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General Research Paper

Natural Ventilation Environment Strategy in Green Building Design

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ABSTRACT

As energy consumption increases and the energy crisis gets worse, environmental pressure for efficient alternatives is growing. The advantages that the natural ventilation strategy has in reducing building energy consumption and improving the indoor environment conditions have become more obvious. Compared to mechanical ventilation or air-conditioning system, there is more potential in the natural ventilation method providing better indoor air quality, while maintaining a healthy and comfortable indoor thermal environment. Based on the principles of stack ventilation, natural ventilation is divided into wind pressure ventilation, thermal pressure ventilation, ventilation under the action of thermal pressure and wind pressure simultaneously and mechanical-assisted natural ventilation. The ventilation principles are respectively described with examples in this article.

INTRODUCTION

The malpractice of the current constructional mode is at the price of the environment and resources are gradually diminishing. The energy crisis and environmental pollution have heightened the importance and urgency of sustainable architecture (Tang Lv & Wang 1989). The 21st century will be an era where a variety of technologies coexist. The technology that belongs to the ecologically responsible construction is incredibly multilevel. Natural ventilation is an architectural, ecological, energy saving strategy, that can effectively reduce building energy consumption and maintenance costs. Compared with mechanical ventilation systems or air-conditioning systems it can effectively improve indoor air quality, and maintain a healthy and comfortable indoor thermal environment. As a result, attention from around the world has been brought to this natural and energy saving alternative (Peter & Jr 1999). This global attention has provided some useful perspectives on the natural ventilation strategy. As a common way of providing fresh air and cooling, natural ventilation has a valuable application to sustainable design. It can reduce the requirements of the mechanical ventilation and air-conditioning to achieve energy saving consumption and utilize resources relying on the natural airflow. The main purpose of the natural ventilation is to ensure the quality of the air, as well as to improve the building's indoor thermal comfort. The invention of air-conditioning technology leads to an independent microclimate in an enclosed space. Even in the summer or winter, it can keep the indoor temperature and humidity in a relatively comfortable range. However, air conditioning has conflicting attributes. Though it can bring comfort to the inside environment, but it has also produced many negative impacts, such as inefficient energy consumption, illness and so on. An appropriate natural ventilation is one of the most effective methods to reduce the negative air-conditioning impacts. Natural ventilation can efficiently reduce air-conditioning consumption and emissions of carbon dioxide to achieve a low-carbon green environment (Regan 2006).

THE STANDARDS OF NATURAL VENTILATION

The building's ventilation sends the fresh cold air into the building, first, to ensure the freshness of indoor air and second, to reduce the indoor temperature and ensure the thermal amenity. According to the desired indoor environment, including the control of air quality and the target of thermal amenity, we can define ventilation performance standards (Long 1999).

The air quality control standard: The air quality control standard can improve the air quality to control the ventilation velocity. In the aspect of ventilation design, designers should correctly choose the minimum requirement for fresh air and the frequency of ventilation. Indoor air quality directly affects the human physical and mental health and work efficiency, especially the workers in the modern enclosed offices. Dr. Sundell carried out a research on 160 buildings in Sweden, and he found the more fresh air that was present, the less building disease syndrome was experienced (Wu 2001). Currently, the chinese indoor air quality standard states that every person requires 30 m^3/h of fresh air.

The thermal amenity standard: Experiments prove that the thermal amenity standards of the buildings with natural ventilation and air-conditioning are different (Table 1). When people can control their surrounding environment, they are more willing to adapt to the change of seasons. Therefore, when using the natural ventilation, the great extent of indoor air temperature is allowed. In the range of 15°C to 18°C, the minimum wind velocity which provides comfort is 0.2m/s, at the temperature of 30°C, the minimum wind velocity that is appropriate is 0.6m/s. In conclusion, the higher environment temperature is, the greater the wind velocity can be. When working indoors, the ideal wind velocity should be controlled within 1.0m/s. If the wind velocity is over 1.5m/s, the air flow will interfere with regular work. It is at this point that we have to control the wind velocity and the flowing path because the indoor environment will be uncomfortable due to the strong wind velocity (Wei et al. 2006).

SEVERAL MODES OF NATURAL VENTILATION COMMONLY USED

According to different classifications, natural building ventilation can be divided into different categories. In accordance with the indoor air movement direction, natural ventilation mainly is split into horizontal ventilation and vertical ventilation. In Fig. 1, the relationship between building's openings and horizontal air flow indoor in normal conditions is shown. In terms of the dynamics of air movement, natural ventilation can also be divided into natural ventilation under the wind pressure, natural ventilation under the thermal pressure, natural ventilation under the action of thermal pressure and wind pressure simultaneously, and the mechanical-assisted natural ventilation (Zhi & Min 2010).

The natural ventilation under the wind pressure: The pressure difference in the atmosphere creates wind. In an area with good external wind environment, wind pressure can be the main method to obtain natural ventilation, which can be used to promote indoor air flow, and efficiently improve indoor air quality. The principle of wind pressure ventilation is that the wind is kept out by the building in the flowing process to produce the energy transition, which the dynamic pressure changes into the static pressure. As a result, the positive pressure is developed at the building's windward side, about 0.5 to 0.8 times as much as the wind velocity dynamic pressure, and the negative pressure is formed at the building's sides and back, at about 0.3 to 0.4 times as much as the wind velocity dynamic pressure. The pressure difference in the front side allows for airflow into the inside of the building, entering from the windward side windows through to the leeward side. This results in the natural ventilation being formed (Fig. 2). The wind pressure difference surrounding the building is related to the building's shape, the angle between the building and the wind, and surrounding environment. When the wind vertically blows over the facade of the building, the positive pressure at the center of windward side is the maximum, and the wind pressure at the corner and ridge of the roof is maximum as well (Zhong & Yi 2004). Additionally, according to the Bernoulli fluid principle (Fig. 3), the pressure of fluid decreases with the increase of the speed. When the fluid quickly flows through the pipe like passage, it will form the negative pressure area in the pipeline. According to this principle, the area in the long corridor construction can be used as a ventilation duct. When the wind passes through the passage, the negative pressure area will be formed and will bring the surrounding air together. This is the kind of natural ventilation that can have a positive effect on the large depth building spaces. This is the draught principle of tubular building (Jiao et al. 2008).

The natural ventilation under the action of thermal pressure: Thermal pressure is caused by temperature difference between indoor and outdoor air. This is called the "chimney effect". The existence of temperature and density difference between indoor and outdoor air occurs, then the pressure gradient along the vertical directions of the wall appears (Xu et al. 2003). According to the hot air rising principle, if the indoor temperature is higher than the outdoor temperature, the upper air outlet of the building can discharge the dirty air and the fresh air outdoors will be inhaled from the bottom of the building. If the temperature indoors is lower than outdoors, the airflow directions will be opposite. The height difference of the air inlet and air outlet, and the indoor and outdoor temperature, decides the magnitude of thermal pressure. The greater the temperature difference and height of the air inlet and outlet, the more obvious the "chimney effect" becomes (Fig. 4). In practical application, architects use the multi-layered vertical cavity for design features such as ventilation tower, courtyard atrium, draft well, and some other forms of "chimneys", to find advantages in the natural ventilation. As a result, buildings can have good ventilated effects (Xue & Su 2011).

The German Frankfurt commercial bank building is a typical case of ventilation under thermal temperature. It was designed by Norman Foster as the tallest building in Europe. Its height is 300 m with 50 stories. As the world's first ecological high-rise tower, its plane is triangular, where a

Table 1: The effect of the wind velocity on humans.

Wind Speed (m/s)	Feelings when working
0-0.25	imperceptible
0.25-0.5	pleasant without any influence
0.5-1.0	pleasant with a bit of care
1.0-1.5	annoying, work with care
>1.5	measures must be taken to improve wind effect

huge atrium in the middle reaches to the top (Fig. 5). Each side of the triangle designed 4 units of height as 12 levels. It also created a shared space with the height of 4 stories where many kinds of plants were added forming a sky-garden. Three nuclei's composed of the toilets and elevators, were created by three huge pillars set on the triangular structure. Setting the arched hollow beams between the huge pillars and the triangles formed three no-column style office spaces. These office spaces surround triangle atrium to form the so-called "chimney". In order to achieve the "chimney effect" and organize the natural ventilation in office areas, the air gardens and atrium are set in shared spaces to act as the air inlet and outlet of the "chimney" (Yang 2002). These air gardens were distributed in three different elevations as the air inlet of the "chimney". The top atrium was regarded as the air outlet that efficiently organized the natural ventilation in the office (Wang 2010). The test results showed that sufficient night ventilation can make the daytime indoor temperature to be reduced by 2 to 4°C.

During the design process of the Frankfurt commercial bank building, in consideration of the natural ventilation conditions in the atrium, Foster and his team conducted computer simulation and wind tunnel experiments many times. The test results showed that, if the entire atrium from top to bottom was without separation, the internal wall will produce turbulence. However, if the "chimney" height is adjusted to 12 levels, it will provide a good natural ventilation effect. Therefore, Foster divided the tower into four ventilation units, separated by transparent glass, with the height of 12 stories that all used the natural ventilation under thermal pressure. Thus, the whole atrium became several natural ventilation units, and no longer one "big chimney" (Fig. 6).

The natural ventilation under the action of thermal pressure and wind pressure simultaneously (Lee & Chang 2011): In the design of architectural natural ventilation, the wind pressure ventilation and thermal pressure ventilation are always used together. The climate, outdoor wind direction, building's shape, and surrounding environment have an influence on wind pressure. The action of thermal pressure and wind pressure simultaneously is not simplistically linear. In general, the shorter depth building usually adopts the wind pressure ventilation, and the larger depth building usually more efficiently uses the thermal pressure ventilation to achieve the ventilation effect. In summary, the various elements should be comprehensively understood to ensure the wind pressure and thermal pressure complement each other. Only a close symbiotic relationship can create the building's effective ventilation.

Queen's building of De Montfort University in England

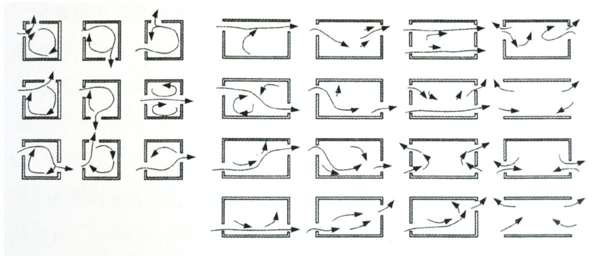

Fig. 1: The relationship between building openings and horizontal airflow indoor.
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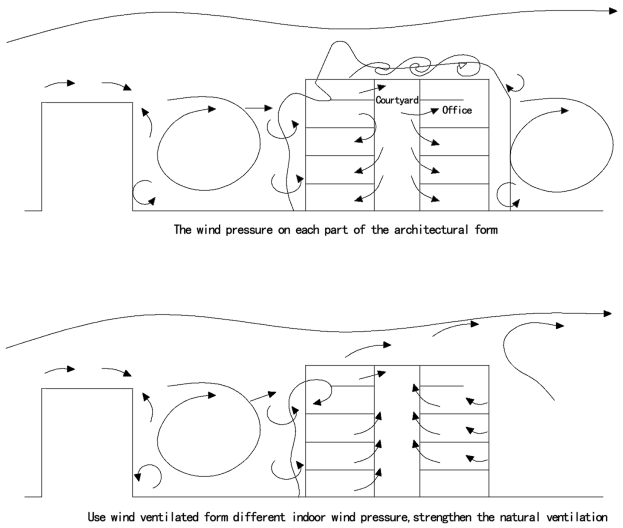

Fig. 2: The principle of wind pressure natural ventilation.

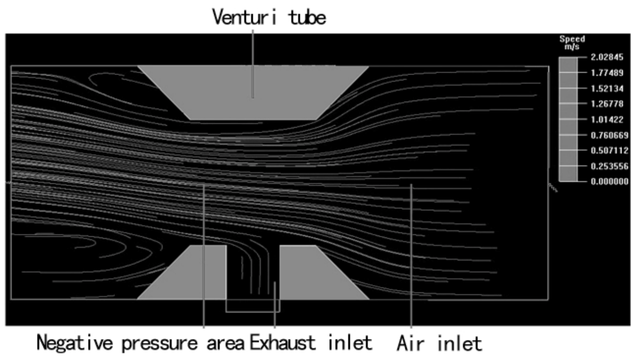

Fig. 3: Bernoulli effect.

is a classic work with combined use of wind pressure and thermal pressure (Fig. 7). Designers divided the huge building into many small units so that when they made the building harmonious with the surrounding environment it also had a certain sense of rhythm. At the same time smaller units also use the wind pressure to allow for natural ventilation (Tao 1988). As a result, the offices directly adopted the wind pressure ventilation. Because a relatively large amount of the lecture hall is located in the middle, architects specially designed the "chimney" to utilize the natural ventilation by thermal pressure.

The mechanical-assisted natural ventilation: The mechanical-assisted natural ventilation usually is applied in some public infrastructure buildings. The ventilation routes of these buildings are very long and the flow resistance is great. Only relying on the natural wind pressure and the thermal pressure it will not allow for natural ventilation. For some cities with serious air and noise pollution, direct natural ventilation will bring in the dirty air and noise, which is harmful to human health (Nathan & Menassa 2012). Under these circumstances, we often adopt the mechanical-assisted natural ventilation system. This system has an intact air circulation channel with ecological processes, such as soil precooling, preheating, deep well water heating and so on, as well as some mechanical systems to accelerate the indoor ventilation (Yang & Wang 2011).

THE LIMIT CONDITIONS IN THE SYSTEM DESIGN OF NATURAL VENTILATION

As a cost-efficient technology, the application of natural ventilation technology has been limited by many factors (Yang 2013a). For regions where the outdoor environmental temperature and humidity is mild, the application of this technology has been used for many years.

The limit of heat gain: The precondition to apply natural ventilation is that the outdoor temperature must be lower than the indoor temperature. With the indoor air ventilation, the outdoor low temperature air will be inhaled to reduce the indoor temperature. The greater the indoor temperature difference is, the better cooling effect the ventilation process will be. Regarding a general building which relies on the air-conditioning system for cooling, using the natural ventilation system can effectively reduce the air-conditioning operation load. For a typical example, an air-conditioning system continuously runs in the transitional seasons of new wind, whereas the effect of the building's use that depends entirely on natural ventilation for cooling is decided by many different factors (Yang 2010). Building heat gain is one of the most significant issues. The greater heat gain is, the less likely the possibility of using cooling to achieve the indoor comfort requirement is. Today, research results show that the indoor heat gain in the buildings, which entirely depend on natural ventilation for cooling, must not exceed 40W/m².

The requirements of building environment (Wu et al. 2010): After the application of the natural ventilation cooling measure, building indoor environment depends on the adjustment of outdoor environment to a great extent. In addition to the air temperature and humidity parameters, indoor air quality and noise control can also be damaged by outdoor environment. According to some present standards, the noise surrounding the building that adopts the natural ventilation should not be over 70dB (Lin et al. 1999). Especially, when the windows are open, the surrounding noise should not exceed 55dB. At the same time, the outdoor air quality used in the natural ventilation air inlet should meet the relevant hygienic requirements (Yang 2013b).

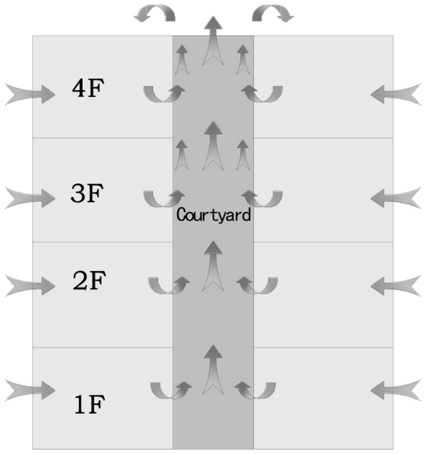

Fig. 4: The stack ventilation of buildings.

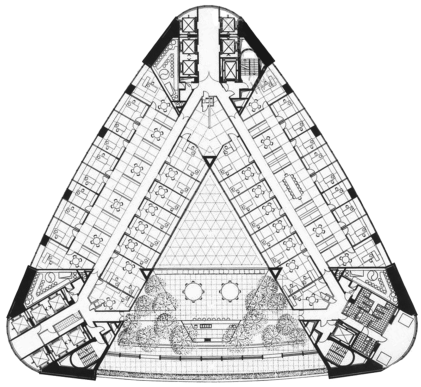

Fig. 5: The tower's standard layer plane.

The buildings that use natural ventilation should consider these two above requirements in order to utilize every advantage of natural ventilation (Fletcher et al. 2001).

The Limit of Building's Conditions

***The limit of building's position*:** In analyzing the building's location, it is important to note whether there are traffic arteries or a railway nearby. It is stated that the building should be 20 m away from a congested main traffic road to avoid the air pollution and noise disturbance. When designing the ventilation system, the areas close to the traffic arteries can serve as the exhaust side. The design of a natural ventilation

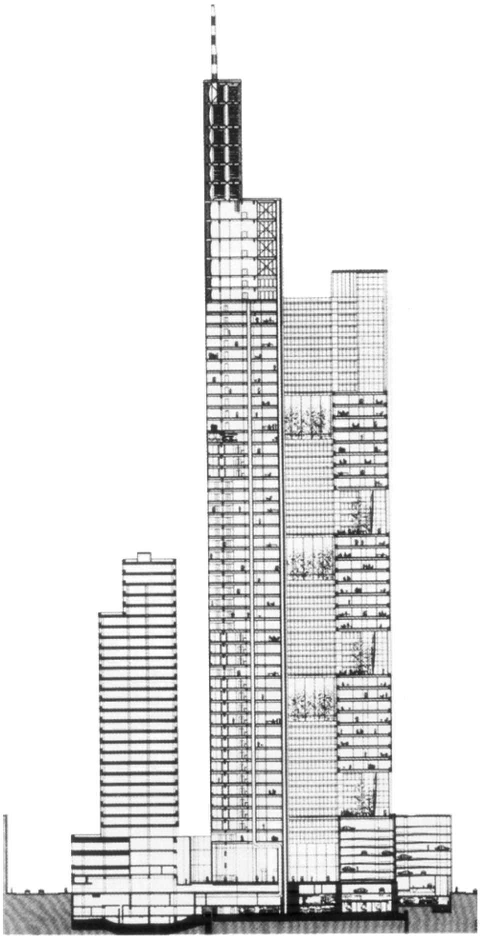

Fig. 6: The building's profile.

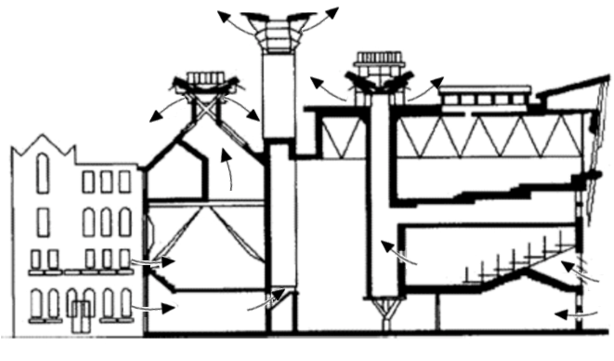

Fig. 7: Queen's Building of De Montfort University.

system can be determined according to the local dominant wind direction and the wind zone, especially whether the building is located in a downstream where polluted air accumulates (Peter & Gao 1998). Since the environment in a city and a village is different, the influence of a building's ventilation system also is different. Especially when considering the nearby construction or the barriers that will affect the wind direction surrounding the building, wind velocity, lighting and noise (Yang et al. 2014a).

***The limit of building's shape*:** A building's depth will directly affect the natural ventilation's form and effect. A building that has a depth less than 10 meters can employ the single side ventilation form. A building that has depth less than 15 meters can use the double sides ventilation form. Depth's larger than 15 meters will need other supporting measures, such as a chimney structure or the mixed mode of mechanical ventilation and natural ventilation. In terms of building's orientations, to make full use of wind pressure effectively, air inlets in the system should face the dominant wind direction. The building orientations are also used in the related process of reducing heat measures. First, when determining the selection of window size, the ratio of the exterior wall to windows, the air inlet side of the system should consider the control of natural lighting and sunlight heat, which always is 30% to 50% (Yang et al. 2014b). Secondly, for selection of the building structure, classifications include light, medium or heavy structure. For the medium or heavy structures, due to its large thermal inertia, it can combine with night ventilation technology to maintain an efficient natural circulation and reduce daytime tempuratures.

***The limit of building's indoor design*:** Buildings with tall story height use the indoor thermal load to form the compressed thermal pressure and strengthen the natural ventilation. The form of indoor division will directly influence the organization and aeration volume of the ventilation airflow. The vertical ventilation duct using the "chimney" effect can effectively organize the natural ventilation (Zhang 2006).

***The limit of the people indoor*:** The influence of indoor personnel density, equipments and lighting heat are important to identify. With regard to the building that has heat over 40w/m², we can set the ventilation system and mechanical refrigeration system in appropriate regions according to the kind of heat sources and dispositions in the building (Yang et al. 2014c). The working hours in the building will affect other assistive technology selection, such as the night ventilation system.

***The influence of outdoor air humidity*:** Using natural ventilation, has significant effects on reducing indoor temperature. However, it has little effect on adjusting or controlling indoor air humidity. Therefore, natural ventilation generally should not be used in humid regions.

CONCLUSION

With the improvement of human living standards and increase in urbanization, especially the standards of living conditions and the increasing requirement of thermal comfort in the living environment, air-conditioning energy consumption is increasing despite the total energy consumption or the proportion of building energy consumption. As a result, renewable energy is increasingly lacking and the environment issues are becoming more serious. Faced with these growing problems, natural ventilation, being the original measure depended on for a long time to adjust the indoor environment, is the best way to solve the problems that advanced technology has created. Sufficient natural ventilation not only can reduce indoor pollutants to create a clean and healthy indoor environment, but it also can take away unnecessary indoor heat to improve thermal comfort and human health. It can efficiently reduce the energy consumption of air-conditioning, carbon emissions to contribute to low-carbon energy saving strategies. Natural ventilation can be combined with various methods, such as the solar energy, natural lighting, underground heat and cold storage. Moreover, it also can use wind tunnel experiments and computer simulation technology to do in-depth research on ecological energy saving design from the quantitative dimension. As the importance of green, ecological and low-carbon environmental protection is more widely understood, buildings to allow for natural ventilation will become more essential as well.

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