind direction is set to come from the south. The reference wind velocity is 1.7 m/s as it is the average wind velocity at 10 meters above ground in Bangkok. Wind profile is specified for urban area. The computational domain is k-ε which is for turbulence modeling. Area for consideration on horizontal plane is 1.5 meters above ground to investigate airflow at pedestrian level while sectional area across the canyon is made vertically to investigate air velocities on leeward and windward sides.

	Road width					
	12	**18**	**24**	**34**	**64**	**94**
H/W	**Building height**					
0.1	-	-	-	-	6.4	9.4
0.2	-	-	-	6.8	12.8	18.8
0.3	-	-	7.2	10.2	19.2	28.2
0.4	-	7.2	9.6	13.6	25.6	37.6
0.5	6	9	12	17	32	47
0.6	7.2	10.8	14.4	20.4	38.4	56.4
0.7	8.4	12.6	16.8	23.8	44.8	65.8
0.8	9.6	14.4	19.2	27.2	51.2	75.2
0.9	10.8	16.2	21.6	30.6	57.6	84.6
1	12	18	24	34	64	94
1.1	13.2	19.8	26.4	37.4	70.4	-
1.2	14.4	21.6	28.8	40.8	76.8	-
1.3	15.6	23.4	31.2	44.2	83.2	-
1.4	16.8	25.2	33.6	47.6	89.6	-
1.5	18	27	36	51	96	-
1.6	19.2	28.8	38.4	54.4	-	-
1.7	20.4	30.6	40.8	57.8	-	-
1.8	21.6	32.4	43.2	61.2	-	-
1.9	22.8	34.2	45.6	64.6	-	-
2	24	36	48	68	-	-

Table 1: Simulation cases

5. RESULT ANALYSIS

Since urban canyon has an impact on airflow characteristics, whether to generate vortex and turbulence, the areas considered in the studies are on leeward and windward sides in the canyon as specified in Figure 1.

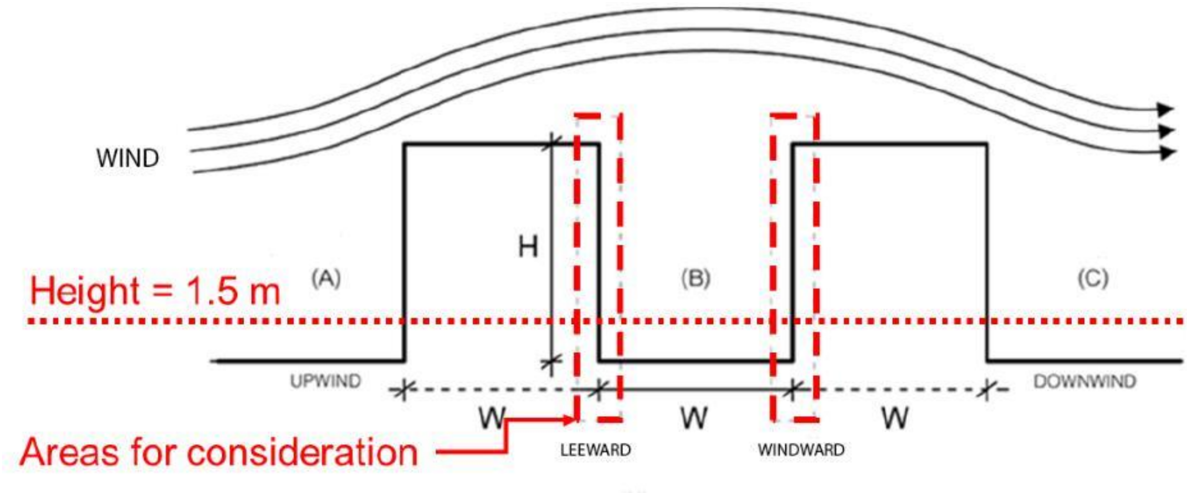


Figure 1: Areas for investigation

Results from the simulation show that wind velocities at pedestrian level in the street canyon perpendicular to the prevailing wind range from 0-0.18 m/s which cause still air. In the canyon parallel to the prevailing wind, the velocities range from 0.73-0.91 m/s which can enable thermal comfort and enhance air pollution dispersion. However, laminar flow occurs when building heights do not exceed 9-9.4 m (3 storeys).

Turbulence and vortex are profound on building's edges and downwind area when H/W Ratios are not less than 0.2 and building heights are above 9-9.4 m (3 storeys). Turbulences is likely to occur with increasing building height in association with increasing road width. The increase in pressure difference between the upwind and the downwind areas is noticeable for the cases with H/W = 0.4 and W = 64 meters. Turbulent flows are distinct. Wind velocities on windward side are generally higher and more distributed in the area than those on leeward side as the radar chart in Figure 2 shows percentages of areas on leeward and windward sides with the frequencies of low, medium and high velocity occurrence.

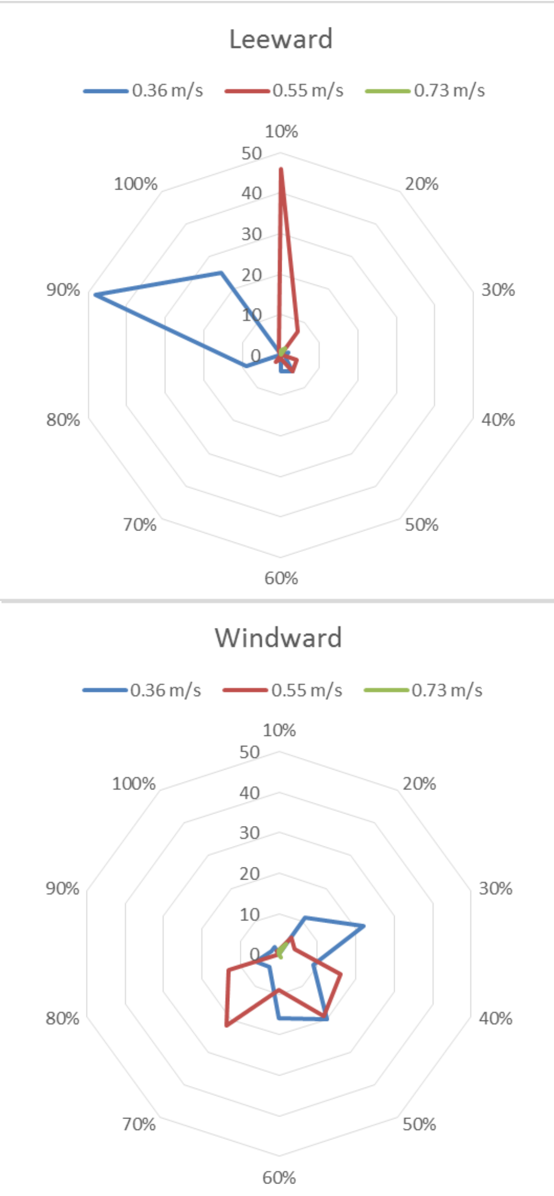
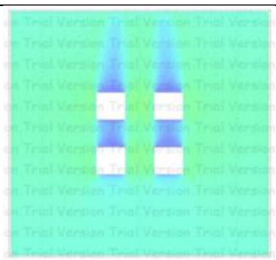
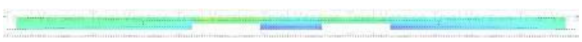


Figure 2: Percentage of area covered with 3-level wind velocities on leeward and windward sides

	Plan	Section
H/W Ratio = 0.1; H = 6.4 m.; W = 64 m.		

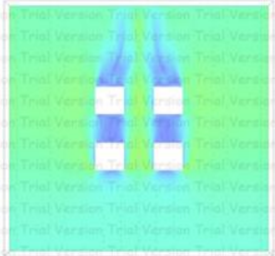
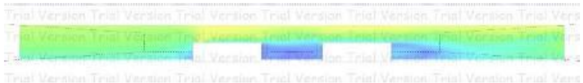
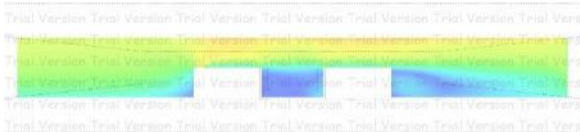
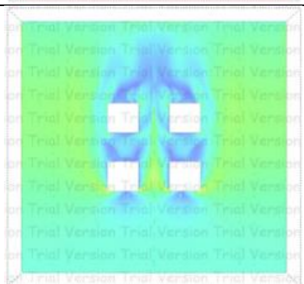
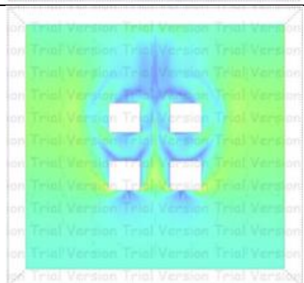
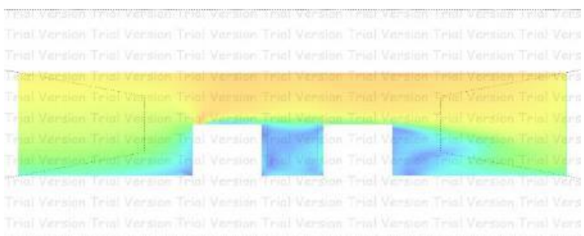
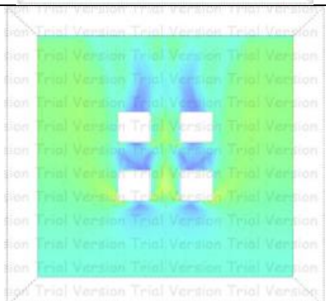
	Plan	Section
H/W Ratio = 0.3; H = 28.2 m.; W = 94 m.		
H/W Ratio = 0.5; H = 47 m.; W = 94 m.		
H/W Ratio = 0.7; H = 65.8 m.; W = 94 m		
H/W Ratio = 0.9; H = 84.6 m.; W = 94 m		
H/W Ratio = 1.5; H = 96 m.; W =64 m		

Table 2: Examples of simulation cases

Table 2 show examples of simulation results of low (less than 0.5), medium and high values of H/W ratios (above 0.5). Wide roads greatly influence turbulence as shown in models with H/W ratios higher than 0.5.

H/W Ratios range from 1-2 can generate turbulence for heat mitigation and air pollution dispersion. The turbulent flow can occur even when the road width is only 12 meters. However, the influences of high H/W ratio are profound when width = 34 meters. For the road of 12, 18, 24 and 34 meter wide, airflow patterns remain the same with increasing potential of turbulence. However, in cases of road width greater than 64 meters, the pattern is different.

On downwind side, vortices occur in the middle of street canyon as shown in the example case of 1.5 H/W ratio with 64-m road width. H/W ratios ranging from 0.5-1.1 potentially promote wind distribution in wider area especially when associated with wide roads: 34, 64, and 94 meters. Based on the overall simulation cases, it is found that the minimum H/W ratio should be 0.5 while the minimum building height should be 9 meters. The optimum road width is 34 meters.

6. CONCLUSION

Results from the study show that medium to high H/W ratios tend to increase air velocities and create turbulence in the canyon, thus promoting cooling effect for pedestrians. Therefore, it is possible to promote high density development for Bangkok. Nonetheless, it is required to balance between high H/W ratio and road width to avoid too deep canyon that traps heat during the night. It is recommended that stagnant conditions in the canyon can be improved by providing wind channel on ground level of buildings especially those that are situated along narrow roads. The recommended H/W ratios range from 0.5-2 while road width should not be less than 12 meters and not less than 34 meters is preferable.

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