Simulation of the effect of horizontal airflow channel on natural ventilation in apartments

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Abstract: Natural ventilation has an important impact on people's work and life. Reasonable use of natural ventilation can effectively improve indoor air quality and thermal comfort, reduce the use of air conditioning and reduce energy consumption. With the continuous development of urbanization, many apartments cannot effectively use natural ventilation. This paper uses CFD simulation to analyze the improvement effect of indoor ventilation after the installation of airflow channel in residential public transportation. The results show that the horizontal airflow channel can improve the indoor air environment and effectively reduce the dissatisfaction rate of indoor thermal comfort and indoor air age.

1. Introduction

Natural ventilation is widely used as a passive cooling method, and a reasonable natural ventilation method can not only effectively improve indoor air quality, improve human thermal comfort, but also reduce the use of air conditioning system and save energy consumption. Natural ventilation is often difficult to control and is affected by a variety of factors, including wind speed, air temperature, relative humidity, window opening behavior, building shape, and urban density. With the continuous development of global urbanization, the penetration rate of multi-unit housing and urban density will increase in the future, which will seriously affect the effective use of natural ventilation. In particular, the multi-family apartment can only carry out unilateral natural ventilation, and cannot carry out cross ventilation, the ventilation effect is poor, the indoor environment is hot, and the pollutants are difficult to be effectively discharged, which seriously affects the air quality and thermal comfort. In response to this problem, Zhang et al. proposed a new method to enhance natural ventilation, adding horizontal airflow channels in apartment buildings can change the ventilation mode of apartments and effectively enhance the potential of natural ventilation. Based on the research, this paper further analyzes the effect of airflow channels on the improvement of indoor air environment. It provides a reference for the practical application of airflow channels.

2. Models and Methods

2.1 Turbulence model

The turbulence model mainly selects two-equation models. The two-equation model in Fluent includes k-ε model, RNG k-ε model and Realizable k-ε model. The RNG k-ε model improves the calculation accuracy of fast shear flow, which can be applied to the calculation of Reynolds number in each interval. Therefore, the RNG k-ε model is used for the turbulence model.

The RNG k-ε equation:

\[
\frac{\partial (\rho k)}{\partial t} = \frac{\partial}{\partial x_i} \left[ \left( \mu_{eff} \right) \frac{\partial k}{\partial x_i} \right] + \mu_i \left( \frac{\partial \varepsilon}{\partial x_i} + \frac{\partial \varepsilon}{\partial x_i} \right) - \rho \varepsilon \quad (1)
\]

\[
\frac{\partial (\rho \varepsilon)}{\partial t} = \frac{\partial}{\partial x_i} \left[ \left( \mu_{eff} \right) \frac{\partial \varepsilon}{\partial x_i} \right] + \frac{\varepsilon}{k} \left( C_{\mu} \varepsilon G_k - C_{2\mu} \rho \varepsilon \right) - R_{\varepsilon} \quad (2)
\]

2.2 Physical model

The study model is the middle house of a ladder of three households. There are five areas inside the house, namely bedroom, living room, kitchen, and bathroom. There is one person in the bedroom and in the living room. Due to the apartment graphic design lead to the family only unilateral can open the window, in order to solve the apartment in the natural ventilation condition of different wind can have good ventilation environment, in the residential apartment public transport into the horizontal airflow channel, the greater the horizontal airflow channel opening area, the better the ventilation effect, the research of horizontal airflow channel area 0.2m×1m size duct. The specific physical model is shown in the Figure 1.
Figure 1. Arrangement of the horizontal airflow channel

2.3 Boundary condition

The site selected for this study was Shenyang, and the seasons were summer. The calculated temperature of outdoor ventilation in Shenyang in summer is 28℃, and the average outdoor wind speed is 2.6 m/s. The heat transfer coefficient of the exterior wall of the building is 0.65 w / m²·k, and the interior wall is the insulation wall surface. There are only personnel as internal heat source, the heat source power is 60W / m², and the influence of other heat sources is ignored. The opening area of the window is 0.6m²×1m. Indoor and outdoor coupling method is used for the simulation, and the gradient wind setting is used for the outdoor wind speed inlet. The expression is as follows:

\[ U(z) = U_r \left( \frac{u}{u*} \right)^\alpha \]  

(3)

3 Evaluation criteria

3.1 aPMV model

Based on the engineering theory and various factors of human heat sensation, Yao Runming proposed the adaptability coefficient \( \lambda \) to correct the PMV equation, and the model considers the difference between the PMV model and the adaptability model, and establishes a connection. The expression is as follows:

\[ aPMV = \frac{PMV}{1 - \lambda \cdot PMV} \]  

(4)

Where \( \lambda \) is greater than 0 in the warm condition and less than 0 in the cold condition. According to the relevant evaluation criteria. Table 1 shows the value of \( \lambda \).Table 2 and Table 3 are the evaluation indicators of aPMV and air age

<table>
<thead>
<tr>
<th>Building climate zone</th>
<th>PMV</th>
<th>Residential, store, offices</th>
</tr>
</thead>
<tbody>
<tr>
<td>cold areas</td>
<td>PMV≥0</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>PMV&lt;0</td>
<td>-0.50</td>
</tr>
</tbody>
</table>

Table 2. The aPMV sensory scaling

<table>
<thead>
<tr>
<th>thermal inductance</th>
<th>cold</th>
<th>cool</th>
<th>Slightly cool</th>
<th>moderate</th>
<th>Slightly warm</th>
<th>warm</th>
<th>hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMV</td>
<td>-3</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 3. Evaluation criteria for air age

<table>
<thead>
<tr>
<th>Air Age T (s)</th>
<th>Air freshness standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;225</td>
<td>Fresh air</td>
</tr>
<tr>
<td>225≤T&lt;400</td>
<td>The air is generally fresh</td>
</tr>
<tr>
<td>T≥400</td>
<td>The air is not fresh</td>
</tr>
</tbody>
</table>

Take the adaptive coefficient, and write the aPMV formula as an udf file, and model the model using the udf file written by fluent read.

4 Results and analysis

4.1 Improvement of air age under different wind direction incidence angles

Figure 2. For the comparison of the average air age in different areas of the apartment without ventilation and no airflow passage. It can be seen from the figure below that the average indoor air age at the incidence Angle of each wind direction is significantly improved. When the incidence Angle was 0, the average air age of bedroom 1 decreased from 750s to 447s, where the air age decreased significantly, but the air was in the stale range. The average air age of bedroom 2 decreased from 560s to 293s. Bedroom 2 improvement effect is obvious, from the air age value can see the indoor air from the fresh improvement to relatively fresh. The average air age of bedroom 1 after adding the horizontal airflow channel at 90° and 225°. and the wind Angle at 315°, the average air age of bedroom 2 has an upward trend, but all are within the range of fresh air. Among them, the living room is the best improvement effect, not ventilated to the incidence Angle under the indoor average air age is reduced.
4.2 Improvement of PMV-PPD at different wind angles

Figure 3. shows the comparative analysis of indoor PMV-PPD with and without horizontal airflow channels. As can be seen from the figure, the summer ventilation indoor hot comfort in Shenyang area is within the level II standard range, and the whole indoor area is between slightly warm and warm. When the wind direction angle is at 0° and 180°, the improvement effect is obvious. Average PMV of bedroom 1 decreased from 1.36 to 1.28, mean air age of bedroom 2 decreased from 1.28 to 1.22, and dissatisfaction rates of both bedroom 1 and bedroom 2 decreased by 4%. The wind direction is in 180° bedroom 2 improvement effect is better, dissatisfaction rate decreased by 3%. Among them, the wind Angle is not improved at 90°, and the indoor dissatisfaction rate of the apartment increases. The reason for this phenomenon may be that the airflow channel is not added, which causes the formation of the pressure difference between the room outside the window and then the window, and then the wind prevents the wind from the window after adding the airflow channel. It can be seen from the chart that after adding the horizontal airflow channel, the indoor thermal comfort can be improved in most of the incident wind Angle, which will reduce the dissatisfaction rate of personnel.

4.3 Leeward indoor environment improvement effect

It can be seen in the above analysis that the improvement effect is obvious when the wind direction Angle of adding the horizontal airflow channel is 0°. Figure 4. is the CFD cloud map of the improvement effect when the wind direction Angle is 0°. It can be seen from the cloud chart that when the horizontal airflow channel is not added, the indoor air age in bedroom 1, living room and kitchen is large and poor ventilation. Although the air at the window is relatively fresh, the wind is difficult to enter the room, and the indoor heat is also difficult to discharge. After adding the airflow channel, the air age of each room is improved significantly, and the air quality of the location of the personnel is better. It can be seen from the PMV cloud diagram that when the horizontal airflow channel is not added, the heat of the personnel is difficult to be effectively discharged. When the airflow channel is added, the heat can be effectively taken away by the wind, and the overall heat and comfort of the room is evenly distributed. When the bedroom joins the airflow channel, the dissatisfaction rate of the indoor room has decreased evenly, not only limited to the location of the personnel. Due to the addition of the horizontal airflow channel, there are obvious wind speed changes at the door of the room, and the dissatisfaction rate is the lowest here. However, after adding the horizontal airflow channel, the ventilation effect in the toilet is inhibited, and the installation position of the airflow channel should be considered.
5 Conclusion

In this study, aiming at the factors of poor natural ventilation effect in unilateral ventilation apartments, the improvement effect of natural ventilation was analyzed by increasing the airflow channel. Through numerical simulation, the following conclusions are drawn.

1. Horizontal airflow channels can improve the indoor air environment and thermal comfort under different wind direction incidence angles. When the wind angle is 0, the indoor improvement effect is the best. The average air age of bedroom 1 dropped from 750s to 447s and bedroom 2 decreased from 560s to 293s, which can meet the freshness standard and reduce the thermal comfort dissatisfaction rate by 4%. The addition of airflow channels has the best effect on improving the natural ventilation of the living room. The location of the airflow channel will affect the ventilation of individual rooms, but the overall ventilation effect is better.

2. Under the trend of urbanization and increasing urban density, the installation of horizontal airflow channels in unilateral ventilated apartments can change the way apartments are ventilated. The use of airflow channels can increase the cross-ventilation effect in the apartment, improve the utilization rate of natural ventilation, improve indoor thermal comfort and air quality, reduce the use of mechanical ventilation, and save energy consumption.

Reference