

Design Study on Ventilation and Sun-shading System of the Ecological Reconstruction

of Guangzhou South logistics complex Building

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Abstract. This article is a design study on the ecological reconstruction of Guangzhou South logistics complex Building, on the basis of keeping the original architectural structure. Through the simulation of computer software and application of effective architectural approaches, this article puts forward a targeted and detailed design to solve the problem from two aspects of ventilation system and sun-shading system, achieving the purpose of reducing building energy consumption and improving indoor thermal comfort. In the meantime, the east and the south elevation design centering on ventilation and the west and the north elevation design focusing on sun-shading, together achieve a harmonious unification on the component and constitute an architectural elevation expression form featuring both energy saving and aesthetics.

Introduction

The hot summer and warm winter zone locates in the south part of China, where the average temperature of the normal hottest month ranges from 25°C to 29°C, and the number of days with daily average temperature greater than or equal to 25°C achieves 100 to 200 annually. As a result, the building in this region must fully meet the requirements for heat protection in summer, the key of which lies in the thermal insulation design of building enclosure. In Lingnan area, intense solar radiation and abundant natural rainfall synthetically form the environment of high temperature and high humidity, causing discomfort to people, which tends to be eliminated through means of sun-shading and ventilation. To add technical tools which adapt to climatic characteristic of southern areas into architectural design, not only can save energy and provide healthy, comfortable and safe space for residence, work and activities, but also express building's regional culture.

Overview of the Research Object

The research object is in Guangzhou, a city located at 112°57' to 114°03' east longitude, and 22°26' to 23°56' north latitude, with the Tropic of Cancer passing through its southern part. Situated in the hot summer and warm winter zone, Guangzhou lives long summers and short winters. On account of its high temperature and humidity all year round, energy conservation of air-conditioning becomes a key consideration; as to its intense solar radiation, building orientation and sun-shading remain another.

The research object is a complex building of commerce and trade in a logistics park of "Zhuangyuan Valley" in Huangpu District, Guangzhou. The building is a single building established during the second-phase expansion of the park, composed of two pieces of warehouse space and office area, covering a ground floor area of about 80000 square meters.(see Fig. 1) It is a 6-storey building without basement. From the first to the fourth floor, every storey contains a large warehouse area with large space, which adopts an integrated logistics management mode of transportation, storage, loading and unloading, handling, packaging, logistics processing, distribution and so on. The fifth and the sixth floor are office area with small space.

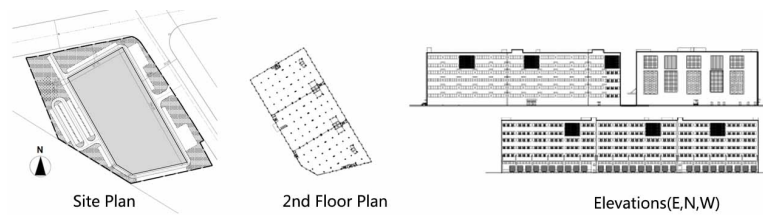


Fig. 1 Existing condition

This design focuses on the ecological reconstruction of the warehouse area. It is required to implement based on actual situation without changing original architectural structure. Our goal is to make an appropriate design taking into consideration the integrated use of climate adaptation theory, the climate characteristics of Lingnan area, the functions and features of logistics park construction, as well as the existing condition of the complex building of commerce and trade. [1]

Existing condition analysis and Strategies

Our design team analyzes the current warehouse situation of ventilation, day lighting and solar radiation through the use of software Ecotect and Fluent, and makes a summary with the SWOT analysis method. We attempt to put forward reasonable ventilation system and sun-shading systems for redesigning of the enclosure structure and use effective means of architectural design to realize energy conservation after the reconstruction.

Strengths. The south and the east elevations receive less solar radiation because of the mountains to the southeast of the building.

Weakness. The building orientation does not fit a standard south-north direction, which requires unconventional handling approaches. The west and the north elevations receive over-high solar radiation but no effective sun-shading measures are taken at present. Moreover, the architectural plan layout is to the disadvantage of ventilation in that the building spreads out along the east-west direction and is deeper in the south-north direction, so it is difficult to effectively guide the wind to the deep inside of the building from the south side. In the meantime, the mountains at the south block the wind from entering and affect its speed, resulting in a lack of ventilation inside the building.

Opportunities. Through the improvement of the building enclosure structure, a set of solutions to the existing problems of insufficient ventilation and high solar radiation can be built.

Threats. Coordination between different systems proves to be a threat. Solutions to different problems may be contradictory. Barrier is in favor of sun-shading but adverse to ventilation. The key is to achieve consistency.

Design Research on Ventilation System and Sun-shading System

Ventilation System Design

Fluent simulation analysis

The prevailing wind direction in Guangzhou is southeast wind, with an annual average speed of 1.9m/s. To the southeast of the building stands Longtou Mountain with an altitude of nearly 200 meters, and close to the south of the building is a hill 35 meters high. Since continuous mountains in the prevailing wind direction is likely to have influence on the direction and the speed of the wind blowing towards the building, the surrounding mountains are incorporated into the simulation analysis of the wind environment.

The initial wind speed is set as 2m/s, and the initial wind direction is southeast. It can be seen that the huge mountain in the southeast barely affects the wind from the east side, while the small hill on the south side directly affects the wind environment of the site. (see Fig. 2) On the warehouse layers, the wind speed on the east side is 1.8m/s and the south side 0.8m/s. With a lot of wind entering into the room in inclined direction from the east side, a large eddy is produced in the central part of the building, and the air intake on the south side is highly affected by the hill. (see Fig. 3)

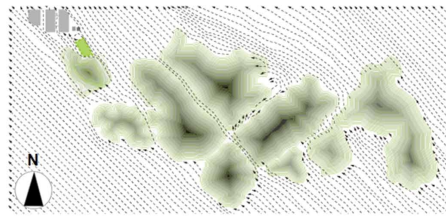


Fig.2 Wind environment influenced by the mountains

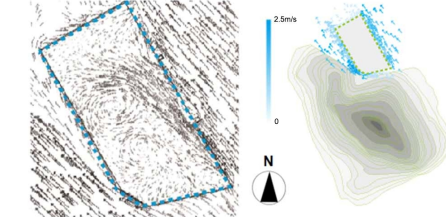
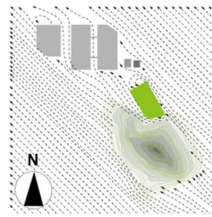


Fig.3 Warehouse layers

Ventilation strategies

The south and the east sides are air intake sides of the building. Because the south side is blocked by the hill, the air intake volume is decreased significantly and the wind speed is small. On the other hand, the angle between the east side and the wind direction is too small, and the wind path indoors is too long, so the intake air direction is adverse to ventilation. Considering the spatial depth of the building in the east-west direction is smaller, the key lies in the creation of the ventilation path from east to west. Based on these two reasons for insufficient ventilation, ventilation strategies for the warehouse layers are as follows: first to increase wind speed and then to guide the wind direction.

Wind speed increase. (see Fig. 4) The building's sharp corner at southeast greatly blocks wind, so there is a need to compensate wind volume at this place. Improvement measure is to make a concave corner processing on part of building volume to produce a trumpet shape to gather wind in the hope to achieve an ideal wind speed distribution map. The simulation shows that the indoor wind speed is significantly improved.

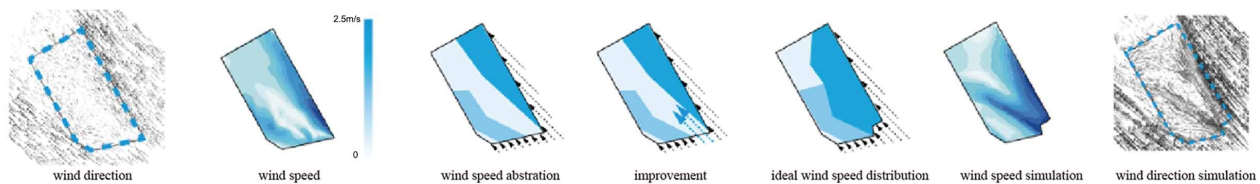


Fig.4 Wind speed increase

Wind direction guidance. When the wind runs through inside the building along the direction of shorter depth, the ventilation has the best effect. Thus, the hope is to convert the southeast wind which blows towards the east wall into the direction which is vertical to wall to enter the building. Based on this point, setting a wind deflector is taken into consideration.

Wind deflector design on east and south elevations

Two different forms of wind deflectors are set up beside the air vent: (A) (see Fig. 5) The wind deflector is perpendicular to the wall, which means that it is parallel to the induced wind, the wind enters the room along the wind deflector into the building [2]; (B) (see Fig. 6) The wind deflector leans towards the air vent with an angle, and assume the wind is induced into the room according to the reflection principle.

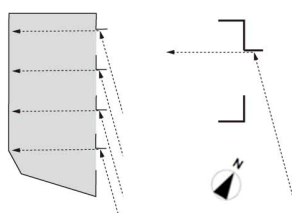


Fig. 5 Wind deflector (A)

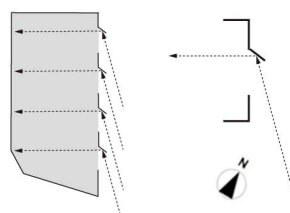


Fig. 6 Wind deflector (B)

By comparing simulation results under these two forms, it is told that form (A) has weaker effect on wind guide, but loss of wind volume is little (18% to 25%); Form (B) does greater work in guiding

wind, but has a large volume of wind loss, and the wind cannot move far indoors. After synthesizing the present indoor wind speed and direction distribution, it is suggested that wind deflector (A) is installed on the exterior wall of the region where the wind speed is high and the wind direction is not ideal, while wind deflector (B) is installed on the exterior wall of the region where the wind direction is ideal and the wind speed is low. As a result, the wind deflectors of different forms can function well according to the actual situations.

The position of windows is coordinated with the wind deflector. (see Fig. 7) Two wind deflectors are set up in in span of two columns and the length of the wind deflectors is defined by the wind direction. Vortex will form behind the wind deflector. By connecting two perpendicular boards, the loss of the wind to the wall is reduced. Meanwhile, each unit forms the shape of a trumpet .Several units act as a group, and two outer walls on the two sides extend outward, which form a bigger trumpet shape to gather wind (see Fig. 8), and creates the rich concavo-convex gradations on the elevations. (see Fig. 9)

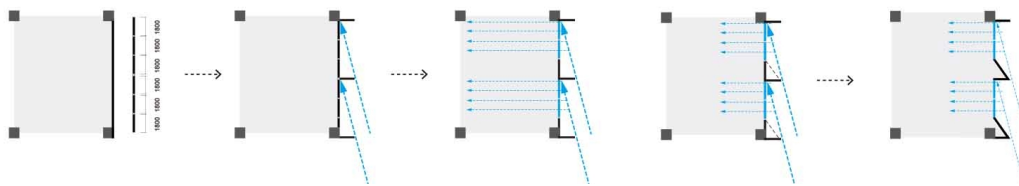


Fig. 7 Windows with the wind deflector

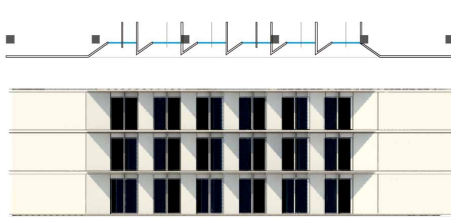


Fig. 8 Bigger trumpet shape

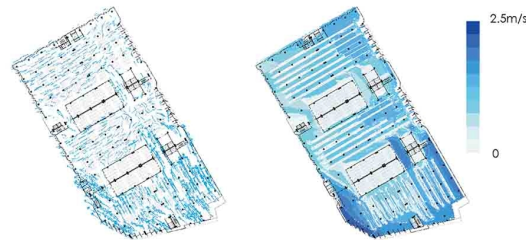


Fig.10 Design effect simulation



Fig. 9 South and east elevations

Design effect simulation

Due to the lack of ventilation, the concave corner is set up in order to increase the wind speed and wind deflectors are installed on east and south elevations to guide the wind. The ventilation effect is evaluated with the evaluation index. [3] The soft wind circumstance is not only helpful for the thermal dissipation of human body, but also can help to create delightedness and to improve work efficiency. The comfortable indoor air velocity is between 0.15 m/s to 0.5 m/s. When the temperature is above 26°C, with the compensation effect of wind on temperature, people can feel better. According to the research and the paper of Guangbei Tu from Tianjin University, every 10% increasing in relative humidity equals to 0.4°C increasing in room temperature. Therefore, the increasing of every 0.15 m/s in air velocity is equivalent to the decreasing of 0.55°C in temperature. [4,5]

The result of simulation shows that the air velocity indoor is uniformly distributed, and most of areas are within the air velocity interval zone which can make people comfortable. The wind direction meets the demands basically and the result is considerable. (see Fig. 10)

Sun-shading System Design

Ecotect Simulation Analysis

The solar radiation is relatively intense in Guangzhou during summer time, especially in July and August. Excessive solar radiation brings about high temperature, and people may feel stuffy and

uncomfortable indoors. Currently, general architecture adopts local daily average temperature over 29°C and solar radiation intensity over 280Wh/ m² as the required condition for setting up shading system. As the daily average temperature of Guangzhou is 31°C during the daytime in summer, it reaches the temperature requirement to set up sun-shading.[6]

Next, the solar radiation intensity on the Beginning of Summer and the Summer Solstice are chosen for simulation. (see Fig. 11,12) On the Beginning of Summer, the daily average temperature rises up to 22°C and over; and on the Summer Solstice, the received solar radiation is approximated to maximum during summer for the sun shines directly to the Tropic of Cancer. Considering that the Beginning of Summer and the Summer Solstice are respectively the first day and the climax of summer, therefore the solar radiation intensity of these two days can be used as a reference to determine the range of solar radiation intensity during summer.

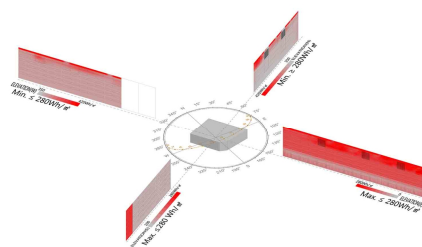


Fig. 11 The Beginning of Summer

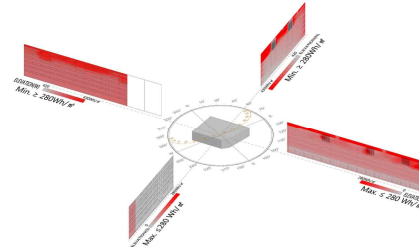


Fig. 12 The Summer Solstice

Table. 1 The solar radiation intensity of the four elevations on the Beginning of Summer and the Summer Solstice.

Elevation orientation	the Beginning of Summer Solar radiation intensity (Wh/ m ²)	the Summer Solstice Solar radiation intensity (Wh/ m ²)	Judgment
East elevation	Max.≤280	Max.≤280	Sun-shading not necessary
West elevation	Min.≥280	Min.≥280	Sun-shading necessary
South elevation	Max.≤280	Max.≤280	Sun-shading not necessary
North elevation	Min.≥280	Min.≥280	Sun-shading necessary

According to the conditions of sun-shading: (a) daily average temperature above 29 °C; (b) daily solar radiation intensity above 280 Wh/ m², we could draw the conclusion that sun-shading is necessary at west and north elevations. (see Table. 1) The solar radiation intensity at one elevation can change over time, and at the west elevation it reaches maximum during 14:00 to 17:00 .Therefore, the sun-shading targeting on this period of time is would be the most effective. (see Fig. 13, 14)

According to the research on the sun's trajectory, it is clear that if the sun-shading can block the sunlight at 14:00 on summer solstice and at 17:00 on August 31, the sun-shading system like this then covers the period from May 1 to August 31. In another word, it is able to cover the entire summer time. (see Fig. 15, 16)To observe solar altitude angle at the particular moments mentioned above, it is concluded that the scope of the incident angle of the sunlight in this period is from 22° to 63°. Accordingly, this range can be used to determine the form of the sun-shading components.

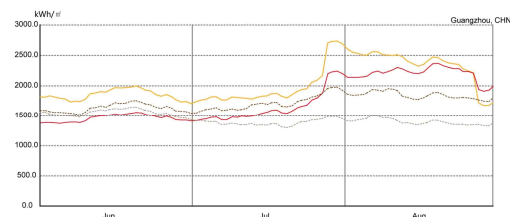


Fig. 13 Average solar radiation intensity

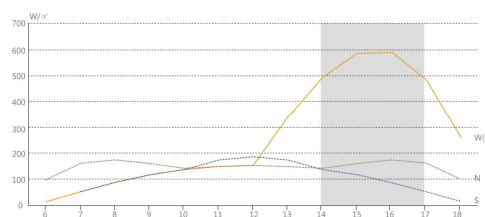


Fig.14 Solar radiation intensity change over time

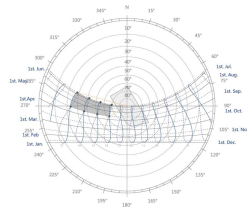


Fig. 15 The sun's trajectory

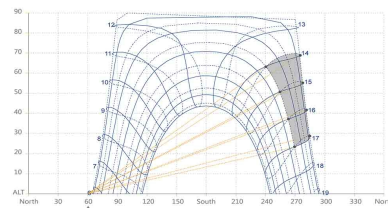


Fig. 16 Solar altitude angle

Sun-shading Form Selection

Since the light incident angle between 22° and 63° is relatively low, horizontal forms of sun-shading would require larger louver shading device, and the effects are neither ideal nor efficient. Vertical form of shading device can solve the problems in shorter length. As a result, vertical forms of shading components should be prioritized in usage for west and north elevation. (see Fig. 17) [7]

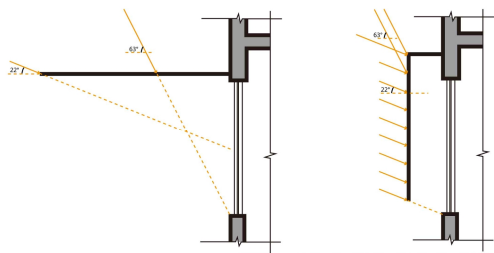


Fig. 17 Horizontal forms vs. vertical forms

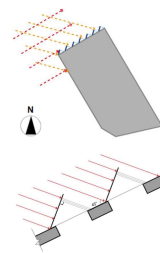


Fig. 18 Form (A)

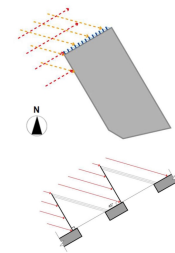


Fig. 19 Form (B)

Sun-shading Design on North Elevation

Form (A). (see Fig. 18) The baffle is perpendicular to the incident light and blocks the light directly. The window is set towards the north which ensures sufficient lighting. But the window area of effective lighting is relatively small.

Form (B). (see Fig. 19) The window is parallel to the incident light, which makes the effective area of the window on normal direction of the incident light is zero. It avoids the solar radiation from the west side, as well as enlarges the effective area of the lighting window and ensures a certain amount of lighting. It is adopted.

Sun-shading Design on West Elevation

Step.1 (see Fig. 20) Although the vertical baffle blocks the solar radiation from the west side, it also keeps out the light and the sight of people completely, as well as hinders the ventilation.

Step.2 (see Fig. 21) When rotating the baffle for some certain angle, it can precisely block the sunlight during the time mentioned above, and allow the light to enter the room during the rest of the time.

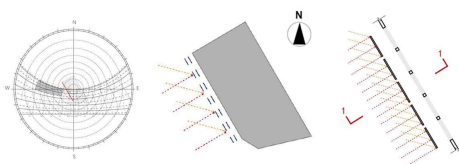


Fig. 20 Step.1

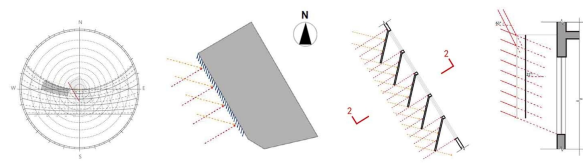


Fig. 21 Step.2

Step.3 (see Fig. 22) Because the west side is the air outlet side, the rotating direction is changed to adapt the east-west ventilation route. However, the sunlight that needs to be blocked will heat up the west side without any obstacles.

Step.4 (see Fig. 23) When the length and spacing of the horizontal sun-shading baffles reach the appropriate proportion, its effect is equivalent to the vertical sun-shading baffle. Therefore, the

horizontal form of shading is added in to form the final sun-shading component together with the vertical form of shading .[8,9]

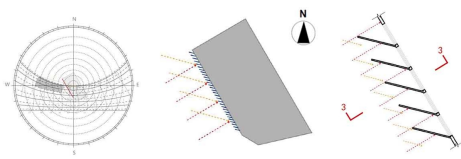


Fig. 22 Step.3

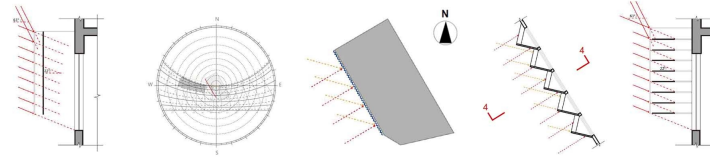


Fig. 23 Step.4

Generally, the sun-shading component has blocking effect to the ventilation, and they are in contradiction to each other to some extent. (see Fig. 24) As for this design, the ventilation system requires that the air passes in from the east and out from the west, so the sun-shading system on the west elevation should be able to block the sunlight while meeting the demands of ventilation. With the combination of both horizontal and vertical forms of sun-shading, the design requirements are satisfied.

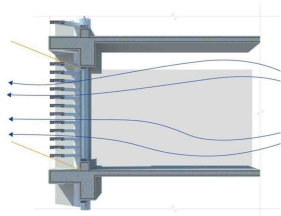


Fig. 24 Sun-shading components

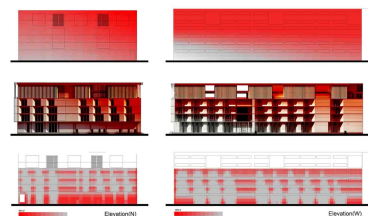


Fig. 25 Design Effect Simulation on north and west elevations

Design Effect Simulation

With the uneven distribution of the solar radiation intensity on the north and the west elevations, the design of the window is also uneven on these elevations. Fewer windows or even no windows are set where the solar radiation intensity is too high. Whether the windows are set or not has the same tendency with the change of the solar radiation intensity. According to the simulation, the sun radiation intensity of the shade area can all be lower than the standard of 280 Wh/m^2 with this sun-shading design, which is more ideal than before. (see Fig. 25)

Comprehensive Simulation Analysis on Ventilation and Shading Systems

We selected points at the space in the fourth floor by using DEST-C software simulation to measure the design's effect on indoor temperature and air-conditioning energy consumption under the circumstance that the temperature changes through the day. Also, with the comparison of the analysis results before and after the improvement, the effectiveness of the sun-shading and ventilation components adopted can be verified.

a.the peak temperatures of multiple dates in every month in summer and autumn. (see Fig. 26)

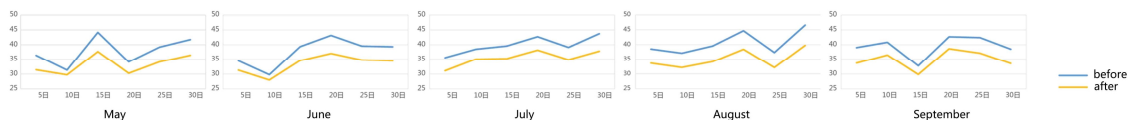


Fig. 26 The comparison of the analysis results before and after the improvement

b. Number of hours that temperatures exceed 30°C and the accumulative temperature over 30°C in every month in summer and autumn. The hours of indoor temperature that makes people uncomfortable are over 600 less than the one before the improvement. (see Fig. 27) The improvement project reduces the number of hours that temperatures exceed 30°C to 67% of the original. (see Fig. 28)



Fig.27



Fig.28



Fig.29



Fig.30

c. Building Energy Consumption Simulation. According to the annual maximum cooling load index (kW/m^2)(see Fig.29) and the annual accumulative cooling load index(kW/m^2)(see Fig. 30), the Energy Consumption is only 76% of the original one after the improvement.

Based on the above analysis, after adding the components of wind deflector, horizontal sun-shading board, vertical sun-shading board, etc., to the original project design, the indoor temperature can be reduced by 5°C effectively, which improves the indoor thermal comfort greatly, and save approximate 23% in energy consumption. For the buildings hot summer and warm winter zone, the adoption of ventilation and sun-shading measures can lower the indoor temperature during summer and reduce the energy consumption of the air conditioning refrigeration effectively.

Conclusions

The measures of the ventilation and sun-shading are varied. For buildings with different locations, orientations, volumes, layouts and functions, there is no one scheme that can be used universally. The ecological rebuilt of the existing building should be based on the existing condition and detailed analysis, as to apply ventilation and sun-shading theory into practice. The design of the ventilation and sun-shading system is a crucial part of the architectural design, which has the very positive effect on reducing the energy consumption of the building and improving indoor thermal comfort. The concept of being green and ecological should penetrate into architecture design from the start till the end. With the appropriate forms of air-inducing and sun-shading, as well as the coordinated processing of the sun-shading board and the wind deflector, the sun-shading board will not have hindering effect on the ventilation, but will have certain inducing function. In this project, the air-inducing components on the east and south elevations of the ventilation system and the sun-shading components on the west and north elevations of the sun-shading system are the design results under the comprehensive consideration. The components design of the four elevations is concise, clear and feasible. It seeks variation within the unification, and creates attractive architecture elevations and the rich effect of light and shadow.

References

- [1] In Chinese. Yaofei Shen. Analysis on ventilation design of industrial workshops [J]. Shanxi Architecture. 2013(4)
- [2] In Chinese. Wu Xiangyang. KEN YEANG. China Building Industry Press. 2007.
- [3] In Chinese. Chunmei Guo, Yufeng Zhang, Shengying Li. Thermal comfort evaluation and analysis of natural ventilation environment. [J] Heating Ventilating & Air Conditioning, 2010(10)
- [4] Richard Aynsley. Estimating summer wind driven natural ventilation potential for indoor thermal comfort. Journal of Wind Engineering and Industrial Aerodynamics. 1999.83.
- [5] In Chinese. Yunzhe Ji, Guang bei TU. The research on air velocity affecting thermal comfort of human body. Journal of Lanzhou University. 2003,39(2)
- [6] Thermal design code for civil building GB50176-93
- [7] Xiaotu Liu. Architectural physics. Beijing: China Building Industry Press. 2000.
- [8] In Chinese. Cunde Ji, Ruizhen Hao, Min Chang. Research on sun-shading design of building in regions of being hot in summer and warm in winter. [J] Industrial Construction. 2007 (02)
- [9] In Chinese. Yongming Chen. The research on integrated design of exterior shading and building in hot summer and warm winter areas. [D] Faculty of architecture and urban planning of Chongqing University. June. 2014.