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Experimental study on thermal environment in large-space building with low sidewall air supply

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Abstract: The thermal environmental characteristics are experimentally studied in terms of different air supply volumes and outdoor meteorological parameters in a large-space building which is air conditioned with a low sidewall air supply. The experimental results show that the indoor vertical temperature distributions under different condition are similar. The maximum vertical temperature difference (MVTD) is up to about 20 ℃, and it linearly changes with the sol-air temperature. The indoor vertical temperature gradients (VTGs) in the upper, central and lower zones are different. The influence of the sol-air temperature on the VTGs in the upper and the lower zones is greater than that in the central zone. The characteristics of the VTGs in the three zones affected by the air supply volume are the same as those affected by the sol-air temperature. Besides, because of the small air velocity, the predicted mean vote (PMV) on comfort in the occupied zone is slightly high and the air temperature difference between the head and the ankle is usually more than 3 ℃.

Key words: large space building; low sidewall air supply; vertical temperature gradient; thermal environment

With the increase in the concerns about air conditioning energy consumption and indoor air quality in recent years, the use of air distribution modes with a downside air supply becomes more and more popular[1]. Many researches on the air distribution of air-conditioning systems with a downside air supply in large-space buildings provide design considerations[2-4]. The vertical temperature gradient (VTG) is a major focus because of energy saving and comfort. It is experimentally observed that the VTG was 3 to 5 ℃/m in a room with a height of 2.6 m[5]. However, to date, experimental studies in large space buildings are rarely reported. In this paper, thermal environment experiments are conducted to investigate the indoor environment with low sidewall air supply. The simulation study on the thermal stratification level of the low sidewall air supply can be referred to in Ref. [6]. The experimental and simulation results provide a scientific basis for the design on the air distribution of the low sidewall air supply in large space buildings.

1 Experiment

1.1 Experimental base

As shown in Fig. 1, an experimental base is reconstructed from a stadium served as a ping-pong hall, whose roof is sloping, at a university, The height of the roof is 6 to 8.75 m. The size of the base is 20 m × 14.8 m. Many large glass

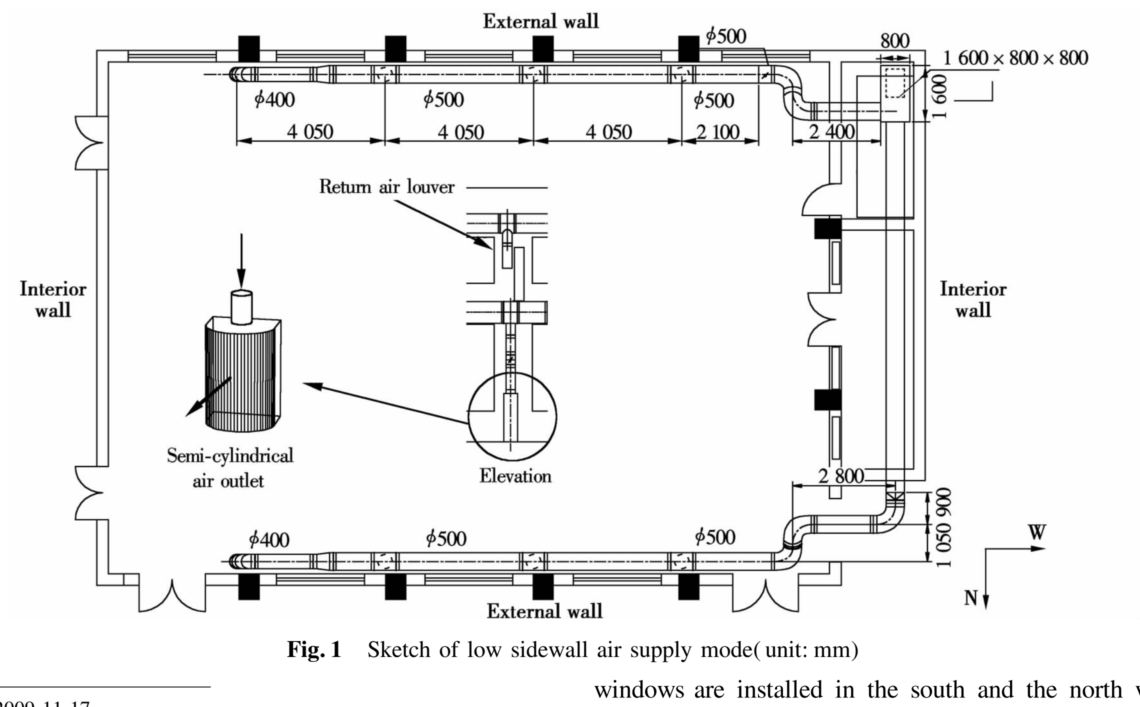

Fig. 1 Sketch of low sidewall air supply mode (unit: mm)

windows are installed in the south and the north walls, and the area ratio of the window to the wall is 9:20. The space cooling load is 42 kW. The design air volume is 9 000 m^3/h and the supply air temperature is 17.6 ℃. The cooling air is delivered by eight semi-cylindrical air supply outlets with a diameter of 600 mm, which are symmetrically placed on the low sides of the north and the south walls. The cooling air is returned either by eight return air louvers with a diameter of

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400 mm arranged symmetrically at a height of 4.6 m, or by four 900 mm × 600 mm return air inlets installed in the west wall.

1.2 Experimental conditions

Thirty-six sets of experimental cases were carried out in the summer of 2008, which were classified into 6 types of air flow modes as shown in Fig. 2. And the experimental conditions are as follows: the air volume is 8 850 to 9 520 m^3/h; the outdoor sol-air temperature is 55 to 63 ℃; the temperature in the occupied zone is 21.2 to 27.2 ℃. Mode A is defined as a standard mode. In mode A, air is supplied from the low sidewall and returns to the high sidewall. Mode A has two cases, case G and case H. Cases G and H in the standard mode under the conditions of different air volumes (9 500 or 7 500 m^3/h) are listed in Tab. 1. Subcases G_1 to G_4 and subcases H_1 to H_4 are carried out with different meteorological parameters.

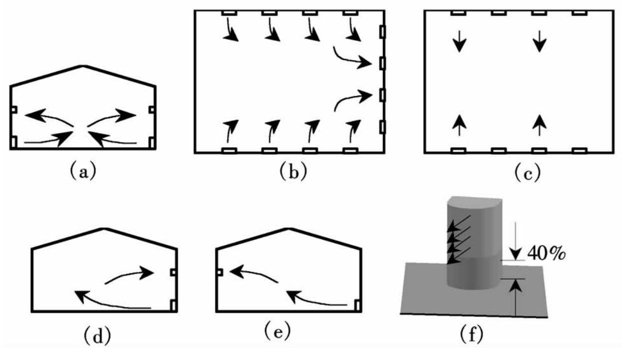

Fig. 2 Six air flow modes. (a) Mode A; (b) Mode B; (c) Mode C; (d) Mode D; (e) Mode E; (f) Mode F

Tab. 1 Experimental conditions of standard mode under conditions of different air volumes and meteorological parameters

Parameter	Case G(9 500 m^3/h)				Case H(7 500 m^3/h)			
	Subcase G_1	Subcase G_2	Subcase G_3	Subcase G_4	Subcase H_1	Subcase H_2	Subcase H_3	Subcase H_4
Air volume/($m^3 \cdot h^{-1}$)	9 843	9 619	9 250	9 735	7 697	7 429	7 120	7 997
Outdoor temperature/℃	25.1	30.3	33.0	38.6	25.9	30.4	32.4	39.6
Solar radiation/($W \cdot m^{-2}$)	90	479	595	327	104	538	576	645
Room temperature/℃	20.8	20.3	25.2	27.0	22.0	21.1	26.6	27.7
Cooling energy/kW	20.5	23.2	26.8	21.0	19.9	20.6	21.4	21.9

1.3 Experimental program

The purpose of the experiments is to observe the indoor vertical temperature distribution. The main test items are the outdoor meteorological parameters, vertical temperature distribution, wall temperature, predicted mean vote (PMV) and so on, which can be measured by the micro weather station, temperature-humidity recorder, thermocouple, infrared camera, etc.

Twenty-five temperature measuring points are arranged as shown in Fig. 3, which are divided into three series. The first series of measuring points are placed at a height of 1.7 m which are denoted as "○" in Fig. 3(a). The second series of points denoted as "●" are measured at the heights of 1.1 and 1.7 m. The third series of points denoted as "⊙" are measured at the heights of 1.1, 1.7, and above 3 m.

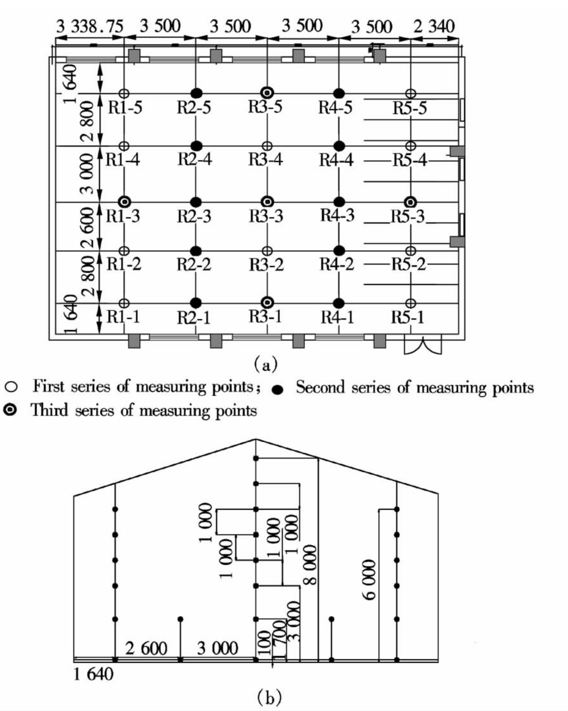

Fig. 3 Layout of indoor temperature measuring points (unit: mm). (a) Layout chart; (b) *A-A* profile chart

The thermal characteristics are tested before the experiments. The results show that it takes 1.5 h to reach a stable condition after running air conditioning. Consequently, in order to record the measurement results under the stable condition, the data logging of each case starts after the air-conditioning runs for more than 2 h. The data are recorded for further analysis. The interval of each test record is 15 min.

2 Indoor Thermal Environment

2.1 Vertical temperature distribution

In Fig. 4, the curve marked with "A-9250-62" indicates the vertical temperature distribution in case A when the air volume is 9 250 m^3/h and the sol-air temperature is 62 ℃. It can be seen that the trends of the vertical temperature distributions in different air flow modes are similar. The inflexions of the temperature distributions mainly appear at the heights of 1.7 and 4 m. The maximum vertical temperature difference (MVTD) is about 20 ℃. Fig. 4(b) shows the vertical temperature distributions with different climates and air volumes. The vertical temperature distribution is greatly affected by the sol-air temperature. The temperature gradient and the temperature near the roof increase with the increase in the sol-air temperature. When it is cloudy, the temperature gradient is small and the temperature is low.

Fig. 4(b) shows that the MVTD is closely related to the outdoor meteorological parameters. The scatter gram of the MVTD per meter in the vertical direction with different outdoor meteorological parameters is presented in Fig. 5.

The MVTD per meter is linearly related to the sol-air

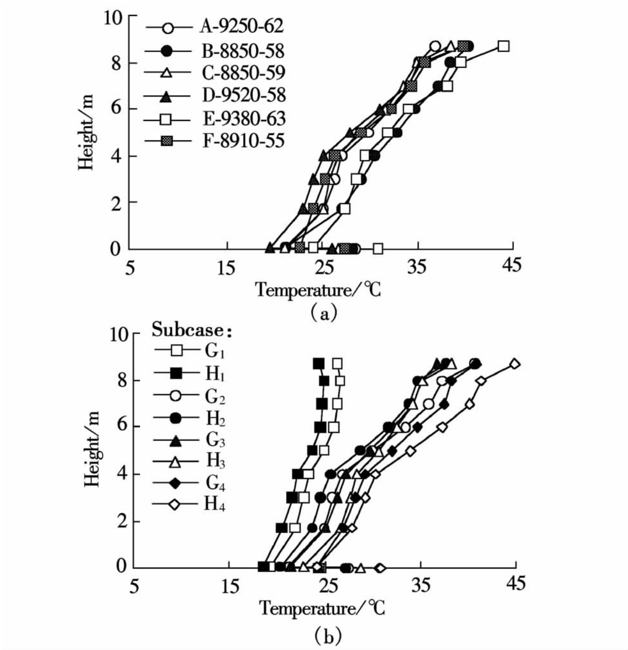

Fig. 4 Vertical temperature distributions. (a) With different air flow modes; (b) With different climates and air volumes

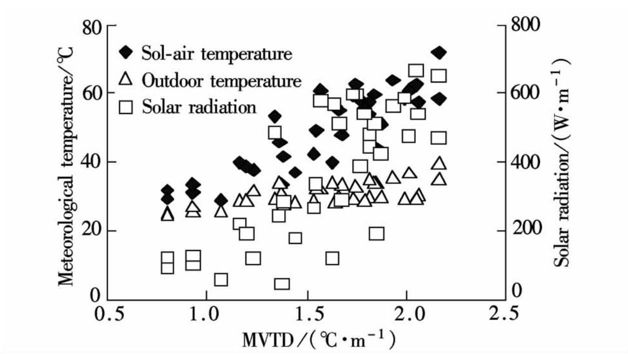

Fig. 5 Relationship of MVTD and outdoor meteorological parameter

temperature. And the measurement data exhibit a good linear relationship between the MVTD and the sol-air temperature, as shown in Fig. 6.

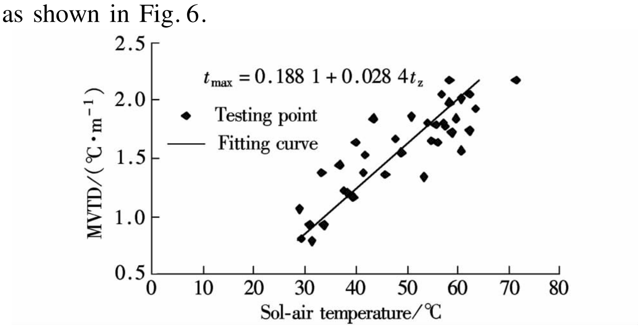

Fig. 6 Fitting curve and testing points of MVTD and sol-air temperature

2.2 Indoor air temperature distribution in different zones

The vertical temperature distribution can be divided into three sections: the lower zone (at the heights of 0.1 to 1.7 m), the central zone (at the heights of 1.7 to 4 m) and the upper zone (at the heights of 4 to 8 m). The vertical temperature gradient in each zone changes with the sol-air temperature, as shown in Fig. 7. It can be seen that the curves are approximately linear. The VTG in the upper zone is much greater than that in the central zone. And the VTG is about 1 ℃/m in the central zone. In the lower region, the VTG increases fast but discretely with the increase in the sol-air temperature.

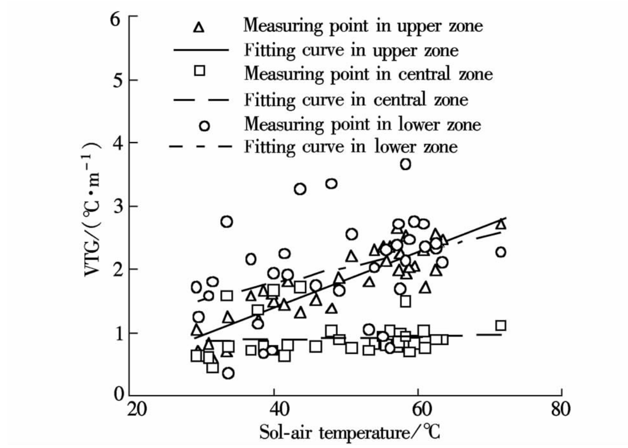

Fig. 7 Vertical temperature gradients

2.3 Impact factors on thermal environment

The indoor vertical temperature distribution is affected by many factors besides the integrated temperature. The correlation coefficient is used to analyze the VTG and the parameters such as the solar radiation, the outdoor temperature, the indoor-outdoor air temperature difference, the unit air volume (defined as the ratio of the air volume to the indoor-outdoor air temperature difference), the unit cooling load (defined as the ratio of the cooling load to the indoor-outdoor air temperature difference) and so on. It can be concluded from Tab. 2 that the sol-air temperature has the greatest impact on the MVTD; the affects of the solar radiation and the sol-air temperature on the VTG are obvious in the upper zones while the influence of the unit-air volume is obvious in the upper and lower zones. The influence of other parameters on the MVTD and the VTG are listed in Tab. 2.

2.4 Thermal environment in occupied zone

Tab. 3 describes the experimental results of the thermal environment at a height of 1.7 m in the occupied zone. The

Tab. 2 Influences of different parameters on MVTD and VTG

Parameter	MVTD	VTG		
		Upper zone	Central zone	Lower zone
Sol-air temperature/℃	0.87	0.89	0.10	0.38
Solar radiation/(W·m^{-2})	0.78	0.89	−0.08	0.27
Outdoor temperature/℃	0.68	0.46	0.53	0.48
Indoor-outdoor temperature difference/℃	0.69	0.56	0.48	0.35
Unit cooling load/(kW·℃$^{-1}$)	0.59	0.58	0.18	0.24
Unit-air volume/(m^3·h^{-1}·℃$^{-1}$)	−0.83	−0.69	−0.19	−0.60

PMV is calculated by 0.5 clo and 1.4 met. When the indoor air velocity is 0.02 to 0.15 m/s and the room temperature is 25 to 26 ℃, the value of the PMV is about 1.0. Only when the indoor temperature is 22 ℃ is the value of the PMV close to 0. It can be concluded that the design air temperature in the occupied zone should be lower than the normal air temperature to meet the comfort requirements. In addition, the air temperature difference between the head and the ankle is above 3 ℃, deviating from the comfort requirements[7].

Tab. 3 Experimental results of thermal environment in occupied zone

Parameter	Case						Subcase							
	A	B	C	D	E	F	G_1	G_2	G_3	G_4	H_1	H_2	H_3	H_4
Airflow rate/($m^3\cdot h^{-1}$)	8 850 to 9 520						About 9 500				About 7 500			
Temperature/℃	25.2	26.8	27.2	24.3	25.0	22.9	26.6	27.7	22.1	24.8	25.2	27.0	20.8	23.6
Humidity/%	49.7	39.8	50.1	49.0	50.3	54.2	51.7	47.3	61.2	46.1	49.7	52.7	66.9	48.3
Air velocity/($m\cdot s^{-1}$)	0.02	0.07	0.09	0.06	0.04	0.15	0.02	0.05	0.04	0.03	0.02	0.04	0.08	0.05
Radiation temperature/℃	26.1	27.6	28.5	25.5	26.1	24.2	27.3	28.9	22.6	25.8	26.1	28.2	21.6	24.6
PMV	0.97	1.02	1.28	0.59	0.82	0.05	1.27	1.44	0.09	0.81	0.97	1.33	−0.30	0.45
Δt/℃	3.8	5.6	3.1	3.1	3.7	3.2	3.8	3.5	2.6	3.6	3.8	2.7	2.1	3.1

3 Conclusions

1) The vertical temperature distributions in different cases are similar. All of them can be divided into three sections: the lower zone (at the heights of 0.1 to 1.7 m), the central zone (at the heights of 1.7 to 4 m) and the upper zone (at the heights of 4 to 8 m).

2) The MVTD is linear with the integrated temperature. The temperature changes in the upper and lower zones become greater with the increase in the integrated temperature, especially in the upper zone. The VTG in the central zone slightly changes about 1 ℃/m.

3) Besides the integrated temperature, the solar radiation is a main factor on the VTG in the upper and central zones. The unit-air volume is an indispensable factor, which has a great impact on the air convection features in the upper and central zones.

4) The value of the PMV is about 1.0 as a result of the low air velocity in the occupied zone with a low sidewall air supply. It can be concluded that the design air temperature should be lower than the normal air temperature. In addition, the air temperature difference between the head and the ankle is above 3 ℃.

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大空间建筑侧下送风热环境的实验研究

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摘要:针对大空间建筑室内空调气流组织采用侧下送风的情况,研究了不同空气送风量和不同室外气象参数等条件下室内热环境的特性. 实验结果表明,各工况下室内垂直温度分布具有良好的相似性,实验范围内最大垂直温差可达 20 ℃,且该值随综合空气温度呈线性变化. 室内上部、中部、下部 3 个区域的垂直温度梯度各不相同,空气送风量和室外综合温度对上部和下部区域垂直温度梯度的影响较大,对中部区域影响较小. 此外,因风速较低,各工况下人员活动区域舒适性预期评价略偏高,人体头足垂直温差一般超过 3 ℃.

关键词:大空间建筑;侧下送风;垂直温度梯度;热环境

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