

# Case Study on the Pedestrian Wind Environment of Commercial Streets in Beijing and Tokyo Based on CFD Simulation



Zhongqing Yang and Xiaojing Zhang

**Abstract** Due to modern lifestyles, commercial streets have become an indispensable place in urban life. Pedestrian wind environment is one of the primary concerns in commercial street design since it has direct influences on urban heat island effect, indoor and outdoor thermal comfort, outdoor air pollution and indoor air quality. To investigate pedestrian wind environment of a commercial street, a case study was performed on Beijing Wangfujing Commercial District in China and Tokyo Sensoji Temple District in Japan separately. First, the original models of these two commercial streets were established based on real streetscapes and the surrounding buildings. The velocity filed under typical summer climatic conditions was then output to assess the wind environment of each street. The results show that pedestrian wind environment under the current design is not comfortable for Beijing street and Tokyo street. To improve this situation, further work was conducted on optimization of current street design, specifically on the determination of a suitable aspect ratio  $H/W$  ( $W$  is the width of the street and  $H$  is the height of the street buildings). In this step, simplified models derived from original models of each street were used for simulation. According to present simulation results, the determined aspect ratio  $H/W$  is about 0.80 and 0.30 for Beijing street and Tokyo street, respectively. It should be noticed that this ratio could differ on the height of the street buildings as well as on the climatic condition of the street locations.

**Keywords** Numerical simulation · Wind environment · Commercial street design · Thermal comfort

---

Z. Yang · X. Zhang (✉)

Key Laboratory of Green Built Environment and Energy Efficient Technology,  
Beijing University of Technology, Beijing, China  
e-mail: [xjzhanger@163.com](mailto:xjzhanger@163.com)

Z. Yang

Graduate School of Architecture and Building Science, Tohoku University, Sendai, Japan  
e-mail: [yang.zhongqing.tohoku.jp@gmail.com](mailto:yang.zhongqing.tohoku.jp@gmail.com)

© Springer Nature Singapore Pte Ltd. 2020

Z. Wang et al. (eds.), *Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)*, Environmental Science and Engineering, [https://doi.org/10.1007/978-981-13-9520-8\\_56](https://doi.org/10.1007/978-981-13-9520-8_56)

## 1 Introduction

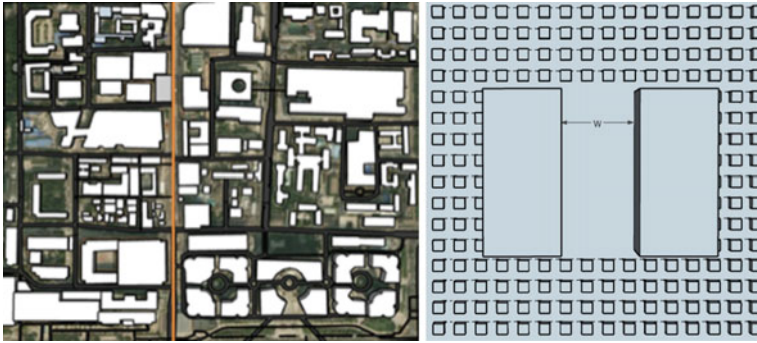
In the mega-cities like Beijing and Tokyo, high urbanization exacerbates urban heat island (UHI) phenomenon. Climate changes show that the annual mean air temperature has increased by 2 °C in Beijing for the last 40 years and by 3 °C in Tokyo for the last 100 years. A number of researches have proved that UHI could cause various problems such as heat stroke and large electric power demand for cooling devices. Among many physical environmental factors, the wind environment has become one of the most important considerations in the study of UHI effects because it has a significant impact on outdoor thermal comfort [1, 2]. Good urban ventilation can take away the excess heat production by citizens in the city, and accelerate the dissipation of pollutants.

Computational wind engineering (CWE) as a branch of Computational Fluid Dynamics (CFD) has developed rapidly over the last decade [3]. Prediction of wind climate for various scales is one of the most important targets for researches in wind engineering because the wind climate in urban areas is a very complicated phenomenon affected by many physical processes. Until now, the rapid growth of CWE applications has greatly expanded the scope of wind engineering and covers various issues ranging in scale from the microclimate around a human body to the mesoscale climate in urban areas. In this study, Flow Designer was used to simulate the wind environment in the pedestrian level of Wangfujing Commercial Street in Beijing, China and the Sensoji Commercial Street in Tokyo, Japan, which represent typical street design cases. The accuracy of the simulation results was explored based on the guidelines of CWE simulation. Common simulation models of commercial streets were first established. Then as a key factor to reach the requirement for “zone of compatibility” in the street design [4], the impact of aspect ratio  $H/W$  ( $H$  represents the height of the buildings on both sides of the pedestrian street and  $W$  represents the width of the pedestrian street) on the street wind environment was explored. Finally, the modified aspect ratios of two types of commercial districts were determined as a reference for the future sustainable street design under similar circumstance.

## 2 CFD Simulations

### 2.1 Case One-Wangfujing Commercial District Model

The target street selected for this study is a part of Wangfujing commercial district. The target street which is highlighted by the orange line and its surrounded buildings are shown in Fig. 1. Google earth is used to download building data in this study. This target area is a rectangle with a length of 1000 m from north to south and a width of 800 m from east to west. According to Google earth data, buildings on two sides of the pedestrian street were both high-rise in the centric area and those in the sub-centric area were middle-rise.



**Fig. 1** Original Wangfujing model on the left and simplified Wangfujing-type model

Original Wangfujing model on the left of Fig. 1 is then simplified for exploring the impact of aspect ratio  $H/W$  on wind environment. Two larger cubes set in parallel represent the high-rise buildings on both sides of the pedestrian street. The height is set to 48 m which equals to the average height of actual high-rise buildings. The width is set to 70 m according to the windward side and prevailing wind direction in summer. The length is 150 m, which is as long as the target street. Smaller cubes are distributed equally in the simplified model representing the middle-rise buildings located in the sub-centric area of the street. Each small cube is 10 m long, 10 m wide and 15 m high. The distance between every two small cubes is 10 m. To obtain different values of aspect ratio  $H/W$ , the width of the street is set to 30, 40, 50, 60 m. Corresponding to the different wideness, the aspect ratios  $H/W$  are calculated to 1.60, 1.20, 0.96, 0.80.

The monthly average air temperature and wind speed of August 2017 in Beijing provided by Beijing Meteorological Service is used for wind environment simulations. For Beijing case, the prevailing wind direction is southeast in August, the average wind velocity at 10 m height is 2.38 m/s, and average air temperature is 30.50 °C.

## 2.2 Case Two-Sensoji Commercial District Model

The Sensoji district is also oriented south and north with a length of 200 m. The target street selected for case two is the main part of the whole district and its surroundings as shown on the left side of Fig. 2. The target area is a rectangle with a length of 400 m from north to south and a width of 350 m from east to west. Unlike Wangfujing commercial district, buildings are relatively low-rise on both sides of the street and the vicinity of Sensoji district.

The figure on the right side shows the simplified model of Sensoji street. The two cubes set in parallel represent the buildings beside the pedestrian street.

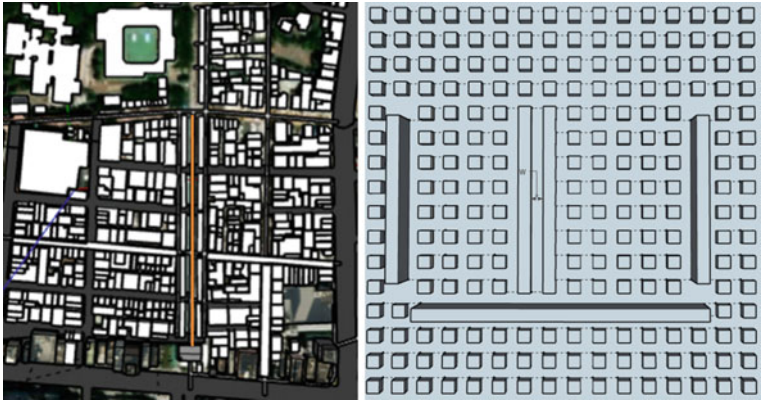


Fig. 2 Original Sensoji model on the left and simplified Sensoji-type model

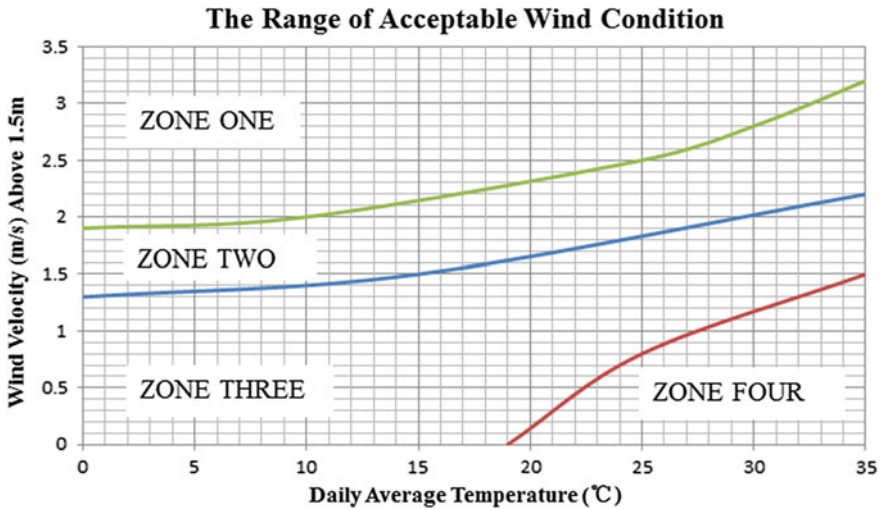


Fig. 3 The range of acceptable wind condition

Both are 200 m long, 10 m wide and 15 m high. The settings are determined by the dimensions of actual buildings with the unified specification. The two outer cuboids with 180 m long, 10 m wide and 30 m high represent the high-rise buildings near the target street. The cubes with a length, width, and height of 10 m represent the low-rise buildings scattered around the target street. The width of the street is set to 10, 30, and 50 m to obtain different values of  $H/W$ , resulting in corresponding aspect ratios  $H/W$  of 1.50, 0.50 and 0.30.

Similarly, the prevailing wind direction, the monthly average temperature and wind speed of August 2017 in Tokyo are also used in Sensoji model.

The meteorological data are provided by Japan Meteorological Agency. For Tokyo case, the corresponding setting is southwest, 29.80 °C and 3.00 m/s.

### ***2.3 High Reynolds Number Revised LK Model***

This study first used Sketch Up software to create models, and then applied the Flow Designer software to numerically simulate the outdoor wind environment. Because the poor prediction accuracy of standard  $k - \varepsilon$  model is unsatisfied with the requirements of practical applications, the high Reynolds number revised LK model [5] is selected to perform CFD simulations.

### ***2.4 Wind Environment Evaluation Method***

The evaluation method of acceptable wind condition [6, 7] is shown in Fig. 3.

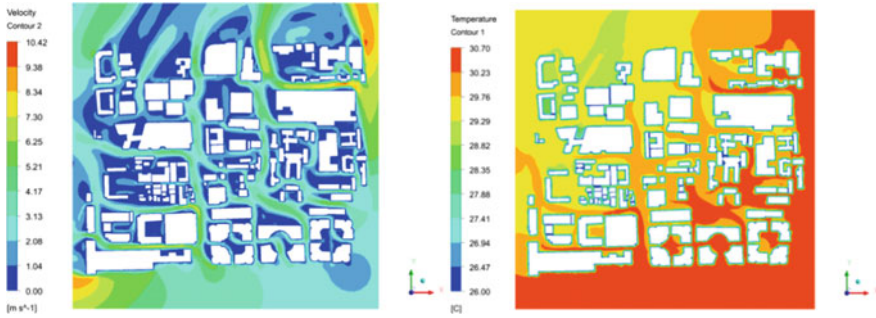
There are four zones in the figure from top to the bottom. In zone one, people feel unacceptable due to strong wind. In zone two, people do not feel unacceptable, but not comfortable, which is the intermediate area to be accepted. In zone three, people feel comfortable. In zone four, people feel unacceptable due to weak wind. In conclusion, the acceptable wind conditions corresponding to daily average temperature can be gained in zone two and zone three.

## **3 Results**

### ***3.1 Wind Environment Evaluation for Wangfujing Commercial District***

The original model simulation result for Wangfujing district is shown in Fig. 4. The average wind velocity of the target area is 3.20 m/s and the average air temperature is 30.21 °C. According to Fig. 3, the range of acceptable wind velocity under the average temperature 30.21 °C is from 1.18 m/s to 2.82 m/s, which means present wind velocity is beyond the highest acceptable level. To improve the wind environment, modified aspect ratio  $H/W$  was then explored based on a simplified model.

The average value of wind velocity and the air temperature were calculated and provided in Tables 1 and 2. It shows that average wind speed decreases from 3.45 to 2.53 m/s as the aspect ratio  $H/W$  decreases from 1.60 to 0.80 while the average air temperature remains relatively stable. Besides, as aspect ratio  $H/W$  is 0.80, the average wind speed is 2.53 m/s which can satisfy the acceptable wind conditions.



**Fig. 4** Simulation results based on original Wangfujing model

**Table 1** Wind environment assessment based on simplified Wangfujing model

Aspect ratio $H/W$	Average temperature ( $^{\circ}C$ )	Average wind velocity (m/s)	Wind environment assessment
1.60	29.83	3.45	Zone I: Unacceptable strong wind
1.20	29.74	3.12	Zone I: Unacceptable strong wind
0.96	29.68	2.86	Zone I: Unacceptable strong wind
0.80	29.60	2.53	Zone II: Uncomfortable wind but acceptable

**Table 2** The range of acceptable wind condition based on simplified Wangfujing model

Average temperature ( $^{\circ}C$ )	Acceptable highest wind velocity (m/s)	Comfort wind velocity (m/s)	Acceptable lowest wind velocity (m/s)
29.83	2.80	2.05	1.18
29.74	2.78	2.04	1.16
29.68	2.77	2.03	1.14
29.60	2.76	2.01	1.13

The simulation results of the wind environment as well as the thermal environment under different values of  $H/W$  show that the wind velocity distribution around the target street keeps the similar pattern through comparing to these four wind environment simulation results. Also, according to the influence of the aspect ratio  $H/W$  on the wind flow over an isolated street canyon [8, 9], in this case, the flow regimes of the target street remain unchanged even if the aspect ratio decreased from 1.60 to 0.80. Therefore, Decreasing  $H/W$  to improve the wind environment around high-rise buildings can be regarded as a key factor to influence the wind environment under such street block design.



### 3.2 Wind Environment Evaluation for Sensoji Commercial District

The original model simulation result for Sensoji area is shown in Fig. 5. Because there are different terrains near the target area which is highlighted in the frame, the water body area and extensive greening are included in the initial simulation to improve the accuracy [10]. An enlarged view of the target street is also provided on the right side of Fig. 5.

The original model simulation result shows that the average velocity of wind maintains a low level at 0.8 m/s which is below the thermal comfort range from 1.92 to 2.69 m/s corresponding to the average temperature at 28.96 °C. The wind environment assessment based on simplified Sensoji model is shown in Tables 3 and 4. By increasing the street width in the simplified models to 50 m, the aspect ratio  $H/W$  decreases to 0.30 and an average wind speed of district at 1.30 m/s which lies in the range of acceptable wind conditions from 1.13 to 2.73 m/s corresponding to an average temperature at 28.62 °C. Therefore, to improve wind environment, the aspect ratio for Sensoji case should be reduced below 0.30.

In the simplified Sensoji-type street block, as the buildings around the target street are all middle-rise buildings, the flow regimes of the target street convert to wake interference flow from the original skimming flow state with decreasing  $H/W$ . It means the bulk of the air flow can enter the target canyon. For this main reason, the average wind velocity of the target street increased as the width of the street increased as well. In addition, setting in a complex street block, the target canyon also can be affected by the vicinal high-rise buildings.

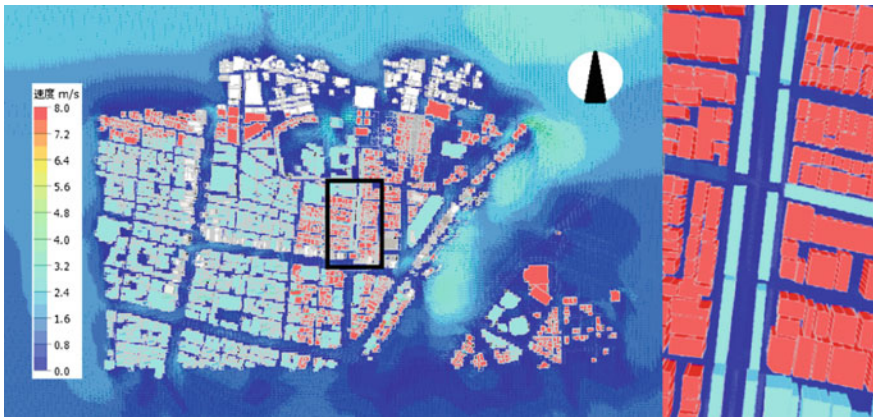


Fig. 5 Simulation result based on original Sensoji model

**Table 3** Wind environment assessment based on simplified Sensoji model

Aspect ratio $H/W$	Average temperature (°C)	Average wind velocity (m/s)	Wind environment assessment
1.50	28.45	0.50	Zone IV: Unacceptable weak wind
0.50	28.53	0.94	Zone IV: Unacceptable weak wind
0.30	28.62	1.30	Zone III: Comfortable wind

**Table 4** The range of acceptable wind condition based on simplified Sensoji model

Average temperature (°C)	Acceptable highest wind velocity (m/s)	Comfort wind velocity (m/s)	Acceptable lowest wind velocity (m/s)
28.45	2.67	1.81	1.10
28.53	2.69	1.84	1.11
28.62	2.73	1.86	1.13

## 4 Conclusions

This study selected Beijing Wangfujing Commercial District and Tokyo Sensoji Temple as examples for wind environment research. The simulation results based on original models of each case show that, under the typical summer climatic condition, the average wind velocity in Beijing is above the acceptable highest level, while it is below the acceptable lowest level in Tokyo. To improve wind environment of both cases, aspect ratio  $H/W$  was then modified and supplementary simulation was performed on simplified models. Eventually, the suitable value of  $H/W$  is determined to be 0.80 and 0.30 for Beijing and Tokyo case respectively. Since this value depends largely on the physical model used, it varies for different cases. Nevertheless, present results could provide a reference for wind environment assessment and design of the typical commercial street like these two cases.

**Acknowledgements** This work was supported by National Key Research and Development Program of China (Project No.2018YFC0704505) and The Rixin Talent Program granted by Beijing University of Technology. The authors are sincerely grateful to Prof. Mochida from Tohoku University and Prof. Jingchao Xie from Beijing University of Technology for their precious suggestions on this work.



## References

1. Mochida, A., Lun I.Y.: Prediction of wind environment and thermal comfort at pedestrian level in urban area. *J. Wind. Eng. Ind. Aerodyn.* **96**, 1498–1527 (2008)
2. Asami, Y., Iwasa, Y., Members of AIJ.: full-scale measurement of environmental wind on new-shinjuku-center-characteristics of wind in built-up area (part 2). In: *Proceeding of Fifth Symposium on Wind Effects on Structures*, pp. 83–90 (1978)
3. AIJ (Architectural Institute of Japan): AIJ guidebook for practical applications of CFD to pedestrian wind environment around buildings. Members of AIJ, Japan. ISBN 978-4-8189-2665-3 (2007)
4. Oke, T.: Street design and urban canopy layer climate. *J. Energy Build.* **11**, 103–113 (1988)
5. Launder, B.E., Kato, M.: Modeling flow-induced oscillations in turbulent flow around a square cylinder. *ASME Fluid Engineering. Conf.* **1993**, 20 (1993)
6. Murakami, S., Iwasa, Y., Morikawa, Y.: Study on acceptable criteria for assessing wind environment at ground level based on residents' diaries. *J. Wind Eng. Ind. Aerodyn.* **24**, 1–18 (1968)
7. Murakami, S., Morikawa, Y.: Criteria for assessing wind-induced discomfort considering temperature effect. *J. Arch. Plan. Environ. Eng.. AIJ* **358**, 9–17 (1985) (in Japanese)
8. Ali-Toudert, F., Mayer, H.: Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. *J. Build. Environ.* **41**, 94–108 (2006)
9. Yoshie, R., Tanaka, H., Shirasawa, T., Kobayashi, T.: Experimental study on air ventilation in a built-up area with closely-packed high-rise building. *J. Environ. Eng.* **627**, 661–667 (2008). (in Japanese)
10. Kondo, H., Asahi, K., Tomizuka, T., Suzuki, M.: Numerical analysis of diffusion around a suspended expressway by a multi-scale CFD model. *J. Atmos. Environ.* **40**(16), 2852–2859 (2006)