RESEARCH ON MEASUREMENT AND SIMULATION OF THE WIND ENVIRONMENT AROUND BUILDINGS IN CAMPUS

Bing Wang[1], Borong Lin[1,*]
1Deparment of Building Science, School of Architecture, Tsinghua University, Beijing, China
* Corresponding E-mail: linbr@tsinghua.edu.cn

ABSTRACT

The wind environment around a building influences human lives and the design of it. Simulation by CFD software is a main method used to study wind environment. But the reliability of the simulation result needs to be proved by comparing to the measured wind environment data. Experiment and simulation on wind environment were carried out in this reasearch. What's more, different simulation methods and different kinds of boundary concdition seetings were studied. As a conclusion, if proper simulation method was taken, the reslut was reliable compared to the measured data and it show great feasibility for engineering application.

INTRODUCTION

The wind environment around a building directly impacts the ventilation and has great influence on the energy consumption of the building as a result. It is always complex and difficult to measure. And it is even more difficult to predict the wind environment before the building is built up. So, wind tunnel experiment and simulation are used to study the wind environment as two main methods today. The simulation is a technology based on Computational Fluid Dynamics (CFD). It calculates numerically solution of the hydrokinetics equations of the air and show the result based on Computer Graphic Techniques. The simulation result is determined by many factors, such as the model simplification method, the calculation model, the boundary condition and so on. The reliability needs to be proved by comparing to the measured wind environment data. The feasibility for engineering application is also influenced by the time cost and the simulation precision. This paper made a research on these problems. At the same time, different factors that influence the simulation were also studied.

EXPERIMENT

Content

The experiment recorded the wind speed and direction data at some points above an intersection between the street and the main building where the wind speed increases as in a wind tunnel. Altogether the data at 5 points were taken, as shown in Figure 1, and at each point each data was taken 5 times before the average was obtained. These data were used to compare with the simulation results.

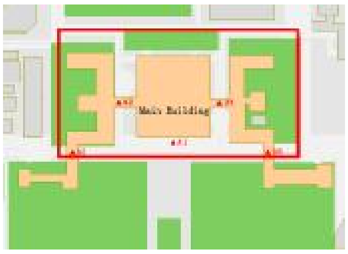

Figure 1 Positions for Measurements

At the same time, the wind environment data of the research boundary (See lines in Figure 1) were taken. Wind speed and direction was recorded every 10 meters along the boundary. These data were used to set the boundary condition in the simulation.

Climate data of the wind environment were taken from a small weather station on the top of a building on the university campus, about 200 meters away from the main building. In some cases the boundary condition setting were based on these data.

Result

The wind environment data was measured by hot-ball anemometers, which were rectified in the wind tunnel laboratory. The experiment date is May 18, 2008.

Table 1
Wind Environment Data Group One

POSITION	WIND DIRECTION	WIND SPEED (M/S)
A1(at 1.5m height)	South	2.99
A2(at 1.5m height)	North	5.24
A3(at 1.5m height)	West	3.65
A4(at 1.5m height)	North	5.48
A5(at 1.5m height)	East	4.89
North Boundary (at 1.5m height)	Northeast	2.98
West Boundary (at 1.5m height)	North	2.47
South Boundary (at 1.5m height)	South	3.02
East Boundary (at 1.5m height)	North	3.03
Small Weather Station(at 20m height)	North	5.73
Weather Report (at 10m height)	North	1.6~3.7

Table 2
Measured Wind Environment Data Group Two

POSITION	WIND DIRECTION	WIND SPEED (M/S)
B1(at 1.5m height)	Southwest	2.75
B2(at 1.5m height)	North	6.63
B3(at 1.5m height)	West	3.04
B4(at 1.5m height)	North	5.05
B5(at 1.5m height)	East	5.30
North Boundary (at 1.5m height)	East	2.99
West Boundary (at 1.5m height)	North	2.53
South Boundary (at 1.5m height)	North	3.81
East Boundary (at 1.5m height)	Northeast	2.94
Small Weather Station(at 20m height)	North	6.16
Weather Report (at 10m height)	North	1.6~3.7

Discussion

The wind environment data showed that wind speed increases at the intersection between the street and the main building and the wind direction is fixed. The average wind speed along the boundary was about 3 m/s, and it is close to the speed given by weather station. But the wind direction there varies greatly.

In conclusion, the wind environment data measured were reliable. It provided the possibility to set the boundary conditions according to the actual wind environment.

SIMULATION

Simulation of the wind environment around the main building was taken, and the result was compared with the measured data to prove reliability. Different boundary conditions were also measured to find a better simulation method.

Boundary Conditions

First, two models are built. One of them is a simplified representation of the main building; the other represents both the buildings and the trees around it, as shown in Figure 2.

Second, the inlet setting was set based on a gradient wind model. In the aerosphere, the wind speed varies with height. The wind near the ground is slowed down by the buildings and vegetation. The vertical distribution of the wind speed is often described as a power law equation:

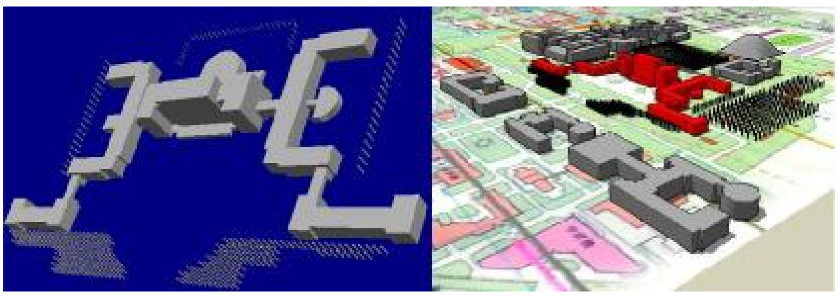

Figure 2 the Two Different Models of the Main Building

$$\frac{V}{V_g} = \left(\frac{h}{h_g} \right)^a \qquad (1)$$

Where V is the average wind speed at height h, and V_g, the average wind speed at hight h_g. When the inlet speed was set based on the measured data, h_g=1.5m. When the inlet speed is set based on the weather data, h_g=10m. The power law index a differs according to the ground condition. In this paper, a=0.3.

Thirdly, three kinds of inlet setting were used in the simulation. Setting one: the wind speed of all boundary of the area were set based on the measured data, inlets were set every 10m along the boundary. Setting two: the wind speed of all four boundaries were set based on the measured data, but only one inlet using the average speed was set. Setting three: the inlet speed was set based on data from the small weather station.

PHOENICS 3.5.1 was used to simulate the wind environment. Other basic setting was mentioned in Table 3.

Table 3
Basic Setting in PHOENICS 3.5.1

TURBULENT MODEL	GRIDDING	DIFFERENCING SCHEMES
Standard k-ε Model	1×1×3(m)in centre, sparser around	HYBRID

Simulation and Result

Taking different boundary conditions into consider, 8 cases(As Table 4 shown) was simulated by PHOENICS 3.5.1.

The simulation result is given in Figure 3 and Table 5. In Table 5, the average error percentage of wind speed and the ratio of same wind direction between simulation and measurement were given, which can be taken as two evaluation of the reliability of the simulation case.

Table 4
Case List of Simulation

CASE NO.	BUILDING MODEL	INLET SETTING	COMPARISON DATA GROUP	GRIDDING NUMBER
1	Setting One	Setting One	Group One	310×160×9=446400
2	Setting One	Setting Two	Group One	310×160×13=644800
3	Setting One	Setting Three	Group One	324×174×13=732888
4	Setting One	Setting One	Group Two	210×170×9=321300
5	Setting One	Setting Two	Group Two	160×135×9=194400
6	Setting One	Setting Three	Group Two	324×274×13=1154088
7	Setting Two	Setting Three	Group One	274×199×13=708838
8	Setting Two	Setting Three	Group Two	274×199×9=490734

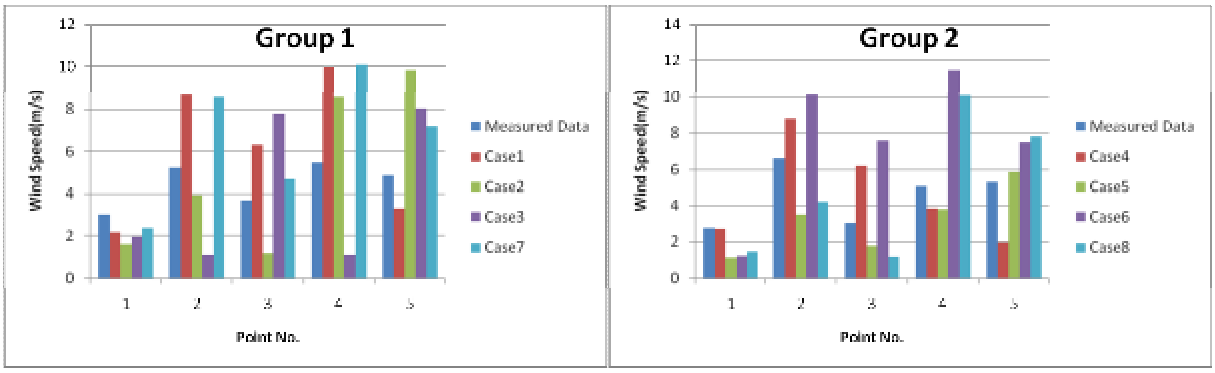

Figure 3 Simulation Results of Different Cases

Table 5
Reliability Evaluation of Different Cases

CASE NO.	DATA GROUP	ERROR OF SPEED	RATIO OF DIRECTION
1	Group One	56.33%	40%
2	Group One	59.38%	20%
3	Group One	74.15%	80%
4	Group Two	45.10%	40%
5	Group Two	37.20%	60%
6	Group Two	85.32%	80%
7	Group One	48.74%	60%
8	Group Two	58.34%	80%

Improved Simulation

As shown above, the errors between simulation results and measured data were great. So some boundary condition settings were improved and simulations were taken again.

First, the turbulence strength, which is used to define the constant change of wind speed, was taken into account, as the equation below shows:

$$I_u(Z) = \frac{v_u}{U(Z)} \tag{2}$$

Where $I_u(Z)$ is the turbulence strength, v_u, the mean-square-root of the fluctuation wind speed, and $U(Z)$, the average wind speed.

The turbulence strength is also described as a power law equation:

$$I_u(Z) = I_0\left(\frac{Z}{H}\right)^{-a-0.05} \tag{3}$$

Where I_0 is the turbulence strength at height H. When H=30m, $I_0=a$, the power law index in gradient wind model. In this paper, after calculation, $I_u(1.5)=0.8$, $I_u(10)=0.4$.

Second, two kinds of inlet setting were used in the simulation. Setting one: the inlet was set based on measured data. On each boundary, if the wind direction of a point is different from most other points, the data was disused. Then the average speed was used to set the inlet. Setting two: the inlet speed was set based on the small weather station data.

Third, durbin model was used to instead Standard k-ε Model.

The new simulation list was shown as Table 6.

The simulation result is given in Figure 4 and Table 7.

Table 6

New Case List of Simulation

CASE NO.	BUILDING MODEL	INLET SETTING	COMPARISON DATA GROUP	GRIDDING NUMBER
1	Setting One	Setting One	Group One	265×198×30=1574100
2	Setting One	Setting One	Group One	305×273×39=3247335
3	Setting One	Setting Two	Group One	304×246×44=3290496
4	Setting One	Setting One	Group Two	260×206×30=1606800
5	Setting One	Setting One	Group Two	368×221×39=3171792
6	Setting One	Setting Two	Group Two	304×246×44=3290496

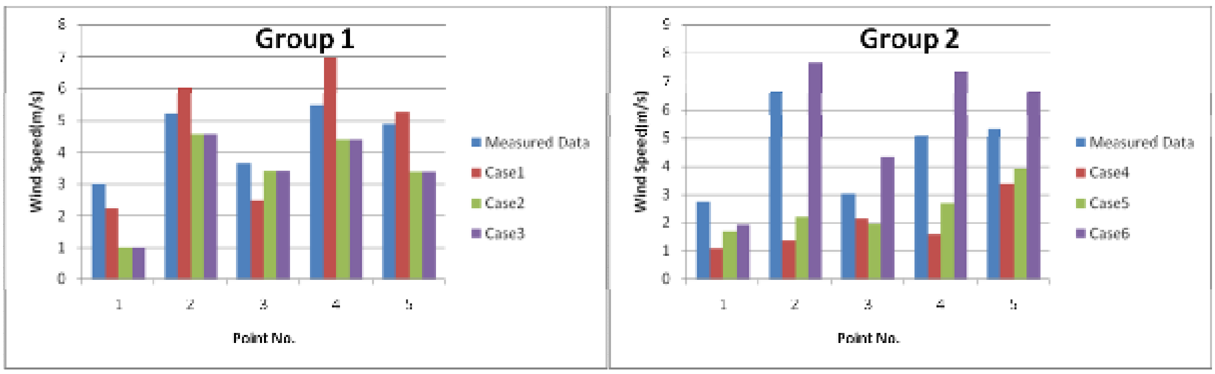

Figure 4 Simulation Results of New Cases

Table 7

Reliability Evaluation of New Cases

CASE NO.	DATA GROUP	ERROR OF SPEED	RATIO OF DIRECTION
1	Group One	21.35%	40%
2	Group One	27.33%	40%
3	Group One	19.42%	80%
4	Group Two	54.99%	60%
5	Group Two	43.01%	60%
6	Group Two	31.81%	100%

Final Simulation

At alst, taking all influent factors we found into consideration, 4 cases(As Table 8 shown) were simulated by PHOENICS 3.5.1.

The simulation result is given in Figure 5 ,Table 9 and Table 10.

Show in the simulation result, the simulated wind speed and direction met the measured data well except Point 1. Presume that the measured data of Point 1 may be wrong because of mistake in measured method. So the data of Point 1 is excluded.

In Table 5, the average error percentage of wind speed and the ratio of same wind direction between simulation and measurement were given, which can be taken as two evaluation of the reliability of the simulation case.

At last, a comparison between different simulation results is given. We can find out that by the third simulation method the average error of speed is the lowest and the average correct ratio of direction is the highest, which means the third simulation method is the best one in this simulation case.

Table 8

Simulated Cases

CASE NO.	BUILDING MODEL	INLET SETTING	COMPARISON DATA GROUP	GRIDDING NUMBER
1	Setting One	Setting One	Group One	213×152×36=1165536
2	Setting Two	Setting Two	Group One	302×244×31=2284328
3	Setting One	Setting One	Group Two	211×200×36=1519200
4	Setting Two	Setting Two	Group Two	452×244×31=3418928

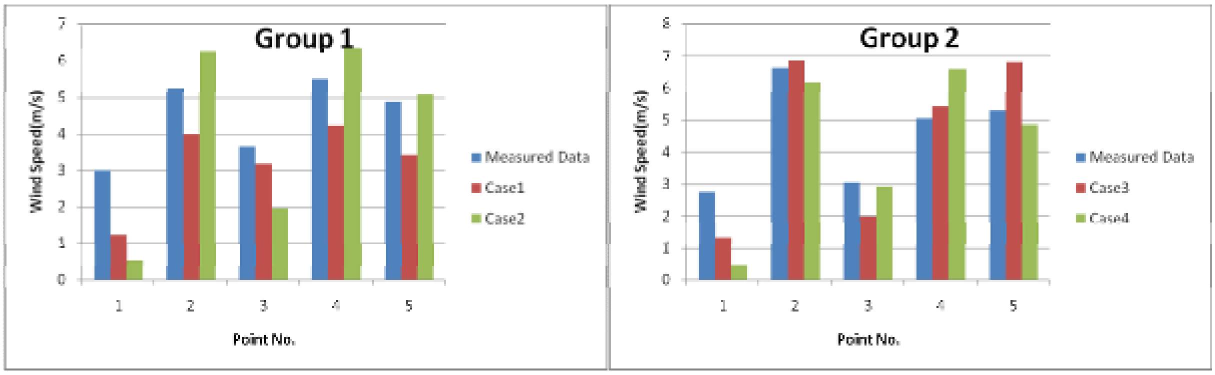

Figure 5 Simulation Results of Different Cases

Table 9

Reliability Evaluation of Different Cases

CASE NO.	DATA GROUP	ERROR OF SPEED	RATIO OF DIRECTION
1	Group One	22.37%	75%
2	Group One	21.48%	75%
3	Group One	18.60%	100%
4	Group Two	12.46%	100%

Table 10

Detail Simulation Results of Different Cases

CASE 1				
MEASUED POINT	A2	A3	A4	A5
MEASURED WIND SPEED	5.24	3.65	5.48	4.89
SIMULATED WIND SPEED	4.00	3.17	4.23	3.43
ERROR PERCENTAGE	-23.66%	-13.15%	-22.81%	-29.86%
MESAURED WIND DIRECTION	N	W	S	E
SIMULATED WIND DIRECTION	N	W	N	E
CASE 2				
MEASUED POINT	A2	A3	A4	A5
MEASURED WIND SPEED	5.24	3.65	5.48	4.89
SIMULATED WIND SPEED	6.25	1.96	6.36	5.10
ERROR PERCENTAGE	19.27%	-46.30%	16.06%	4.29%
MESAURED WIND DIRECTION	N	W	S	E
SIMULATED WIND DIRECTION	N	W	N	E
CASE 3				
MEASUED POINT	B2	B3	B4	B5
MEASURED WIND SPEED	6.63	3.04	5.05	5.30
SIMULATED WIND SPEED	6.84	1.97	5.44	6.80
ERROR PERCENTAGE	3.17%	-35.20%	7.72%	28.30%
MESAURED WIND DIRECTION	N	W	N	E
SIMULATED WIND DIRECTION	N	W	N	E
CASE 4				
MEASUED POINT	B2	B3	B4	B5
MEASURED WIND SPEED	6.63	3.04	5.05	5.30
SIMULATED WIND SPEED	6.16	2.92	6.59	4.86
ERROR PERCENTAGE	-7.09%	-3.95%	30.50%	-8.30%
MESAURED WIND DIRECTION	N	W	N	E
SIMULATED WIND DIRECTION	N	W	N	E

Table 11

Results Comparison Between Different Simulation Methods

SIMULATION METHOD 1		
CASE NO.	**ERROR OF SPEED**	**RATIO OF DIRECTION**
1	56.33%	40%
2	59.38%	20%
3	74.15%	80%
4	45.10%	40%
5	37.20%	60%
6	85.32%	80%
7	48.74%	60%
8	58.34%	80%
Average	**58.07%**	**58%**
SIMULATION METHOD 2		
CASE NO.	**ERROR OF SPEED**	**RATIO OF DIRECTION**
1	21.35%	40%
2	27.33%	40%
3	19.42%	80%
4	54.99%	60%
5	43.01%	60%
6	31.81%	100%
Average	**32.99%**	**63%**
SIMULATION METHOD 3		
CASE NO.	**ERROR OF SPEED**	**RATIO OF DIRECTION**

1	22.37%	75%
2	21.48%	75%
3	18.60%	100%
4	12.46%	100%
Average	**18.73%**	**88%**

Discussion

This research is a example of the wind environment simulation research. The building selected has a cross-street construction which makes the wind tunnel effect easy to measure. Buildings ahd trees around make the wind environment relatively stable. Also we choose Durbin model as the turbulent model. All of these help to achive a reliable simulation result.

By analysing the results above, conclusion can be made that different simulationmethod will give results of great difference so choosing a proper simulation method plays a quiet important role in wind environment simulation. On the other hand, the inlet setting is relatively not so important. But the simulation method is more complex when measured data is used to set the inlet than using weather data. But simulation based on measured data costs less simulation time and less grid number.

In conclusion, the building model should cover the buildings around and the boundary condition should be set based on weather data. It is the most easy way to get the simulation result for engineering application. But the measured data of wind speed can help to reduce the time cost of simulation and the requirement of total gridding number. On the other hand, it costs more time and effort on preparing the boundry conditions of simulation.

But there are still some issues to be discussed in this research. One of them is the standard to judge the simulation result. In this research, the standard is the measured data of the wind environment, which is just relatively reliable.

So, more research on this topic is needed, including both simulation and experiment.

CONCLUSIONS

In engineering application, the simulation method is used to predict the wind environment before completion of the building so that it can help with the design of a building. It can also be used to evaluate the wind environment around the existing building. But it is difficult to perform a perfect simulation. The research taken by the author proves that it is possible to get a reliable simulation result if the right simulation method is chosen and proper boundary conditions are set. But in actual application, a balance between the precision and the time cost also should be take into consider. All in all, the wind environment simulation is a complicated problem which is still under research but it has a bright future, especially for engineering application.

ACKNOWLEDGEMENTS

This research is supported by NSFC No.50878111 an d the National 11th-five Research Plan Project No.2006BAJ02A02.

REFERENCES

A. Mochida,, Y. Tominaga and R. Yoshie, "AIJ Guideline for Practical Applications of CFD to Wind Environment around Buildings", *Computational Wind Engineering 2006*, (2006).

R. Yoshie, A. Mochida, Y. Tominaga, H. Kataoka, K. Harimoto, T. Nozu and T. Shirasawa, "Cooperative Project for CFD Prediction of Pedestrian Wind Environment in the Architectural Institute of Japan", *CD Pro Proceedings of EACWE4-The fourth European & African Conference on Wind Engineering* (2005), Paper #292.

R. Yoshie, A. Mochida, Y. Tominaga, H. Kataoka and M. Yoshikawa, "Cross Comparison of CFD Prediction for Wind Environment at Pedestrian Level around Buildings" (Part 1), *Proceedings of The Sixth Asia-Pacific Conference on Wind Engineering* (APCWE-VI), (2005), 2648-2660.

R. Yoshie, A. Mochida and Y. Tominaga, "CFD Prediction of Wind Environment around a High-rise Building Located in an Urban Area", *Computational Wind Engineering 2006,* (2006).

S. Murakami, R. Ooka, A. Mochida, S. Yoshida, S. Kim. CFD analysis of wind climate from human scale to urban scale. *Journal of Wind Engineering and Industrial Acronymic*. 1999, 81: 57-81

Y. Tominaga, R.Yoshie, A. MochidaH. Kataoka, K. Harimoto and T. Nozu, “Cross Comparison of CFD Prediction for Wind Environment at Pedestrian Level around Buildings” (Part 2), *Proceedings of The Sixth Asia-Pacific Conference on Wind Engineering* (APCWE-VI), (2005), 2661-2670.