# Urban renewal based wind environment at pedestrian level in high-density and high-rise urban areas in Sai Ying Pun, Hong Kong

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**Abstract.** In high-density and high-rise urban areas, pedestrian level winds contribute to improve comfort, safety and diffusion of heat in urban areas. Outdoor wind study is extremely vital and a prerequisite in high-density cities considering that the immediate pedestrian level wind environment is fundamentally impacted by the presence of a series of high-rise buildings. In this paper, the research site of Sai Ying Pun in Hong Kong will be analysed in terms of geography, climate and urban morphology, while the surrounding natural ventilation has also been simulated by the wind tunnel experiment Computational Fluid Dynamics (CFD). It has found that, the existing problems in this district are the contradiction between planning control and commercial interests, which means some areas around tall buildings are not benefit to the residents because of the unhealthy wind environment. Therefore, some recommendation of urban renewal strategy has been provided.

## 1. Introduction

Urban renewal plays important role in urban economic development and urban construction, which is also an unavoidable problem in contemporary urban development in developing countries [1]. Despite Hong Kong has only approximately 150 years history, the severe conflict between human and land, leading to urban development strategy with the characteristic of high-density and high-rise, increases the work of urban renewal in Hong Kong. However, based on the urban renewal in Hong Kong, the environmental problems are emerging and may affect the residents' health and comfort. For example, many people died due to severe acute respiratory syndrome (SARS) in Hong Kong in 2003, which led the government to establish a Government Team Clean Committee to improve local urban design policies. In 2006, all development projects funded by the government had to apply a new system of air ventilation assessment (AVA) [2]. Using AVA, urban designers and architects can optimize the natural air ventilation in high-density areas of Hong Kong to avoid stagnant and slow air movement to obtain an appropriate air change rate in urban open public spaces. This is intended to generate a healthy and comfortable outdoor environment. According to previous research focused on Hong Kong, improving air ventilation to create a better wind environment has been demonstrated as the most important consideration in designing and developing sustainable cities, especially under the situation of urban renewal [3].

Sai Ying Pun is situated in the Western District of Hong Kong Island and is a key administrative region for both the Western and Central districts. In the local tongue, Sai means "west" while Ying Pun translates as "camp", generally a military camp. The British military were based in this area and the locality was one of the first developmental zones in wider Hong Kong. Although the existing
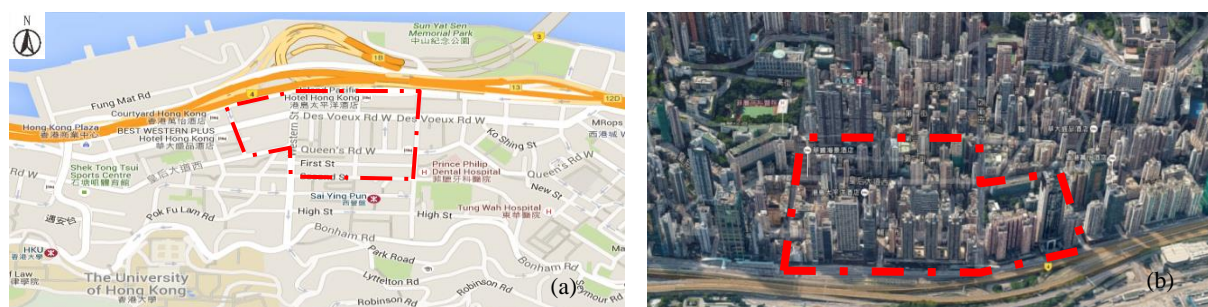
buildings are in poor repair, most of these are residential buildings and a lot of shops, selling sea food products and traditional Chinese medicinal materials, exist on the ground level (figure 1). In Sai Ying Pun, there are many small lanes and the majority of these are only open to pedestrians. While these lanes may have been quite significant in the past as they provided access to local residential properties, they now primarily function as back alleys and shortcuts between housing units. Furthermore, the area has a primarily aging population and as many elderly people living in this district prefer to socialise outdoors, the stipulation for a safe, comfortable and healthy outdoor wind environment at the pedestrian level is crucial, not only for the inhabitants, but also for those working here. Additionally, there are many similar narrow streets surrounded by tall buildings in other regions of Hong Kong, which may account for Sai Ying Pun being a popular outdoor thermal comfort research case study for researchers. Although the geometry, urban and building layout in this site are applied as a convenient case study with a high-density tall building district to compare the results between wind tunnel tests and CFD simulation, understanding of some aspects of social environment, neighbourhoods, residents' requirement etc. is conducive to analysing and generating some recommendation of urban renewal strategy in Hong Kong and other developing regions facing urban renewal.



**Figure 1.** Introduction of Sai Ying Pun: (a) location in Hong Kong (blue point) and (b) street view.

The red dashes illustrate the target research site area for wind tunnel testing and CFD simulation (figure 2a and 2b). Connaught Road West and the ocean are north of this site, whilst the Sai Ying Pun Metro Station is on the south. There are approximately 36 tall buildings and podiums that link a number of these. The local meteorological data is always monitored by the nearest meteorological station, and some are in airports (rural area) while some are located at the top of buildings or mountains (urban area). The nearest station around Sai Yin Pun belongs to the latter one, and it is located on the roof of one tall building (approximately 60m height) in the University of Hong Kong, and their straight-line distance is about 300m.
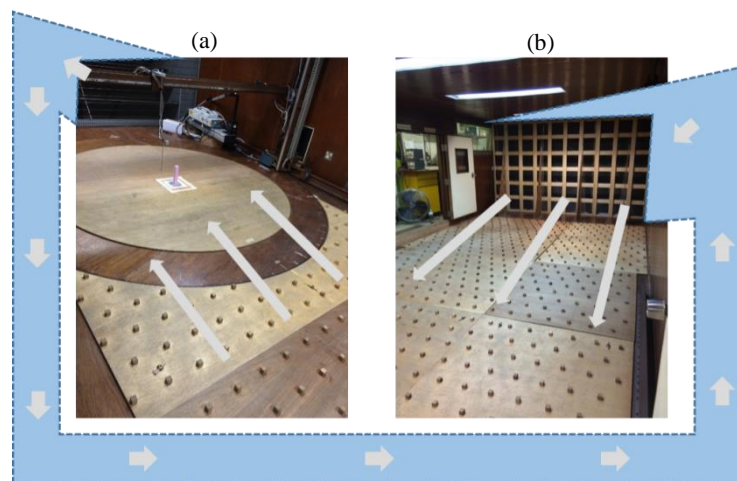


**Figure 2.** Target research area in Sai Ying Pun, Hong Kong: (a) 2D version and (b) 3D vision.

## 2. Wind tunnel tests

This section details the equipment, experiment set-up, procedure and also results of wind tunnel tests applied in the outdoor wind environment simulation in Sai Ying Pun to modify the parameter settings of CFD simulation. Wind tunnel tests are carried out to evaluate the interference effects attributed to several medium-rise and high-rise buildings.

*2.1. Test cases and experiment set-up*
The experiments were performed in the boundary layer wind tunnel at the Department of Civil Engineering, University of Hong Kong. The working section is 12m long, 3m wide and 1.8m high. To simulate natural wind conditions, 8m long fetch of floor roughness elements have been applied (figure 3b). The inlet wind for simulation is provided by the fan from behind the wooden rail fence. Opposite the simulation room (figure 3a), the target building models could be fixed on a rotatable round plate (2.5m diameter). After passing through the building target site, the air will enter another empty room beneath the simulation room, following which it is brought back by the fan into the simulation room creating one closed air flow pipe with the direction of movement depicted by grey arrows.



**Figure 3.** The boundary layer wind tunnel in HKU: (a) the rotatable round plate for fixing target models and (b) floor roughness elements in wind tunnel.

Two pressure sensors connected to a pitot static tube respectively, and they were employed to measure wind factors, such as wind speed, direction and pressure. One sensor and tube unit was installed on the moveable frame above the model, whilst the other one was fixed onto a further frame ahead of the models. This category of sensor and tube unit projects an "L" shape and it can only move vertically and horizontally when controlled by the external control panel. The wind speed can be monitored from the control panel that is also able to set up inlet wind velocities.

The shielding effects of various configurations of surrounding medium-rise buildings in the same wind tunnel laboratory have been tested in HKU [4]. In their research, the vertical profiles of mean wind speeds and turbulence intensities have been measured at the centre of the turntable for the simulated wind, for two terrain types: open land and suburban. Both the terrains have employed the mean wind profile following the power law with power exponent =0.13 and 0.20, respectively. Due to the geographical location (the north of Sheung Wan is sea) and urban morphology (located in high-dense tall building district), the suburban land terrain is chosen to describe Sai Ying Pun and the power exponent 0.20 will also be applied in the latter CFD simulation.

*2.2. Procedure*
The target geometric scale is 1:300; therefore, the tallest building with an approximate height of 150m will be 50cm in model-form. It is important to note that East and North are the two prevailing wind directions with the mean inlet wind velocity as 6m/s for both wind tunnel tests and CFD simulations.

## 3. CFD simulation

### 3.1. Set-up of the Simulation

The target site area is approximately 260 * 450 * 160m (W * L * H), while the whole computational domain size for this validation experiment is 2000 * 2000 * 400m. In this paper, considering software limitations, an adaptive meshing method has been employed in view of its ability to obtain increasingly accurate data on wind environment at the pedestrian level, which can, subsequently, utilise the computational resources efficiently too. In addition, three more layers are arranged below the evaluation height (1.5m above ground level, roughly human head/chest height where the thermal environment is sensed) and the maximum grid size ratio is set to 1.2. There are three levels of cells: In total, the domain is divided into 7,776,000 cells. Furthermore, the grid distribution is established based on the recommendation by the Architectural Institute of Japan (AIJ) [5], whereby 10 cells correspond to a cube root of building volume, which means the footprint of each building is divided into at least 10 cells to increase the accuracy of results. In this condition, the smallest size of cell in the interested with the most density area is about 1 * 1.2 * 0.5m (W * L * H).
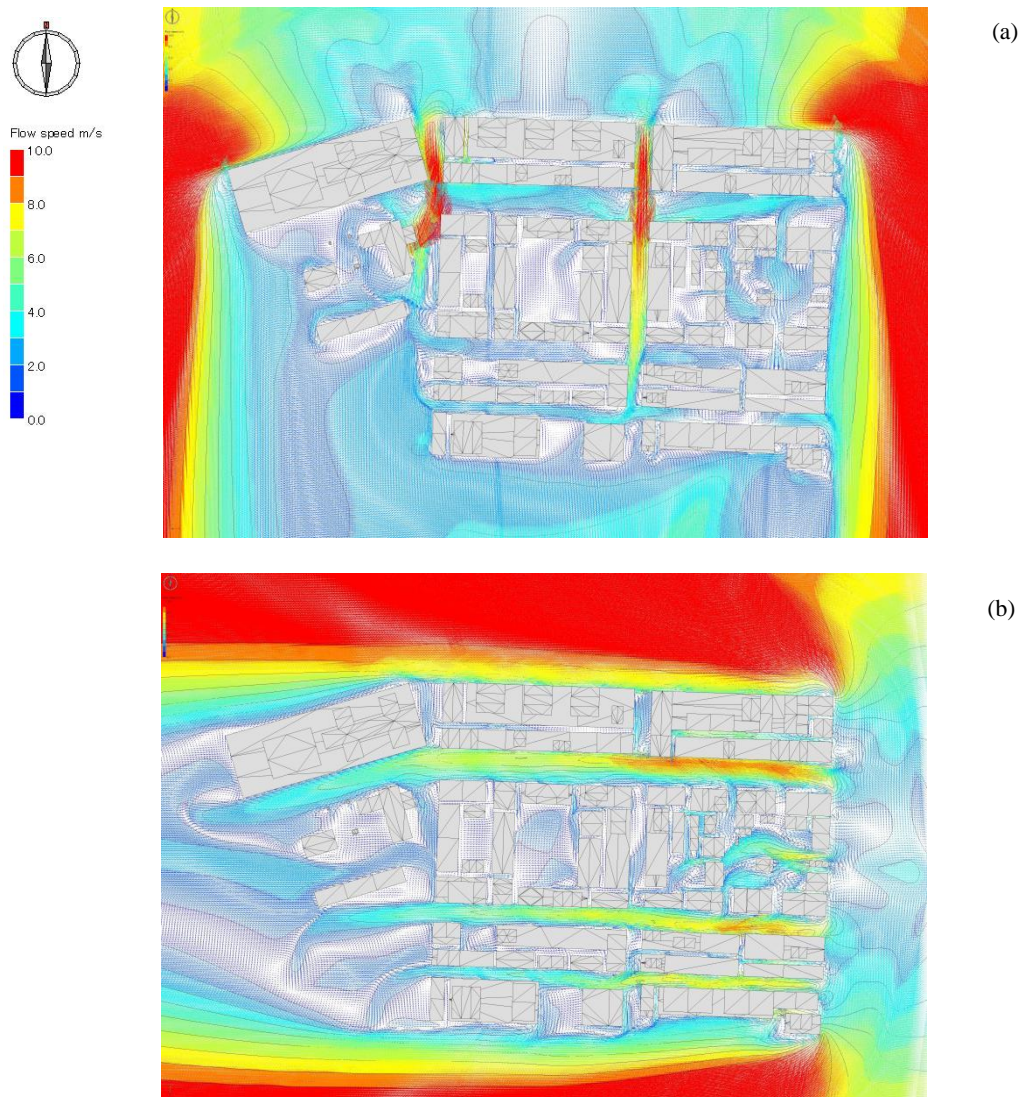
### 3.2. Parameter settings

The boundary conditions, turbulence model and other boundary parameters have been considered according to relevant research [6-7]. For the purposes of this research, the CFD simulations have applied the 3D steady RANS equations and the standard k-ε turbulence model provides closure. A basic algorithm is used to stabilise pressure velocity-coupling. For the convection and viscous terms of the governing equations, pressure interpolation is the second order utilised.

### 3.3. Results

The wind flow can be influenced by objects as well as building patterns and orientation. Generation of high-pressure zones by wind deflection on windward facades is a well recognised phenomenon, while low-pressure zones are attributed to wind separation over the leading sharp edge and leeward façade. Indeed, wind environments with high velocity and turbulence may exist in the leeward and particular attention should be paid towards tackling such occurrences.

Simulation results at the pedestrian level performed using FlowDesigner with two prevailing wind inlet directions are presented in figure 4. Likewise for both wind directions, the central space is mostly wind-shaded (areas with blue dashes) and may experience low air movement. Surrounding buildings enclose these spaces and the corridors linking to main streets may be too narrow. Consequently, the majority of separate airflow over the wind-ward buildings did not enter these central spaces. On the other hand, the highest wind velocities are present in the outdoor spaces (purple dashes) for both wind directions as these areas face the inlet winds directly allowing the airflow to penetrate these narrow areas liberally. Comparison of the wind environment depicted by the green dashes indicates that the average wind speed and turbulence levels are higher in figure 4b than figure 4a due to there being increased airflow at the pedestrian level when the wind is from east, allowing wind to pass through the aisles between buildings. Furthermore, by analysing the distinction in wind pressure for both variables, the longer windward facades by buildings and podiums encourage greater wind deflection.

**Figure 4.** CFD simulation results in Sai Ying Pun: (a) north wind inlet and (b) east wind inlet.

## 4. Results comparison and discussion between wind tunnel tests and CFD simulations

For both wind tunnel tests and CFD simulation experiments, the mean wind velocity measurements were analysed at an equivalent full-scale height of 1.5m and a scaled height of 0.5cm in wind tunnel tests. The positions where comparisons of pedestrian level wind speeds were made are detailed in figure 5. The majority of these locations were selected after careful consideration during the experiment, whereby two positions (locations 4 and 9) encompassed the central aisles and three positions (locations 7, 10 and 11) covered the courtyard region.

There were two monitoring sensors were used during each wind tunnel test; one was always set ahead of the first building facing the incoming wind with a distance of 20cm and a height of 30cm from ground level in scaled, which equals to 60m and 90m respectively. This sensor was applied to ensure the inlet wind speed was keeping at the level of 6m/s. Meanwhile, another remotely operated sensor measured the wind speed of selected points. Once the wind speed at all thirteen positions was recorded with the north wind the building models were rotated 90$^{\circ}$ anticlockwise for the subsequent simulation.

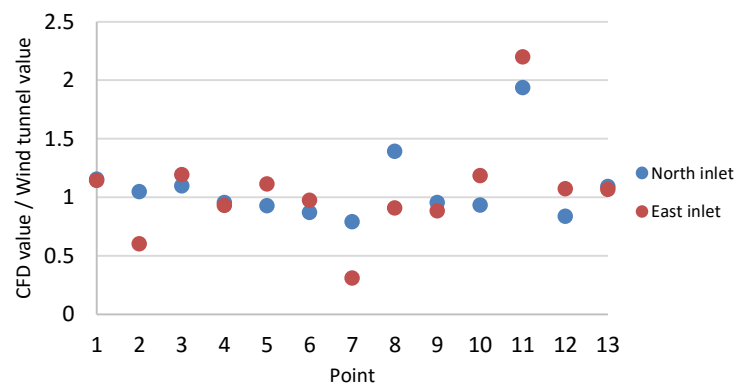**Figure 5.** Positions in the site for comparing the results of wind tunnel tests and numerical simulation.

As shown in table 1, discrepancies in the findings with both inlet wind directions show an equivalent order of magnitude. Location 12 shows the maximum inconsistency between each wind direction variable, which is greater than approximately 200%. Conversely, the deviations are within 20% for most of the other locations. The maximum difference tends to occur within the courtyard areas (Locations 7 and 11), while the lowest variation arises nearest to the building corners (Locations 4, 9 and 10). This divergence may be explained by limitations of CFD in modelling complicated air flow patterns, including those in re-circulating regions. Alternatively, it may be caused by errors made when taking measurements on account of interference by sensors during wind tunnel experiments. In addition, the roughness of model surface in the wind tunnel is not as smooth as CFD, and it may reduce the level of details when meshing the model in CFD.

**Table 1.** Mean wind speeds with north and east wind in wind tunnel and CFD.

| Location | North wind speed (m/s) | | | East wind speed (m/s) | | |
|---|---|---|---|---|---|---|
| | wind tunnel reference wind velocity | wind tunnel | CFD | wind tunnel reference wind velocity | wind tunnel | CFD |
| 1 | 6.1 | 7.06 | 8.16 | 6.39 | 5.72 | 6.54 |
| 2 | 6 | 6.01 | 6.3 | 6.44 | 2.95 | 1.78 |
| 3 | 6.08 | 2.28 | 2.5 | 6.38 | 4.83 | 5.76 |
| 4 | 5.96 | 3.78 | 3.61 | 7.24 | 3.35 | 3.12 |
| 5 | 5.93 | 3.62 | 3.36 | 6.61 | 5.52 | 6.15 |
| 6 | 6.12 | 4.2 | 3.65 | 6.45 | 6.45 | 6.28 |
| 7 | 6.23 | 3.97 | 3.14 | 6.66 | 1.75 | 0.54 |
| 8 | 6.14 | 2.75 | 3.83 | 6.42 | 5.97 | 5.43 |
| 9 | 6.01 | 3.55 | 3.39 | 6.4 | 3.12 | 2.76 |
| 10 | 6.07 | 2.89 | 2.7 | 6.87 | 0.76 | 0.9 |
| 11 | 6.02 | 3.32 | 6.43 | 6.69 | 1.05 | 2.31 |
| 12 | 5.87 | 2.53 | 2.12 | 6.29 | 4.63 | 4.97 |
| 13 | 6.09 | 2.05 | 2.24 | 6.46 | 5.81 | 6.2 |

Therefore, from the ratio between the measured wind speed and the reference wind speed at each selected location in wind tunnel tests and CFD simulation shown in figure 6, the great majority are

between 0.8 and 1.3, which is suggesting that application of the standard k－ϵ model in FlowDesigner can predict accurately the pedestrian-level wind environment.



**Figure 6.** Wind speed ratio of CFD simulation and wind tunnel tests.

### 5. Summary

This paper has addressed the experimental and computational assessment of pedestrian outdoor wind environments neighbouring a series of tall buildings in Sai Ying Pun, Hong Kong. Local inhabitants' living conditions and natural wind statuses in the urban environment have been introduced. Therefore, the buildings have been used in wind tunnel tests and CFD to analyse the outdoor ventilation. The existing problems are the contradiction between planning control and commercial interests, the incongruity between public interest and individual interests, the ambiguity between society, environment and economic benefit is the long-term discussion topic in urban renewal. Integrating the results to the realistic state can demonstrate that, the elderly may have to use some narrow streets with high velocity, followed by dangerous, and citizens may also have to apply the courtyards with stagnant wind that is not beneficial to the healthy air change. The important way to deal with these contradictions is co-ordination, which means with regard to urban renewal and transformation movement in such high-density and high rise district, under the balance of society and economy, improving environmental comfort, health and safety in advance is the key strategy to make Hong Kong become environmental-friendly and sustainable. In future research about local urban renewal, elevating the podium of these tall buildings for allowing more wind to pass through the calm zone could be studied to improve the air exchange rate, especially at the pedestrian level.

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