Multi-stage optimization of local environmental quality
by comprehensive computer simulated person

Faculty of engineering science,
Kyushu university

Sung-Jun YOO
Kazuhide ITO
The prevention of exposure to hazardous indoor environment is an important issue in the interest of public health.

Previously, we have developed a comprehensive computer simulated person (CSP), and comprehensive prediction method by integrating computational fluid dynamics (CFD) analysis with advanced CSP for estimation of indoor environmental quality targeting micro-climate around human body and respiratory area with high accuracy.
Background and purpose of this study

- We attempted to develop a new HVAC control method by using comprehensive CSP as a IEQ sensor.
- The local environmental analysis results concerning IAQ and thermal comfort were fed back to the HVAC control, and could be used to find a more suitable ventilation rate and energy requirement for air conditioning system.

Objectives of this study

- Indoor environmental factors including temperature/contaminant in the simple room model were analyzed in detail.
- Inhalation risk and thermal comfort of occupants was predicted using CSP, and sent to HVAC control scheme as a real time feedback.
- An improvement under new optimized HVAC control scheme was investigated by comparing to the result under traditional HVAC control method.
Virtual manikin, virtual airway, and computer simulated person

Grid design of virtual manikin

✓ For analyzing the impact of indoor environment on the human
✓ A model that reproduced actual shape of human body with average scale of Japanese male
✓ A Shape Data of the Virtual Manikin (Ito and Hotta, 2006)

The adjacent meshes from the wall $y^+ < 1$

<table>
<thead>
<tr>
<th>Feature</th>
<th>Standing Model</th>
<th>Seated Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of the body surface [m²]</td>
<td>1.745</td>
<td>1.681</td>
</tr>
<tr>
<td>Minimum size of a mesh [mm²]</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>The number of surface meshes</td>
<td>About 45,000</td>
<td></td>
</tr>
</tbody>
</table>
Virtual manikin, virtual airway, and computer simulated person

Grid design of virtual airway

The total number of computational cells: 7.5 million

Real human airway → CT scanning → Geometry data → Analytical grid generation

Computational human airway model

Grid design from nasal cavity to bronchi based on CT data (DICOM format)
Virtual manikin, virtual airway, and computer simulated person

Comprehensive grid design of Computer Simulated Person (CSP)

Virtual Manikin  Virtual airway  Comprehensive Human Model (CSP)

- Grid of comprehensive human body incorporating human body geometry and internal respiratory tract
Outline of an analytical domain and analysis condition

- **Outline of analytical domain**

<table>
<thead>
<tr>
<th>Analytical cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case (1) : Non-controlled case</td>
</tr>
<tr>
<td>Case (2) : Traditional control method based on the measured data from sensor in air conditioner</td>
</tr>
<tr>
<td>Case (3) : A new control method based on the inhalation concentration and skin surface temperature analysis result using CSP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>✓ Summary of analysis conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target contaminant</strong></td>
</tr>
<tr>
<td><strong>Contaminant condition</strong></td>
</tr>
<tr>
<td><strong>Algorithm</strong></td>
</tr>
<tr>
<td><strong>Breathing</strong></td>
</tr>
<tr>
<td><strong>Scheme</strong></td>
</tr>
<tr>
<td><strong>Thermoregulation</strong></td>
</tr>
<tr>
<td><strong>HVAC Control scheme</strong></td>
</tr>
<tr>
<td>&amp; $C_{inhaled}=80.0 \pm 20.0[\mu g/kg]$</td>
</tr>
</tbody>
</table>
Analysis result around computer simulated person (Case 2)

- **Velocity distribution**
- **Temperature distribution**
- **Humidity distribution around CSP**
- **HCHO concentration distribution**

$t = 2000.0 \text{ [s]}$
Comparison of Non-controlled, traditional control and optimized control

Temperature distribution around CSP

HCHO concentration distribution in breathing area

$t = 2000.0 \text{ s}$
Analysis result of inhalation exposure risk and thermal comfort

- **Inhalation concentration**
- **Averaged skin surface temperature**
Concluding Remarks

- This study introduced an optimized HVAC control method as an application of comprehensive prediction method using CSP, and we confirmed a new control method could be an effective way to create a healthy, comfortable indoor environment.

- In a future stage, high-level control scheme, and more specific data (thermal comfort index, quantitatively estimated respiratory exposure risk) should be considered for HVAC control.
Physiologically Based Pharmaco-kinetic (PBPK) model

→ for an prediction of contaminant sorption/transfer phenomenon from airway wall surfaces into a human body through the mucus, epithelium, and sub-epithelium.

Outline of PBPK—CFD hybrid analysis targeting formaldehyde

\[ \frac{\partial C_a}{\partial t} + (\mathbf{U} \cdot \nabla) C_a = D_a \nabla^2 C_a \]

\[ \frac{\partial C_t}{\partial t} = -\frac{V_{\text{max}} C_t}{K_m + C_t} - K_f C_t - K_b C_t + D_t \nabla^2 C_t \]

\[ \frac{\partial C_b}{\partial t} = -K_f C_t - K_b C_b - \left( \frac{Q_b}{V_b} \right) C_b + D_b \nabla^2 C_b \]

\[ \frac{\partial C_b}{\partial x} = 0 \]

Outline of PBPK—CFD hybrid analysis targeting formaldehyde

\[ C : \text{Formaldehyde concentration} \quad [m^2/s] \]
\[ D : \text{Diffusion coefficient} \]
\[ V_{\text{max}} C : \text{Saturable metabolism} \quad [\mu g/m^3/s] \]
\[ K_m : \text{Michaelis constant} \quad [\mu g/m^3] \]
\[ K_f : \text{Non-specific first-order metabolism rate constant} \quad [s^{-1}] \]
\[ K_b : \text{Non-specific binding} \quad [s^{-1}] \]
\[ Q_b : \text{Blood flow} \quad [m^3/s] \]
\[ V_b : \text{Volume of subepithelial layer} \quad [m^3] \]
Analysis result of respiratory exposure by using Computer Simulated Person

- Velocity distribution
- Formaldehyde concentration distribution
- Formaldehyde adsorption flux distribution during 1 breathing cycle