

Research on Green Systems of the Historical Buildings Protection

Li Yang^{*} and Feng Qian

College of Architecture and Urban Planning, Tongji University, Key Laboratory of Ecology and Energy Saving Study of Dense Habitat (Tongji University), Ministry of Education, Shanghai, P. R. China

^{*}Corresponding author

Abstract—Natural ventilation is a technique that utilizes the natural environment. Compared with air conditioning, it can reduce the energy consumption and maintain good air quality at the same time. However, in past research methods, wind environment design was ignored. In this paper, the ventilation system of the historic buildings at the University of Shanghai for Science and Technology are analyzed by the use of fluid analysis software. An effective solution for energy-saving, ecological architecture is also investigated. In the future, we can optimize the design by making use of computational fluid dynamics software, Fluent Air-Pak simulation analysis, to achieve more sustainable alternatives.

Keywords-gymnasium; conservation of historic building; natural ventilation; computational fluid dynamics

I. INTRODUCTION

The University of Shanghai for Science and Technology, or USST, used to be known as simply the University of Shanghai. It is located on the west bank by the Huangpu River in North-East Shanghai. Since 1906, more than 50 Gothic buildings have been built, and filled campus with historic, well-constructed buildings, creating a beautiful environment [1].

Buildings at the University of Shanghai were famous within the China-Christian universities. The historic buildings witnessed the changing of the times in China. There are 30 existing historic buildings and villas on the campus listed as outstanding historical buildings in Shanghai. These buildings preserved the spatial patterns of the campus over time. They are precious, cultural heritages for Shanghai and for China.

The University of Shanghai campus was designed like a three-section compound model in its layout. The architectural design is similar to the same period campus style used for universities in America. American architects at the Henry Murphy's Institute developed the University of Shanghai in 1919. This was Murphy's second campus planning and design in China (Figure I). Of the original historical buildings of University of Shanghai, there are many characteristics that describe the collegiate Gothic Style: steep roofs, vertical lines, elaborate windows, buttress walls, decorative minaret, castle-like entrance, through-type towers, relief walls, among others [2]. However, compared with the cold and gloomy collegiate Gothic campus, the architectural style of University of Shanghai is crisper and the appearance of the Gothic architecture reveals a trend of convergence. This particular style is considered simplified Gothic Revival style (Figure II).

Gothic architecture originated from France in the second half of the 11th century and from the 13th to 15th century it became a popular architectural style throughout Europe. It was mainly embodied in the Catholic Church and affected other secular buildings as well. With its superb techniques and artistic characteristics the Gothic style plays an important role in the history of architecture. The most famous Gothic architecture includes the Cathedral of Cologne (Figure III), Notre Dame Cathedral, Milan Cathedral, and Westminster Abbey [3].

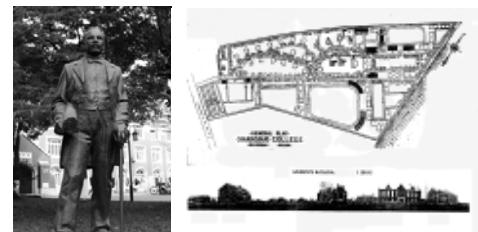


FIGURE I. HENRY MURPHY AND PLAN OF UNIVERSITY OF SHANGHAI



FIGURE II. WHITE CHAPEL IN UNIVERSITY OF SHANGHAI (SIMPLIFIED GOTHIC REVIVAL)



FIGURE III. COLOGNE CATHEDRAL (GOTHIC ARCHITECTURE)

This paper uses the ventilation system of these historical and protected buildings at USST as the research object. Natural ventilation is very effective, and has advantages in energy conservation, and improvement of indoor thermal amenities

and indoor air quality (IAQ) [4]. It has been a basic way to adjust the indoor environment throughout the history of enclosed structures. Because of the popularity of air-conditioning and mechanical ventilation, scientists around the world began to re-examine natural ventilation technology due to great pressures to conserve energy use and maintain good IAQ [5]. This paper aims at studying the ventilation systems of protected historical buildings, and will act as a guide to the future eco-friendly building, promoting energy conservation.

The optimal design of building energy efficiency is based on computational fluid dynamics. In view of this theory, room ventilation and pollution will be analyzed during the hypothesis and evaluation design phases [6]. However, CFD needs a large calculation and lengthy computation due to a large number of rooms in the building and the complicated forms. That is why this analysis must be carried out with necessary technical analysis and model simplification. This paper, focusing on Evanston and Virginia Hall at USST, will give further theoretical analysis.

II. NATURAL VENTILATION

The driving force of the passive ventilation system is wind and temperature. Natural ventilation of the interior space is caused by leeway and thermal pressure difference as the result of wind speed and temperature variations between the inside and outside of the building. The magnitude of wind pressure on buildings depends mainly on the wind direction, wind speed and the shape of the building. Compared with the wind pressure ventilation, thermal pressure ventilation can be better adapted to the constantly changing outside variables and an undesirable wind environment [7].

The implementation principles of natural ventilation have several forms. They are thermal pressure, wind pressure, the combination of these two pressures and mechanically assisted ventilation. Currently, natural ventilation is achieved by comprehensive utilization of indoor and outdoor conditions, instead of simply opening windows and doors. The comprehensive natural ventilation can be organized and induced by the surrounding environment, building layout, building construction, solar radiation, climate, indoor heat source and so forth. In terms of building construction, a suitable natural ventilation system is largely dependent on the optimized design of the atrium, double walls, wind towers, doors, windows, roofs and among components.

The substitution of natural ventilation for air condition and refrigeration technology, contributes to two significant factors. One is the realization of a passive cooling. Natural ventilation can lower the indoor temperature and improve indoor thermal environment without the consumption of non-renewable energy [8]. The other is a continuous supply of fresh, clean air, which can reduce humidity and benefit the user's physical and mental health.

The implement methods of natural ventilation commonly used in the architecture are as follows:

A. To Achieve Natural Ventilation by Use of Wind Pressure

The basic drive of natural ventilation is wind pressure and thermal pressure. Wind pressure can be used as a primary means of natural ventilation in the favorable external wind environment regions.

In addition, it is necessary to understand the basic law of airflow, the Bernoulli Law, which refers to when the air velocity increases, static air pressure will decrease. Therefore, the negative pressure zone, which has an "absorb" effect on airflow, forms the contraction part of the Venturi tube as a result of the increasing air velocity (Figure IV).

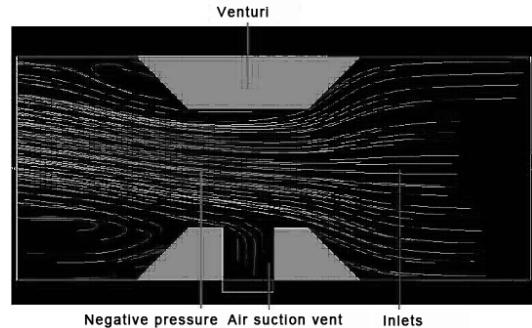


FIGURE IV. BERNOULLI EFFECT

B. To Achieve Natural Ventilation by Means of Thermal Pressure

Another drive of passive ventilation is temperature, known as thermal pressure ventilation. It takes advantage of thermal pressure difference between the air on the inside and outside of the buildings (the "Stack Effect") to achieve its natural ventilation. According to the principle of hot air rising, the indoor dirty, hot air will be discharged through the air outlet in the upper part of the building, while the outdoor fresh, cold air will be sucked through the bottom [9]. (Figure V)

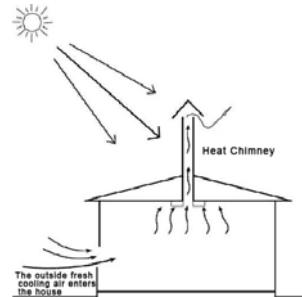


FIGURE V. PRINCIPLE OF SOLAR CHIMNEY

C. The Combination of Wind Pressure and Thermal Pressure to Achieve Natural Ventilation

The combination of thermal pressure ventilation and wind pressure ventilation is often used for natural ventilation in building design (Figure VI). Generally speaking, wind pressure ventilation can be used in areas of less depth while thermal pressure can be used in areas of greater depth due to the limitation of traditional wind pressure [10]. Queen's Building, De Montfort University located in Leicester, UK, is an excellent example. Architects Short and Ford divided the

massive construction into smaller pieces. The scale of the building was coordinated with the surrounding historic blocks, and created an appearance of continuity. The natural ventilation can be improved by a specific design; wind pressure ventilation is applied to the laboratories and offices located in finger-like branches with less depth and the “Stack Effect” is responsible for the lecture room, halls and others in the middle part. At the same time, in order to reduce the building’s internal heat to a minimum, thick heat storage materials have been used on the external security structure [11].

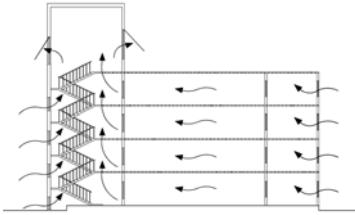


FIGURE VI. THERMAL PRESSURE VENTILATION BETWEEN STAIRS

D. Mechanically Assisted Ventilation

In some large buildings, because of the longer ventilation path and the higher flow resistance it is impossible to achieve natural ventilation relying solely on natural wind pressure and thermal pressure, especially for the city with sever air and noise pollution. Using direct natural ventilation will bring outdoor, polluted air and noise inside. This is quite harmful to the user’s health. In this case, mechanically assisted ventilation system is often recommended. The system has a complete set of air circulation channels, supported by air-handling methods, that follow the ecological concepts utilizing soil pre-cooling, preheating, and heat exchange of deep well water, as well as accelerates indoor ventilation in a mechanical way [12].

E. Two-Tier Maintenance structure

The two-tier maintenance structure is an advanced technology commonly used in the ecological architecture. It is often compared to “the breathable skin”. This kind of structure consists essentially of double-glazing or triple-glazing. The skin is created with certain widths between two sheets of glass, in which an air interlayer is formed and adjustable dark-colored shutters are made. In winter, the air interlayer and shutters can work as a solar air heater to raise the temperature of external walls of the building and to be conducive to heat preservation and heating. In summer, the hot air will be discharged from the building at the top of the interlayer to lower the temperature [13]. For a high-rise building, the issue is that opening windows directly will cause uncontrollable turbulence. The two-tier maintenance structure is an appropriate solution for this problem (Figure VII).

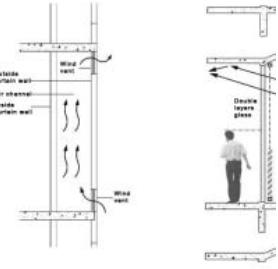


FIGURE VII. A: SCHEMATIC DIAGRAM OF DOUBLE-LAYER CURTAIN WALL VENTILATION B: DOUBLE-SKIN GLASS CURTAIN WALL

III. NATURAL VENTILATION SIMULATION OF HISTORICAL PROTECTION BUILDINGS IN USST

In this paper, we use CFD software, Fluent Air-pak, based on the Finite Volume Method to calculate the building ventilation and air conditioning, and to analyze the airflow field of historic preservation buildings in USST. Air-pak software can accurately simulate the airflow, air quality, heat transfer, pollution, comfort and other aspects of ventilation systems. This helps to improve design methods, reduce design risks and costs [14].

Two historic buildings are selected in this simulation. The first simulation takes the average floor layout of Evanston Hall (Figure VIII) as an example. The building was founded in 1919 with the style of late Gothic architecture and now is dormitory No.4 at USST. This building used to be a three-floor, brick-wooden structure, with a double-sloping roof and consecutive dormer windows [15]. In 1984, it was rebuilt into a four-floor flat-topped building, removing the roof chimney and the dormer windows. It is clear to see from the construction plans that the corridor is located in the middle. Alongside it, the classrooms sit symmetrical on both sides. Assuming that wind enters the building from the right, the air inlet’s velocity is 5m/s, then it exhausts through the left vents (Figure IX).



FIGURE VIII. EVANSTON HALL

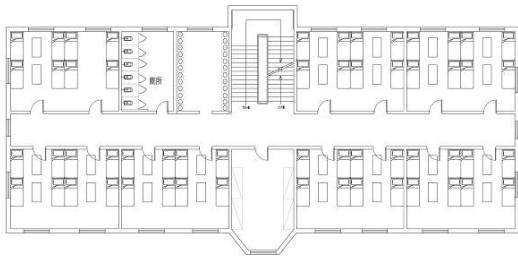


FIGURE IX. STANDARD FLOOR PLAN OF EVANSTON HALL

In Figure X, the air velocity vector distribution at the height of 2 meters shows that if the windows on both sides of the corridor are open, wind will come in from the right windows, pass through the corridor, and then to be discharged through the left windows. The simulation assumes that if the windows and doors on both sides are open, outside air could enter the dormitory through the windows in the rooms, into the corridor [16]. This allows for proper ventilation in the dormitory, as well as maintenance of the indoor thermal comfort. The results of the experiment match the Bernoulli effect previously mentioned. Assume that the outside atmospheric pressure is P_1 and the pressure in the corridor is P_2 when the space suddenly becomes smaller in the corridor and the wind velocity becomes faster. According to the Bernoulli effect, speed will increase when pressure is reduced, $P_2 < P_1$. The pressure difference will drive air, to pass from windows on both sides, to the corridor. Under the suitable conditions in summer, the frequency of air conditioning will be reduced and eco-energy savings will be achieved if we choose to lower the temperature via natural ventilation [17].

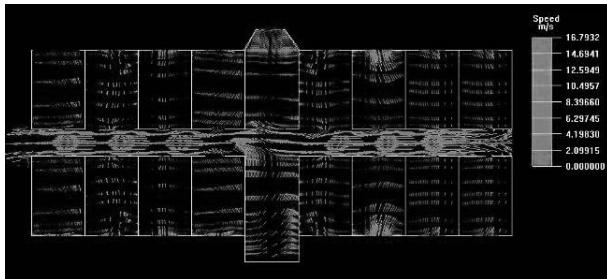


FIGURE X. AIR-PAK NATURAL VENTILATION SIMULATION OF EVANSTON HALL

The second simulation object is Virginia Hall (Figure XI). This building has two floors and a brick and concrete structure, a style of the late Romans. It was originally missionary apartments of priestess, and now is the International Exchange Center of USST. From the elevation, we can see that on the top of the building there are two protruding chimneys. To the south, there is a balcony supported by the brackets decorated with floral scrolls [18]. On the southwest wall there is a row of semicircular dentate headdresses. In the east, there are octagonal bay windows under the balcony and to the back, there is a balcony decorated with an Aquarius-shaped railing. Although the building has been repaired, it these decorative accents remain intact (Figure XI).



FIGURE XI. VIRGINIA HALL



FIGURE XII. ELEVATION OF VIRGINIA HALL

Thermal pressure ventilation can be a better alternative when wind pressure ventilation is ineffective due to depth or a complex layout. It makes use of “Stack Effect” by discharging the hot air through the “chimney”, reducing internal heat, and in-taking the fresh, cooler air from outside to accomplish the purpose of indoor temperature reduction [19].

Undistorted model of Virginia Hall is built by Air-Pak, which sets up air outlets in the two rooms with “chimneys” to simulate indoor airflow. According to the simulation experiment, the air velocity vector distribution in different heights can be calculated (Figure XIII, XIV, XV). At 1-metre height, the air from each room tends to gather into the two rooms with a fireplace. This trend becomes more noticeable at 2-metre height. The closer to the air outlet the more noticeable the trend and the faster the wind velocity will be [20]. Figure XVI further attests to this from a vertical section. A comprehensive understanding of the principle of natural ventilation of Virginia Hall can be gathered from the mimetic diagrams. In spring, autumn or early summer when the outdoor temperature is suitable, thermal pressure ventilation can effectively decrease the indoor temperature, and improve thermal comfort and air quality. It is an energy-saving, ventilation alternative.

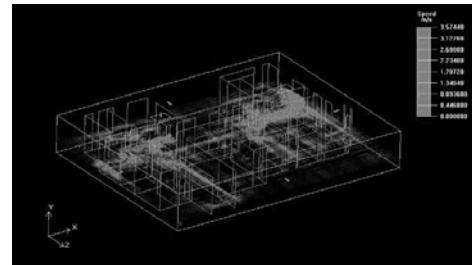


FIGURE XIII. WIND VECTOR DISTRIBUTION AT THE HEIGHT OF 1 METER

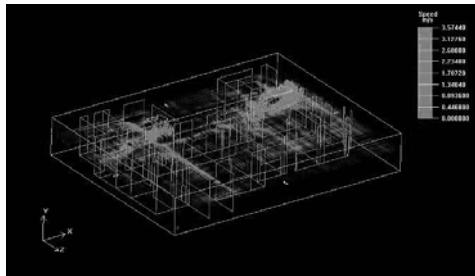


FIGURE XIV. WIND VECTOR DISTRIBUTION AT THE HEIGHT OF 2 METERS

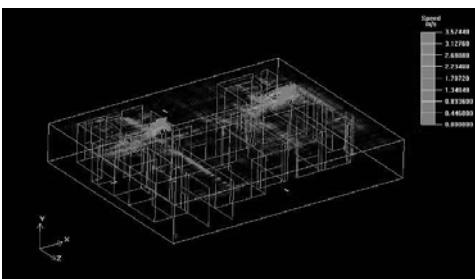


FIGURE XV. WIND VECTOR DISTRIBUTION AT THE HEIGHT OF 3 METERS

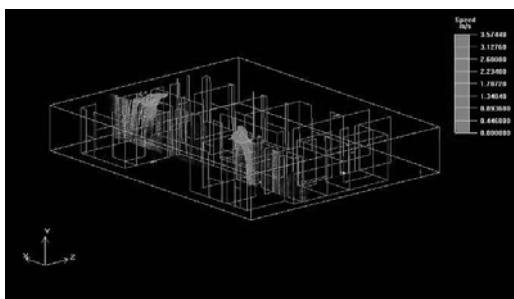


FIGURE XVI. LONGITUDINAL SECTION OF WIND VECTOR DISTRIBUTION

IV. CONCLUSIONS

Natural ventilation of buildings can effectively lower the indoor temperature, improve thermal comfort and air quality, and save air conditioning energy consumption.

In this paper, we have analyzed the ventilation system of historic buildings at USST through fluid analysis software, and exploring effective technical solutions for ecological and energy efficient buildings. In the future, we can optimize the design by use of computational fluid dynamics software, Fluent Air-Pak simulation analysis, to produce an ideal effect. Natural ventilation systems treat the buildings more like living organisms. It is also better suitable for the climate, and meets the health and living standards of users. Compared with developed countries, natural ventilation systems and green building in China is still relatively new, but with the increasingly urgent demand of energy-saving alternatives, the concept of ecology and “green” in the infrastructure is becoming more important. Encouraging the transformation of thoughts and design process to be more environment-centered,

green buildings with natural ventilation systems will spring up all over the city.

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REFERENCES

- [1] F. Bauman, T. Webster, “Outlook for underfloor air distribution”, ASHRAE Journal, 2001, 6, 18- 27.
- [2] L. Yang, B. J. He, M. Ye, The application of solar technologies in building energy efficiency: BISE design in solar-powered residential buildings. Technology in Society, 2014; 38: 111-118.
- [3] C. GLADSTONE, A.W. WOODS, “On buoyancy-driven natural ventilation of a room with a heated floor”, Journal of Fluid Mechanics, 2011, 616, 293-314.
- [4] S. Han, B. Guo, “Temperature effect of Building natural ventilation”, Building energy conservation, 2008, 9, 18-22.
- [5] J. P. Liu, L. Yang, Indoor thermal environmental design, Beijing, Mechanical Industry Press, 2005, pp 4.
- [6] F. Qian, Analysis of Energy Saving Design of Solar Building-Take Tongji University solar decathlon works for example, Applied Mechanics and Materials, Vol.737, pp139-144, 2015.
- [7] J. Q. Min, Z.B. Xu, “Multi-ventilation indoor temperature area and air quality of the numerical analysis”, Fluid Machinery, 2006, 12, 29-33.
- [8] K. Matsunawa, H. Lizuka, S. Tanabe, “Development and application of an under floor air-conditioning system with improved outlets for “smart” building in Tokyo”, ASHRAE Transactions, 1995, 101 (2), 887-901.
- [9] L. Yang, Green building design: Wind environment of building, Shanghai: Tongji University Press, 2014.
- [10] Y. Shen, et al., ““Double skin” outside maintenance structure ventilation simulation analysis” Building Science, 2008, 24 (6), 85 - 89.
- [11] T. Webster, F. Bauman, “Under floor air distribution: thermal stratification”, ASHRAE Journal, 2002, 5, 28-36.
- [12] F. H. Wang, D. Y. Wang, X.L. Luo, “The existing building envelope and energy consumption simulation analysis”, Building Science, 2007, 23 (2), 22-26.
- [13] L. Yang, Green building design: Building energy efficiency, Shanghai: Tongji University Press, 2016.
- [14] Z. F. Xue, al et, Ultra-low power architecture technology and its application. Beijing, China Building Industry Press, 2015, pp 3.
- [15] Q. S. Yan, Q. Z. Zhao, Building thermal process. Beijing, China Building Industry Press, 1986.
- [16] H. L. Zhou, K. Wang, “Natural ventilation study and application” Shanxi construction, 2008, 1, 193-194.
- [17] J. P. Zhang, A. G. Li, “The application and study quo discussion of natural ventilation” HVAC, 2005, 35 (8), 32 ~ 38.
- [18] Z. Q. Zhang, Z.J. Wang, L. M. Lian, “Indoor thermal environment of residential buildings Numerical Simulation”, Building heat ventilation air-conditioning, 2004, 23 (5), 88-92.
- [19] China Academy of Building Research Institute of air conditioning. Tall building air conditioning technology Research Report.1982.
- [20] N. Jun, Urban culture from the perspective of urban design. Regional Research and Development, 2010, 6: 1-8