Journal of Southeast University (English Edition) Vol. 26, No. 2, pp. 246 – 248 June 2010 ISSN 1003—7985

Draft sensation distribution of air jet supply system in large space building in summer

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Abstract: To study the draft sensation distribution of an air jet supply system in a large space building in summer, experiments are conducted in a large laboratory. The temperature, velocity and draft sensation distributions at a nozzle height of 4 m in the occupied zone are obtained. Then, the numerical simulation under the test condition is carried out by the computational fluid dynamics (CFD) method. The calculation results of the indoor vertical temperature and the draft sensation distribution are validated by the test data. Simulations with different nozzle heights are conducted. The satisfactory air supply condition is determined by analyzing the draft sensations and the temperatures in the occupied zone under three conditions. The simulation results show that the optimal draft sensation distribution and the uniform temperature and velocity fields can be obtained at a nozzle height of 5 m.

Key words: computational fluid dynamics; draft sensation; air jet supply; thermal comfort

Different types of air flow distribution have distinct impacts on indoor human thermal comfort. An air jet supply system is often adopted in large space buildings in summer. In this kind of air conditioning system, the velocity in some areas may exceed the scope of human thermal comfort and a high air velocity may cause a sensation of draft.

The methods used to research draft sensation are based on field studies, numerical simulations and experimental tests. Toftum et al. [1] conducted a field study and showed that at the same air temperature, the air movement was considered to be the reason for discomfort when people felt slightly cold. Harbara et al. [2] carried out an experimental study to test the impact of draft on the air velocity, the air temperature and the workload. By using CFD tools, Gan[3] exhibited that thermal discomfort in offices with displacement ventilation can be avoided by optimizing the air supply velocity and the temperature.

Many studies have shown that draft sensation was not only caused by the indoor air temperature and the average velocity, but also was related to the air flow turbulence intensity and the frequency[4-5]. Fanger et al. [6] indicated that draft sensation was easily generated with a high turbulence intensity. The reason was that the convective heat transfer was increased by the air flow turbulence intensity[7]. The standards of ASHRAE 55—2004 and ISO 7730 adopted the concept of draft sensation[8]. That is,

$$P=(34-t_a)(v_a-0.05)^{0.62}(0.37v_aT_u+3.14) \qquad (1)$$

where P is the percent of discomfort caused by the cooling air; t_a is the local air temperature; v_a is the local air velocity; T_u is the turbulence intensity.

In this paper, P is studied by experiments and the CFD method. Numerical simulations with different nozzle heights are carried out. By verification and comparison, an appropriate distribution condition of draft sensation is chosen.

1 Method

A large laboratory at the University of Shanghai for Science and Technology is chosen. The dimensions of the construction are 20 m × 14.8 m × 6 m. It has a sloping roof, and the tiptop of the roof is 8.75 m. There are three different nozzle heights: 4, 5 and 6 m. At each height, there are ten nozzles with a diameter of 174 mm. The model is shown in Fig. 1.

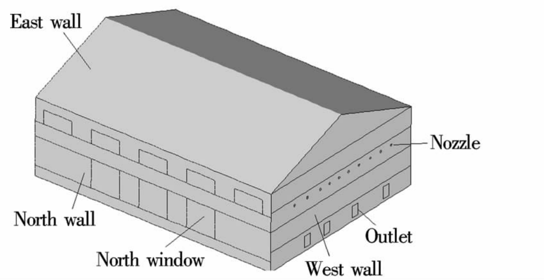

Fig. 1 Construction model

In summer, when the ten nozzles at a height of 4 m are used, the air supply temperature is 15.2 ℃ and the air supply velocity is 8.9 m/s. The indoor air temperature and the velocity field are recorded. The temperature sensor is a copper constantan thermocouple and the corresponding accuracy rate is ± 0.3 ℃. The velocity sensor is an anemoscope H103. T. 0 and the corresponding accuracy rate is ± 0.05 m/s. In order to analyze the draft sensation in the occupied zone, the temperatures and the velocities of five test points at a height of 1.7 m are chosen, as shown in Fig. 2. P can be calculated by Eq. (1).

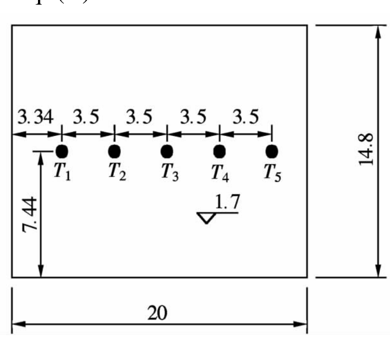

Fig. 2 Positions of test points (unit: m)

Received 2009-11-12.

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Foundation items: The National Natural Science Foundation of China (No. 50478113), the Leading Academic Discipline Project of Shanghai Municipal Education Commission (No. J50502).

Citation: Cai Ning, Huang Chen, Cao Weiwu. [J]. Draft sensation distribution of air jet supply system in large space building in summer Journal of Southeast University (English Edition), 2010, 26(2): 246 – 248.

Based on the above-mentioned experiment, the FLUENT software is used for simulation. Because there is no draft sensation model in the FLUENT software, the user-defined function (UDF) is adopted. In the experiment, the wall temperatures are different in vertical directions. Thus, in the simulation model, the west and the east walls are divided into five blocks, and the north and the south walls are divided into four blocks. The detailed boundary conditions are listed in Tab. 1. The air supply temperature and the air supply velocity are 15.2 ℃ and 8.9 m/s, respectively. GAMBIT is used to generate grids, and the grids in the nozzles are refined for accurate results. The number of the grids is 242 379. The standard k-ε turbulent model, the BOUSSINESP hypothesis and the SIMPLE scheme are adopted under the simulation conditions.

Tab. 1 Detailed boundary conditions

Boundary		Temperature/℃	Boundary		Temperature/℃
North wall	1	28.7	East wall	1	28.9
	2	29.2		2	29.4
	3	29.5		3	30.4
	4	30.0		4	35.3
				5	37.1
North window	1	32.2	West wall	1	28.8
	2	33.4		2	32.7
South wall	1	29.4		3	34.5
	2	29.6		4	36.4
	3	29.7		5	38.4
	4	30.4			
South window	1	32.3	Roof		36.9
	2	33.9	Floor		30.1

2 Results and Discussion

Fig. 3(a) shows the vertical temperature gradient in the center of the room, and Fig. 3(b) exhibits the values of P of five test points. It can be seen that, because of the sink effect of the cooling air supply, the value of P increases as the distance between the nozzle and the test point increases. At the position of T_3, the value of P reaches a maximum. Because of the inertia of the air flow, the value of P in the front of the room is greater than that in the back of the room. The simulation results accord well with the experimental results.

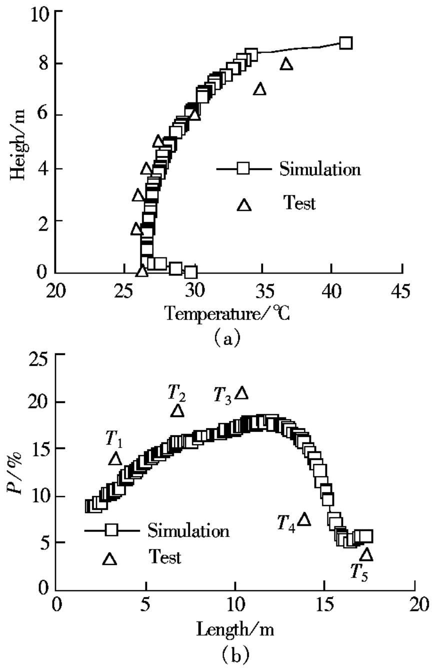

Fig. 3 Comparison of temperatures and P values between test and simulation conditions. (a) Temperatures; (b) P values

In order to analyze the impact of the nozzle height on the sensation of draft, with the same nozzle diameter, air supply quantity and boundary conditions, the simulations with different nozzle heights are carried out to calculate P. Here, the nozzle heights are 4, 5 and 6 m, and the corresponding conditions are called cases 1, 2 and 3, respectively. The results are shown in Figs. 4 and 5.

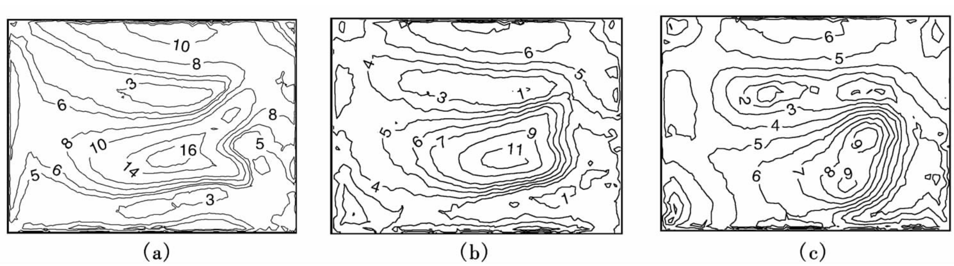

Fig. 4 Contours of distribution of P values at a height of 1.7 m (unit: %). (a) Case 1; (b) Case 2; (c) Case 3

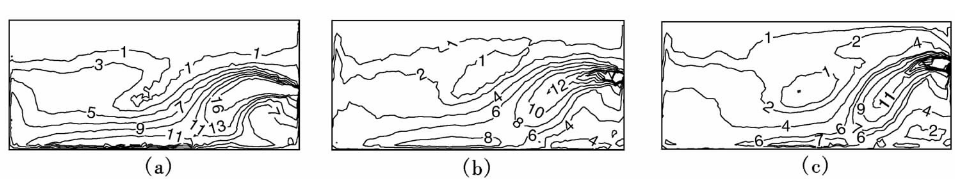

Fig. 5 Contours of distribution of P values along supply air direction (unit: %). (a) Case 1; (b) Case 2; (c) Case 3

The distribution of P values at a height of 1.7 m is shown in Fig. 4. It can be seen that the nozzle height increases with the decrease in the value of P. The value of P in case 1 is evidently greater than that in case 2. In case 1, P_{max} = 17.45%; in case 2, P_{max} = 12.44%; in case 3, P_{max} is almost the same as that in case 2. It indicates that when the nozzle height increases to a certain value and the air supply direction and the air supply volume are unchanged; the increase in the nozzle height cannot improve the distribution of the draft sensation.

Some parameters related to the values of P and the temperatures in the three cases are listed in Tab. 2. It can be seen that with the increase in the nozzle height, the distance between the point of P_{max} and the nozzle decreases while the average temperature increases. The temperature fields in cases 2 and 3 are more uniform than that in case 1. As a result, case 2 has the best thermal comfort and energy saving effect at the same indoor air temperature.

Fig. 5 exhibits the distribution of P values along the air supply direction. The impact of the sink effect of the air supply on the draft sensation in the occupied zone is evident in case 1, especially in front of the room. In cases 2 and 3, the effects of the cooling jet are reduced and then the values of P are less than that in case 1.

Tab. 2 Parameters in three cases

Case	P_{max}/%	d/m	P_{min}/%	$P_{average}$/%	T_{max}/℃	T_{min}/℃	$T_{average}$/℃
1	17. 45	8. 69	0. 02	7. 00	27. 52	26. 50	27. 15
2	12. 44	7. 59	0. 01	4. 60	28. 68	27. 62	28. 26
3	12. 85	6. 06	0. 03	4. 55	28. 79	27. 51	28. 37

Note: d means the distance between the point of P_{max} and the nozzle.

3 Conclusion

The nozzle height has an evident impact on the draft sensation in human activity regions. In case 1(nozzle height: 4 m), the value of P is greater but the average temperature is lower than that in case 2(nozzle height: 5 m). And the temperature distribution in case 1 is not uniform while it is uniform in case 2. In case 3(nozzle height: 6 m), the value of P is almost the same as that in case 2, but the temperature distribution is worse. Therefore, case 2 can meet the requirements of thermal comfort and energy saving.

When the nozzle height increases to a certain value, the increase in the nozzle height cannot improve the distribution of P values. Then the supply air direction and the supply air volume should be changed. Because of the limitations of experiments and simulations, researches on the draft sensations under different air flow distributions should be further carried out.

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高大空间建筑夏季喷口送风系统的吹风感分布

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摘要:为了研究高大空间建筑喷口送风系统的吹风感分布,在大空间实验室中进行了夏季工况的实验测试,得到了喷口高度为 4 m 时人体活动区域温度场、速度场和吹风感的分布. 然后,采用计算流体力学的方法对实验工况进行模拟计算. 将室内垂直温度和冷吹风感分布的计算结果和实测数据进行对比验证,结果显示吻合良好. 在此基础上进行了不同喷口高度处工况的模拟计算,通过分析 3 个工况下人体活动区域的吹风感和温度,获得了较理想的送风工况. 模拟结果显示,喷口高度为 5 m 时吹风感分布较为理想,温度场和速度场较为均匀.

关键词:计算流体力学;吹风感;喷口送风;热舒适性

中图分类号:TU83