Benchmark Tests of CFD of Airflow around Human Body in a Room with Displacement Ventilation

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Outline

- Experimental Conditions
  - Displacement Ventilation
  - Thermal Mannequin
- Space Distributions of Velocity and Temperature
- Skin Temperature and Velocity around the mannequin
- CFD Conditions
- CFD Results
- Comparisons
- Conclusions
Experiment Condition

1. Test chamber size 0.3m X 3.5m X 2.5m
2. Supply Opening Condition
   1) Velocity : 0.182m/s
   2) Size : 0.4m(W) X 0.2m(H)
   3) Temperature : 21.8°C
3. Exhaust Opening Condition  Size : 0.3m(W) X 0.3m(H)
4. Thermal Manikin Condition
   1) Heat flux : 76W (Area : 1.471m², 51.6W/m²)
   2) Stable inhaled : 19.2 L/min (=0.00032m³/s)
5. Wall
   Adiabatic wall
Measurement Position of Air Velocity and Temperature

- Air Velocity: Ultrasonic anemometer (Average of 3 times, each time was measured 5 minute after stable air velocity)
- Air Temperature: T-type of Thermocouple (Average of 4 times, each time was measured 6 hour after stable air temperature)
Distribution of Air Velocity [V: m/s] and Turbulence Intensity [Tu:%]

- **L1**
  - V: 0.016
  - Tu: 54.4

- **L2**
  - V: 0.016
  - Tu: 54.7

- **L3**
  - V: 0.027
  - Tu: 56.6

- **L4**
  - V: 0.015
  - Tu: 57.7

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- **L1**
  - V: 0.015
  - Tu: 55.1

- **L2**
  - V: 0.016
  - Tu: 49.3

- **L3**
  - V: 0.024
  - Tu: 51.2

- **L4**
  - V: 0.014
  - Tu: 58.3

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- **L1**
  - V: 0.013
  - Tu: 57.9

- **L2**
  - V: 0.019
  - Tu: 43.9

- **L3**
  - V: 0.018
  - Tu: 43.3

- **L4**
  - V: 0.016
  - Tu: 53.1

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- **L1**
  - V: 0.027
  - Tu: 46.3

- **L2**
  - V: 0.022
  - Tu: 41.4

- **L3**
  - V: 0.027
  - Tu: 49.3

- **L4**
  - V: 0.025
  - Tu: 37.8

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- **L1**
  - V: 0.158
  - Tu: 26.0

- **L2**
  - V: 0.039
  - Tu: 46.1

- **L3**
  - V: 0.045
  - Tu: 35.5

- **L4**
  - V: 0.042
  - Tu: 44.3
Distribution of Air Temperature [°C]

L1
26.4  26.4
26.3  26.3
26.1  26.2
26.0  26.1
25.6  25.8
25.1  25.2
22.8  24.7

L2
26.8
26.4
26.4
26.4
25.8
25.1
24.7

L3
26.5
26.3
26.2
26.0
25.7
25.1
24.9

L4
26.3
26.3
26.2
26.0
25.7
25.1
24.9
Skin Temperature of Thermal Manikin [°C]

<table>
<thead>
<tr>
<th>Region</th>
<th>Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>32.2</td>
</tr>
<tr>
<td>L. Foot</td>
<td>30.5</td>
</tr>
<tr>
<td>R. Foot</td>
<td>30.5</td>
</tr>
<tr>
<td>L. Low Leg</td>
<td>31.4</td>
</tr>
<tr>
<td>R. Low Leg</td>
<td>31.5</td>
</tr>
<tr>
<td>L. Thigh</td>
<td>32.0</td>
</tr>
<tr>
<td>R. Thigh</td>
<td>32.0</td>
</tr>
<tr>
<td>L. Hand</td>
<td>32.5</td>
</tr>
<tr>
<td>R. Hand</td>
<td>32.3</td>
</tr>
<tr>
<td>L. Forearm</td>
<td>32.7</td>
</tr>
<tr>
<td>R. Forearm</td>
<td>32.6</td>
</tr>
<tr>
<td>L. Shoulder</td>
<td>32.6</td>
</tr>
<tr>
<td>R. Shoulder</td>
<td>32.8</td>
</tr>
<tr>
<td>Pelvis</td>
<td>32.3</td>
</tr>
<tr>
<td>Chest</td>
<td>32.7</td>
</tr>
<tr>
<td>Back</td>
<td>32.8</td>
</tr>
<tr>
<td>Head</td>
<td>32.7</td>
</tr>
</tbody>
</table>

◆ Heat Flux : 76W (=51.6W/m²)
◆ Area : 1.471m²
◆ Measurement : Average of 4 times, each time was measured 6 hour after stable air temperature
Measurement Velocity around Thermal Manikin using PIV

Measurement Principle of PIV
(by Dantec Dynamics)
Air Velocity around each Region -1

Low Leg

Pelvis

Above of flow 1.12m
Air Velocity around each Region -2

Chest

Head

![Diagram of chest and head with air velocity data](image)
## Analysis Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Number of Grids</th>
<th>Radiation and Convection Couple Calculation</th>
<th>Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Space [Hundred Thousand]</td>
<td>Surface [Thousand]</td>
<td></td>
</tr>
<tr>
<td>3CM</td>
<td>3</td>
<td>19</td>
<td>x (Only Convection Calculation)</td>
</tr>
<tr>
<td>3RU</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>3RM</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>6CU</td>
<td>6</td>
<td>34</td>
<td>x (Only Convection Calculation)</td>
</tr>
<tr>
<td>6CM</td>
<td></td>
<td></td>
<td>x (Only Convection Calculation)</td>
</tr>
<tr>
<td>6RM</td>
<td></td>
<td></td>
<td>○</td>
</tr>
</tbody>
</table>
## Analysis Boundary Condition for CFD

### CFD
- Software: Star-CD
- Unsteady State Analysis
- Algorithm: PISO
- Turbulence Mode: Non-Linear Low Reynolds Number K-e Model
- Scheme: ① UD (First Order Upwind)  
  ② MARS (=MUSCL-TVD Method)

### Supply Opening
- Size: 0.4m(W) X 0.2m(H)
- Air Temperature: 22°C
- Air Velocity: 0.18m/s
- Airflow: 51.8m³/h
- Turbulence Intensity: 30%
- Length Scale: 0.1m

### Exhaust Opening
- Size: 0.4m(W) X 0.2m(H)
- free-slip

### Computational Thermal Manikin
- Heat Flux
  ① Radiation and Convection Coupled Calculation: 76W
  ② Only Convection Calculation: 38W (=27.02 W/m²)
- Surface: no-slip

### Wall
- Heat Flux
  ① Radiation and Convection Couple Calculation: Adiabatic Wall
  ② Only Convection Calculation: 38W (=0.712W/m²)
- Surface: no-slip
Analysis Grid

Space: 3 Hundred Thousand Grids
Surface: 19 Thousand Grids

Space: 6 Hundred Thousand Grids
Surface: 34 Thousand Grids
## Computational Thermal Manikin

### Area of Thermal Manikin [m²]

<table>
<thead>
<tr>
<th>No.</th>
<th>Region</th>
<th>Experimental</th>
<th>Computational</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L.Foot</td>
<td>0.044</td>
<td>0.042</td>
</tr>
<tr>
<td>2</td>
<td>R.Foot</td>
<td>0.043</td>
<td>0.042</td>
</tr>
<tr>
<td>3</td>
<td>L.Low Leg</td>
<td>0.089</td>
<td>0.083</td>
</tr>
<tr>
<td>4</td>
<td>R.Low Leg</td>
<td>0.089</td>
<td>0.083</td>
</tr>
<tr>
<td>5</td>
<td>L.Thigh</td>
<td>0.163</td>
<td>0.164</td>
</tr>
<tr>
<td>6</td>
<td>R.Thigh</td>
<td>0.165</td>
<td>0.164</td>
</tr>
<tr>
<td>7</td>
<td>L.Hand</td>
<td>0.038</td>
<td>0.031</td>
</tr>
<tr>
<td>8</td>
<td>R.Hand</td>
<td>0.037</td>
<td>0.031</td>
</tr>
<tr>
<td>9</td>
<td>L.Forearm</td>
<td>0.050</td>
<td>0.047</td>
</tr>
<tr>
<td>10</td>
<td>R.Forearm</td>
<td>0.050</td>
<td>0.047</td>
</tr>
<tr>
<td>11</td>
<td>L.Shoulder</td>
<td>0.074</td>
<td>0.072</td>
</tr>
<tr>
<td>12</td>
<td>R.Shoulder</td>
<td>0.078</td>
<td>0.072</td>
</tr>
<tr>
<td>13</td>
<td>Pelvis</td>
<td>0.174</td>
<td>0.147</td>
</tr>
<tr>
<td>14</td>
<td>Chest</td>
<td>0.144</td>
<td>0.143</td>
</tr>
<tr>
<td>15</td>
<td>Back</td>
<td>0.133</td>
<td>0.122</td>
</tr>
<tr>
<td>16</td>
<td>Head</td>
<td>0.100</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>1.471</strong></td>
<td><strong>1.407</strong></td>
</tr>
</tbody>
</table>

* Height of Manikin: 1.65m
Airflow Field: Vector Velocity [m/s]

6CM

6RM
Airflow Field: Scalar Velocity [m/s]

3CM

3RM

6CM

6RM
Air Temperature [°C]

3CM

3RM

6CM

6RM
Wall Surface Temperature [°C] - 1

3CM

6CU

6CM
Wall Surface Temperature [°C] - 2

3RU

3RM

6RM
Distribution of Air Velocity in a Room [m/s] - 1

L1

L2

L3

L4
Distribution of Air Velocity in a Room [m/s] - 2

L1

L2

L3

L4
Distribution of Air Temperature in a Room [°C] - 1
Distribution of Air Temperature in a Room [°C] - 2

- L1
- L2
- L3
- L4
Distribution of Skin Surface Temperature [°C] - 1

3CU 6CU 6CM
Distribution of Skin Surface Temperature [°C] - 2
Distribution of Skin Surface Temperature [°C] - 3
Comparison of 2D Air Velocity of CFD and PIV above Head [m/s]

(1) Analysis result of CFD in Case 6RM
(2) Measurement result of PIV in area of ABCD
Distribution of 2D Scalar Air Velocity around each Region [m/s]

- **Head**
  - Height [Z*: m]
  - Velocity [m/s]

- **Pelvis**
  - Distance [Y*: m]
  - Velocity [m/s]

- **Low Leg**
  - Distance [Y*: m]
  - Velocity [m/s]
Heat Balance between Human Body and Surrounding Walls [W]

3RU

3RM

6RM

Radiative Heat Transfer [W]

Convective Heat Transfer [W]
Conclusions

• The rising stream around the thermal mannequin was observed in the experiment and the CFD

• The maximum velocity of the rising stream was about 30 cm/s

• CFD with 600,000 mesh system gave good correspondence to the experiment

• CFD with MRAS scheme gave good result comparing that with first order upwind scheme

• CFD coupled with radiation simulation gave good result