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Comparative analyses of the air distributions created by attached ventilation with different air outlets

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Abstract. As an innovative ventilation mode, attached ventilation has been widely used in different types of buildings due to its high ventilation efficiency and energy saving. At present, the commonly used air outlet form is slot outlet. Considering the diversity of application places, different air outlet form models (Slot outlet (SO), Rectangular outlet (RO), Circular outlet (CO), Semi-circular outlet (SCO)) were established in this paper. Air distributions of the attached ventilation under different air outlet forms are analyzed and compared. The results show that the attached jet thickness is larger under RO, CO, and SCO form. Compared with SO form, the jet velocities of other three forms decay slowly in the vertical region. The attached ventilation with different outlet forms can form an "air lake" in the occupied zone to ensure the comfort environment. This research provides design references for the design and application of the attached ventilation under different air outlet forms.

1 Introduction

Air conditioning is an important means to ensure the occupants comfort and health. A reasonable airflow organization design should aim to achieve higher ventilation efficiency. There are two commonly used ventilation modes: mixing ventilation and displacement ventilation. Mixing ventilation has low ventilation efficiency and high energy consumption [1]; and the air-conditioning vents affects the overall aesthetics. Displacement ventilation has high ventilation efficiency, but it is not suitable for supplying hot air, and carries a small amount of cooling and heating loads [2].

In order to ensure the comfort and health of the indoor air environment, many scholars have researched and optimized the air supply mode of indoor air conditioners. Li [3] studied the advantages of the two traditional ventilation modes, creatively used the "column-wall-body" common in tall spaces to achieve "traction support" for the supply air flow, and turned mixed ventilation into a "quasi-displacement" Ventilation, which greatly improved ventilation efficiency and air quality.

Attached ventilation is widely used in various buildings, due to its high ventilation efficiency, indoor comfort and energy saving [4, 5]. At present, the commonly used outlet form is slot outlet. Considering the different characteristics of the application site, different air outlet forms (Slot outlet (SO), Rectangular outlet (RO), Circular outlet (CO), Semi-circular outlet (SCO)) were selects in this paper. Computational fluid dynamics (CFD) simulations are carried out to compare the air distribution under different air outlet forms. The axial velocity and indoor temperature were analyzed. This study can provide design reference for the application of attached ventilation in different buildings.

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2 Numerical methods

2.1 Physical model

Based on the previous research on slot outlet [6], a computational model was established to study the airflow organization of attached ventilation under different air outlet forms. The room size (length × width × height) is 5.4 m × 7.0 m × 2.5 m. In order to ensure the identical air supply volume for different forms of air outlets, the area of the air outlet is set to be the same, the size of the SO (length × width) is 2.0 m × 0.05 m, the size of RO (length × width) is 0.32 m × 0.32 m, the size of CO (diameter) is d=0.356 m, the size of SCO (diameter) is d=0.504 m, and the size of the return air outlet (length × width) is 0.4 m×0.4 m.

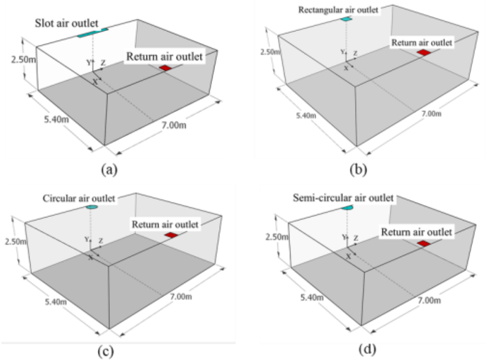


Fig. 1. Physical model: (a) SO; (b) RO; (c) CO; (d) SCO.

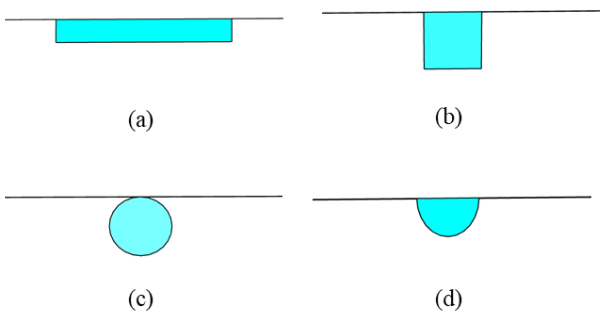


Fig. 2. Physical model of the air outlets: (a) SO; (b) RO; (c) CO; (d) SCO.

2.2 Boundary conditions and assumptions

The boundary conditions and initial conditions of the calculation model have a great influence on the calculation results. A reasonable boundary conditions and initial conditions are determined, and finally the simulation calculation results closest to the actual situation can be given. Combined with the experimental and simulated calculation conditions of SO [2], the boundary conditions and initial conditions of the attached ventilation under different air outlet forms are as follows.

(1) Inlet boundary condition

Velocity-inlet, u_0=-1.0 m/s, -1.5 m/s and -2.0 m/s (the negative sign means the velocity direction is the vertical air outlet downward), air supply temperature T_0=17℃.

(2) Outlet boundary conditions

Outflow, U=0, $\frac{\partial U}{\partial y}=0$.

(3) Wall boundary conditions

Stationary wall, No-slip.

(4) Heat source boundary condition

Constant heat flux (Heat flux), q=50 W/m^2.

To obtain accurate results of the air characteristics, a set of assumptions were made as follows. (1) The airflow of the attached ventilation in the room was assumed to be incompressible; (2) the effects of air-density variation were considered by adopting the Boussinesq hypothesis [5]; (3) coupled heat transfer in the wall was not considered [8].

2.3 CFD solver settings

In this paper, a commercial CFD program FLUENT 16.1 was used to compute the physical model and analyse the air distribution of attached ventilation with various air outlet forms. Based on the previous studies [2, 4], the standard k-ε model was employed to predict the three-dimensional airflow characteristics of the attached ventilation. The second-order upwind scheme was used to discretize the transport equation, and the semi-implicit method for pressure linked equations (SIMPLE) was applied to obtain accurate results. The convergence criteria were set to 10^{-3}. The Boussinesq hypothesis was applied to predict the impact of air-density change [5, 7].

2.4 Grid independence validation

The number of grids has a great influence on the results. In order to verify the independence of computational grids, three different grid resolutions (see Table 1) were examined to test the grid independence. Table 2 shows the comparison of the axial velocity distribution in the indoor vertical wall attachment region under the condition of air supply speed of 1.0 m/s.

Table 1. Model grid numbers of different air outlet forms.

Outlet form	Grid 1	Grid 2	Grid 3
Slot outlet (SO)	695296	1334400	1530816
Rectangular outlet (RO)	885112	1113528	1456152
Circular outlet (CO)	858210	1252866	1568824
Semi-circular outlet (SCO)	795804	1083648	1578412

The results of the simulation calculations are shown in Table 2. Among the three grid resolutions, the maximum difference of the axial velocity of the attached ventilation with different air outlet forms is 1.59%. In general, the average deviation of the air velocities among different grids were similar. Considering the calculation time and computing power, Grid 2 is used for numerical calculation.

Table 2. Comparison of the average deviation of the axial velocity between different grids and Grid 2.

Outlet form	Grid 1	Grid 3
Slot outlet (SO)	1.59%	0.86%
Rectangular outlet (RO)	0.82%	0.36%
Circular outlet (CO)	0.41%	1.42%
Semi-circular outlet (SCO)	0.68%	0.14%

3 Results and discussion

3.1 Air velocity distribution under different air outlet forms

As shown in Figure 3, the supply air from the air outlets attached to the surface of the wall and flowed into the occupied zone based on the Coanda effect. The mixing of the main body of the jet with the surrounding air is small. The airflow with the four air outlets occurs in the phenomenon of wall separation. Compared with SO form, RO, CO, and SCO form have the jet gathering effect and produce obvious vortex in the impact area close to the ground. The air lake phenomenon can be formed in the occupied zone. Compared with SO form, the thickness of the air lake formed under the other three air outlets is smaller. The thickness of the air lake is about 0.15 m.

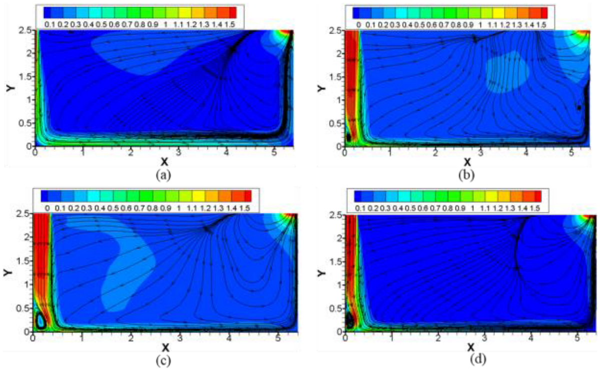


Fig. 3. The velocity distribution under different outlet forms at z= 0 m: (a) SO; (b) RO; (c) CO; (d) SCO.

In order to observe the airflow in the horizontal area with attached ventilation under different air outlet forms, the cross-section at y= 0.1 m was chosen for analysis. Since the airflow from the air outlet flows along the floor after impinging the ground, the velocity at the corners below the outlet is higher. Under various air outlet forms, the airflow pattern after impinging the ground corner is different. Comparing the air flow in the air lake area where the vertical wall is attached to the supply air under the four air outlet forms, it is found that when the air supply velocity is the same, the size of airflow diffusion area is: SO > SCO > CO ≈ RO. It shows that the air diffusion performance of SO form is better.

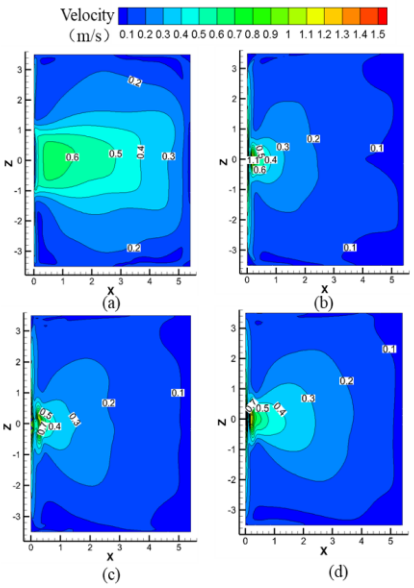


Fig. 4. The velocity distribution under different outlet forms at y = 0.1 m: (a) SO; (b) RO; (c) CO; (d) SCO.

3.2 Air temperature distribution under different air outlet forms

Due to the various shapes of the air outlets, the air supply characteristics is different. In the vertical attachment area, the jet thickness of the airflow is different, and the jet thickness is proportional to the width of the air outlet. After the airflow impinges the ground, an "air lake" is formed near the ground. It can be seen that the vertical temperature decay rate of the RO, CO, and SCO form are lower than that of the SO form. The indoor temperature under different air outlet forms is 23℃-24℃.

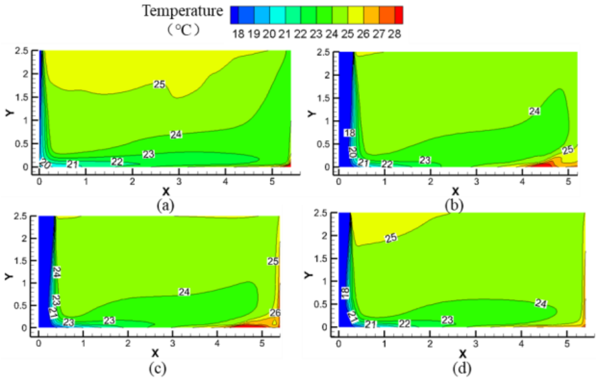
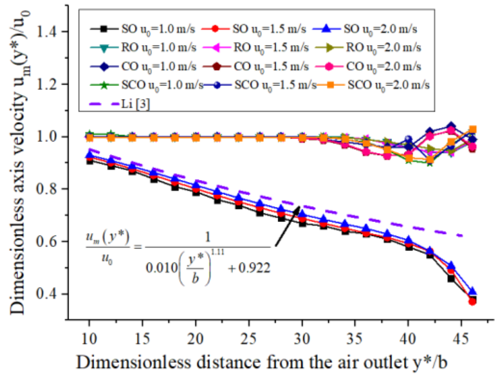


Fig. 5. The temperature distribution under different outlet forms at z= 0 m: (a) SO; (b) RO; (c) CO; (d) SCO.

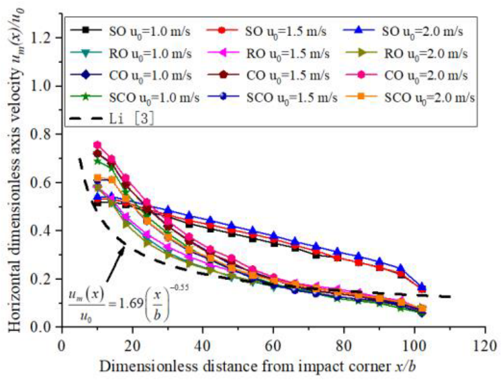
3.3 Dimensionless axial velocity and indoor temperature distribution

The difference in the form of the air supply outlet will affect the distribution of the axial velocity and temperature. In order to facilitate further research and comparison of the air distribution characteristics of the attached ventilation, Figure 6 shows the dimensionless axial velocities and temperature distribution in the vertical attachment area and the horizontal area of the attached air supply, when the air supply velocity is 1.0 m/s, 1.5 m/s and 2.0 m/s, respectively.

In the vertical attachment area, compared with the SO form, the dimensionless axial velocity distributions of the other three air outlet forms are similar. In the vertical area, due to the influence of the shape of the air outlet, the dimensionless axial velocities of the RO, CO, and SCO form have obvious jet aggregation and slow attenuation of the axial velocity, when the dimensionless distance y*/b is less than 33. When y*/b =45, the airflow enters the impact area of the corner, and the dimensionless velocity increases and then decreases. It is quite different from the fitting formula of the axial velocity in the vertical zone of the SO form. In the horizontal area, the velocity decay of the SO form is slower than that of the other three air outlet form. Comparing the formulas, the RO, CO, and SCO form are similar to the formula reported by Li [3], the axial velocity attenuates rapidly at first, after x/b>40, the attenuation speed slows down, and the final velocity change tends to be stable.



(a)



(b)

Fig. 6. The dimensionless axial velocity under different outlet forms.

It can be seen from Figure 7 that under various air supply velocities and air supply temperatures, different air outlet forms have similar trends in temperature differences along the height direction of the room. Cross-sections at different room heights are chosen to study the temperature distribution along the room height. Figure 7 shows the temperature distribution in the height direction of the room under different air supply velocities when the indoor load is 50 W/m^2 with the four air outlet forms. As the ground height increases, the average temperature on the section increases. Therefore, to improve the uniformity of temperature distribution in the occupied zone and reduce the impact of head-to-foot temperature difference on the thermal comfort of indoor personnel, a higher air supply speed and temperature can be considered.

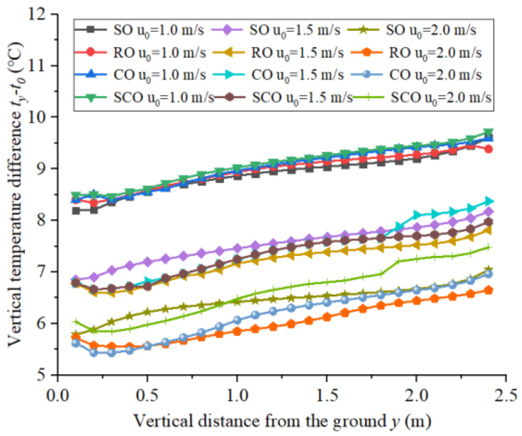


Fig. 7. The indoor air temperature distribution under different outlet forms.

3.4 Air distribution evaluation index

When the treated air is sent out from the tuyere, it is mixed with the indoor air, resulting in a large temperature difference in different indoor locations, which may cause differences in the temperature of the head and feet of personnel. The maximum allowable temperature difference in the vertical direction of the working area stipulated by relevant domestic and foreign norms and standards is 3 °C. It can be seen from the above research that the temperature distribution in the active area of the ventilation personnel under different tuyere forms is good, and the temperature difference between the head and feet is less than 3°C, which meets the specification requirements.

4 Conclusion

In this paper, the air distributions of attached ventilation with different air outlet forms were compared and analyzed by numerical simulation. Through grid-independent analysis, computational models were established. Based on our comparison and analysis, the following conclusions were drawn.

Compared with the SO form, the attached jet thickness is larger under RO, CO, and SCO form due to obvious jet aggregation.

In the vertical area, due to the influence of the shape of the air outlet, the dimensionless axial velocities of the RO, CO, and SCO form have obvious jet aggregation and slow attenuation of the axial velocity, when the dimensionless distance y*/b is less than 33. In the horizontal area, the velocity decay of the SO form is slower than that of the other three air outlet form.

The temperature difference between the head and feet is less than 3°C, which meets the specification requirements.

The supply air speed has a great influence on the airflow movement attached to the vertical wall of different air outlet forms. When the air supply velocity increased, the vertical temperature difference under RO, CO, and SCO form decreases. For engineering applications, the air supply velocity can be increased to handle indoor loads more efficiently.

Acknowledgements

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References

1. G. Cao, H. Awbi, R. Yao, Y. Fan, K. Sirén, R. Kosonen, J. (Jensen) Zhang, Build. Environ. **73** 171–186 (2014).
2. H. Yin, A. Li, Z. Liu, Y. Sun, T. Chen, Build. Environ. **109** 112–120 (2016).
3. A. Li, Attachment Ventilation Theory and Design, China Architecture and Building Press, Beijing, 2020.
4. J. Li, A. Li, Y. Hou, C. Zhang, C. Yang, X. Zhang, J. Che, J. Guo, Build. Environ. **204** 108226 (2021).
5. C. Liu, A. Li, C. Yang, W. Zhang, Build. Environ. **125** 15–25 (2017).
6. H. Yin, Y. Li, X. Deng, Y. Han, L. Wang, B. Yang, A. Li, Build. Environ. **186** 107363 (2020).
7. C.Q. Yang, T. Gao, A.G. Li, X.P. Gao, Int J Therm Sci **159** (2021).
8. Y. Wang, K.K.L. Wong, H. Du, J. Qing, J. Tu, Energy Build **72** 167-176 (2014).