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General Research Paper

# Wind Tunnel Technology in Green Building Environment

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## ABSTRACT

With the rapid increase in China's development, the cities have become immensely more dense putting pressure on design and infrastructure. In the past, most of the China's buildings imitated the foreign architectural styles and had a lack of scientific and meaningful design. These buildings became to be known as the 'the cheap copy buildings'. The primary cause was the shortage of proper technology, such as building wind tunnel test equipment. Therefore, scientific design was not always an option, only reversal or empirical design could be utilized. This meant architects were restricted to construct the same design or imitate foreign buildings. Now that China has access to wind tunnels, building designs can be analysed at a higher level. Forward and scientific designs can be used to improve the buildings' capabilities with low cost.

## INTRODUCTION

The first wind tunnel was designed to study the performance of aircraft aerodynamics. The wind tunnel is in a specially designed pipe, in which power equipment produces an approximation of the real atmospheric conditions. Due to the control of air flow, this equipment can provide many different kinds of air dynamic tests. Wind tunnels can be divided into two main types; straight flow and return flow wind tunnel. Compared to return flow (Figs. 1, 2), straight flow wind tunnels occupy a small area, and are low cost. There are some drawbacks, being that, this type is loud and the quality of the simulations may vary. When testing, the velocity can be disturbed by the inlet and the outlet atmosphere of the wind tunnel and the air pressure of test section can only be the air pressure outside.

With the development of the airplane, and spacecrafts, the wind tunnel technology peaked from the 1930s to the 1980s. Various types of wind tunnels were developed rapidly. Since the 1990s, foreign scholars began working on various active simulation methods (Kobayashi & Hatannaka 1994), some progress was made but it was still far from being widely used. According to the ongoing development, at present, there are more than 300 productive wind tunnels built in the world. With the continuous development of industrial technology, starting from 1960, wind tunnel tests, mainly the low-speed wind tunnel, expanded from civil aviation and space industries. The expansion allowed access to the automotive and construction research and design methods. This transition between industries proves that various types of development need the analysis of aerodynamics, utilizing the wind tunnel. Due to the transition, new corresponding disciplines have been formed; industrial aerodynamics and wind engineering. The wind tunnel technology dedicated to studying buildings has been further developed to simulate the relative air flow and other surroundings. It allows for design with better functionality and creates a more suitable environment for the users.

With the rapid increase in China's development, the city has become immensely more dense putting pressure on design and infrastructure. Formerly, most of the China's buildings imitated the foreign architectural styles and had a lack of scientific design. These buildings became to be known as the 'the cheap copy buildings'. The primary cause was the shortage of proper technology, such as building wind tunnel test equipment. Therefore, scientific design was not always an option, only reversal or empirical design could be utilized. This meant architects were restricted to construct the same design or imitate foreign buildings. Now that China has access to wind tunnels, building designs can be analysed at a higher level. Forward and scientific design can be used to improve the buildings' capabilities with low cost.

The Chinese construction industry is in a transition from mass production to quality production. Through the innovation of computers, CFD simulation technology continues to improve, but the use of the wind tunnel experiments is invaluable. Improvement of China's wind tunnel technology for the use of architectural design will soon reach the international and advanced level. This will have a significant role in promoting the utilization of the wind tunnel analysis for future development.

### An Overview of Building Wind Tunnel

**World building wind tunnel:** Currently, there are about 300 productive wind tunnels in the world, mainly in Europe, the

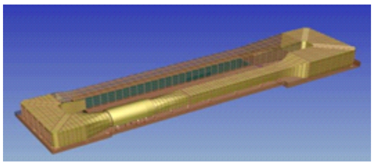

Fig. 1: Panorama of return flow wind tunnel (picture from the wind tunnel design principle).

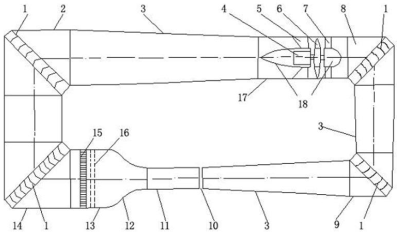

Fig. 2: Constitution of return flow wind tunnel (picture from the wind tunnel design principle). 1-Deflector; 2-Third corner; 3-Diffuser; 4-Motor; 5-Rotary vane; 6-Fan; 7-Oriented film; 8-Second corner; 9-First corner; 10-Regulator seam; 11- Test section; 12-Contraction section; 13-Stable segment; 14-Fourth corner; 15-Rectifier; 16-Whole drift; 17-Power segment shell; 18-Fairing.

United States and Japan. Early wind tunnel simulations were primarily used in the aerospace field. In 1871, British Wenham, also known as FH Wenham, built the world's first wind tunnel. It was a length of about 3 meters, and had wooden bellows open at both ends. In America, the Wright brothers created a wind tunnel with a test section area of 0.56 square meters and a wind speed of 12 m/s in 1901. Shortly after, they invented the world's first practical airplane in 1903. In 1916, the University of Gottingen, located in Germany, built the first modern wind tunnel, named the Prandtl wind tunnel (Fig. 3). The wind tunnel was 2.2 × 2.2m, featuring installed corner deflectors, and an increased experimental segment contraction section at the front-end, so that the flow field in the test section is more uniform.

The first example of architectural application using wind tunnel tests can be traced back to the 1930s, when the Empire State Building, located in America, was tested using the wind tunnel (Fig. 4). In the 1930s, while conducting research on wind tunnel manometry of a building model, Bailey found that the same model in the test section for uniform flow and shear flow, measured differing results. The shear flow was more consistent with the measured data, but at that time this did not cause enough attention (Bailey & Vincent 1943). In 1940, the Tacoma Bridge, located in Tacoma, Washington, USA, collapsed due to stall flutter. This tragedy drew attention to the significance of aerodynamics on infrastructure. Between 1960 and 1970, a number of boundary layer wind tunnels were built in the world.

In 1962, an American, Jack Cermak, built the world's first boundary layer wind tunnel (Fig. 5). The wind tunnel

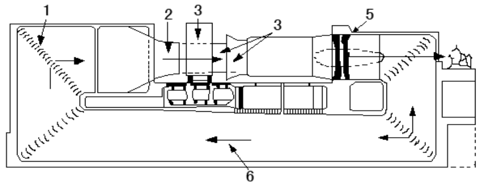

Fig. 3: Schematic plan view of Prandtl wind tunnel (Picture from the wind tunnel design principle). 1-deflector; 2-shrink segment; 3-model stent; 4-working segment set air intakes; 5-fan;6-reflux segment.

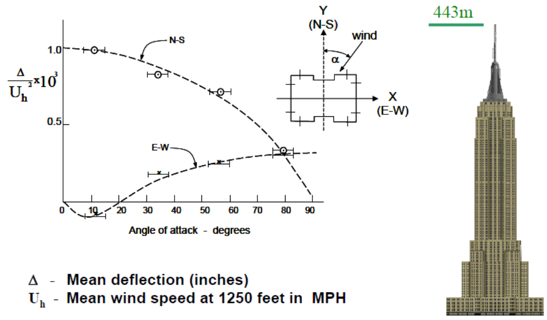


Fig. 4: Wind tunnel tests of American Empire State Building (Picture from the wind tunnel test techniques and data analysis, Yue Wu, Ying Sun, Harbin Institute of Technology).

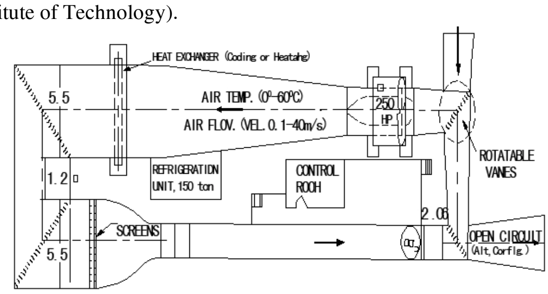


Fig. 5: the world's first boundary layer wind tunnel (Picture from wind tunnel test techniques and data analysis, Yue Wu, Ying Sun, Harbin Institute of Technology).

test section was 1.8 × 1.8 × 26m, with a maximum wind speed of 36m/s. We can study the flow characteristics and building pressure of the atmospheric boundary layer through adjusting the temperature, humidity, surface roughness and axial static pressure gradient. In 1964, the first architectural atmospheric boundary layer wind tunnel tests were completed for a project called, The World Trade Center. These two towers were built in New York City, and due to a terrorist attack, collapsed on September 11, 2001. Through the investigation, we summarized the comparison of several large boundary layer wind tunnels in the world (Table 1).

**China building wind tunnel:** The construction of the atmospheric boundary layer wind tunnel is relatively new in China. Some of the early wind tunnel tests were done using an aeronautical wind tunnel (Wu et al. 2001). In 1934, the Department of Aerospace at Tsinghua University, built China's first self-designed medium-low speed wind tunnel. In 1955, the first new low-speed wind tunnel was built in

Table 1: Comparison of several large boundary layer wind tunnels in the world.

| Affiliate unit | Wind tunnel type | Test Section Size m(w·h·l) | Maximum wind | Turbulence velocity (m/s) | Velocity field uniformity |
|---|---|---|---|---|---|
| Japan Civil Engineering Institute | DC Vertical | 41*4*30 | 12 | ≤ 0.5% | ≤ 2% |
| Chinese Tongji University | Reflux Vertical | 15*2*14 | 17.6 | ≤ 2% | ≤ 2% |
| Danish Institute of Oceanography | DC Vertical | 13.6*1.7*9 | 7 | ≤1.5% | ≤ 2% |
| Japan's Mitsubishi Heavy Industries | DC Horizontal | 10*3*19 | 28 | | |
| China Air Center | DC Horizontal | (1)12*16* (2) 8*6* | 100 | ≤ 0.1% | ≤ 0.5% |
| NRC Canada | | 9.1*9.1*22.9 | | | |

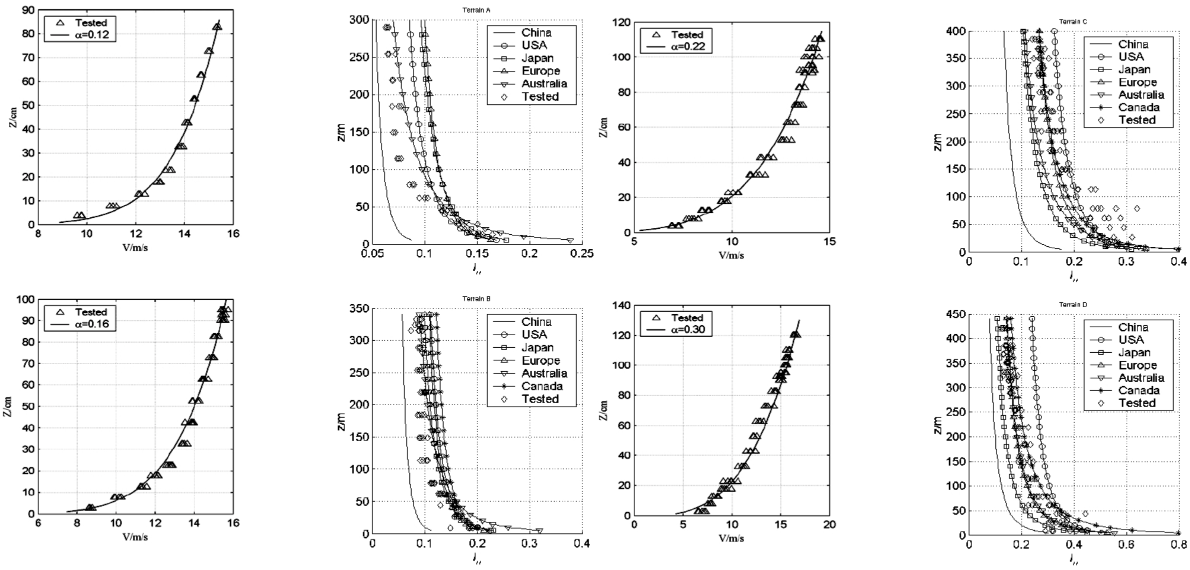


Fig. 6: The mean wind profile and turbulence distribution of four types of landforms (Shi et al. 2007).

Harbin. In 1958, the first scientific wind tunnel of China built at Peking University, with a diameter of more than 2m. In Mianyang, located in southern China, Asia's largest group of low-speed wind tunnels were built in 1977. Table 2 gives a basic overview of the major domestic wind tunnel developments in China.

## Research of Atmospheric Boundary Layer

The trends of building wind tunnels can be divided into two aspects; large-size test sectors and the diversified functions. Studying the wind tunnel simulation of the atmospheric boundary layer is the key to solving wind engineering issues, such as the effects of wind on the building structure and wind environment around buildings, which both play an important role in the urban setting.

Since Counihan (1969) and Standen (1972) proposed two analog devices of the atmospheric boundary layer, wind tunnel simulation techniques and methods have progressed greatly. Later, Irwin (1981) made some improvements for the Standen spire and furthered the empirical formula for a combination of minaret and analog wind gradient elements (Isyumov 1999). According to the characteristics of the atmospheric boundary layer from domestic and foreign simulations, the results of average wind profile seem satisfactory, but the distribution of turbulence, or turbulence structures show obvious differences (Farell & Iyengar 1999, Huang et al. 1999). Passive simulation methods commonly used a triangular spire, however, with turbulence simulation the triangular spire height decays too quickly. This leads to the upper part of the turbulent atmospheric boundary layer wind tunnel to be too low. The studies at Shantou University were done through the use of a trapezoid with curved edge spires and a roughness element simulation. This combined with a passive device for the wind tunnel of the atmospheric boundary layer, gives A, B, C and D, the four kinds of landform profiles; average wind speed, turbulence intensity distribution, a wind profile and a turbulence integral scale. From the simulation results (Fig. 6), we can see that the curved trapezoid steeple is more conducive to improving the boundary layer turbulence above middle height, which makes the turbulence intensity profile better than the triangle steeple.

Through the four kinds of simulations of the atmospheric boundary layer in different landforms, it was found that the wind tunnel test cannot produce satisfactory results by sim-

Fig. 2: Basic overview of the major domestic wind tunnel developments in our country.

| Wind Tunnel Names | Affiliate unit | Main Performance | | | |
|---|---|---|---|---|---|
| | | Cross section of the test section (m) | | | Cross section of the test section (m) |
| $4^{\#}$wind tunnel(1958) | Peking University | $\phi$ 2.25*3.65 | $4^{\#}$wind tunnel(1958) | Peking University | $\phi$ 2.25*3.65 |
| CGB-1(1986) | Guangdong Construction ASTRI | 3*2*10<br>1.2*1.8*9 | CGB-1(1986) | Guangdong Construction ASTRI | 3*2*10<br>1.2*1.8*9 |
| XNJD-1(1991) | Southwest Jiaotong University | 3.6*3*8<br>2.4*2*16 | XNJD-1(1991) | Southwest Jiaotong University | 3.6*3*8<br>2.4*2*16 |
| TJ-1(1991)<br>TJ-2(1994)<br>TJ-3(1994) | Tongji University | 1.8*1.8*12<br>3*2.5*15<br>15*2*14 | TJ-1(1991)<br>TJ_2(1994)<br>TJ_3(1994) | Tongji University | 1.8*1.8*12<br>3*2.5*15<br>15*2*14 |
| STDX-1(1996) | Shantou University | 3*2*20<br>D3.5*7.0 | STDX-1(1996) | Shantou University | 3*2*20<br>D3.5*7.0 |
| HD-2(2004) | Hunan University | 5.5*4.5*15<br>3.0*2.5*17 | HD-2(2004) | Hunan University | 5.5*4.5*15<br>3.0*2.5*17 |
| CA-1(2004) | Chang'an University | 3*2.5*15 | CA-1(2004) | Chang'an University | 3*2.5*15 |
| DUT-1(2006) | Dalian University of Technology | 3*2.5*18 | DUT-1(2006) | Dalian University of Technology | 3*2.5*18 |
| 2008 | China Construction Research Institute | 4*3*22<br>6*3.5*21 | 2008 | China Construction Research Institute | 4*3*22<br>6*3.5*21 |
| NH-2 | Nanjing University of Aeronautics and Astronautics | 5.1*4.26*7<br>2.5*3.0*6 | NH-2 | Nanjing University of Aeronautics and Astronautics | 5.1*4.26*7<br>2.5*3.0*6 |
| FL-8 | 627 Institute | 3.5*2.5*5.5 | FL-8 | 627 Institute | 3.5*2.5*5.5 |

ply applying the empirical formula. It must also improve the analog device in order to reach the intended target.

**Study on the building wind tunnel used in the wind environment**

Building wind tunnel tests are significant for research when designing wind resistant architectural structures (Cermak 2003). Also, with the development of the modern high-rise building and new building layouts, concerns of safety, health, energy and many other wind environment problems have surfaced. Research on the built environment can lead to high-rise designs that can be effective in many ways. At present, the main means of building wind environment is the boundary layer wind tunnel test (BLWT). We can solve this problem through model tests in a wind tunnel. New building design can be based on the results of the wind tunnel simulations, testing for comfort and effectiveness, to name a few. This can be done by taking corresponding measures, according to the simulation results, to construct an eco-friendly city with environmentally coordinated development and to ensure the sustainable development. In short, wind tunnel simulation experiments create good conditions for high-rise design and layouts of building groups to obtain better wind environment.

The building wind tunnel test model is designed to determine the correspondence between the pedestrian level wind speed around buildings and air flow speed. Then it combines the test results and statistical data of meteorological wind, according to the result, to evaluate the comfort of wind environment around the buildings. Wind tunnel test can only give us the relationship between wind speed around

Table 3: Effect of wind.

| Beaufort scale | Name | Wind velocity/ (km·h$^{-1}$) | Wind velocity/ (m·s$^{-1}$) | Effect |
|---|---|---|---|---|
| 0,1 | breezeless-light air | 0-5.4 | <1.5 | Calm, no perceptible wind |
| 2 | Breeze | 5.8-11.9 | 1.6-3.3 | Feel the wind blowing on the cheek |
| 3 | Gentle breeze | 12.2-19.4 | 3.4-5.4 | Light flagsDisturbance of hairThe skirt fluttering |
| 4 | Soft breeze | 19.8-28.4 | 5.5-7.9 | Dust, flying disk Hair blowing |
| 5 | Fresh breeze | 28.8-38.5 | 8.0-10.7 | The body can feel the wind The snow was blowing off the ground A feel good ground The wind cap |
| 6 | Strong breeze | 38.9-49.7 | 10.8-13.8 | Difficult to hold an umbrella The hair was blowing straight The steady walking difficulty The ears of the wind unpleasant Over the snow blew off the ground Pedestrian height |
| 7 | Gale | 50.0-61.6 | 13.9-17.1 | Walking inconvenience |
| 8 | High wind | 61.9-74.5 | 17.2-20.7 | Walking inconvenience The balance of the body is extremely difficult to maintain in the blast |
| 9 | Strong gale | 74.6-87.8 | 20.8-24.4 | People were blown down by the gust |
| 10 | Stom | 81.9-102.2 | 24.5-28.4 | Uprooted trees, building damaged,Not common in land |

Note: The speed in the table refers to the average wind speed on 10 m height of open ground.

Table 4: Principle of estimation on Aeolian environment.

| Activity | The applicable area | Tolerable | The relative comfort | |
|---|---|---|---|---|
| Trot | Sidewalk | 6 | Trot | Sidewalk |
| Walk | Park | 5 | Walk | Park |
| Short time standing, sitting | Park, Plaza | 4 | Short time standing, sitting | Park, Plaza |
| Long time standing, sitting | Outdoor restaurant | 3 | Long time standing, sitting | Outdoor restaurant |
| Acceptable representative rule | | <once a week | <once a month | Acceptable repre sentative rule |

Note: The relative comfort standard represented by Beaufort scale.

buildings and air flow speed. Wind tunnel tests cannot produce the exact kind of wind in a building's location. A judgment must be made based on the analysis of long period historical wind data.

The wind environment research is concerned with the impact of buildings on the local circulation. The research specifically looks at the negative effects that can result in disrupting pedestrian activity, which leads to the idea of building "comfort". The highest acceptable frequency of discomfort at different heights is usually described as "comfort evaluation criteria"; a specific division and definition are detailed in Table 3 (Davenport 1972) and Table 4.

Investigation results and statistics show that, pedestrian's position safety depends on the wind speed and surrounding wind speed distribution of the location. The calculation of comfort parameters is based on the average wind speed and airflow direction under various influences at varying pedestrian heights (Penwarden & Wise 1975).

## Study on Wind Tunnel Used in Green Building

China is currently working on completing "green building evaluation criteria" and "green building technology guide", as well as national conditions for the scientific definition of green building. These initiatives will be important to maximize the conservation of resources (energy, land, water, material) through the building's life cycle, protect the environment, reduce pollution and provide a clean, enjoyable and useful space for people, where architecture coexist in harmony with nature (Ou et al. 1995) .

There is increasing importance for architects to design with emphasis on energy savings. Bad wind environment in the city hinders the flow of indoor and outdoor ventilation, increases air conditioning use in the summer, and leads to an increase of energy consumption for heating in the winter. Modern technology used in analysing the efficiency of buildings' design for good wind environment quality can effectively reduce the energy consumption of buildings. In the long-term, using natural ventilation provides a healthier, more low-cost method to provide clean air and other benefits to the users' physical health and psychological needs. This method also has a positive relationship with nature, and utilizes energy conservation, contributing to environmental protection. Wind tunnel test simulation application in design work can create an organization of the wind environment, promoting the application of natural ventilation.

Along with the need for reduction of energy use, the

Fig. 7: Bahrain world trade center designed by Atkins- the world's first large-scale building combined wind turbine (picture from Baidu pictures).

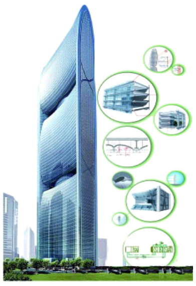

Fig. 8: Guangzhou zero energy building designed by SOM design office-the Pearl River Tower (pictures from the Baidu pictures.

source of power has become very urgent. The improvement of renewable, green energy will become an important part of the social sustainable development. Wind power with the characteristics of clean, pollution-free and sustainable, has been highly anticipated by the world. Wind will be the most promising green energy in the 21st century, as a major source of power for future sustainable development. Therefore, studying the effects of using wind energy for buildings, or the entire city, will have an inestimable amount of significance for our future. In the built environment the use of wind power has many advantages. The wind generated energy and building integration, can lead to the development of green buildings and zero energy buildings. Therefore, this research direction and wind tunnel application for green building is worthy of our concern and attention. Figs. 7 & 8 are the examples of wind energy applied in building environment.

## CONCLUSION

According to the 2005 CFD capability analysis report by American Science and Technology Institute (STPI), if the calculation ability follows the previous development trend, it will take forty years to complete an aircraft design database with CFD. Therefore, although CFD is playing an increasingly important role, the fundamentals of wind tunnel experiments are still irreplaceable. The simulation data combined with the research of foreign projects are necessary for the future development of the wind tunnel; the following points are very important.

1. The establishment of a knowledge based test team is the key of national wind tunnel test facility constructions.
2. To improve testing technology to ensure the future development of research projects.
3. The repair and reconstruction of key test equipment is a crucial aspect of the future to ensure test capability; disabling the standby and nonessential test equipment is necessary to focus on limited resources to research the simulations and new wind tunnel facilities construction.

In order to explore the mechanism of the aerodynamic force and the flow problems in the early 20th century, the wind tunnel has emerged as the most effective method. With innovations over time, new analysis is required from the existing tunnel, promoting the development of tunnel technology to a higher level. Through wind tunnel reconstruction, new wind tunnel construction, and exploration of new concepts to improve the simulation results, both home and abroad, the future development of wind tunnels will prove to be challenging. Foreign wind tunnel construction and operation has had a strong reference to the development of domestic wind tunnels in China. Innovation development and efficient operation of wind tunnel simulations will promote the rapid development of the future of green buildings. Therefore, the research and application for the construction of wind tunnel technology will have an important significance to the new development of the Chinese architectural industry.

## ACKNOWLEDGEMENTS

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