Study on optimal design of airport control hall ventilation environment based on butterfly software—Taking the design of Sining air traffic control support building as an example

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Abstract. Airport control hall is the key organization of air traffic control system, mainly used to manage various flight activities of the airport. The control hall contains numerous control seats and control personnel. It is particularly important to create a comfortable indoor environment for the control personnel in a high-intensity working environment. But due to the current design code and standard lack for airport control hall and affiliated offices of the requirements of the physical environment, designers often excessive attention to functional requirements in the design and the facade, while ignoring the control hall indoor environment requirement, so the chaos such as plane layout, facade window problems such as unreasonable. As a result, natural ventilation is not smooth, air conditioning energy consumption increases, and indoor comfort is seriously affected. Sining AIR traffic control Support Building is one of the three major air traffic control projects in northwest China during the 13th Five-Year Plan period. In the preliminary design process of the scheme, the design team used Butterfly tool based on Grasshopper software to conduct computer simulation analysis on the natural ventilation condition of the scheme, comb out the optimization design method and conduct comparative verification. Improve indoor comfort, reduce building energy consumption, and finally summarize the air traffic control hall design strategy adapted to Sining's unique natural environment, which provides reference for other air traffic control support building projects in northwest China.

1. Background

It is now recognised that construction, industry and transportation are called the three major areas of energy consumption. Today, the use of mechanical ventilation by users to meet the comfort of the indoor environment results in a large consumption of non-renewable energy. The green buildings design is a global environmental demand that cannot be ignored.

It is different from the general office building in that the control hall is a overall height space with 24 hours of uninterrupted operation. Its control equipment needs a low temperature environment, and the operator needs a normal comfort temperature. The indoor environment of most existing control halls is satisfied by the air-conditioning system. At present, most of the relevant researches on control halls are mechanical design studies for HVAC, and there is a lack of design requirements for the physical environment of airport control halls and their affiliated offices. An example of the Chengdu Shuangliu Airport Control Center. Through calculation, the total cooling load of the air conditioner in the summer is 927 kw; the heating load of the air conditioner in winter is 443 kw¹. It can be seen that using the air-conditioning system does not meet the requirements of contemporary green buildings, and is also not conducive to the health of control personnel.

It is sufficient to illustrate that the control hall is special and that its energy consumption is greater than that of an ordinary office building. Controllers also work well above average. Therefore, it is very important to consider the design strategy when designing the scheme. In view of the current situation, a questionnaire was designed for the control personnel. For the new control hall in the future, and the results were obtained that: The existing control hall is cooled by air conditioners from May to October, and heated by air conditioners from October to April of the following year. The indoor ventilation method is a combination of natural ventilation and air-conditioning, but the existing ventilation method cannot meet the health needs of the control personnel. 89.47% of users indicated that the ventilation is poor and the number of windows is insufficient. For the new control hall in the future, 84.21% of the users believe that ventilation is the primary factor in the design.

This paper uses the climate adaptation method². Firstly, the corresponding thermal comfort temperature range is obtained according to the thermal comfort requirements of the people in the room, and then the natural ventilation meteorological data is obtained, which corresponds to the indoor thermal comfort. Finally, these parameters are analyzed using Grasshopper's wind simulation plugin - Butterfly.

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2 Analysis of wind environment potential

This paper selects the hourly meteorological data (Chinese Standard Weather Data) jointly developed by Tsinghua University and the Meteorological Data Office of China Meteorological Information Center. According to the typical weather year data of Sining, the meteorological conditions of Sining City are calculated (Fig.1).

![Fig. 1. Sining temperature & wind speed (Jan. to Dec).](image)

Sining is located between the river valleys of the Qinghai-Tibet Plateau, and belongs to the semi-arid climate of the continental plateau. Sining Caojiabao International Airport is located in Haidong Tu Autonomous County, southeast of Sining City, Qinghai Province, China, 28 kilometers away from the city center of Sining. The airport is close to the Huangshui River and has a good ecological environment. The Air Traffic Control Support Building is located at the core of the construction of the third-phase expansion air traffic control project of Airport (Fig.2). The control hall is located on the top floor of the building. The south and southeast sides of the building are the internal traffic roads of the airport, and the north side is the warehouse, the terminal building and the aircraft flight area. The overall environment is not blocked by tall buildings. From the figure, the average temperature in summer is 15-19°C, and the maximum temperature is below 25°C. It can be seen that if the outdoor natural wind can be reasonably utilized in summer, the purpose of indoor ventilation and cooling can be achieved.

Fig. 2. Sining airport general layout

3 Boundary condition setting

From D.K. Fidaros and et al. results, it can be concluded that the consideration of external temperature variation is very important since the internal thermal field of indoor zones is determined by the convection induced from the outdoor environment. Therefore, according to indoor thermal environment comfort standards of China, the conditions for engaging in activities mainly in sitting positions are: a) the working temperature should be between 22°C and 28°C; b) the relative humidity should be between 30% and 70%. The minimum outdoor temperature for natural ventilation set according to the code is 12°C. It is more reasonable to choose natural ventilation from May to September.

Referring to Chengdu Shuangliu Airport, if calculated according to the maximum heat dissipation of seat equipment at full load and the required mechanical supply air temperature, the average temperature increase of the equipment in the control hall is 8-12°C. In this simulation, the maximum temperature increase for heat dissipation of the equipment is set to 12°C. The control hall of Sining Airport is affected by the heating of the equipment. The average temperature in the indoor control hall during the day from May to September is as follows (Table 1):

|                | May | Jun. | Jul. | Aug. | Sept. |
|----------------|-----|------|------|------|-------|
| Outdoor(°C)    | 14.1| 16.8 | 18.7 | 19.5 | 17.2  |
| Indoor(°C)     | 26.1| 28.8 | 30.7 | 31.5 | 29.2  |

It is sufficient to show that in order to meet the indoor comfortable temperature requirements, the control hall can rely on natural ventilation to eliminate indoor residual heat from June to September, without the use of mechanical ventilation or air conditioning. Effective ventilation strategies can provide reference for the natural ventilation design of Sining Control Hall.

![Table 2. Somatosensory temperature and wind speed.](image)

From A. Stamou results, the SST k–ω based model is applied to calculate air-flow velocities and temperatures in a model office room, which shows that they are correlated. Referring to the thermal comfort requirements of the people in the room, according to the human comfort index formula, the corresponding data of somatosensory temperature and wind speed are calculated (Table 2). The thermal comfort temperature
range required by the human body in summer is 22°C to 28°C, and the corresponding indoor wind speed is 0.87 m/s to 2.9 m/s.

4 Ventilation simulation of the original design scheme

4.1 Layout Difference Model Comparison

Set the outdoor ventilation simulation value, when the southeast wind speed is 2.2 m/s. Based on this, a difference model is established, and the different positions of the control hall in the control and security building are used as control variables for indoor ventilation, so a variety of indoor ventilation schemes are obtained, which are used as case samples for simulation calculation. We compared and analyzed the indoor wind environment factors such as wind speed, wind pressure, and quiet wind area of the indoor wind environment in different locations, and obtained the position that is conducive to the indoor natural ventilation of the control hall. According to the actual research and use requirements, and considering the different postures of the personnel in the control room, 0.7m-1.8m is selected as the effective observation height range. The environment at a height of 1.5m is set as the average wind speed calculation value, and the doors and windows are all in the maximum open state. The simulation results of 6 typical location data are selected for analysis.

(Table 3).

| Point a (m/s) | SW | NW | SE | NE |
|--------------|----|----|----|----|
| Point b (m/s) | 0.1 | 0.3 | 0.3 | 0.3 |
| Point c (m/s) | 0.3 | 0.1 | 0.3 | 0.8 |
| Point d (m/s) | 0.2 | 0 | 0.9 | 1.5 |
| Point e (m/s) | 0.1 | 0 | 0.9 | 0.8 |
| Point f (m/s) | 0.3 | 0.5 | 2.0 | 1.5 |

When the control hall is located in the southwest or northwest part of the fifth floor (Fig.3&Fig.4), the indoor ventilation effect is not ideal and cannot meet the requirements of indoor air environment; When the hall is located in the southeast (Fig.5), which is the windward corner of the whole building. The indoor wind environment can basically meet the needs, but due to the hall needs to avoid direct sunlight from the south. Therefore, the hall is not suitable to be located on the south part of the building. When the hall is located in the northeast (Fig.6). The indoor air environment is relatively uniform. Compared with other schemes, passive ventilation strategies are more suitable to meet the thermal comfort requirements in the control hall.

To sum up, according to the layout difference model of the control hall, the most reasonable ventilation scheme is obtained for the control hall to be located in the northeast of the fourth floor of the control and security building. And use it as a case sample for further simulation calculation.

4.2 Simulation analysis of interior design scheme

The control hall is a large space connected with the fifth and sixth floors. The current design has windows on the east, west and north facades and two locker rooms are designed in the north to meet the needs of personnel. The main entrance to the room is on the south, connected to the corridor. By selecting the wind environment data of six typical indoor locations at different elevations, the obtained simulation results are analyzed. The following figures respectively convey the indoor ventilation conditions of different elevations in the control hall (Table 4):

Table 4. Indoor ventilation of different elevations.

|        | before | after |
|--------|--------|-------|
| Point a (m/s) | 0.6 | 0.3 |
| Point b (m/s) | 0.3 | 0.3 |
| Point c (m/s) | 0.6 | 1 |
| Point d (m/s) | 0.1 | 1.5 |
| Point e (m/s) | 0.2 | 1.5 |
| Point f (m/s) | 0.6 | 1.5 |

When indoor elevation of 0.9m or 2.4m (Fig.8&Fig.9). The continuity of the east-west wind environment is weak. The fact that the dressing room is located on the north side affects the ventilation effect of the north side windows; When indoor elevation of 6.0m (1.5m elevation of the 6th floor) (Fig.10). Since only the north facade of the six floors has openable windows, the continuity of the wind environment on the upper floors of the space is weak.

It can be seen from the wind environment profile that there is an obvious wind pressure difference between the east and west sides of the control hall. However, the interior mainly relies on the east window to promote natural ventilation (Figure 11), and it is
difficult to form air convection. The wind from the north and south is blocked by the locker room as it passes through the interior of the hall (Figure 12). The existing window opening situation does not meet the demand.

![Wind speed in east-west section](image1)

![Wind speed of north-south section](image2)

**5 Simulation Analysis of Ventilation Optimization Strategy**

The Rotunda of the New National Museum of Korea is a overall height space.In order to improve thermal comfort in the Rotunda, eight ventilation fans were installed near the ceiling of Rotunda. Through numerical simulation analysis, the results show that in the case without fans, thermal stratification with 16°C of temperature difference occurs along the height of the Rotunda .In the case with fans, However, the vertical temperature difference were reduced to 9°C. Consequently, the use of stratified ventilation in the overall height space that is prone to thermal stratification can effectively improve the thermal comfort of the large space structure.

![Design improvement strategies](image3)

![1.5m elevation](image4)

![6.0m elevation](image5)

By analyzing the simulation results of indoor wind environment data at different elevations, the following design optimization strategies are proposed for the existing control hall design scheme (Fig.13):

1. In order to promote east-west air convection in the control hall, window holes are added in layers at the same heights as the east and west facades.
2. In order to promote the north-south air convection of the hall, high windows are added to the south facade.
3. In order to reduce the obstruction to the airflow, the dressing room is designed at the inner corner of the room.

The optimized wind environment is (Table 4): when the wind environment of the control hall is at an elevation of 1.5m (Fig.14), the indoor thermal comfort meets the requirements. When the elevation of the indoor control hall is 6.0m (the elevation of the 6th floor is 1.5m) (Fig. 15), the indoor air environment is uniform.

**6 Conclusion**

In this paper, a difference model is established based on the simulated values of the outdoor ventilation environment. The deficiencies were optimized by comparing various ventilation design options for the control hall. Compared with the original plan, the optimized plan can make more reasonable use of outdoor natural wind from May to September. It achieves the purpose of ventilation and cooling, reducing energy consumption and improving indoor thermal comfort. Summarizing the design strategy of control halls in Sining and Northwest similar climate zones: the layout of the halls is as close as possible to the upwind direction of the current season. The layered design ventilation windows can take advantage of the ventilation of the hall to take away the indoor heat. The number of indoor partitions is reduced to ensure the smoothness of the room, etc. Therefore, the sustainable development of a modern large-scale air traffic control center can only be achieved by selecting a reasonable design scheme appropriately according to the particularity of the project, and continuously optimizing the scheme to improve the design quality in the process.

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