Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 121 (2015) 225 – 231

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

A Case Study on Optimization of Building Design Based on CFD Simulation Technology of Wind Environment

Weihong Guo[a,b], Xiao Liu[a,b,*], Xu Yuan[a]

[a]*Architectural Design Research Institute, South China University of Technology, Guangzhou 510640 ,China*
[b]*School of Architecture, South China University of Technology, Guangzhou 510640 ,China*

Abstract

For green buildings, the building technology needs to fit the climatic characteristics to adjust to the existing conditions and create a more livable environment. CFD is a combination of modern fluid dynamics, numerical mathematics and computer science. It is employed in green building design to offer the architect an important basis for optimizing the architectural design. The Paper takes a case study to show the research on application of CFD simulation technology of wind environment in optimizing architectural design, gives some ideas to architects in green building design optimization.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: CFD simulation; architectural design optimization; green building; wind environment

1. Introduction

The term "passive design" refers to design approaches that facilitate the natural ventilation and the use of renewable energies like the solar energy through the architectural vocabulary (designs of site, plan, section, detail and node), thus eventually cut the building energy consumption and improve the built environment [1, 2]. Passive design respond to the natural context, while it is also affected and confined by the geographic environments hence is evidently local- and climatic-adaptive [3].

Compared to active design that features straight-forward metering method and obvious cost-driven effect, passive design has its weaknesses in terms of evaluation and performance quantification. On the other hand, when an

* Corresponding author. Tel.: +86 13560228796; fax: +86020-87590425.
E-mail address: lxscut@139.com

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.08.1060

architect lacks a clear understanding of the importance of passive design, he/she fails to come up with suitable strategies that meet up to climate characteristics and project features at an early design stage of green building projects. Instead, the architect would rely on complex and expensive technology and equipment, putting green building design on the wrong track as it becomes piling up of technologies [4].

Wind environment affects how human bodies feel to a high degree; therefore, importance should be attached to it in green building design. CFD simulation technology not only brings convenience to architects but also open up a new area in design where CFD wind environment simulation and architectural design strategy are put together. With the CFD wind environment simulation technology, architects are able to better project and more intuitively describe the wind environment in a design scheme, and conduct the analysis based on relevant building technologies and simulation results, so as to provide more basis for evaluation and performance quantification of wind environment design [5].

2. Design scheme of an art gallery in Guangzhou

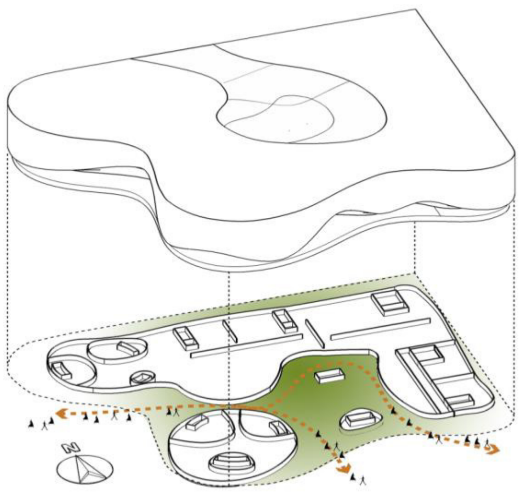

Fig. 1. design option 1.

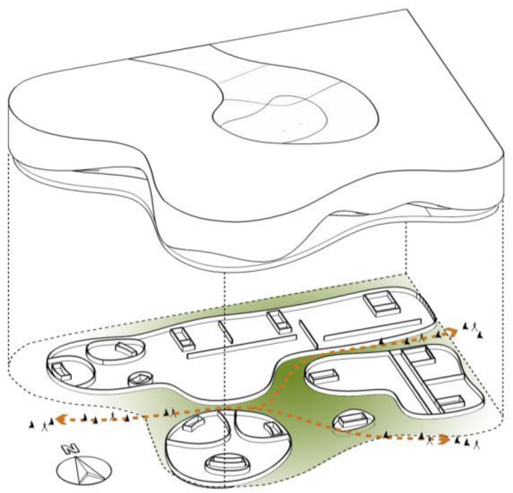

Fig. 2. design option 2.

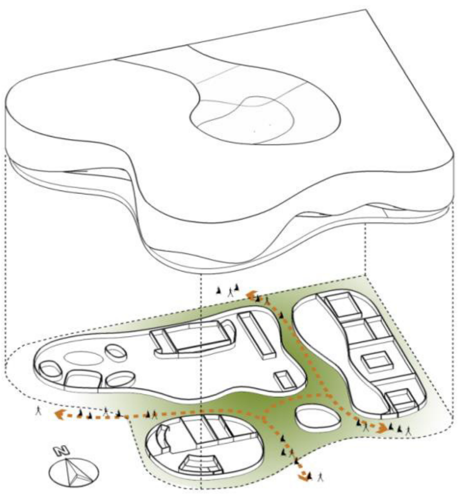

Fig. 3. design option 3.

Guangzhou is located in a semi-tropical coastal zone with abundant sunlight and heat and long summer. The average temperature of the hottest month records 28.7 degrees Celsius and the annual average relative humidity as high as 77%. This makes the natural ventilation particularly important in architectural design. The art gallery is part of the "Three Museums One Square" project in Guangzhou. The project site is located to the south of the Canton Tower, and in the core area of the southern part of Guangzhou's new urban central axis. With a site area of around 2.92 hectares and a GFA of about 80,000 sqm, the project is comprised of collection storage area, exhibition/display area, culture/education/public service area, research & administrative offices, mechanical area, basement car park and public spaces. It will become one of the most important cultural facilities of Guangzhou upon completion.

According to the Design Brief and the design concept, the functions planned on the ground level include foyer of exhibition area, temporary exhibition halls, foyer of conference areas, the relatively independent exchange and reception area, art workshop & interaction space, dedicated entrance/exit to research & administrative offices, ground level entrance/exit of collection storage, area as well as service facilities like souvenir shops and cafés.

Four movable green platforms gradually rise from the perimeter of the site, which, together with the open-up activity spaces on the ground level, constitute an important part of the design. As they also function as building access and public activity venue, the comfort level of the open-up level should be carefully addressed.

Based on the reasonable functional circulations, various site planning options are experimented and three preliminary options for the open-up spaces are developed to explore the different open-up forms.

Option 1: As shown in Fig. 1, the open-up space on ground level divide the building massing into two parts. Except for the foyer of conference areas and the exchange and reception area at the southwest corner, all other functional spaces make up an L-shaped block.

Option 2: As shown in Fig. 2, an east-west passage is added to Option 1 to further divide the L-shaped block into two parts. This way, the foyer of exhibition/display area, temporary exhibition halls, souvenir shops and café and other service facilities are placed in the east-west block on the north, while the dedicated entrance/exit to research & administrative offices and the ground level entrance/exit to collection storage area are both located in the southeast block.

Option 3: As shown in Fig. 3, part of the east-west passage in Option 2 is re-oriented to be north-south. The functional layout remains unchanged, while the building massing and spatial forms are revised.

3. CFD building wind environment simulation technology and outdoor wind environment evaluation criterion

Along with the development of computer technology and numerical computing technology, computational fluid dynamics (CFD) has made rapid progress as well. CFD technology involves fluid mechanics, computing methods, computer graphics and many other disciplines. In CFD simulations, computer models are set up based on the architectural design scheme, where the CFD software such as FLUENT and PHOENICS is employed to simulate the surrounding and indoor wind environment of a built and occupied building and draw the simulation diagrams of wind speed and wind pressure under natural ventilation, so that the architects could revise architectural design schemes accordingly [6].

Wind environment affects how human bodies feel to a high degree. In an outdoor environment where human activities exist, the physical environment about 1.5 meters above ground affects how a person feels most directly [7]. The wind speed of this area, when it is within a suitable range, will make people within feel comfortable. Table 1 shows the different feeling levels of human body that vary by wind speed. In general, when the outdoor wind speed is within the range of 1m/s~5m/s, it is believed to be the most comfortable environment for human.

Table 1. Wind speed and human body feeling [8].

Wind speed range	Human body feeling
<1.0m/s	breezeless.
1.0~5.0m/s	comfortable.
5.0~10.0m/s	uncomfortable with movements affected.
10.0~15.0m/s	very uncomfortable with movement greatly affected.
15.0~20.0m/s	intolerable.
>20.0m/s	dangerous.

An outdoor wind field is a complex system. A space or an area is mainly under the influence of thermal pressure of heat convection, which is caused by temperature difference resulting from inlet air pressure and sun radiation [9]. However, in an outdoor area or an open-up space, when inlet air has a high wind pressure and the pressure remains steady, wind pressure plays a more important role in the wind environment.

4. Analysis of CFD simulation results and finalization of design option

4.1. PHOENICS Simulation of wind-pressure ventilation in open-up spaces

With only the wind pressure considered, PHOENICS is employed to simulate and analyze the effects of natural ventilation of the above three options. According to the direction and power of summer monsoon in Guangzhou, southeaster at a speed of 1.8m/s is set for the outdoor wind environment of the art gallery.

There are many mathematical models for simulating numerical flow fields surrounding a building, such as DNS, LES, RSM and K-ε two-equation turbulent model, among which, the K-ε model features cost effectiveness, small fluctuation and high precision and is consequently rather employed in many low-speed turbulent numerical simulations [10]. Likewise, it is also used in this paper.

The simulation results are shown in the figures below:

As shown in Fig. 4, the wind speed in most open-up spaces in the art gallery in Option 1 is below 1m/s, and exceeds 1m/s in only a few areas. The L-shaped building massing blocks convective air between east and west, creating a rather large calm zone at Point 1 and resulting in a poor wind environment.

As shown in Fig. 5, the wind speed in Option 2 is basically within the range of 0~1.5m/s. And the wind speed at Point 1 and Point 2 is both below 1m/s and that at Point 3 is relatively higher and is around 1.5m/s. The whole wind environment is moderately comfortable.

As shown in Fig. 6, only Point 1 has a wind speed of lower than 0.5m/s in Option 3 and that in other areas is basically within the range of 1m/s~2.5m/s. The wind speed is not very variable and is evenly distributed. With the additional north-south open-up corridor at Point 2, generally southerly wind, the prevailing wind in Guangzhou, makes convective airflows even smoother. The wind speed in this area is about 2m/s and is quite comfortable.

The simulation results of the three options and the comfortable levels of human body against different wind speeds show that, the average wind speed as shown in Option 3 is optimal as it provides the most appropriate average speed, evenly distributed wind fields and the smallest calm zone.

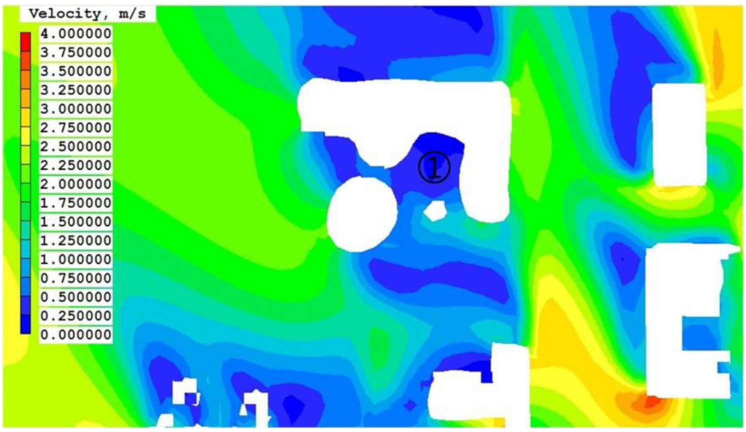

Fig. 4. simulation results of outdoor wind environment at 1.5m above ground, option 1.

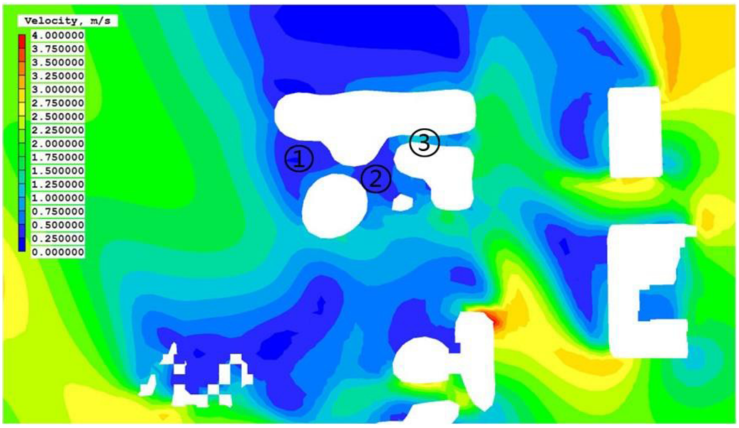

Fig. 5. simulation results of outdoor wind environment at 1.5m above ground, option 2.

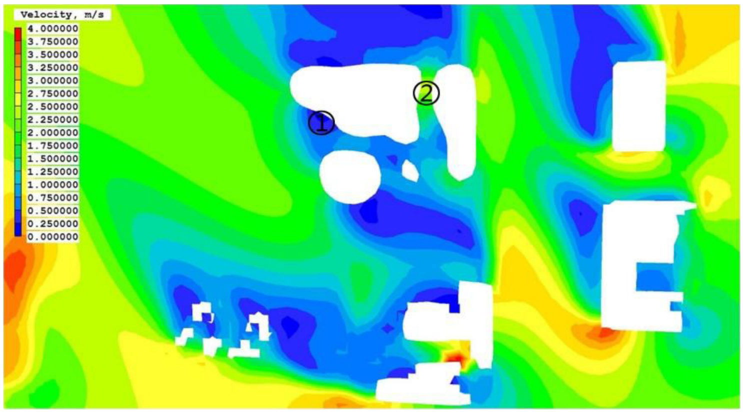

Fig. 6. simulation results of outdoor wind environment at 1.5m above ground, option 3.

4.2. Fluent simulation of wind-pressure ventilation and thermal pressure ventilation in open-up spaces

As wind pressure plays a bigger role in wind environment, it is taken into consideration at stage 1 and the optimal option for open-up spaces is finalized through PHOENICS simulations. At stage 2, impact of the outdoor multi-level atrium on thermal pressure ventilation in open-up spaces is taken into account, so as to provide basis for design of the outdoor atrium. Therefore, Fluent is used to simulate and analyze the two outdoor wind environment scenarios where an outdoor multi-level atrium is or is not provided.

A southeaster at a speed of 1.8m/s is set for the outdoor environment in simulations of wind pressure and thermal wind pressure ventilation for the art gallery. The set time is 13:00 on June 21, the Summer Solstice. The geographical location set in the simulations is 113°17' E and 23°8' N. Again a standard K-ε model is used to do the calculations. Simulation results are shown as below:

Comparison between Fig. 7 and Fig. 8 shows that, the outdoor multi-level atrium brings a strong stack effect when the wind is at a speed of around 1.5m/s and has an upward direction. This is very favorable to indoor ventilation and exchange of fresh air. At the same time, with the atrium, the wind speed in the open-up spaces on ground level is higher and within a reasonable range compared to the scenario where there is no atrium.

Fig. 9 and Fig. 10 show the two different scenarios of wind environment 1.5 meters above ground where there is and there is not an atrium. Comparisons between the two figures show that at Point 1-4, the wind speed near ground is generally increased and is still within a comfortable range when the atrium is included. This is because the stack effect created by the atrium leads to a negative wind pressure value at the bottom of the multi-level atrium, which then results in a wind pressure difference and a higher wind speed in the open-up spaces on ground level. In doing so, the previously moderate wind environment is improved and indoor natural ventilation on ground level is better as well. The connection between the atrium and the open-up spaces and the connection between the atrium and the roof should be retained, which not only enrich building forms and spatial forms but also facilitate natural ventilation in open-up spaces on ground level for a more comfortable wind environment. When there is an atrium, the wind speed at Point 5 is relatively lower. However, the decrease is small and it only affects a small area. Moreover, Point 5 is on the perimeter of the project site of "Three Museums One Square", thus, it has a slight impact on the activity venues within the project site.

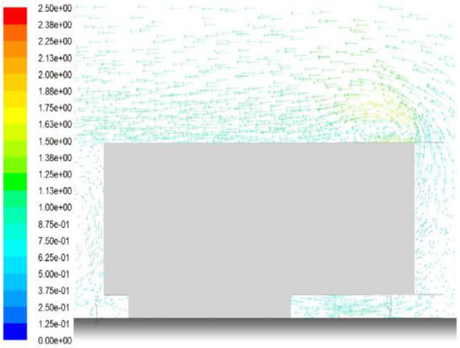

Fig. 7. wind environment at section without atrium.

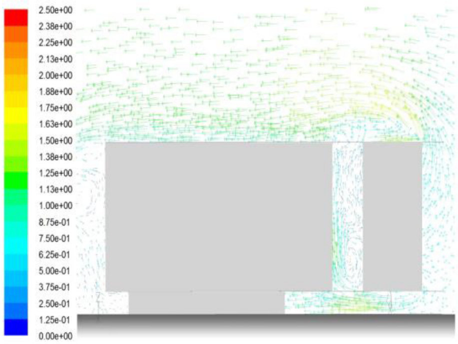

Fig. 8. wind environment at section with atrium.

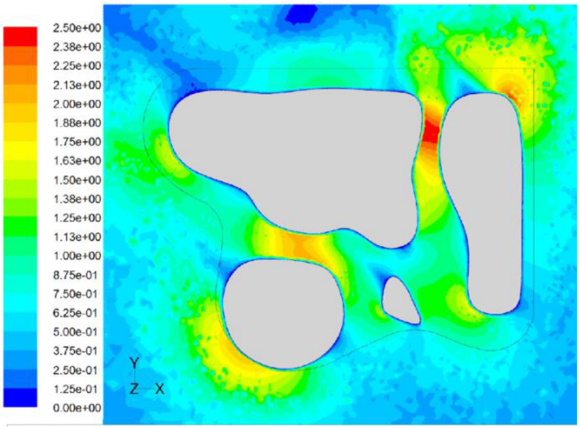

Fig. 9. wind environment of art gallery at 1.5m above ground, without atrium.

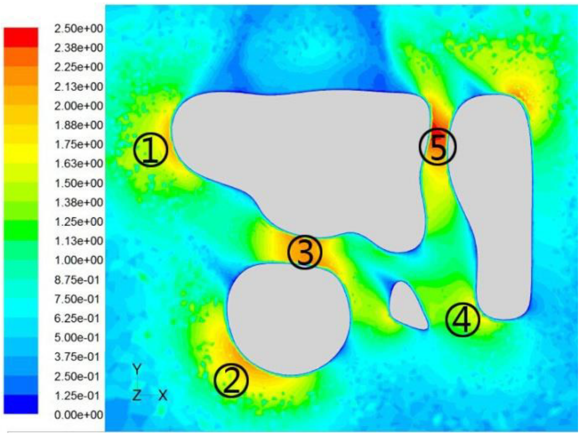

Fig. 10. wind environment of art gallery at 1.5m above ground, with atrium.

5. Conclusion

In conclusion, CFD wind environment simulation results indicate that Option 3 that includes an outdoor multi-level atrium is the optimal design for the art gallery. With the art gallery as an example, this paper explains the methods to optimize the green building design where CFD outdoor wind environment simulations are conducted. In refining and detailing the building shape and floor plan, an architect needs to look at the following three aspects. First, after the functional requirements are met, make sure room depths are reasonable. Second, with comprehensive consideration given to elevation aesthetics and plane functions, create certain forms at suitable positions of a building to deflect wind and form through wind tunnels by distributing building volumes and creating open-up spaces and openings, so as to facilitate natural ventilation. Third, create spatial forms that help thermal pressure ventilation when necessary, such as atrium, patio and alleyway. With basic ventilation theories and knowledge, an architect can get a clear picture of the factors that influence natural ventilation in a project, thus improving building natural ventilation in designs of plane, elevation and section. The CFD simulation technology enables the architects to effectively and efficiently complete quantitative analysis and evaluation of the passive design, hence plays a key role for green building design optimization.

Acknowledgements

Supported by National Natural Science Foundation of China (Grant No. 51378212), and also supported by Science and Technology Planning Project of Guangdong Province, China (Grant No. 2012A010800028).

References

[1] B. Givoni, Passive and Low Energy Cooling of Buildings, Van Nostrand Reinhold Company, New York, 1994.
[2] B. Givoni, Climate Considerations in Building and Urban Design, Van Nostrand Reinhold Company, New York, 1998.
[3] L. Yang, J.C. Lam, and J. Liu, Bioclimatic building designs for different climates in China, Architectural Science Review. 48 (2005) 187–194.
[4] G. John, D. Clements-Croome, and G. Jeronimidis, Sustainable building solutions: A review of lessons from the natural world, Building and Environment. 40 (2005) 319–328.
[5] S. Murakami, CFD and Building Environment Design, China Architecture & Building Press, Beijing, 2007.
[6] A. Mochida, I.Y.F. Lun, Prediction of wind environment and thermal comfort at pedestrian level in urban area, Journal of Wind Engineering and Industrial Aerodynamics. 96 (2008) 1498–1527.
[7] Y. Tominaga et al., AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings, Journal of Wind Engineering and Industrial Aerodynamics. 96 (2008) 1749–1761.
[8] X. Wen, Employment of CFD Simulation on Outdoor Wind Environment for Residential Project Planning and Construction, Science and Technology Innovation Herald, 2010, pp. 113–114.
[9] X. Chen et al., Building Design and Natural Ventilation, China Power Press, Beijing, 2012.
[10] L. Yang, Green Building Design: Wind Environment of Building, Tongji University Press, Shanghai, 2008.