Applying Numerical Simulation for Wind Availability
Studies of Urban Morphology for Urban Planning in Hong Kong

LAW PUI YIN KATHY[1], YIU KAM PO VINCE[1], NG YAN YUNG EDWARD[1]

[1]Department of Architecture, The Chinese University of Hong Kong, Shatin, NT, Hong Kong, China

ABSTRACT: To design a well ventilated environment for densely populated areas has always been a challenge for urban planners. The wind availability at pedestrian level is especially crucial in hot and humid climate. Given the same wind availability, the urban microclimates within the same region of the city could be very different due to various urban morphologies. Planners could control a number of design parameters like building bulk, building alignment and site coverage to prevent wind blockage and increase the wind availability. This paper aims to provide urban design guidelines for future development in order to increase the pedestrian level wind availability in congested hot and humid urban situations based on real examples in Hong Kong. Our study focused on how different urban morphologies would affect the pedestrian level air ventilation in the city and resulted in different microclimates. To achieve this, results of a LES feasibility study of two selected urban areas in Hong Kong, which is conducted by Leibniz University of Hannover, would be analyzed and some urban design guidelines would be recommended.
Keywords: air ventilation, building morphology, urban planning

INTRODUCTION

The population of Hong Kong had reached 6.96 million in 2007 and its population density is around 6,350 inhabitants per square kilometers. Hong Kong's terrain is mountainous and suitable land for building is extremely scarce. To accommodate the increasing number of inhabitants, buildings were densely packed and the development density had become very high (Fig. 1). Situated in the subtropical climate zone, the weather during summer is hot and humid. As wind velocity contributes to the increase or decrease in temperature, a well-ventilated environment in the outdoor urban space is especially crucial to the public health and thermal comfort during that time of the year. [1] [2] A comfort outdoor temperature chart for Hong Kong was developed by Cheng and Ng and it stated that a steady mean wind speed at pedestrian level of around 1.5 m/s will be beneficial for human thermal comfort in Hong Kong summer. [3]

Given the same wind availability, the microclimates within the same region could be very different due to various urban morphologies. According to Oke, the air space above a city is consisted of two layers, the urban canopy layer and the air dome layer. [4] The urban canopy layer is the space bounded by the urban buildings up to their roofs, while the air dome layer is the space above the canopy layer.

There are numerous microclimates generated by the various urban morphologies in the urban canopy layer as the specific climatic conditions at any given point within the canopy are determined by the nature of the immediate surroundings like the geometry of the buildings. In comparison, the air dome layer is more homogenous in its properties over the urban area at large as it is not much affected by the urban morphologies. [5]

Figure 1: Typical residential development in Hong Kong

Urbanization led to the decrease in wind availability is evidenced in Hong Kong. The annual average of 12-hourly 10-minute mean wind speed of King's Park during 1968-2005 showed a sustained decrease, while that of Waglan Island showed no significant trend. (Fig. 2) [6] Waglan Island is located offshore without the impact of urbanization, so the wind measurement reveals the background climate. On the other hand, King's Park is located on a knoll surrounded by Yau Ma Tei, Mong Kok, Ho Man Tin and, slightly further afield, Hung Hom. Urbanization in the broad vicinity of King's Park led to the steady decrease in the wind speed. The urban roughness elements are responsible for retarding the wind flow in the urban areas. [7]

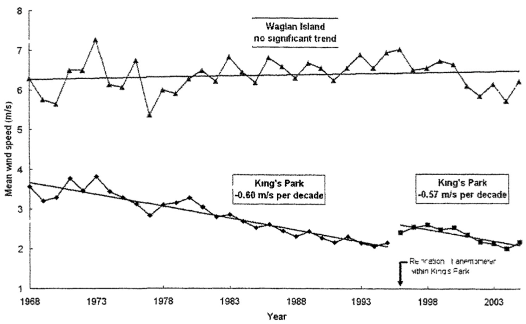

Figure 2: Time series of mean speed measured at King's Park and Waglan Island in 1968-2005

According to Givoni, there are a few main urban parameters that contributed to the urban roughness, which are the ground coverage, the building height differentials, the street orientation, and they are taken into account for the differences in wind availability at the pedestrian level. [8] The combination of different street widths, street lengths and building heights resulted in different types of urban canyons and it is another major factor affecting the pedestrian air flow. [9] Our research is to use real life examples' simulations to illustrate how these factors related to the wind availability if there is any relationship.

METHODOLOGY

Using PALM to obtain the Urban Wind information

The wind availability data in this research were generated with the Parallelized Large-Eddy Simulation (LES) Model (also known as PALM) by the Leibniz University of Hannover. LES is a powerful computational fluid dynamics scientific technique known to produce reliable results for turbulence studies and it is widely used to simulate atmospheric flow. For example, LES was used by the Tokyo Institute of Technology to estimate the environmental degradation at the urban heat island due to densely arrayed tall buildings as concerns about the new towers blocking the passage of sea breeze into the downtown of Tokyo were raised. [10]

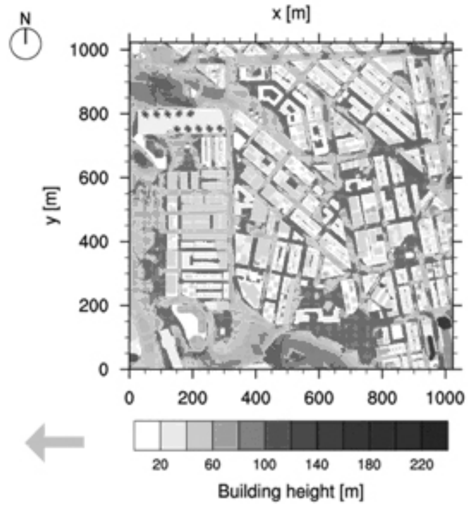

Figure 3: Stimulation of Mong Kok, wind comes from East

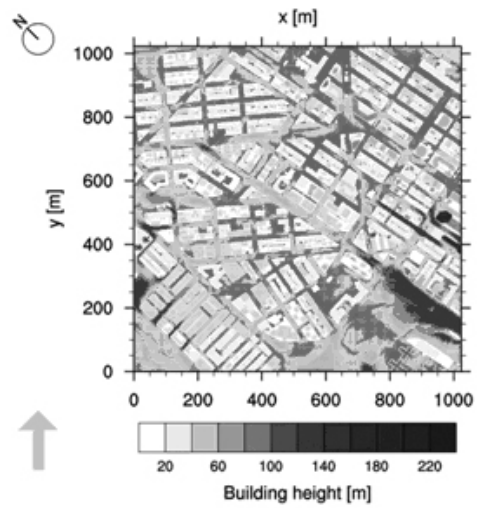

Figure 4: Stimulation of Mong Kok, wind comes from Southwest

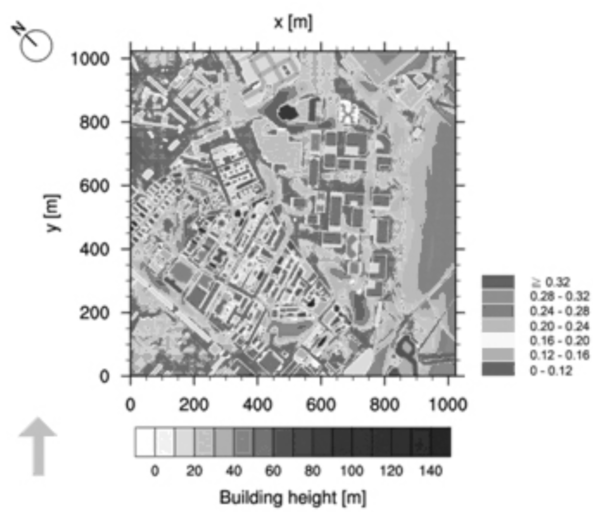

Figure 5: Stimulation of Tsim Sha Tsui, wind comes from Southwest

PALM is the parallel version of an LES model and it is optimized for use on massively parallel computers, and it is therefore very well suited for simulations with an extremely large number of grid points. [11] The original version of PALM was developed by Prof. Siegfried Raasch with his research team from 1997-1999 at the Institute of Meteorology and Climatology of the Leibniz University of Hannover. In 2000, Siegfried Raasch, Michael Schröter and Jens Bange used PALM in the investigation of the homogenous heated convective boundary layer. [12] In 2003, Siegfried Raasch and Marcus Oliver Letzel used PALM in the investigation of the heterogeneous heated convective boundary layer. [13] In 2008, Siegfried Raasch, Marcus Oliver Letzel and Martina Krane investigated urban turbulence characteristics at street canyon and neighborhood scale with PALM. [14]

Method of Study Tsim Sha Shui and Mong Kok were selected for the simulation as they are two of the most densely built up area in Hong Kong and the topography of the sites is quite generous so that the topographical effects could be minimized. In order for the Leibniz University to conduct the PALM simulations, some data of the Kowloon area were provided, such as the topography map, land use map, 1 to 1000 scale street maps, building ground plan, building podium plan and podium heights, building tower plan and building heights, the QuickBird satellite images, and regional and local climate data. The assessment area of each model was 1 km². Simulations with different wind directions were generated for direct comparison. The models of Tsim Sha Tsui and Mong Kok were simulated under the southwest wind, because southwest monsoon often occurred in summer. And the model of Mong Kok is also simulated under the east wind as the prevailing wind of Hong Kong is from the east. [15] (Fig. 3, 4 & 5) Through the PALM stimulation, the wind velocity ratios and the wind pattern would be captured to reveal the features of air movement in the high dense urban context. The wind velocity ratios captured were at a level of 2m above ground as the wind availability at the pedestrian level is the main focus of this research. The wind velocity ratios were categorized into a scale of 7 ranges which are the 0-0.12, 0.12-0.16, 0.16-0.20, 0.24-0.28, 0.28-0.32, and all larger than 0.32. Our focus would be on the relationship between the obtained wind availability from PALM and various combinations of urban parameters, such as building heights, building density, street widths, and street orientation, etc. Abnormal wind patterns, like extremely weak or strong wind availability at a point in the site, would be spotted out and further studied with the surrounding urban parameters. The result would be used in generating new design guidelines for buildings and city planning concerning with the betterment of air ventilation in the city.

ANALYSES & FINDINGS

Super high-rise buildings located among lower buildings From the two selected sites, there are noticeably super high-rise buildings among lower buildings, such as Concordia Plaza (Fig. 6, 7) in Tsim Sha Tsui and Langham Place in Mong Kok (about 120m and 250m respectively). These tall buildings would draw downwash air-flow and create strong turbulences around them, thus stir up air on pedestrian level.

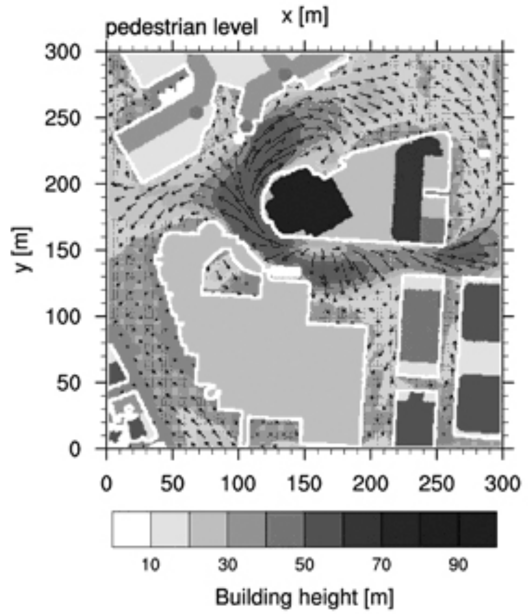

Figure 6: Downwash air flow and turbulence created by super high-rise

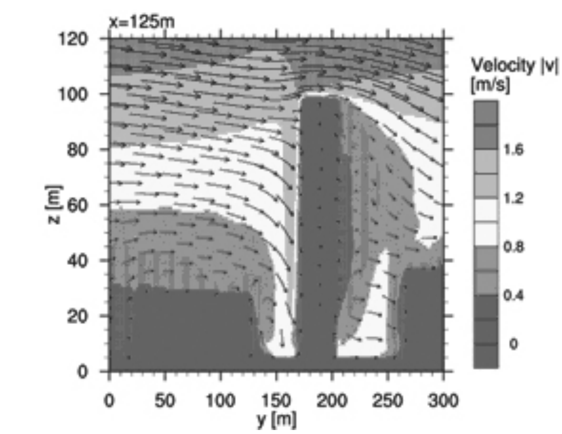

Figure 7: Stimulation in section showing downwash air flow and turbulence

Podium effect The tendency to build towers sitting on top of podium has been adopted by Hong Kong developers for years. Usually the podium would cover most of the site area to provide as many shop fronts as possible, so as to optimize the monetary profit.

Figure 8: Podia with high ground coverage become the major wind barrier on pedestrian level

But on the other hand, building density on pedestrian level would be extremely high. (Fig. 8)This phenomenon discourages air ventilation on ground level and contaminants in air would accumulate, directly influencing habitants' health.

Examples from the two areas show that most of the narrow streets between podia have relatively low air movement.

Slab buildings together form a big building mass Above the podia, building positioning and building forms are also highly related to the availability of wind. It is common to find towers aligning in rows, which create wall-like building groups. (Fig. 9) These wall buildings, if aligned perpendicular to prevailing wind direction, would act as wind barriers and avoid wind penetrating into the inner city.

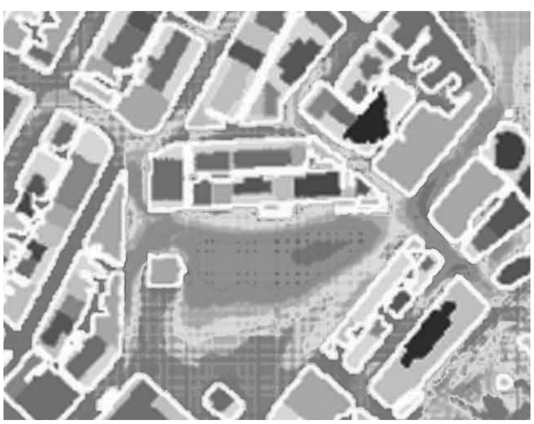

Figure 9: Buildings align in a row and sit on top of podium

Streets parallel to prevailing wind direction Theoretically, streets that are parallel to the prevailing wind direction are most likely to have better air ventilation. Boundary Street in Mong Kok has well demonstrated how an unobstructed wide street can achieve better air availability. (Fig. 10) On the other hand, Prince Edward Road West, Bute Street, Mong Kok Road and Argyle Street are also parallel to the wind direction, but they are performing just slightly better than those streets which are perpendicular to the wind direction. (Fig. 11)

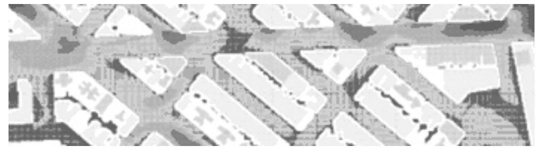

Figure 10: Boundary Street in Mong Kok

Figure 11: Obstructed streets in Mong Kok that are parallel to the East prevailing wind

Stagnant spaces and cul-de-sac Due to the high dense development and urban roughness, wind availability on pedestrian level is already reduced. Therefore, it is not surprising to find that spaces surrounded by towers and at culs-de-sac are extremely stagnant.

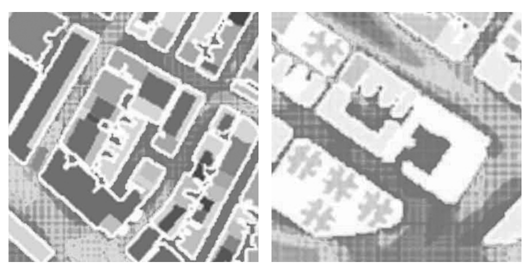

Figure 12: Stagnant zones in the cul-de-sac

DESIGN RECOMMENDATION

Fragmentation of podia & re-positioning of towers As the podia have deepened the urban canopy and have blocked direct wind flow and downwash wind towards the pedestrian level, one possible suggestion is to break the massive podia into smaller fragments to increase wind permeability.

Moreover, strategically position and orient towers on top of podia is also crucial. It is common for Hong Kong developers to design and align buildings in rows to capture view. One should consider creating wind path for prevailing wind by rotating the towers.

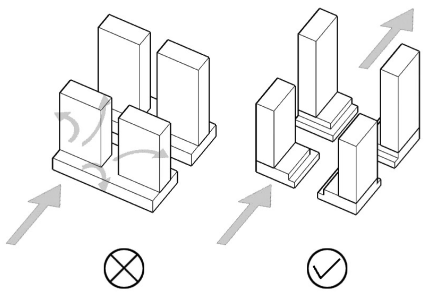

Figure 13: Fragmented building mass with strategically oriented towers would enhance urban ventilation

Increasing building permeability One should try to avoid creating dead ends or stagnant spaces by increasing building permeability. Design of building form is therefore highly associated to the urban wind environment. It is encouraged to lift up buildings to create open spaces on ground level for pedestrians and to enhance air movement.

Slab buildings should be carefully oriented and not to block the prevailing wind. Another alternative would be creating large openings as urban windows.

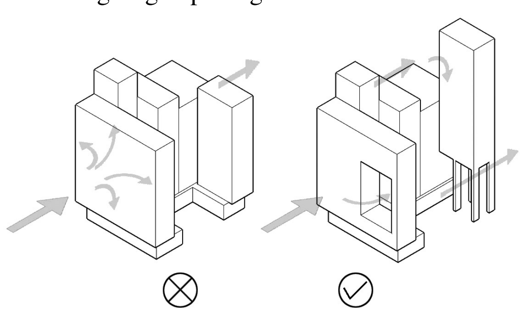

Figure 14: Building forms should be designed with consideration of air flow so that stagnant zones are minimized

Creating building height differential & providing more open space A group of towers with similar height would act as a single and large building mass with poor wind availability inside. One might consider designing towers with different height so that the same population density can be achieved, but more open space is created. Tall buildings with sufficient open space around would allow downwash wind to reach the ground level, hence, to improve air ventilation on ground level.

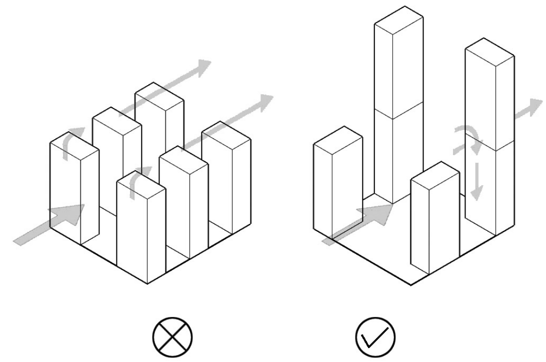

Figure 15: The same population density can be achieved with lower ground coverage, and more open space is created

To arrange streets & buildings in parallel to the prevailing wind From the illustrations in Mong Kok (Fig. 9, 10), even some streets are parallel to the wind direction, they are still not guaranteed to have good air ventilation as there are blockages at the end of the paths.

It is crucial to have wind paths clear by positioning towers in a way cooperating with the urban wind flow. Towers should be separated in a certain distance to create wind paths. Mega-structures should be deliberately placed with sufficient open space surrounded as they would generate great impact to the neighbor environment. Large wind turbulences are formed around them and the surrounding occupants, especially those at the leeward side of the mega-structure, would suffer from stagnant condition.

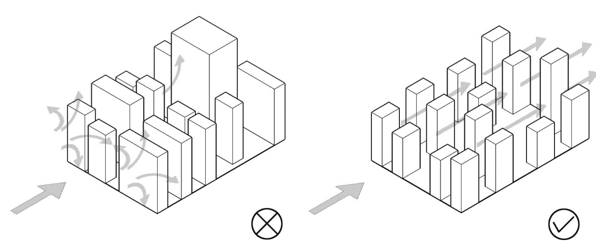

Figure 16: Streets and buildings should be designed with consideration of prevailing wind direction

POSTCRIPT

Lately, a controversial development on top of Nan Cheong west rail station has been redesigned. [16] Originally, government planned to build 10 residential towers and 1 commercial building, with plot ratio up to 8 (Fig. 17). The final decision was to take away 1 residential and commercial tower, resulted to a reduced 6.6 plot ratio, as well as two wind paths between the towers. In addition, the podium height was lowered 12m, so as to enhance air ventilation on the pedestrian level. This is a good start showing that environmental consideration is taken into account in development. Public interests have also been aroused. Therefore, different approaches and strategies should be applied according to the wind environment. Planners and architects can also use different kinds of numerical simulation as tools to understand and design our living environment.

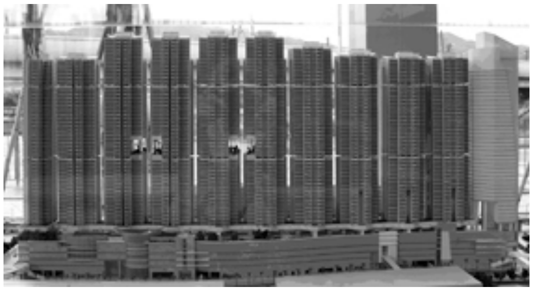

Figure 17: Model of the original purposed scheme of the development on top of Nan Cheong west rail station

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