AIRBORNE INFECTION PREVENTION: A COMPARISON OF MIXING VENTILATION AND DISPLACEMENT VENTILATION IN A MEETING ROOM

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ABSTRACT

Usually, displacement ventilation is characterized by a higher ventilation effectiveness than mixing ventilation. Is it therefore a better prevention of airborne infection? This CFD investigation shows a correlation between the ventilation effectiveness and the contribution of the exhaled air of an infectious person to other occupants in a meeting room.

Keywords: computational fluid dynamics (CFD), computer simulated person (CSP), ventilation effectiveness, residual lifetime air, airborne particle contribution

1 METHODS

1.1 Geometry and boundary conditions

The geometry of the room is a fictional meeting room for 14 people (see Figure 1). The room dimensions are derived from a case study in the Rehva ventilation guidebook for displacement ventilation [1]. The dimensions are 9 m x 4.7 m x 2.8 m (W x L x H). Six exhaust air outlets are arranged symmetrically on the ceiling. The displacement air inlet is a wall diffuser and the air inlets for mixing ventilation are two swirl diffuser in the ceiling. The investigated air flow rates are 500 m³/h and 1000 m³/h. The supply air is contaminant free (use of a HEPA-filter or no air recirculation).
Table 1: Boundary conditions and solver settings

<table>
<thead>
<tr>
<th></th>
<th>Inlet ( Q_{sa} = 250 \ldots 1000 \text{ m}^3/\text{h}, t_{sa} = 18 , ^\circ\text{C} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply air</td>
<td>Outlet</td>
</tr>
<tr>
<td>Exhaust air</td>
<td>Adiabat</td>
</tr>
<tr>
<td>Walls</td>
<td>Heat source ( P_{CSP} = 1190 , \text{W} )</td>
</tr>
<tr>
<td>CSP</td>
<td>Inlet ( Q_{exp} = 0.5 , \text{m}^3/\text{h}, t_{exp} = 30 , ^\circ\text{C} )</td>
</tr>
<tr>
<td>CSP_10</td>
<td>Realizable ( \text{k-}\varepsilon ) Two-Layer with all ( y^+ )</td>
</tr>
<tr>
<td>Turbulence model</td>
<td>Surface to surface radiation</td>
</tr>
<tr>
<td>Radiation model</td>
<td>Segregated solver, ideal gas, gravity.</td>
</tr>
</tbody>
</table>

1.2 Ventilation Effectiveness

Ventilation effectiveness includes several evaluation criteria. The most common are the assessment by the air renewal (age of air \( \tau \) and air change efficiency \( \varepsilon_a \)) or the pollutant removal (contaminant removal effectiveness \( \varepsilon_c \)) [2]. Normally, the contaminant removal effectiveness is assessed for a fix contamination source. Here the definition of the residual lifetime of air \( \tau_{rl} \) is used parallel to the size age of air to determine the contamination removal effectiveness for every point in a room. For the definition of age of air and residual lifetime see Figure 2. The residence time correspond to the nominal time constant \( \tau_n \).

![Figure 2: Definition of different ages, adapted from [3]](image)

The following equations show the relations in one point \( p \).

\[
\tau_n = \frac{V}{Q} \quad (1)
\]

\[
\varepsilon_a^p = \frac{\tau_n}{2 \, \tau} \quad (2)
\]

\[
\varepsilon_{c, p} = \frac{\tau_n}{2 \, \tau_{rl}} \quad (3)
\]
In this study the values for ventilation effectiveness are averaged for the breathing zone of the room. The breathing zone according to ASHRAE Standard 62.1-2010 [4] is located between two horizontal levels at heights of 0.075 and 1.8 m and 0.6 m from the walls.

1.3 Spreading of an infectious person
To simulate the danger of infectious aerosol spreading, CSP 10 exhales a passive scalar. In respiratory zones in front of each CSP face the volume fraction of this passive scalar will be determined. The definition of the respiratory zone is a cubic foot of air (a cube measuring about 30 centimeters to a side).

2 RESULTS
The age of air and the residual lifetime of air in the breathing zone are lower for displacement ventilation. Therefore, the air change efficiency and contamination removal effectiveness is higher. For higher volume flow rates the age of air and the residual lifetime are reduced. The influence of the volume flux increase on the air change efficiency is low for the contamination removal effectiveness is a downturn visible.

Figure 3: Ventilation efficiency for different ventilation strategies (mixing ventilation MV and displacement ventilation DV) and volume flow rates

The displacement ventilation strategy has a higher ventilation effectiveness and a better protection for nearly all CSP to get in contact with exhaled aerosols from CSP 10 using the same supply air flow rate (see Figure 4).
3 DISCUSSION

Taking a look at the correlation between the different values for ventilation effectiveness and the averaged volume fraction exhaled air of the infectious CSP 10 in the respiratory zones, shows the highest correlation for the age of air and the residual lifetime air ($r \approx 0.982$ and $0.985$). But the local values for age of air (see Figure 5) show the influence of the ‘fresh air lake’ is improving the average ventilation effectiveness for displacement in the breathing zone, which is defined from 0.075 to 1.8 m. Shrinking the breathing zone with a higher start level would change the outcome. It is better to use the residual lifetime of air to determine the performance of removing the exhaust and contaminated air (see Figure 6) and making the correlation to the risk of infection.
Figure 5: Age of air on the central plane section along the table

Figure 6: Residual lifetime air on the central plane section along the table

For the displacement ventilation the peaks for the volume fraction of the exhaled air of CSP 10 are the neighbors or the CSP, which sit opposite. Thus, a distance order in rooms has a synergy with displacement ventilation.

4 CONCLUSIONS
Displacement ventilation uses the buoyancy to supply the user with fresh air from the floor and displace all airborne contamination to the ceiling and further to the exhaust. Thus, the passive risk of infection for a healthy person joining a room with an infectious person is lower than in a room with mixing ventilation by same supply air flow rate. To assess a correlation between the ventilation effectiveness and the passive risk of infection the residual lifetime should be assessed.
A raise of the supply air flow reduce the residual lifetime of air and minimize the risk of infection. The simultaneous decrease of the contamination removal effectiveness indicates a limit for this effect. Additionally, thermal comfort criteria should be considered.

REFERENCE


