

Design of a Natural Ventilation System in the Dunhuang Museum

Yali Zhang, Wenji Guan,
 Engineer, Director (senior engineer),
 China Architecture Design & Research Group
 Beijing China
 Zhangyl @cadg.cn

Abstract: Fresh air and good air quality can be obtained by a natural ventilation system, to fulfill the requirement of near natural conditions for the psychological health of mankind. A natural ventilation system is an ecological, energy saving system that also meets architectural standards. Natural ventilation design methods are presented in this paper. A natural ventilation system is designed in the DunHuang museum. Thermal dynamic simulation and CFD simulation were analyzed in the exhibition hall. The results show that, for the exhibition hall, indoor temperature can fulfill the occupant thermal comfort requirements through natural ventilation in transition season and in summer.

Key words: natural ventilation; thermal buoyancy; wind forces; dynamic simulation; CFD simulation

1. INTRODUCTION

Indoor thermal condition is unchangeable completely depended on traditional air conditioning system. Adapted abilities of occupants with different climates will be decreased. While natural ventilation being passive cooling can provide fresh air and good air quality. Natural ventilation is one of the widely adopted techniques in ecology oriented architecture.

2. NATURAL VENTILATION APPLICATIONS IN BUILDINGS

A large number of governing factors affect natural ventilation of buildings, such as weather condition on site, building structure, the heat sources, the envelope conductance, solar radiation and so on. Thus natural ventilation design is integrated with weather, environment and building.

Natural ventilation has practical applications in multistoried and high rise buildings, such as thermal workshop, laboratory, office building and school building.

3. NATURAL VENTILATION DESIGN

3.1 Confirm the potential of natural ventilation

Before design, hourly weather parameters should be collected, such as wind speed, wind direction, outdoor temperature, humidity, solar radiation and so on.

3.2 Confirm the natural ventilation design method

(1) Ventilation by windows

Ventilation by windows is widely used, window mode, window size and installing location affect the efficiency of ventilation^[1].

(2) Double-skin façade

There are air spaces inside double-skin façade, like “breath facade”. The air inlet and outlet are switched on and off depended on outside temperature differences. In winter, the surface façade temperature is improved based on greenhouse effect; In summer, thermal buoyancy drives natural ventilation of building like chimney effect^{[2][3]}.

(3) Building characteristic optimizations

Building orientation, form of air inlet and ventilation route are important parameters affecting thermal conditions of building. Wind speed is changing frequently for different orientation, thus in order to use wind forces, air openings are need to install at different orientation. Another ventilation way is to utilize thermal buoyancy forces from shafts in atrium or stair well.

4. PROJECT EXAMPLE

4.1 Project general situation

Dun Huang museum is located at Dun Huang the province of Gan Su. The main building is exhibition hall, assistant buildings are cultural relic storerooms, office and manage rooms. The whole building area is 7400m², the height of building is 23.8m.

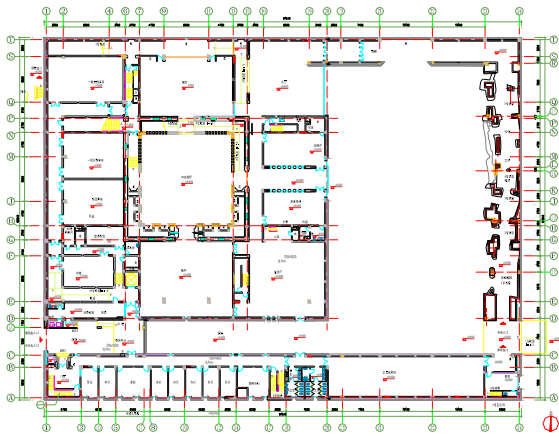


Fig.1 The plan drawing of DunHuang museu

The plan drawing is shown in Fig. 1.

4.2 Ventilation simulation

(1) Indoor and outdoor design conditions in summer:

Outdoor design conditions:

Outdoor design dry-bulb temperature for air conditioning: 34.1°C;

Outdoor design wet-bulb temperature for air conditioning: 20°C;

Outdoor design temperature for ventilation: 30°C;

Average daily range: 11.9°C; Outdoor mean wind speed: 2.2m/s;

Outdoor dominant wind direction: ENE.

Indoor design conditions of exhibition hall:

Indoor temperature: 26~29°C; Relative humidity: 40~50%; Indoor noise:<50dB(A).

Building envelope:

Wall: double skin wall, outside is concrete slab whose thickness is 120mm, middle side is poly-benzene heat preservation layer, interior side

is clay air brick, heat transfer coefficient is 0.43W/m²·°C.

Window: alloy aluminium window interior shading device with low-e properties, heat transfer coefficient is 2.0 W/m²·°C.

Roof: 120mm concrete slab, outside is 80mm polyurethane heat preservation layer, heat transfer coefficient is 0.30W/m²·°C.

(2) Dynamic simulation for natural ventilation

Through-flow is difficult to design, because outdoor mean wind speed is lower in Dun Huang and without fixed wind direction. Thus natural ventilation is considered mostly by thermal buoyancy, assistant by wind forces.

Natural ventilation simulation is calculated for 1.00 level exhibition hall (as shown in Fig.2 and Fig. 3). Indoor air is fully cooling by intermittent ventilation. Intermittent ventilation means enhanced ventilation flow rate when outside temperature is lower than indoor temperature, while lower the ventilation flow rate only to ensure hygienic require for occupants when outside temperature is higher.

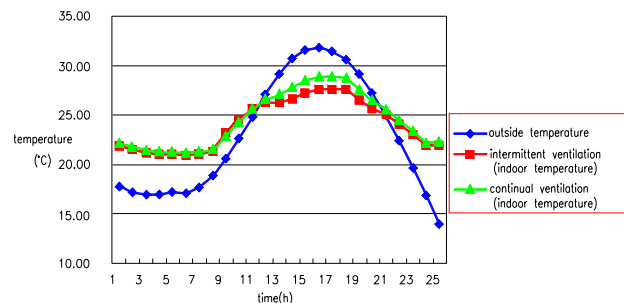


Fig.2 Temperature simulation curve with intermittent ventilation and continual ventilation in July

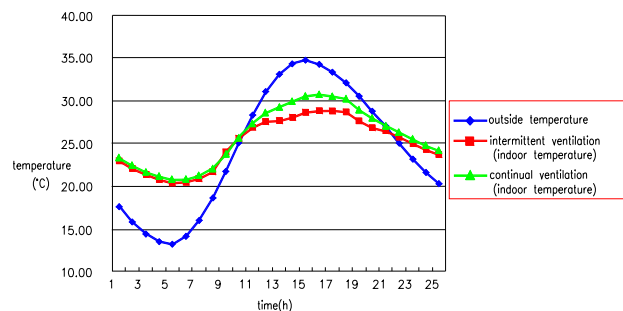


Fig.3 Temperature simulation curve with intermittent ventilation and continual ventilation in August

Thermal properties of roof are important factors influence on indoor thermal conditions. Thermal dynamic calculation is shown in Fig. 4. one roof is 80mm poly-urethane slab heat preservation, heat resistance is $3.3 \text{ m}^2 \cdot \text{ }^\circ\text{C/W}$. Another roof is 120mm cellular concrete, heat resistance is $1.074 \text{ m}^2 \cdot \text{ }^\circ\text{C/W}$. As the result shown, the higher the heat resistance, the more thermal comfort.

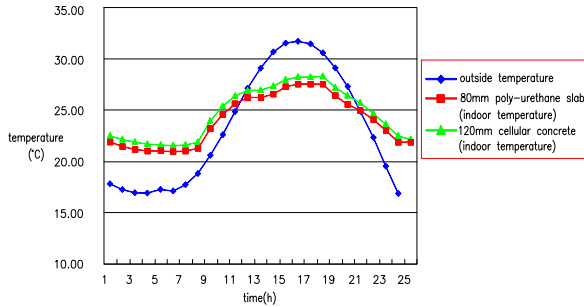


Fig.4 Temperature simulation curve with different preservation roof

Indoor thermal comfort will be sufficient based on good properties of envelope and reasonable ventilation mode. Take the south exhibition hall (the height 6.5m) for example, CFD simulation is shown in Fig. 5 and Fig.6. Indoor excess heat is exhausted by natural ventilation. Indoor air temperature is stratification by natural ventilation, temperature is lower in occupant activity zone, while higher temperature is centralized at the upper hall.

(3) Natural ventilation design

The calculation of natural ventilation is considered mostly by thermal buoyancy, assistant by wind forces.

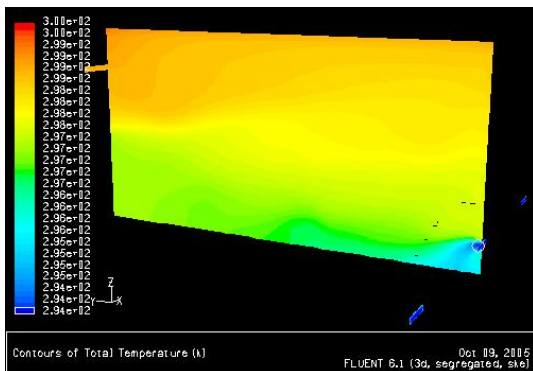


Fig.5 CFD simulation of temperature by the south exhibition hall

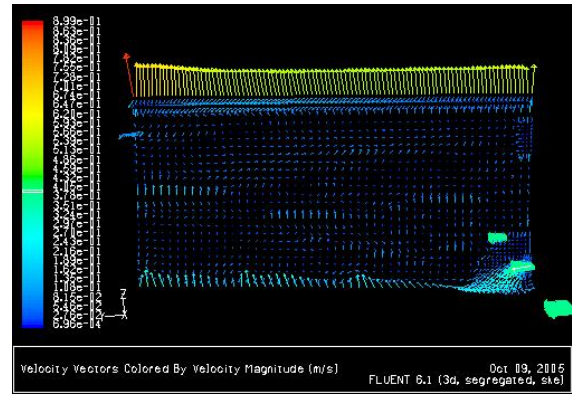


Fig.6 CFD simulation of velocity by the south exhibition hall

$$(1) L = \mu F \sqrt{\frac{2\Delta p}{\rho}}$$

- L : volumetric flow rate (m^3/s);
- μ : air flow coefficient by opening;
- Δp : pressure difference by opening (Pa);
- ρ : air density of outdoor (kg/m^3);
- F : area of opening (m^2)

$$(2) \Delta p_b = \Delta p_a + gh(\rho_w - \rho_n)$$

- Δp_a : pressure difference by the top opening (Pa);
- Δp_b : pressure difference by the bottom opening (Pa);
- g : acceleration of gravity (m/s^2);
- h : height between two openings (m);
- ρ_w : air density of outdoor (kg/m^3);
- ρ_n : air density of indoor (kg/m^3)

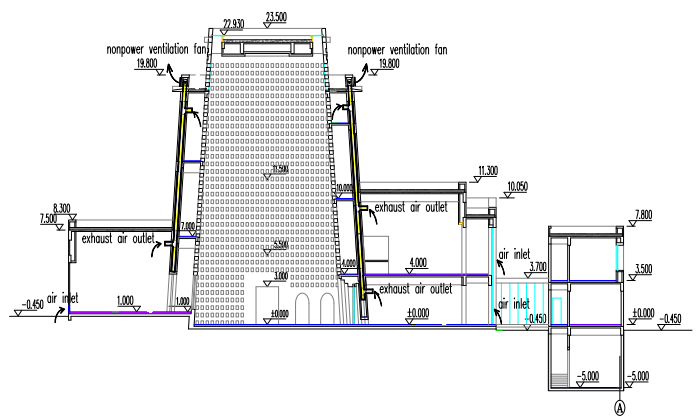


Fig.7 System plan of ventilation with exhibition hall

For fully taking use of natural ventilation, the

right openings are need to install at envelope. Based on the present architecture mode, air openings are directly installed at wall. In order to fully utilize thermal buoyancy, the level of air openings are lower (mostly 500mm above the indoor floor). Air openings are installed at dominant wind direction of summer (ENE) as far as possible, and avoid the dominant wind direction of winter (WSW). Air openings of exhibition hall are slotted louvers which reduced the solar radiation from directly opening windows. 8 exhaust air shafts are installed at air spaces between double-skin walls of central hall. Natural ventilation system planning is shown in Fig.7.

Exhaust air design for natural ventilation have two solutions. The first is solar chimney assisted wind tower system for natural ventilation. Thesecond is using nonpower ventilation fan for natural ventilation. For fully satisfied with the architectural façade, the second solution is adopted.

5.CONCLUSIONS

Natural ventilation system is energy saving system and also improves indoor thermal comfort. Accurate calculation of natural ventilation at design stage is often difficult. Natural ventilation design for Dun Huang museum is presented at detail. Indoor temperature can meet the demand of thermal comfort requirement by natural ventilation based on thermal dynamic simulation and CFD simulation.

REFERENCES

- [1] Heiselberg Per. Characteristics of airflow from open windows. *Building and Environment*, 2001,36:859-869.
- [2] Hensen Jan. Modeling and simulation of double-skin façade system. <http://www.bwk.tue.nl/fago/hensen>.
- [3] Croxford Ben. Ventilation of double façade. <http://www.hvac.okstate.edu/pdfs>.