

# Numerical Simulation of Displacement Ventilation in a Gymnasium in a Large Space Building

Xuehui Wu  
Doctoral  
Candidate

Xiaodong Li  
Associate  
Professor

School of municipal and environmental engineering, Harbin Institution of Technology  
Harbin, China  
wu99099@sohu.com

**Abstract:** Since athletes' records can vary greatly depending on air velocities in sports halls, airflow patterns have played a very important role in HVAC design in gymnasiums. HVAC designers and researchers have paid more and more attention to this problem. However, there still remains a lot to do in providing a suitable airflow pattern for competitions, with less energy consumption. Recently the displacement ventilation (DV) system has been adopted in northern Europe. It is used in large spaces such as gymnasiums, but is still not commonly used in China.

By using BusinessSoft, we analyzed the airflow, thermal comfort, the effects of ventilation and other parameters on the HVAC in two main zones of the gym, the competition zone and the stands zone. Results indicate that the DV can meet design requirements.

**Key words:** large space building; displacement ventilation; airflow; thermal comfort; numeric simulation

## 1. INTRODUCTION

The researches of airflow in large space building always are the point and the difficulty of academic study. And because the cubage is large, the height is tall in gym large space building; both the means and depth of study are limited. Although some important works have been done, it is difficult to get data of experiment that are integrated, effective and convictive. Present researches and analysis of design mainly is base on experiments<sup>[1]</sup>. To the appliance of DV in gym large space, it also is the same story. And the content of this paper is belonged to new exploration. As a comprehensive, deep and detailed numerical experiment, it is very significant.

## 2. THE NUMERICAL SIMULATION OF AIRFLOW IN THE COMPETITION ZONE

According to the different of purpose of zones of gym, gym is divided into competition zone and stands zone. The request of temperature and velocity in different zone is different. The airflow of competition zone is one of the points concerned in gym that adopts DV. The distribution of airflow in competition zone largely reflects the characters of airflow in whole gym hall.

### 2.1 The Basic Parameter of Ventilation of Gym

This simulation uses model simplified of certain gym to analysis airflow of DV system when it runs in summer. Its geometric dimension is  $72 \times 71 \times 22\text{m}$  (length $\times$ width $\times$ height). It can accept 7000 spectators. And the competition zone is  $40 \times 23\text{m}$ . Whole gym is symmetrical in south and north, as well in east and west. Table 1 is design parameter of gym displacement ventilation system. The temperature designed is  $24^\circ\text{C}$  in summer and the relative humidity is 60 %. Gym ventilates from seats. There is a rectangular air supply opening of DV that is  $0.443 \times 0.21\text{m}$ . the cold air treated is supplied from these openings which velocity is  $0.8 \sim 1\text{m/s}$ . The temperature of air supplied is  $20^\circ\text{C}$  and the different is  $4^\circ\text{C}$ .

When the system of DV is designed, the quantity of heat in upside room does not be reckoned in total load because airflow move from down to up. Then the load of mean seat is litter in DV than other system of ventilation.

**Tab.1. Design parameter of gym displacement ventilation system**

Person load (KW)	Light load (KW)	Enclose structure load (KW)	total load (KW)	Load of mean seat (KW)	Temperature of supply (□)	velocity of supply (m/s)	Total Volume of supply (m3/s)	Total Volume of excluding (m3/s)
492	127.8	85.8	705.6	100.8	20	0.8	145.6	35

## 2.2 The Model of Simulation

According to symmetry, we take 1/4 of gym as studying zone of this simulation. Its size is 36(X)×35.5(Z)×22(Y)m. And the area of competition zone is X (16—36m) ×Z (24—35.5m). In view of complexity of simulation, the model is simplified. Table 2 is situation and dimension of opening and heat-source in model. Negative X is north. The load of light on the top of gym is considered as uniformity. And it is 50W/m<sup>2</sup>. Both part of the convention and radiation is 1/2. Because the competition is carried at night usually, the radiation from the sun is not considered. Every step of stand in figure 2 denotes ten lines seats of stands. The temperature of supply air is 20□. And the velocity is 0.8m/s. the function of the space in every step bottom just like air plenum. The far field

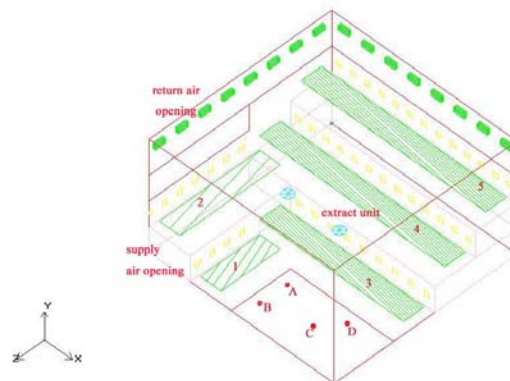
is affected by spectators mainly because spectators are a kind of heat source (the load is 70W/person). Then spectators are simplified as plane heat source. There are 2 roof extract units in the top of model and 16 return air fans in the height of 19m which size are 1 (height) ×2 (width) m. Simulation adopts k—ε standard model<sup>[2][3][4][5]</sup>.

## 2.3 Results of Simulation.

The system of DV adopts supply air from seat. So the distance between openings and competition zone is large. And the velocity is lower. The effect of ventilation is the point that is cared by people in competition zone. By results of simulation in condition designed, the distribution of airflow in the distribution of airflow in competition zone is studied. According to the need of velocity of airflow

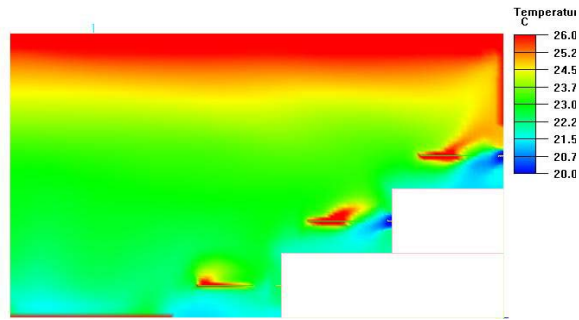
**Tab.2. Situation and Dimension of Opening and Heat-Source in Model**

Stand	1	2	3	4	5
The height of openings (m)	2.5	7.5	2.5	7.5	12.5
The quantity of openings	4	6.5	9	13	13
The size of plane heat source (L×W) (m)	11.5×4	19.5×4	28×4	36×4	36×4
The quantity of plane heat source (w)	14770	25060	35980	46270	46270

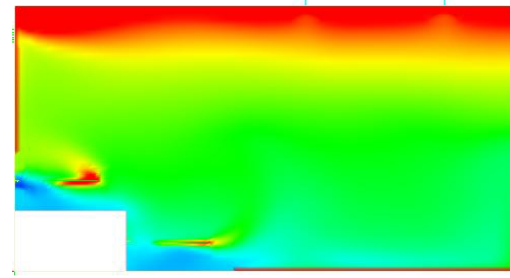
**Fig1. Model**

in gym (velocity  $\leq 0.2\text{m/s}$  as using little ball , velocity  $\leq 0.5\text{m/s}$  as using big ball) and the function of usage of hall of gym, this zone--- X (16,36); Y(0,22); Z(24,35.5) is considered as key zone of studying of this paper. Figure 3 is the distribution of temperature and velocity on plans which X=26m, Z=30m. Figure 4 is distribution of temperature and velocity on lines LA, LB, LC, LD, which respectively pass point A (17, 0, 25), B (17, 0, 33), C (26,

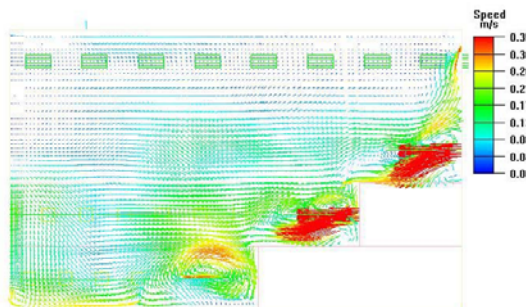
0, 30), and D (34, 0, 25) and which direct are Y. From figure 2 and 3 we know that the temperature is low in the bottom and high in the top, and has obvious upright gradient. It is typical character of DV. The temperature on the line LA, LB, LC, LD almost are consistent. And the direction of temperature changing is consistent also. Namely the distribution of the temperature in gym is homogeneous.



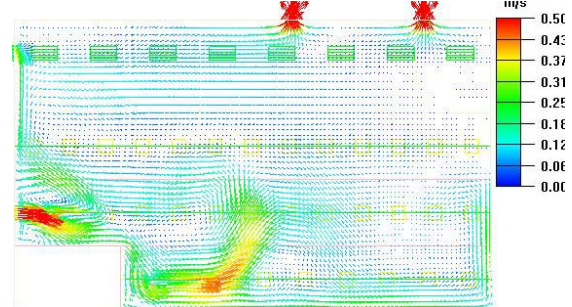
(a) Distribution of temperature on plan which X=26m



(b) Distribution of temperature on plan which X=30m

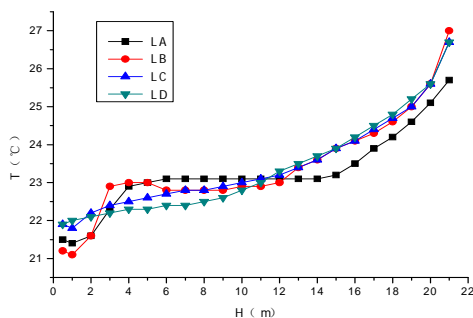


(c) Distribution of velocity on plan which X=26m

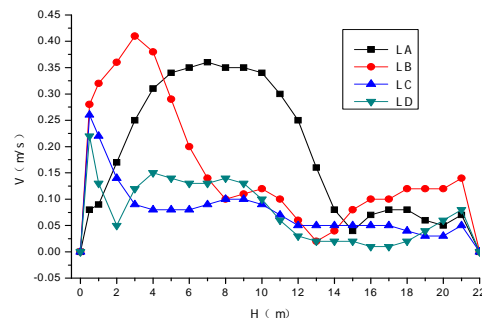


(d) Distribution of velocity on plan which X=30m

**Fig2. Distribution of Temperature and Velocity on Some Plans.**



(a) Distribution of temperature on line LA, LB, LC, LD



(b) Distribution of velocity on line LA, LB, LC, LD

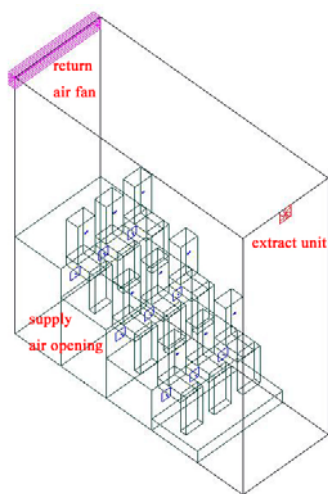
**Fig3. Distribution of Velocity and Temperature on Line LA, LB, LC, LD.**

In figure 3 (b), the value and the direction of change of velocity almost is consistent respective in the east (LD) and center (LC) of competition zone. And velocity is low, which distribution is homogeneous. While in the corner (LA) and the north (LB) is the disorder of airflow stronger because the volume of supply air is more than others every volume. Just like in figure 2 (d), zone disordered is not large and mainly centralize in north small range.

The mean velocity and temperature respectively is 0.14m/s and 22.94℃ in the range from 0 to 10m in competition zone. That meets requirements of design. And the temperature is lower in whole gym. Because of the effect of heat feather flow that is produced by heat source, the velocity of airflow attenuates quickly. Although velocity is higher near border of competition zone (velocity > 0.2m/s), when adopt DV diffusers that are adopted in practical appliance, the velocity of airflow will attenuate more quickly. And the volume of velocity in competition zone will be lower too.

### 3. THERMAL COMFORT OF SUPPLY AIR FROM SEAT IN STANDS

The distribution of spectators and supply air outlets has outstanding characters in DV. (1) Heat source of spectators is centralized. (2) It is different in height obviously. (3) Supply air outlets are closer to bodies and so on. Thermal comfort of stands is other point when ventilation in gym is studied.



**Fig4. geometry model**

### 3.1 Dimensional Geometry Models

In this part a typical stands zone is adopted to study the thermal comfort and its factors of effect of stands. Dimensional geometry models adopted is 4(X) × 1.5(Z) × 4.5(Y) m.

There are 3 stands in the model and 3 spectators on every stand. The space under stands is air supply plenum. There is a DV diffuser below every seat. The height of diffusers respectively is 0.45m, 0.9m, 1.45m. And return air fan and roof extract unit are set on the top of model to keep the same condition of ventilation as supplying air from seats in gym.

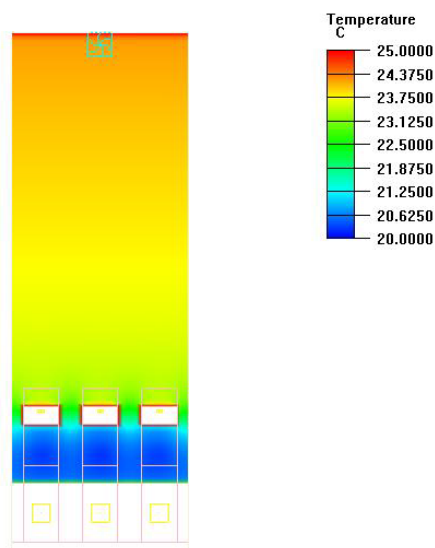
### 3.3 Physics Parameters

Because the numeric model of DV diffuser is complex, presently there is no method proved. In this paper it is simplified as rectangular air supply opening. Its size is 0.155×0.155m under condition designed. And the speed of supplying air is 0.8m/s. The single volume supplied is 0.0192m<sup>3</sup>/s. Temperature is 20℃. Return intake is set on the top of a plane which X=0. And the volume of extract fan is 0.045m<sup>3</sup>/s. And the rate of metabolism of spectator is 93W/m<sup>2</sup>.

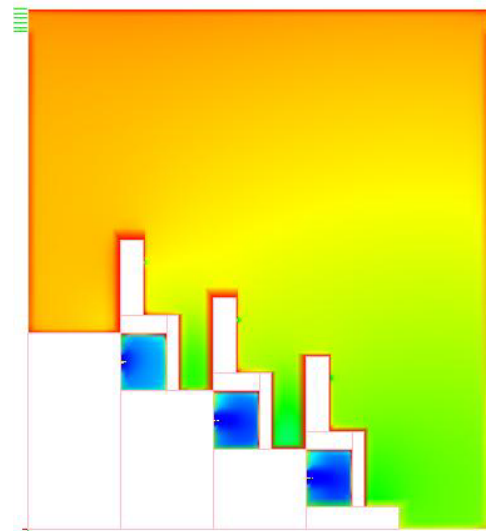
### 3.4 Result of Simulation

#### 3.4.1 The Distribution of Temperature Field.

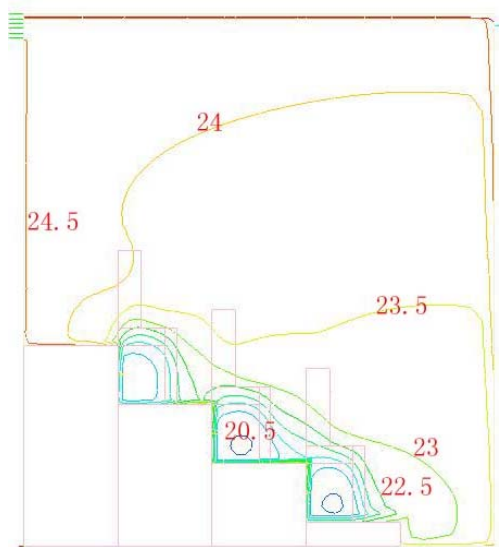
Figure 9 is distribution of temperature on X=1.9m on plane. And figure 10 is distribution of temperature on Z=0.75m plane. They show clearly that temperature present obvious gradient in upright direct. It is typical character of DV. ISO7730 specify that the different of temperature is not more than 3℃ from 0.1m to 1.1m above ground. ASHRAE55-92 standard suggest the different of temperature is not more than 3℃ from 0.1m to 1.8m above ground. Fig.11 is distribution of isothermal curve on X=0.5m plane. Fig. 12 is distribution of isothermal curve on Z=0.75m plane. They show that the temperature meet design requirement mostly in model. The gradient of temperature is high in the low part of model. But in the top of model temperature is homogeneous. And the gradient of temperature is low. Although the gradient of temperature is obvious in whole model, there is no obvious horizontal



**Fig.9 Distribution of temperature where  $X=1.9\text{m}$**



**Fig.10 Distribution of temperature where  $Z=0.75\text{m}$**

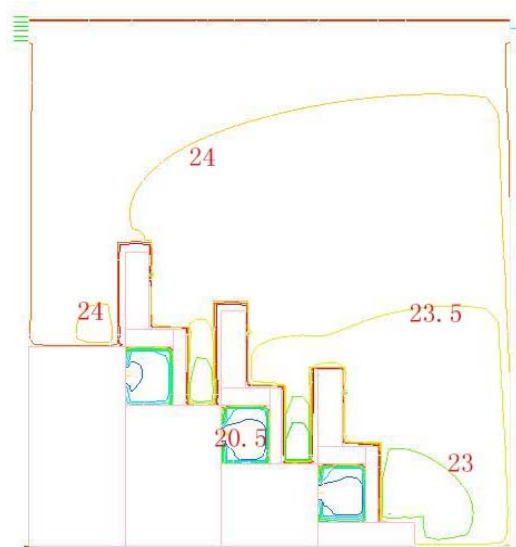


**Fig.11 Distribution of isotherm where  $X=0.5\text{m}$ .**

Thermodynamics stratification of temperature that appears in other buildings. In the back of the 3<sup>rd</sup> stand, higher temperature appears because of gradient distribution of spectators. So it is possible that the temperature is higher than design condition in the back row of stands.

### 3.4.2 The Distribution of Velocity Field.

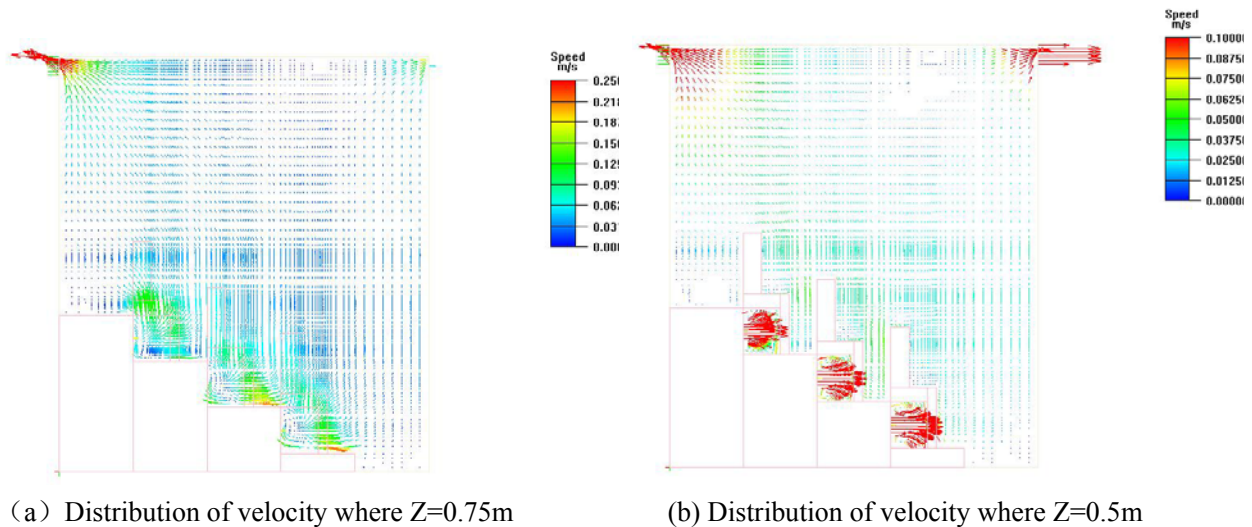
The velocity in work zone is other factor effect thermal comfort. Chinese Standard [6] requires that the speed of air of comfortable air controlling is not more than 0.3m/s in summer. But it is easy to produce draft because temperature of supply air is low and opening is near to spectators<sup>[7]</sup>. Draft is that



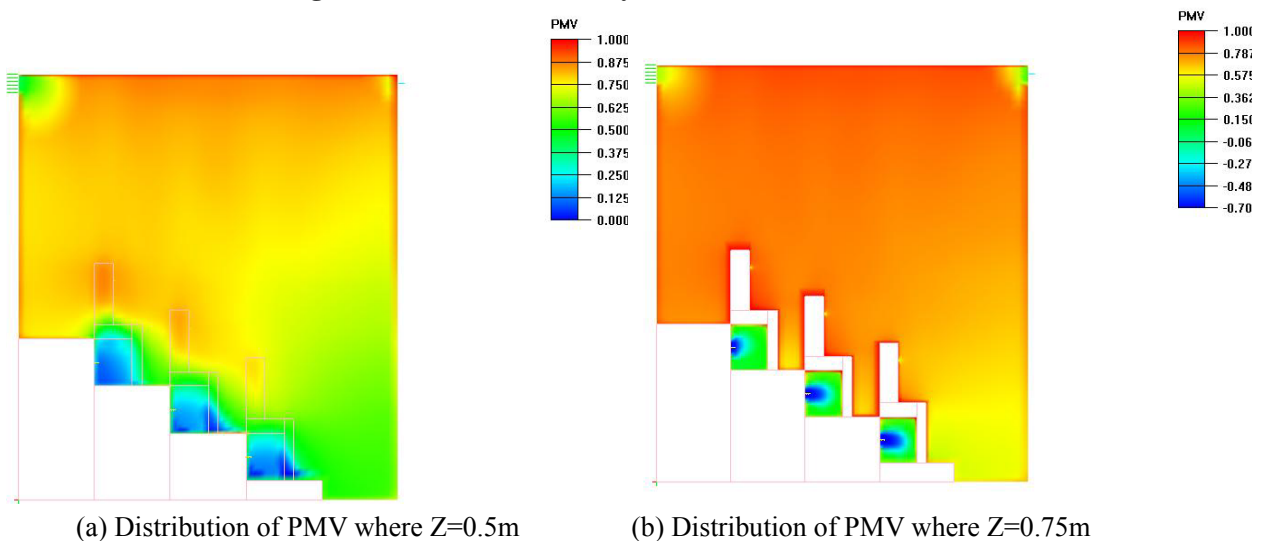
**Fig.12 Distribution of isotherm where  $Z=0.75\text{m}$**

people in part of room feel cold is due to the temperature and speed of flow. Literature [8] points that when the speed of air flow is lower than 0.15m/s in stay zone, stable thermal comfort is acquired easily, because airflow of DV is homogeneous. Literature [9] points that if speed is too high, feet will feel draft because DV adopts supply from bottom and return from top. Then there will be problem to comfort. In normal standard when the temperature is 20℃, the speed should be lower than 0.15m/s near feet. And when the temperature is 24℃, the speed should lower 0.20m/s. Figure 9 is distribution of velocity on  $Z=0.5\text{m}$  and  $Z=0.75\text{m}$  plane.





**Fig. 9 Distribution of velocity where  $Z=0.5\text{m}$  and  $Z=0.75\text{m}$**



**Fig.10 Distribution of PMV where  $Z=0.75\text{m}$  and  $Z=0.5\text{m}$**

Figure 9 show the distribution of velocity is homogeneous and the speed is lower than  $0.15\text{m/s}$  in the model, except nearby rectangular air supply opening. That meets requirements of Standard. On  $Z=0.5\text{m}$  plane, the speed is high slightly because a block is wider than a person.

#### 3.4.3 The PMV Analyses of Stands

We assume that the clothes of spectator is  $1.0\text{clo}$ , the rate of metabolism is  $1.2\text{ met}$ , relative humidity is  $60\%$  [10]. Other parameters are acquired by simulation. Figure10 is distribution of PMV on  $Z=0.75\text{m}$  and  $Z=0.5\text{m}$  planes. They show that the PMV is high slightly in whole model and only spectators in the front line meet the recommendation value of ISO7730. The PMV is 1 in the back line. Its average value is  $0.72$  that is higher than  $0.5$  in whole model. These are mainly because the height of model

is lower than gym and the radiation temperature is higher due to radiation heat is larger than practical gym. The condition will be better as practically DV is applied.

#### 4. CONCLUSIONS

(1) Because of the characters of airflow of DV, the cooling load of gym building is lower than other ventilation mode.

(2) The air distribution in gym building adopts DV meets the requirement of airflow of competition hall. In whole gym, the distributions of temperature and velocity are homogeneous and the value is small.

(3) Because the heat source distribute as ladder, the thermodynamics stratification are not obvious contrast to other buildings adopt DV. And the indoor temperature meets design standard. But it is possible that the temperature is too high in back seat. And that

should be regarded when DV is designed in gym.

(4) The average speed is 0.04m/s that meets the stipulation of criterion. But the front spectators will feel draft possible.

(5) Because light heat source is larger that effects the thermal comfort of stands, PMV is 0.72. Spectators maybe feel warm. But that can be accepted in practical angering.

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