Study on energy saving of non-uniform air supply in office environment

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Abstract. There is a situation that the personnel in the office building are not concentrated and scattered, and some personnel will not always work at the workstation, and the creation of local comfort at the unmanned workstation will only cause great waste, so it is necessary to create an environment with uneven distribution of indoor parameters. In view of this situation, we simulate two working conditions: uniform and inconsistent airflow provision within the office space. Analyze the comfort of these two working conditions in the office room, discuss the unevenness and energy efficiency of the ventilation openings above and near personnel in the office room. The simulation results show that creating non-uniform indoor air supply can greatly save energy.

1. Introduction

Currently, the ventilation system approach of most public buildings is ceiling air supply, which creates a uniform state of indoor environment with a single parameter [1]. According to research, most public buildings have some spaces that are not used in daily lives [2]. Unused areas and spaces no longer need to maintain the comfortable environment required by the human body. In this case, opening the entire floor of air vents to maintain the indoor human comfort environment will only cause a waste of resources. Personalized ventilation (PV) represents a solution by installing a personalized terminal near office personnel to achieve independent control of the local environment around each individual [3]. E.Biyik designed a personalized air supply system in the early stage in the guise of a table-mounted units, called the Tabletop Environment Conditioning (TAC) system [4], this concept is gradually being applied to other indoor conditions. Current research on vent layout is concentrated on air quality management and energy efficiency saving [5]. The traditional end control method is to adjust the end damper opening based on the temperature of the return air duct [6]. Yang et al. [7] proposed the use of ceiling-type personalized terminals to provide individualized air jets, which avoid the installation of air ducts in areas of human activity, but this increases the distance between the occupants and the terminals, thus creating an overlapping effect in adjacent terminal wind areas [8]. According to the current research status, based on satisfying the basic comfort of human and not changing the original air-conditioning system of the building, the indoor environment with uneven distribution of indoor environmental factor is created to achieve the effect of energy saving.

2. Model and research techniques

2.1 Physical model

One of the offices in an office building is taken as the main object of study, the office model was identified as a standard layer, the thermal exchange between the ceiling and the floor was negligible, and the office was surrounded by internal walls. The model parameters are shown in Table 1, the office floor plan is shown in Figure 1, and the geometric model is shown in Figure 2.

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural entities</td>
<td>14.5 m×13.5 m×3.0 m</td>
</tr>
<tr>
<td>Air outlets</td>
<td>0.24 m×0.24 m</td>
</tr>
<tr>
<td>Return air outlets</td>
<td>0.77 m×0.19 m</td>
</tr>
<tr>
<td>Table</td>
<td>1.2 m×0.6 m×1.1 m</td>
</tr>
<tr>
<td>Computer</td>
<td>0.6 m×0.1 m×0.3 m</td>
</tr>
</tbody>
</table>

Figure 1. Office Floor Plan.

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2.2 Mathematical model

For the actual situation and specific simulation analysis,
\[
\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = - \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\mu}{\rho} \left( \frac{\partial^2 u_i}{\partial x_j \partial x_j} - \frac{2}{3} \frac{\partial u_i}{\partial x_k} \right) + g_i
\]

where: \( u_i \) denotes the velocity of the fluid in the \( x_i \) direction, m/s; \( p \) denotes stress; \( \mu \) denotes dynamic viscosity, N·s/m²; \( g_i \) denotes the same gravitational force, N/kg.

\[
\frac{\partial}{\partial t} (\rho h) + \nabla \cdot (\rho h \omega) = \nabla \left[ \left( k + k_i \right) \nabla T \right] + S_h
\]

where: \( h \) denotes the total energy per unit mass of the fluid, J/kg; \( k \) denotes the molecular thermal conductivity, W/(m·K); \( k_i \) denotes the thermal conductivity due to turbulent transport, W/(m·K); \( S_h \) indicates that all user-defined volumetric heat source terms are included.

\[
\frac{\partial}{\partial t} (\rho \varepsilon) + \nabla \cdot (\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left( \alpha_{t,\text{eff}} \varepsilon \frac{\partial \varepsilon}{\partial x_j} \right) + G_k + G_b - \beta \varepsilon - Y_m + S_{\varepsilon}
\]

where: \( k \) a denotes turbulent energy, J; \( \varepsilon \) a denotes the turbulent dissipation rate, %; \( u_i \) denotes the velocity component, m/s; \( k_i \) denotes the turbulent transport coefficient; \( \alpha_{t,\text{eff}} \) denotes the turbulent reaction Plante numbers of the \( k \) and \( \varepsilon \) are 1.0 and 1.3; \( S_k \) and \( S_{\varepsilon} \) are user-defined data.

2.3 Research Techniques

In order to further explore the non-uniformity of the indoor environment, we introduce the non-uniformity coefficient \( k_y \), the unevenness in the office is judged by calculating the unevenness coefficient of the office [9], its expression is (6):

\[
k_y = \frac{\sigma_y}{y}
\]

where: \( y \) denotes temperature or velocity; \( \sigma_y \) denotes the root mean square difference; \( y \) denotes the arithmetic average; \( k_y \) indicates that the smaller the value, the more uniform the distribution, and the opposite is not uniform [10]. The energy-saving cooling capacity is calculated as our turbulence model is solved by the RNG k-ε model. The fundamental equations encompass: continuity equation, momentum equation, the energy conservation equation, and \( k \) and \( \varepsilon \) equations. The specific equation is as follows: the continuity equation is denoted by (1), the momentum equation is represented by (2), the energy conservation equation is represented by (3), the RNG k-ε equation model is derived from the transport equations (4) and (5):

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0
\]

where: \( \rho \) denotes the fluid’s mass density, kg/m³; \( V \) denotes fluid velocity, m/s; \( t \) denotes time, s.

3. Numerical solving

3.1 Meshing

For most employees in the office, they tend to work in a sedentary state, to satisfy meet the requirements of human comfort, the air emitted by the air outlet located in the ceiling needs to reach at least the height of the human chest in order to effectively adjust the surrounding environment of the office personnel [11]. To save calculation time while ensuring simulation accuracy, supply vent, return vent, computer, personnel, tables and chairs are partially encrypted, and the generated grid elements are 3781919, the minimum orthogonal mass of the grid is 0.22, and the grid quality is good, which meets the calculation requirements, and the office grid is shown in Figure 3.
3.2 Setting of simulation conditions

The office model is a closed model, the temperature of the supplied air is established at 20 °C, the supply air velocity is set to 2.8 m/s, and the return air outlet is set to the pressure outlet. To facilitate the computation process, the floor slab and the ground can be regarded as adiabatic boundary conditions without temperature difference, and the surrounding walls are all internal walls, and the heat transfer is assumed to be a constant heat flow boundary condition, and The coefficient of heat transfer is 3.2 W/(㎡·K); The free flowing wall surface temperature is 28 °C, the human and computer are used as indoor heat sources, with a heat generation of the human is 55 W/㎡, and the heat generation of the computer is 100 W/㎡ [12]. The opening and closing of the tuyere is controlled by user-defined functions, and the opening of the tuyere when creating a non-uniform air supply environment is shown in Figure 4.

4. Simulation results and analysis

According to the above conditions, the model is simulated under two working conditions, and the findings from the simulation are presented below:
When the air outlet above or near the person is opened, it can be concluded from Figure 9~12 that the indoor temperature is roughly 21.8 °C, and the overall internal airflow velocity is about 0.1 m/s. The internal airflow velocity and temperature can still meet the comfort requirements of the human body. According to equation (6), the non-uniformity coefficient of temperature and wind speed is are 0.4 and 2.18. From this, it can be concluded that the distribution of the environment in the office is uneven, creating an uneven indoor environment.

The energy-saving situation is mainly considered in the following aspects:

1. **Energy-saving cooling capacity:**
   According to equation (7), the cooling capacity savings can be calculated:
   
   \[
   Q_{\text{uniform}} = 1.003 \text{ kJ/(kg·k)} \times 1.29 \\
   = 59.086 \text{ kW} \\
   Q_{\text{non-uniform}} = 1.003 \text{ kJ/(kg·k)} \times 1.29 \\
   = 58.252 \text{ kW} \\
   Q_{\text{save}} = Q_{\text{uniform}} - Q_{\text{non-uniform}} = 59.086 \text{ kJ} - 58.252 \text{ kJ} = 0.834 \text{ kW}
   \]

2. **Energy-saving electricity:**
   Fans and water pumps are important components of the central air conditioning system, fans and water pumps account for a significant portion of electricity consumption during operation [13]. The air conditioning on workdays is calculated based on 11 hours.
   
   \[
   \text{Save} \text{ electricity} = \text{Cooling capacity}\times\text{Time} = 0.834 \text{ kJ} \times 11 \text{ h} = 9.174 \text{ kWh}
   \]

### 5. Conclusion

In this paper, the indoor non-uniform environment of traditional tuyeres is simulated. Through the comparative analysis of the outcomes of the modeling analysis, it can be concluded that the indoor non-uniform air supply can save about 0.834 kW of cooling capacity per day, and about 9.174 kWh of electricity can be saved per day. Since the actual office situation cannot be realized in the setting process, the precision of the simulation outcome data needs to be further demonstrated and tested by actual experimental data.

### References


