

Comparison on Energy Consumption of Large Space with Sidewall Opening and Top Opening

Xin Wang¹, Chen Huang¹

¹ School of thermal energy engineering, Shandong University of Architecture and Engineering

² College of urban construction and environmental engineering, University of Shanghai for Science and Technology

Abstract: With the study results based on numerical simulation and site measurements, the paper simulates a series of thermal environment conditions in a large space of stratified air conditioning varied with different height of nozzle and upper openings, area of upper and bottom openings, inflow velocity through the upper openings with sidewall opening and top opening respectively. And the paper investigates the energy consumption in large space. In any case, upper opening is advantageous to improve the indoor air quality. Top opening is superior to sidewall opening in getting a better temperature field and airflow distribution. And it is seen that the cooling load in the case of sidewall opening is larger than that of top opening. The results of this paper are important to engineering and air-conditioning design. It will provide the theoretical foundation and design basis for structure design.

Keywords: Sidewall opening, Top opening, Energy consumption, Large space

1. INTRODUCTION

Generally, there are two primary forms of upper opening of a large space: sidewall opening and top opening for ventilation, daylight, structure and so on. When planning the thermal environment of an air-conditioning system for a large space, it is important to analyze the usage of upper opening in a effective and reasonable way for energy-saving. Since indoor air quality and energy consumption vary with different upper opening sizes and locations, the effect of upper-opening sizes and locations on thermal environment and energy consumption must be analyzed.

With this in mind, the authors takes the Shanghai

International Gymnastics Stadium as the study object for investigating the indoor thermal environment and energy consumption in this large space of stratified air-conditioning with sidewall opening in summer using site-measurement and predicting the temperature distribution and air-flow field of the large space with sidewall opening and top opening in summer using CFD technique. The cooling load differences are discussed in the paper based on two kinds of upper opening difference, air-conditioning running parameters difference and structure parameters difference respectively.

2. CFD METHOD AND RESULTS

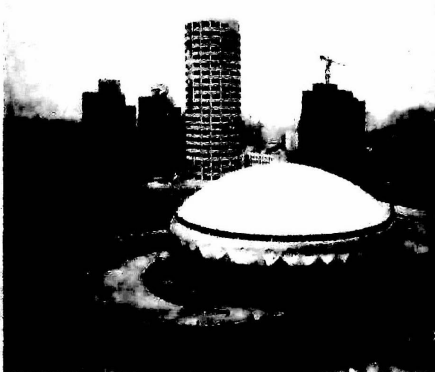
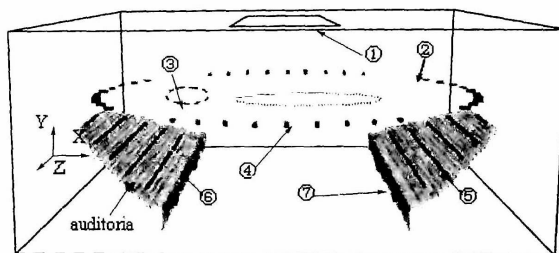


Fig1.(a) A bird's eye

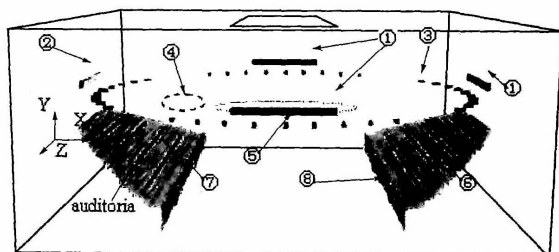


Fig1.(b) indoor scene



1. upper-opening(outflow) 2. nozzle(short) ϕ 550 2 $\times$ 10 3. nozzle(short) ϕ 550 2 $\times$ 4
4. nozzle(long) ϕ 550 2 $\times$ 5 5. return air 6. return air 7. bottom-opening(4 $\times$ F)

Fig2. CFD model with top opening



1. upper-opening(outflow) 2. upper-opening(inflow) 3. nozzle(short) ϕ 550 2 $\times$ 10
4. nozzle(short) ϕ 550 2 $\times$ 4 5. nozzle(long) ϕ 550 2 $\times$ 5 6. return air
7. return air 8. bottom-opening(4 $\times$ F)

Fig3. CFD model with side-wall opening

A bird's eye picture of the Shanghai International Gymnastics Stadium and an indoor scene of the building are shown in Fig.1 (a) and (b) for simulation and site-measurement. The building is 26m height with diameter 68m. There are 19 rows of fixed seats and 7 rows of movable seats around the Stadium, which has 4330 seats at a maximum. There are two central air-conditioning systems symmetrically in the stadium. Indoor air flow is the typical upper-side wall supply air and the lower-side wall return air. The main supplied duct is installed annularly at 15m high. The site-measurements have been carried out 9 times during summer, winter, and transitional seasons from 1998 to this day^[1]. It is satisfied that the CFD results agree well with the measured data^[2].

The temperature and velocity fields in the large space are simulated by PHOENICS software. Fig2 and Fig3 show that CFD modes of sidewall opening and top opening. It is well known that K- ϵ turbulence model of Lam-Bremnorst is most proper^[3] for simulating the turbulent airflow near the wall surface in large space. Given these wall surface temperature as boundary conditions, wall temperature equations are established using heat balance theory and Gebhart absorbing coefficient. The indoor cooling loads are calculated by the method of the cooling load calculation of stratified air-conditioning mode with a series of CFD indoor air temperature results.

A large number of experimental data CFD

simulations are used to study certain parameters in detail. With sidewall opening, several factors effecting the indoor thermal environment are geometrical parameters and running parameters such as nozzle height, upper-opening size and height, bottom opening size and inflow velocity through upper-opening. With top opening, the factors are nozzle height, backpressure of opening and opening sizes. A great amount of different running conditions (presented in table1 and 2) varying with these factors are simulated to analyze the effect of the factors on indoor thermal environment with sidewall opening and top opening respectively^{[4][5]}. It is found that upper opening, that in any case, is advantageous to improve the indoor air quality. Different location of upper opening has different influence on indoor energy consumption. The effect of these factors on indoor energy consumption with these two types of upper opening are analyzed in more detail in the paper.

3. COOLING LOAD ANALYSIS

The indoor cooling load can be calculated by the method of load calculation of stratified air-conditioning mode based on a series of CFD results of temperature and velocity field. The effect of these factors on indoor energy consumption with this two types of upper opening are discussed.

Table1 simulated conditions with top-opening

parameter	Conditions	marks
Nozzle height/m	11,13,15,17,19	N11,N13,N15, N17,N19
Top-opening area /m ²	4,9,16	T2O3,T3O4, T4O6
Bottom Opening area/m ²	0.322,0.644,1.365	FXQ,FXH, FX
Top-opening pressure/Pa	-10,-5,-2.5,0,2.5,5,10	-10P,-5P,-3P, 0P,3P,5P,10P

Table2 simulated conditions with side-wall opening

parameter	Conditions	marks
Nozzle height /m	13,15	N13,N15
Top-opening height/m	15,17,19	IN15,IN17,IN19
Bottom opening area/m ²	0,0.93,1.86,3.72	0F,1F,2F,4F
Top-opening area /m ²	56,10.45	SO,WO
velocity of inflow m/s	0,0.863,1.5,2.25,3	ALLEXH,UPIN08, UPIN15,UPIN23, UPIN30

3.1 Top opening

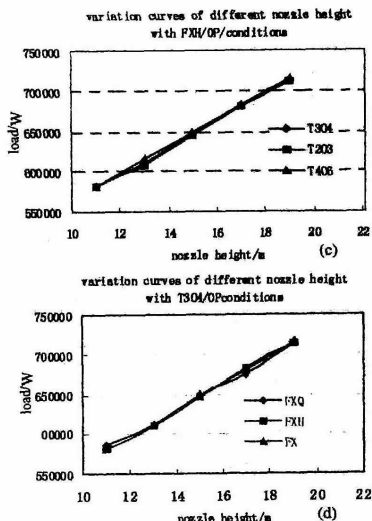
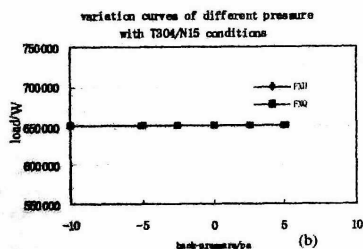
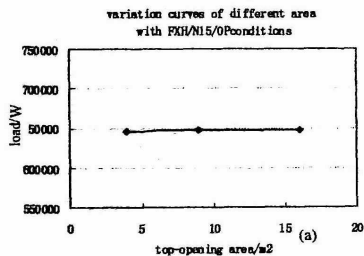


Fig4. cooling load with top opening of different geometrical and running parameters

Fig 4 illustrates the effect of upper opening size, nozzle height and backpressure on cooling load with top opening of large space. Fig4-7(b) (d) shows the relation of cooling load and nozzle height with different top and bottom opening sizes. The cooling load is seen to increase almost linearly with an increase in the nozzle height. Since the contributions of the opening size increase and pressure drop are very small, the nozzle height has the biggest effect on indoor cooling load. Consequently, the relation of cooling load and nozzle height can be expressed using Eqs.

$$y = 16.8x + 395.3$$

where y is indoor cooling load , kW; x is nozzle height, m.

correlative: 0.999, error: 0.004.

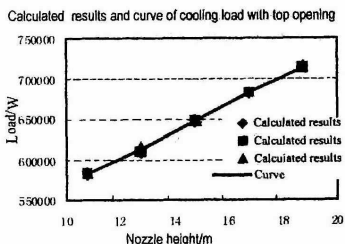


Fig5. Calculated results and curve of cooling load with top opening

3.2 Sidewall opening

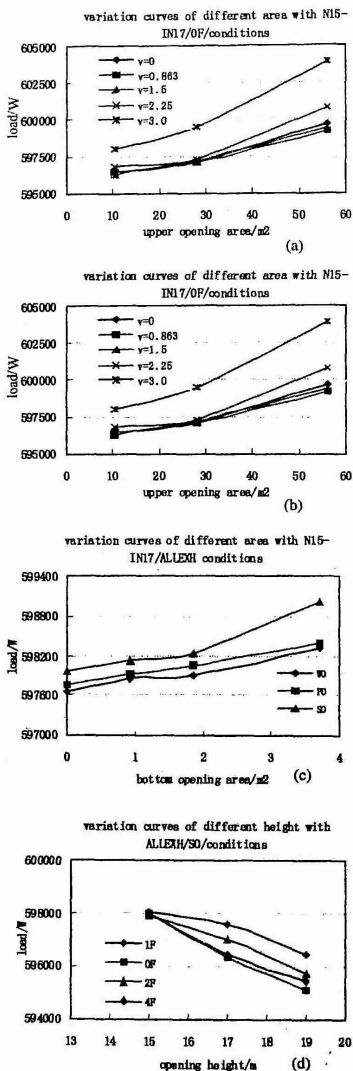


Fig6 cooling load with sidewall opening of different geometrical and running parameters

Figure 6 indicates the effect of upper and bottom opening size, opening level and inflow velocity through upper opening on cooling load with sidewall opening of large space. When upper opening size increases, the indoor cooling load increases evidently. When inflow velocity is close to 3m/s, there is an obvious increase of indoor cooling load. And the bottom opening size has slight influence on cooling load. However the indoor cooling load decreases with opening height increasing shown in (d).

More important, it is found that the cooling load in the case of sidewall opening is larger than that in the case of top opening.

4. CONCLUSION

The results presented in this paper have shown that different type of upper opening has different influence on indoor energy consumption. In any case, upper opening is advantageous to improve the indoor air quality. And it is seen that the cooling load in the case of sidewall opening is larger than that in the case of top opening. The results of this paper are important to engineering and air-conditioning design. It will provide the theoretical foundation and design basis for structure design.

5. ACKNOWLEDGE

This paper belongs to the program of national natural science foundation of China No. 50478113.

REFERENCES

- [1] Site Measurement and Analysis of Indoor Thermal Environment in a Large Space Building in Typical Seasons Shanghai 2003 HVAC forum in China and Japan.
- [2] Chen Huang, Meiling Li, Tao Zuo. CFD Analysis of Airflow and Temperature Fields in a Large Space with Openings. 4th. International Conference on IAVECB, Changsha. 2001.10; 269-276.
- [3] K.G.Lam, K.Bremhorst, A modified form of the k- ϵ model for predicting wall turbulence. ASME J. Fluids Eng., 1981; Vol.103: 456-460.
- [4] Research on Indoor Thermal Environment Characteristics in Large Space Building with Upper-side Openings. J.HVAC 2004; Vol.23(4): 1-4.
- [5] Huangchen, Wangxin, Yangjiangang, Huangwugang, Limeiling. Study of Thermal Environment Characteristics of Large Space with Stratified Air Conditioning and Openings 2003 ICE