

Benchmark Tests for Computer Simulated Person

- Mixing Ventilation Cases-

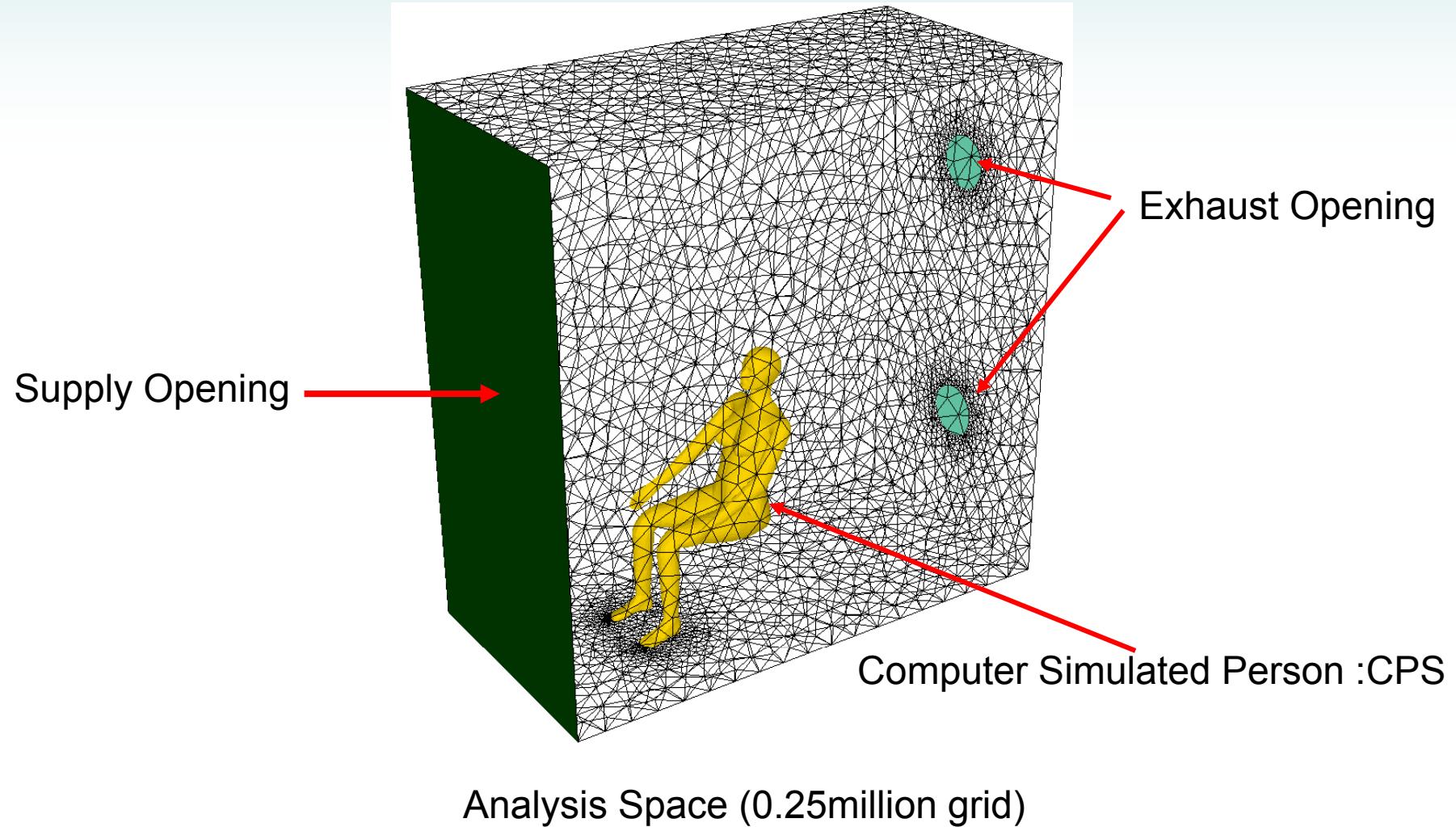
S. Murakami

Keio University

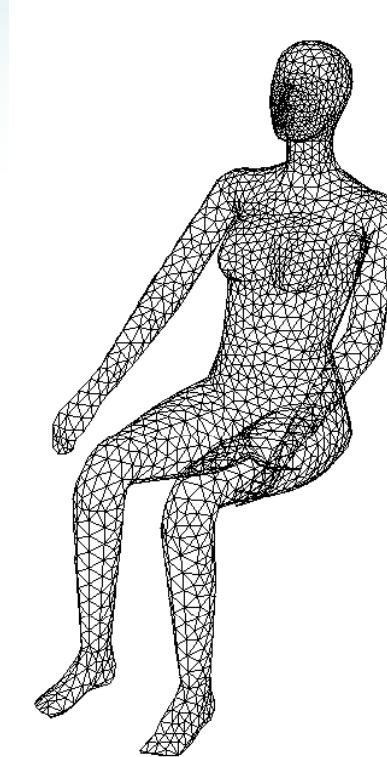
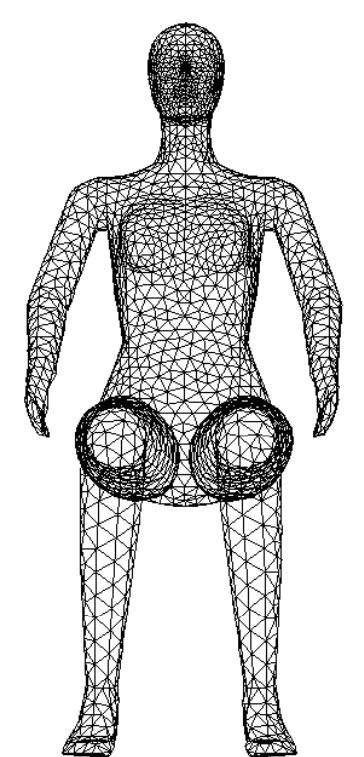
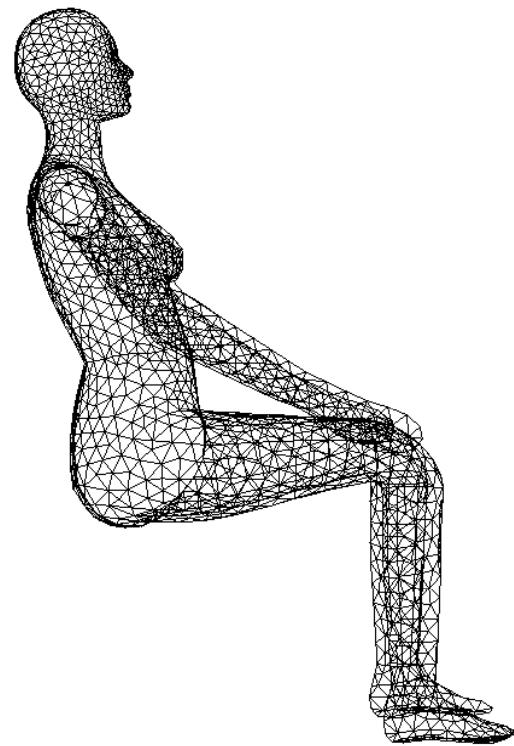
S. Kato J.H. Yang

University of Tokyo

Analysis Space



Outline of CPS



*Area : 1,473m²

*Height of seat CPS : 1.2m

Analysis boundary conditions

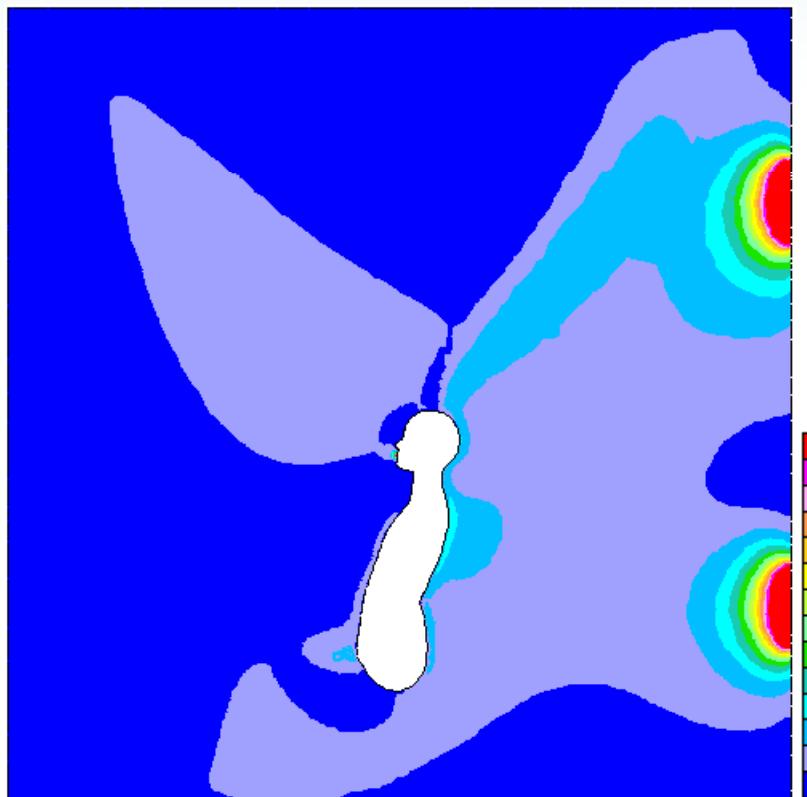
- (a) Software: Star-CD
- (b) Steady state Calculation
- (c) Algorithm: SIMPLE
- (d) Turbulence Model: Low Reynolds number k- ϵ model
- (e) Scheme: MARS (for Tetra mesh)
- (f) Grid: 0.25million, 0.5million, 1million
 - Tetra Mesh in Space, Hybrid Mesh around CPS
- (g) Convection and Radiation combined simulation
 - *Heat flux is 76W
 - *Radiation Program have been developed by Dr.Omori at Tokyo Gas Co. of Japan
- (h) Breathing: Steady breathing at mouth
 - *Amount of breathing: 19.2 liters/min (=0.00032m³/s)
 - *Mouth area: 9.726E-05 m²

Analysis cases

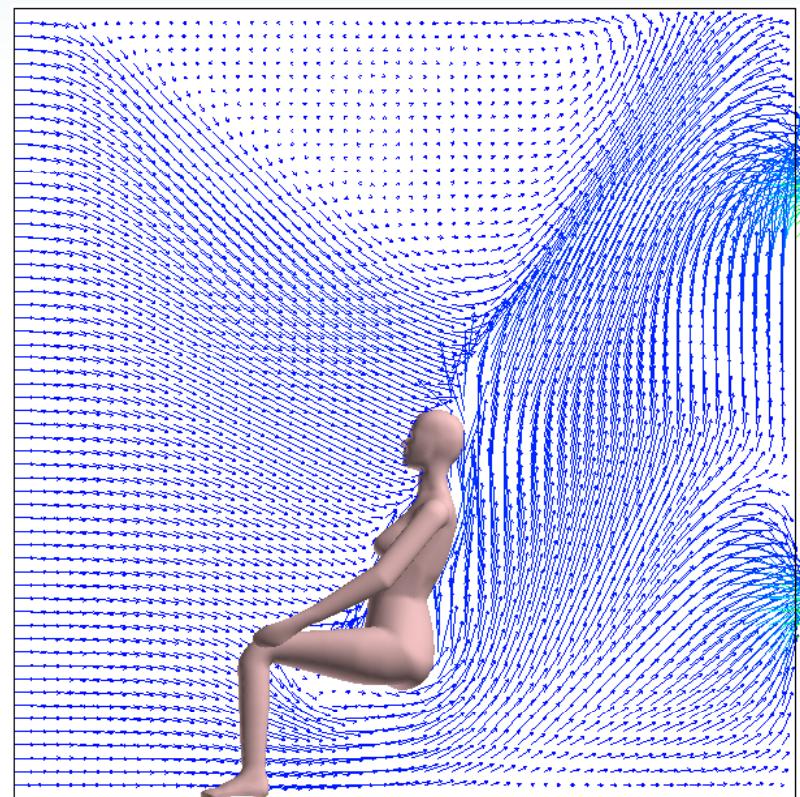
| Case | Air Characteristics | Number of grid | | |
|------|---------------------|--|-------------------------------|------|
| | | Space [million] | Human Surface [thousand] | |
| 1 | 1-1 | $U_o=0.05\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=6.0\text{E-}04$ $\varepsilon_o=4.8\text{E-}06$ | 0.25 | 12.8 |
| | 1-2 | | 1 | 21.9 |
| 2 | 2-1 | $U_o=0.2\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=9.6\text{E-}03$ $\varepsilon_o=3.1\text{E-}04$ | 0.25 | 12.8 |
| | 2-2 | | 0.5 | 16.1 |
| | 2-3 | | 1 | 21.9 |
| 3 | 3-1 | $U_o=0.5\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=6.0\text{E-}02$ $\varepsilon_o=4.8\text{E-}03$ | 0.25 | 12.8 |
| | 3-2 | | 0.5 | 16.1 |
| | 3-3 | | 1 | 21.9 |

Result of Case1

1) Distribution of air velocity: Case1-2



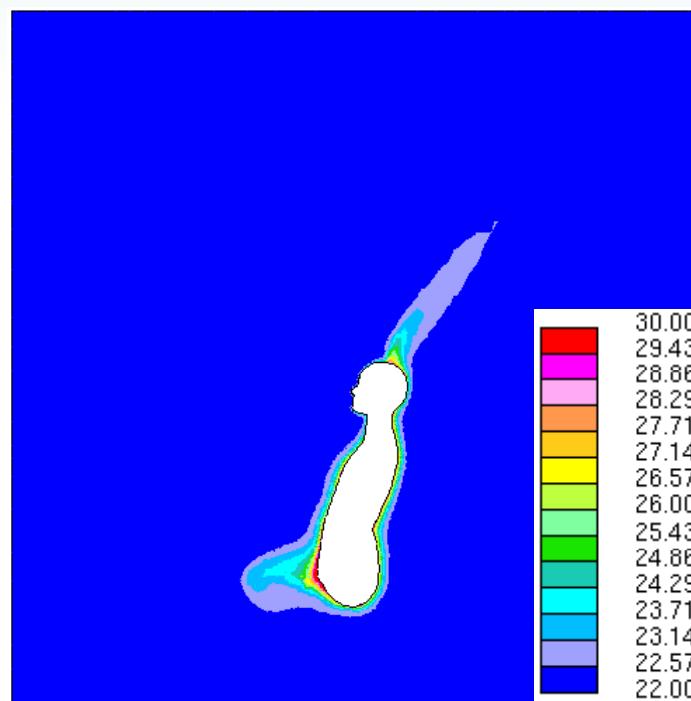
(a) Scalar air velocity [m/s]



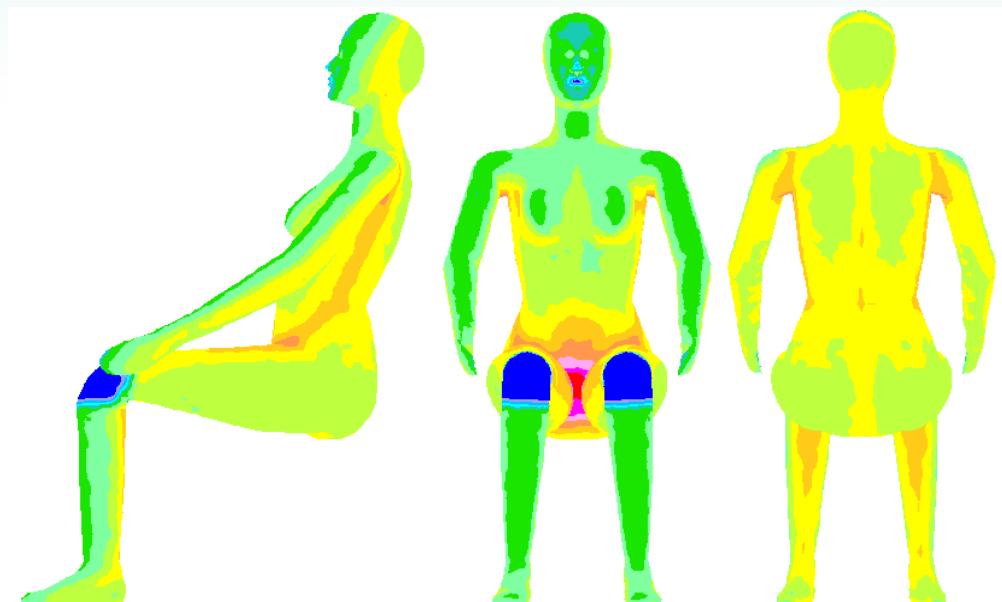
(b) Airflow pattern

Result of Case1

2) Distribution of temperature: Case1-2



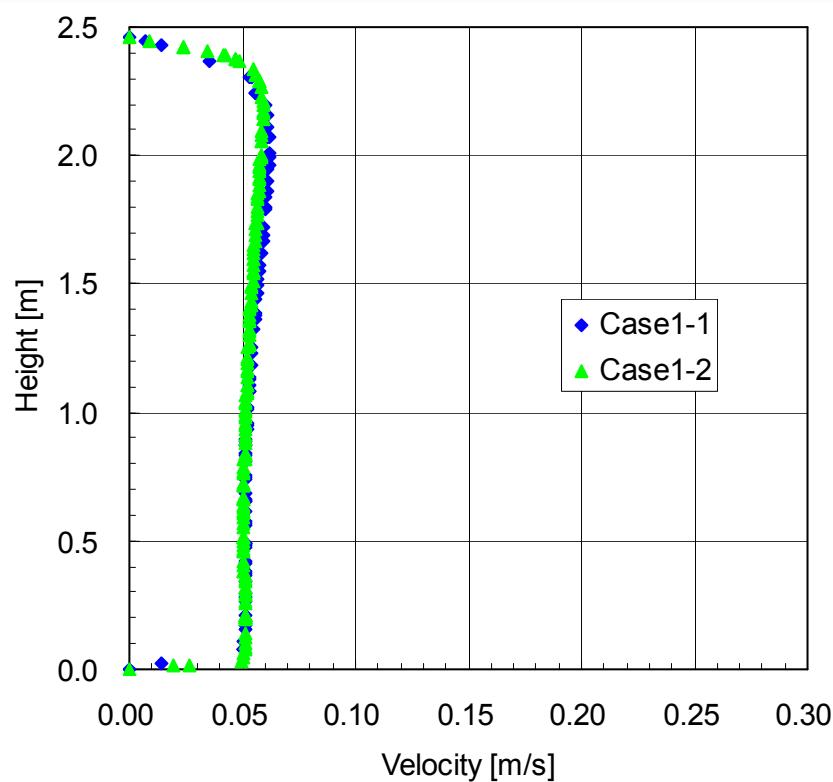
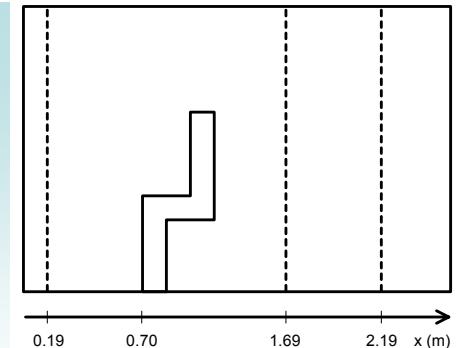
(a) Distribution of air temperature [°C]



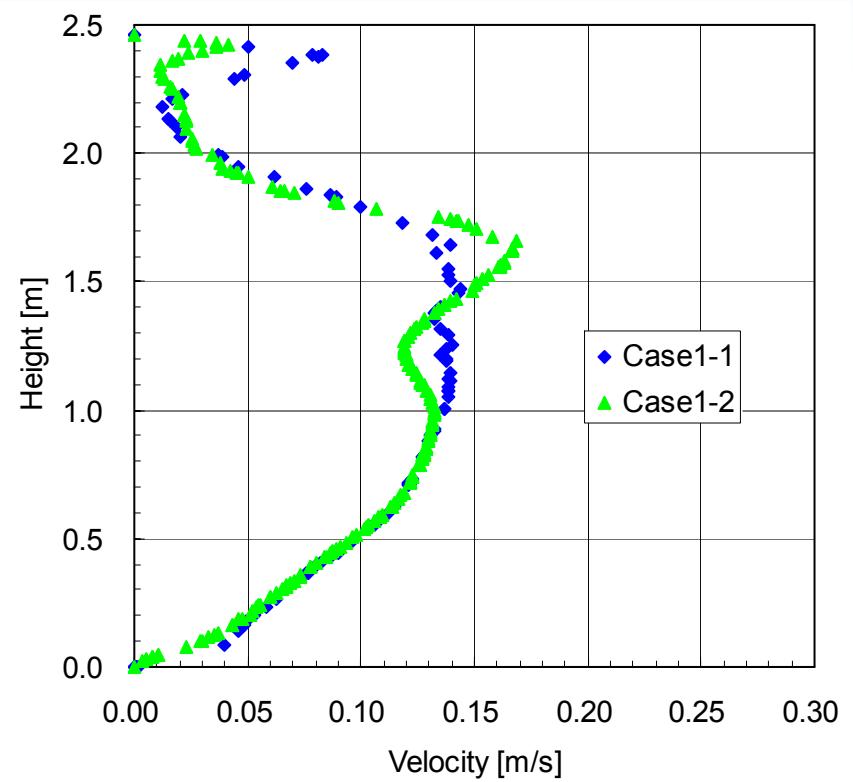
(a) Distribution of CPS's surface temperature [°C]

Result of Case1

3) Vertical air velocity profile at each position



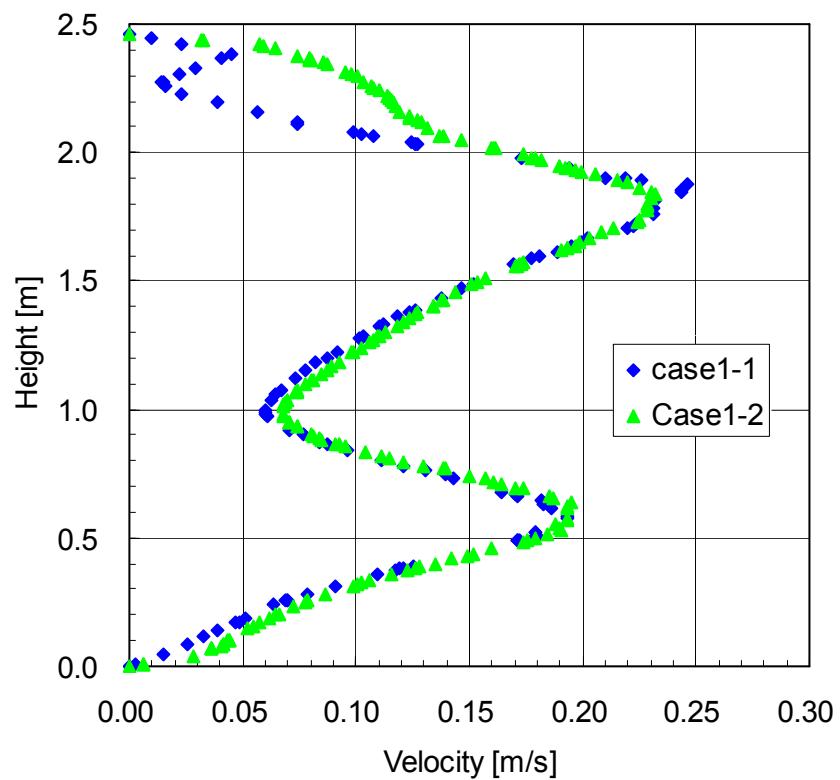
(a) $X: 0.19$ m



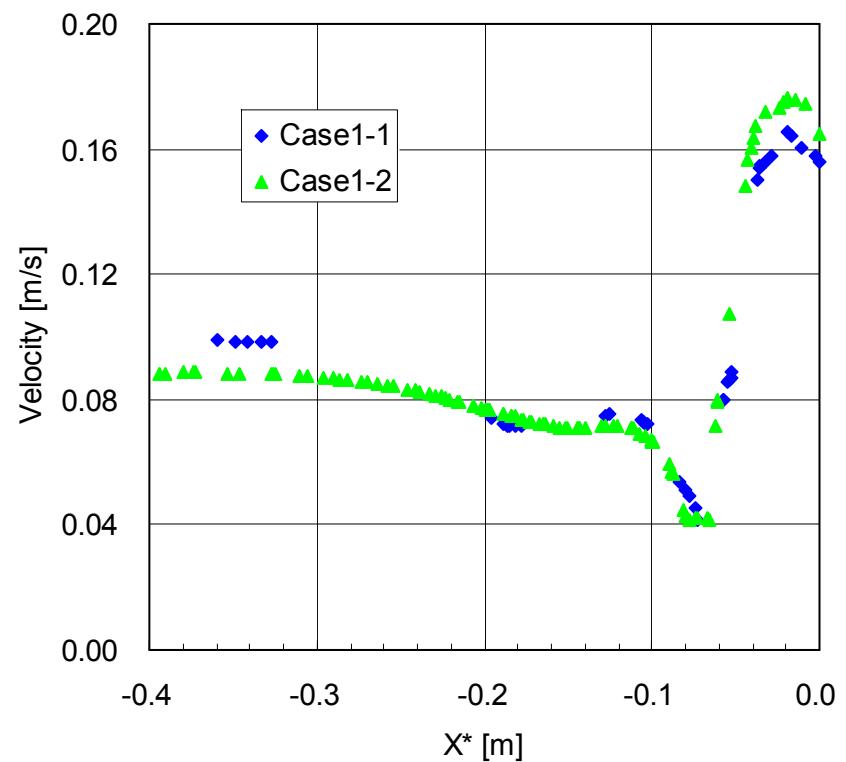
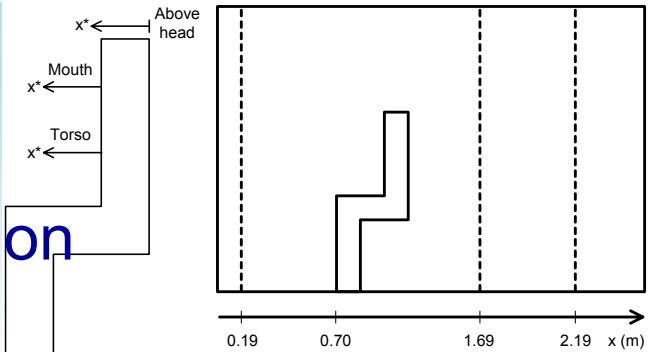
(b) $X: 1.69$ m

Result of Case1

3) Vertical air velocity profile at each position



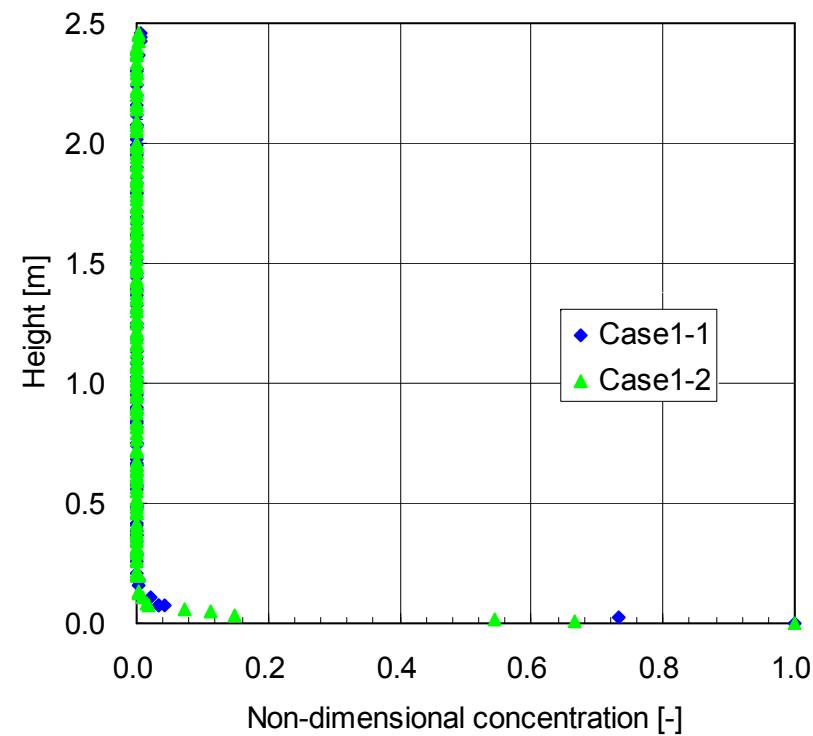
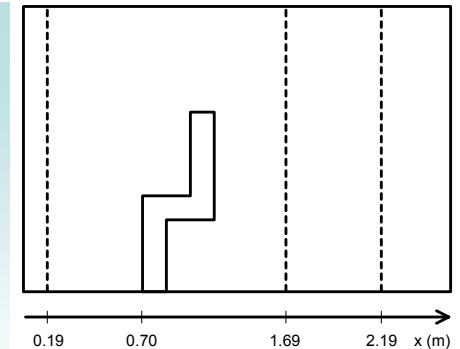
(c) $X: 2.19\text{m}$



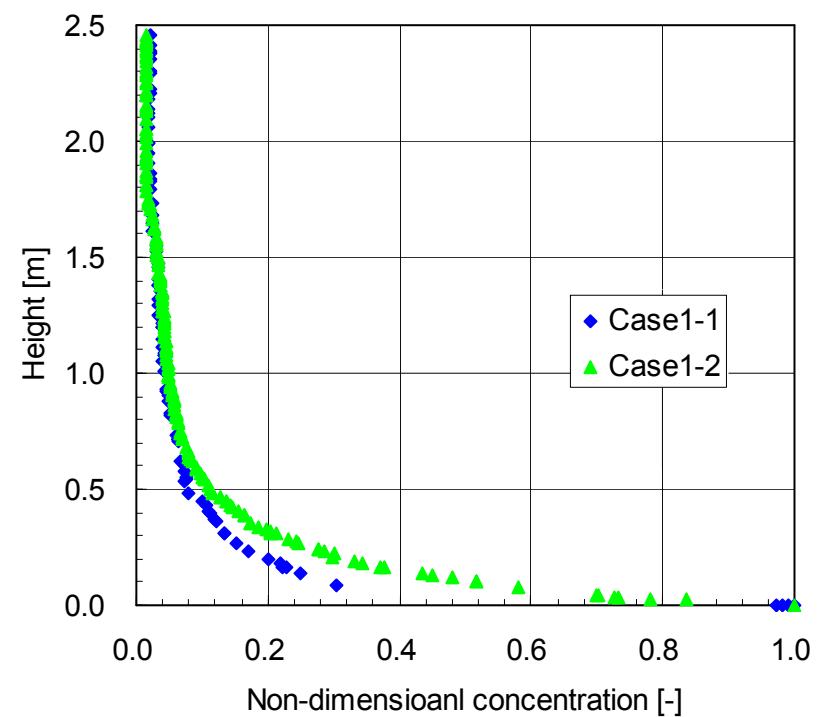
(d) Above head

Result of Case1

4) Concentration gradients at each position



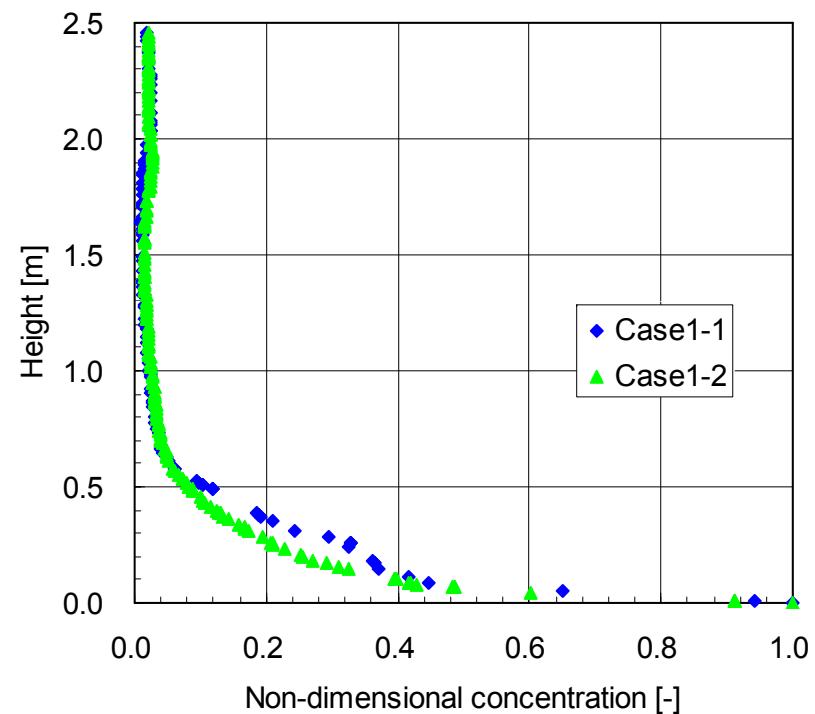
(a) $X: 0.19\text{m}$



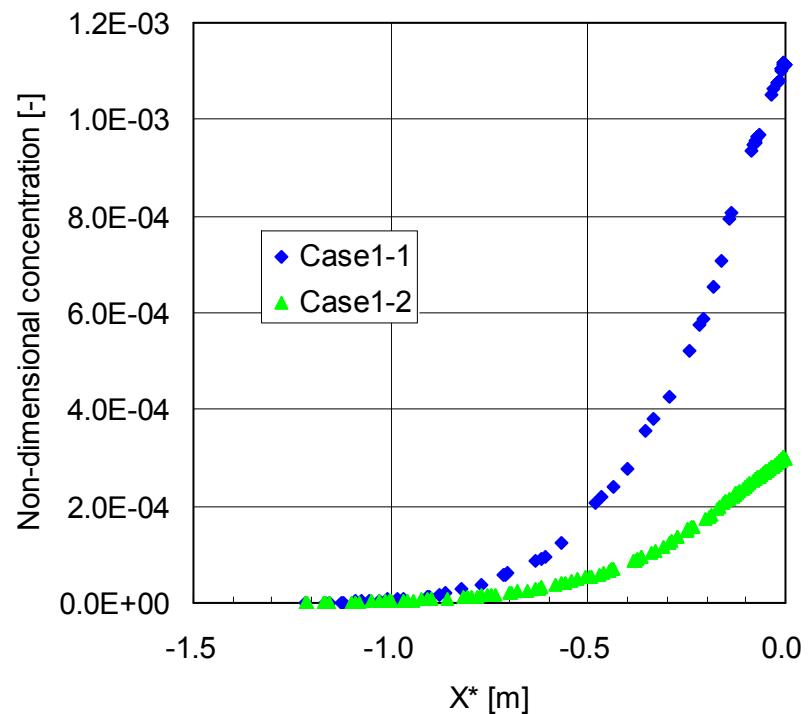
(b) $X: 1.69\text{m}$

Result of Case1

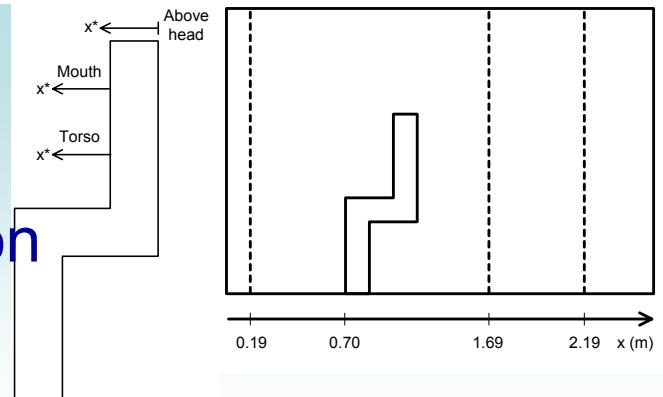
4) Concentration gradients at each position



(c) X: 2.19m

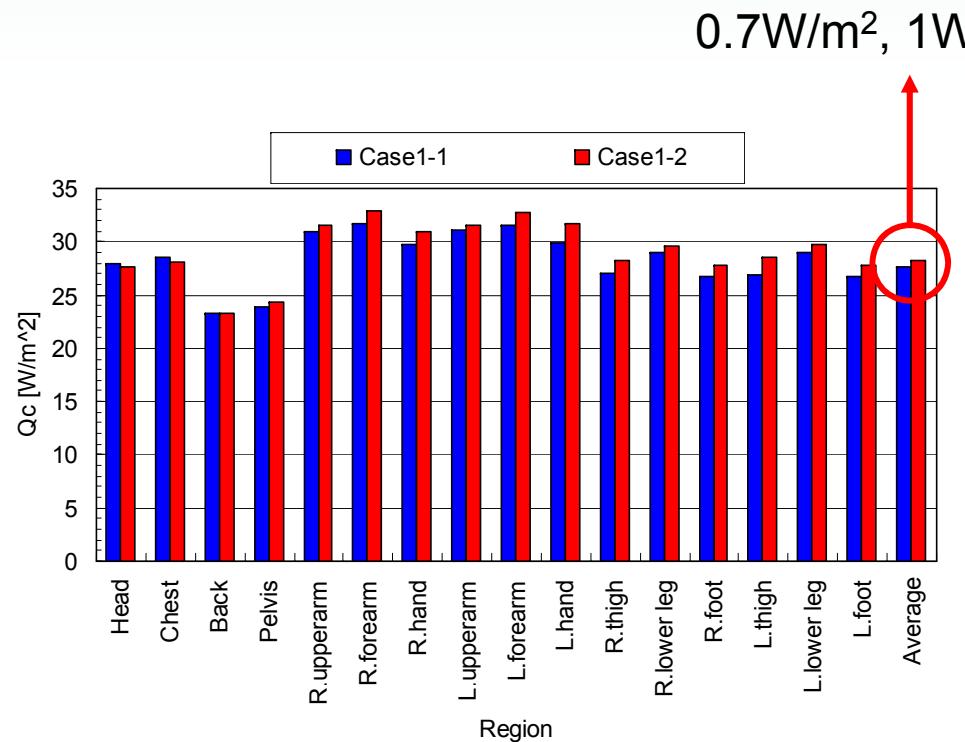


(d) Mouth



Result of Case1

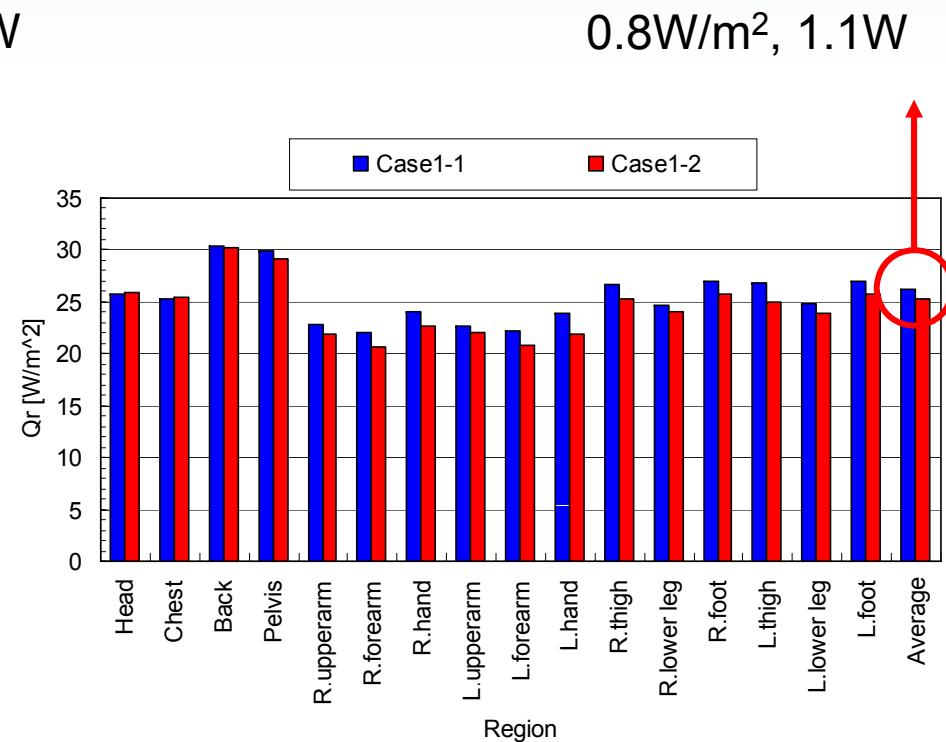
5) Result of radiation analysis



(a) Convective heat transfer rate [W/m²]

*Case1-1:27.57

*Case1-2:28.25



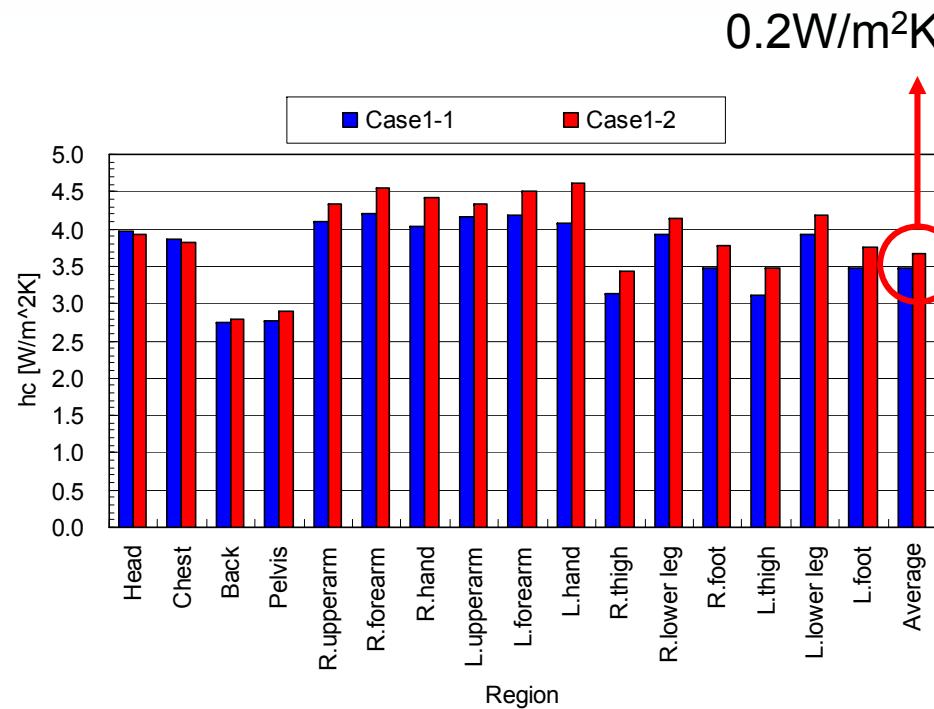
(b) Radiative heat transfer rate [W/m²]

*Case1-1:26.14

*Case1-2:25.32

Result of Case1

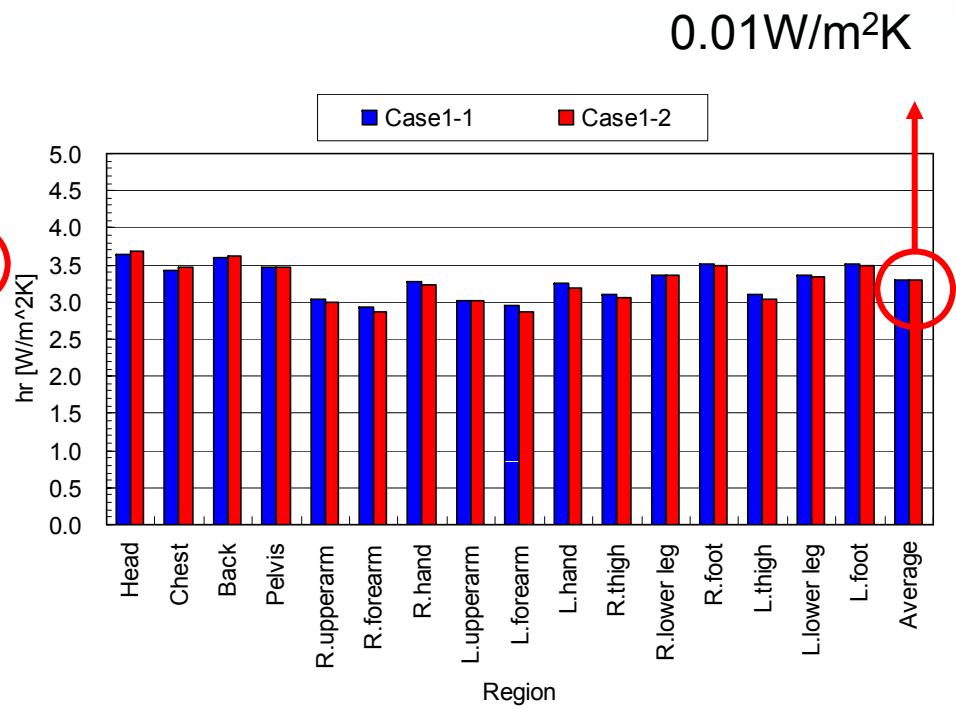
5) Result of radiation analysis



(c) Convective heat transfer rate coefficient
[$\text{W/m}^2\text{K}$]

*Case1-1:3.49

*Case1-2:3.67



(d) Radiative heat transfer rate coefficient
[$\text{W/m}^2\text{K}$]

*Case1-1:3.3

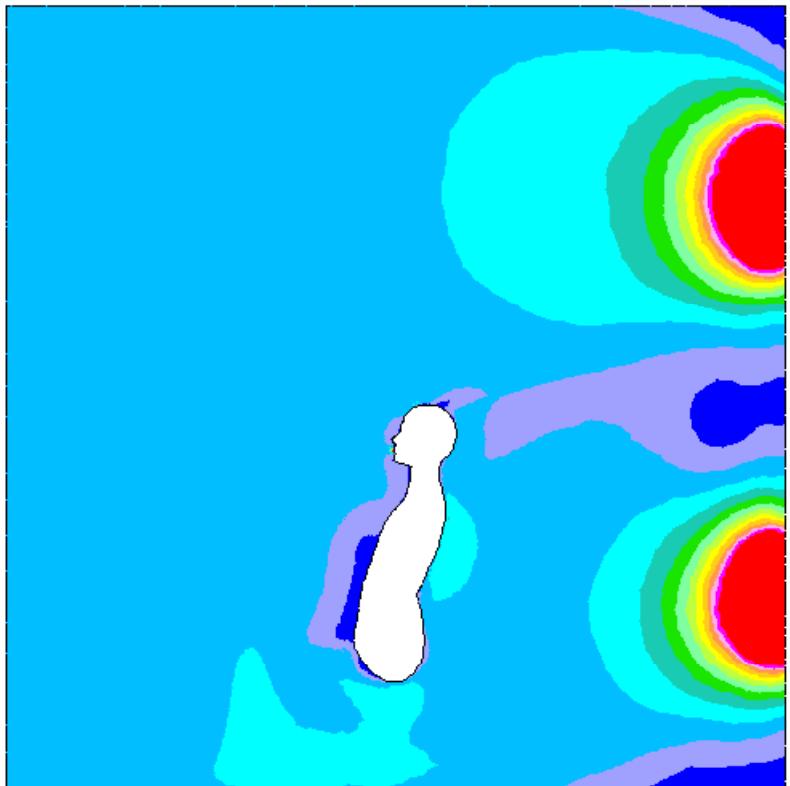
*Case1-2:3.29

Analysis cases

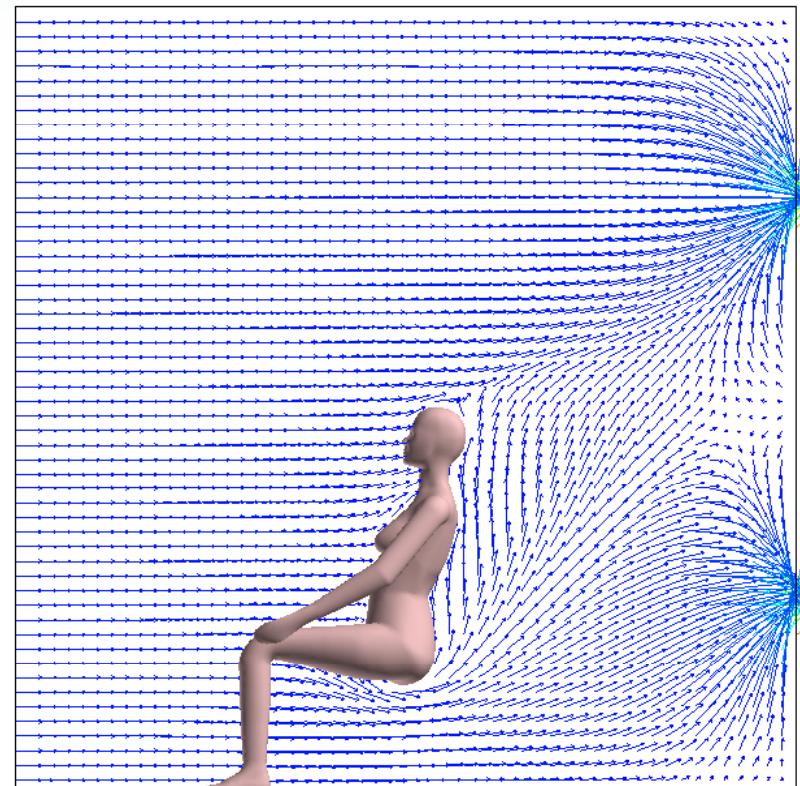
| Case | | Air Characteristics | Number of grid | |
|------|-----|--|----------------------|-------------------------------|
| | | | Space [million] | Human Surface [thousand] |
| 1 | 1-1 | $U_o=0.05\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=6.0\text{E-}04$ $\varepsilon_o=4.8\text{E-}06$ | 0.25 | 12.8 |
| | 1-2 | | 1 | 21.9 |
| 2 | 2-1 | $U_o=0.2\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=9.6\text{E-}03$ $\varepsilon_o=3.1\text{E-}04$ | 0.25 | 12.8 |
| | 2-2 | | 0.5 | 16.1 |
| | 2-3 | | 1 | 21.9 |
| 3 | 3-1 | $U_o=0.5\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=6.0\text{E-}02$ $\varepsilon_o=4.8\text{E-}03$ | 0.25 | 12.8 |
| | 3-2 | | 0.5 | 16.1 |
| | 3-3 | | 1 | 21.9 |

Result of Case2

1) Distribution of air velocity: Case2-3



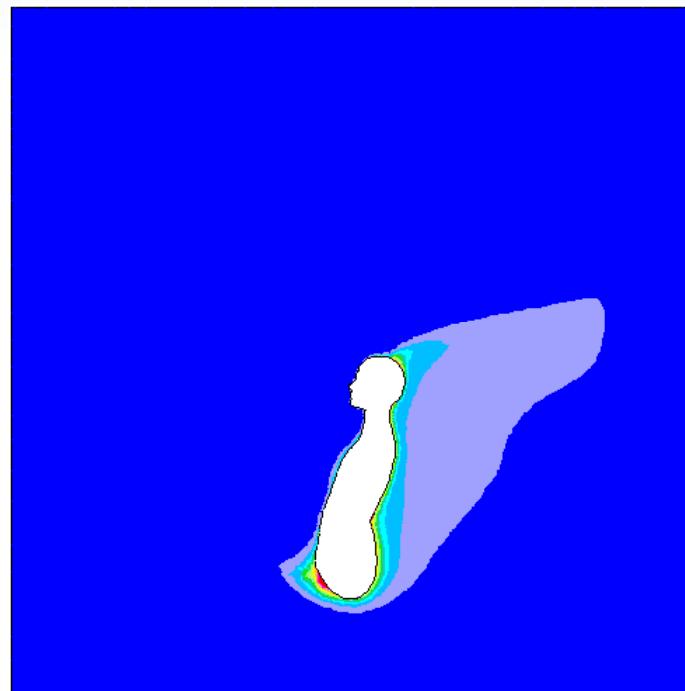
(a) Scalar air velocity [m/s]



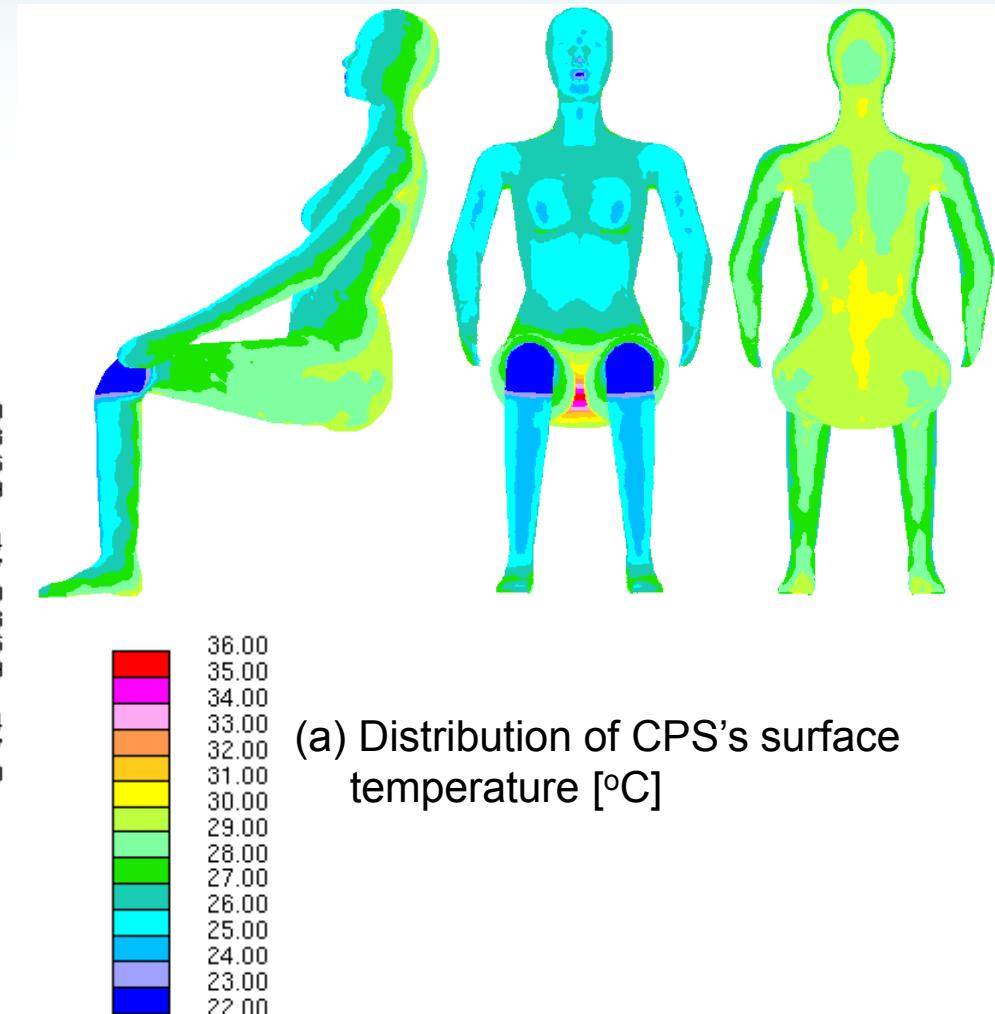
(b) Airflow pattern

Result of Case2

2) Distribution of temperature: Case2-3



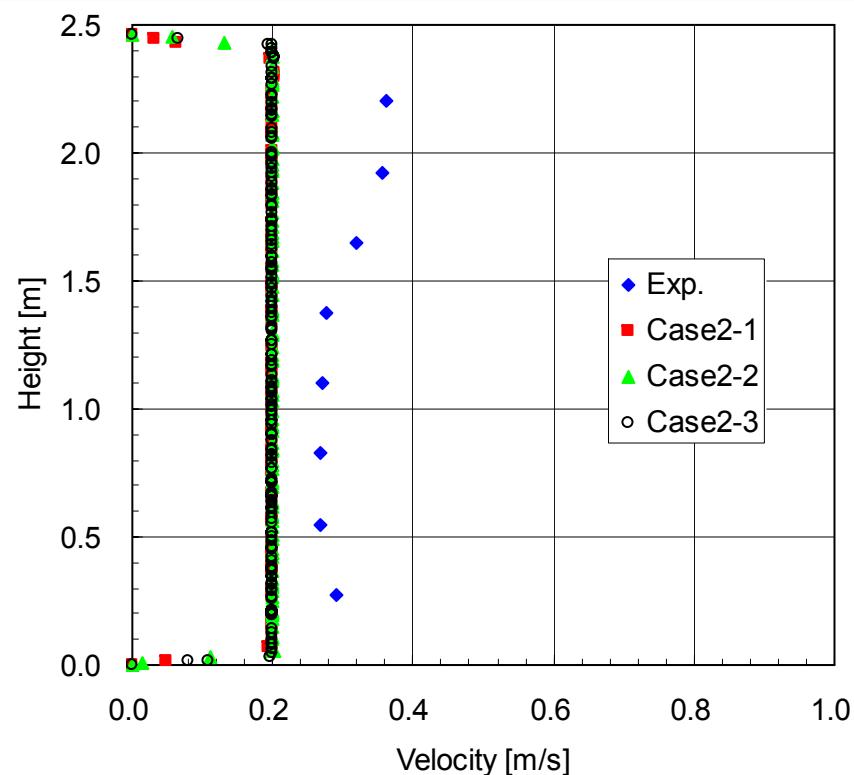
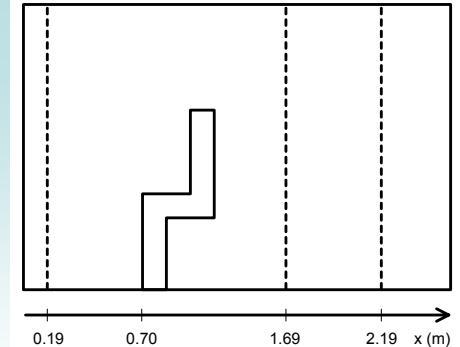
(a) Distribution of air temperature [°C]



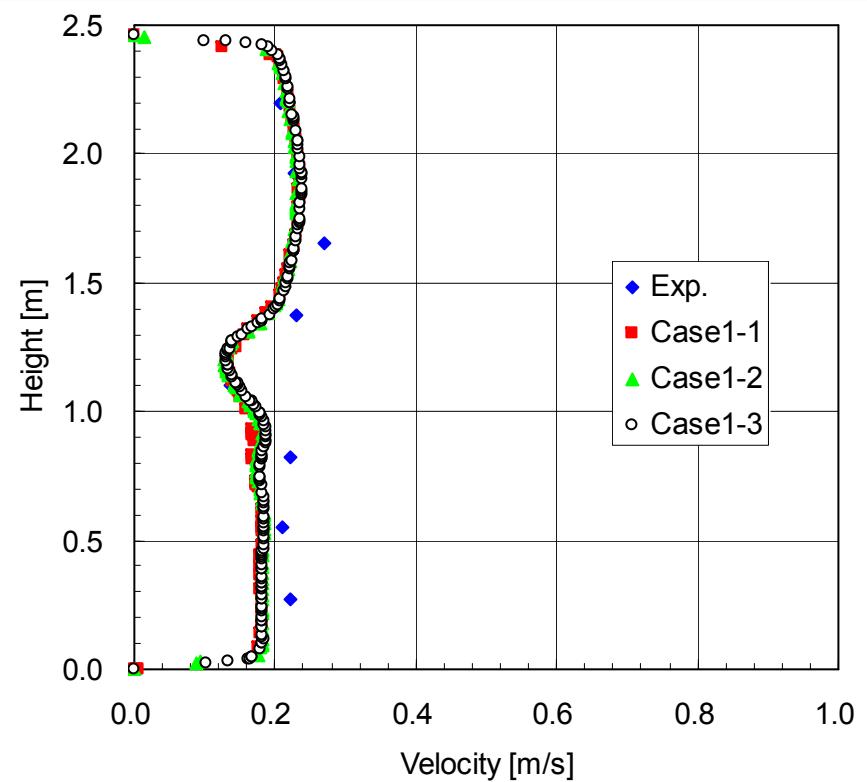
(a) Distribution of CPS's surface temperature [°C]

Result of Case2

3) Vertical air velocity profile at each position



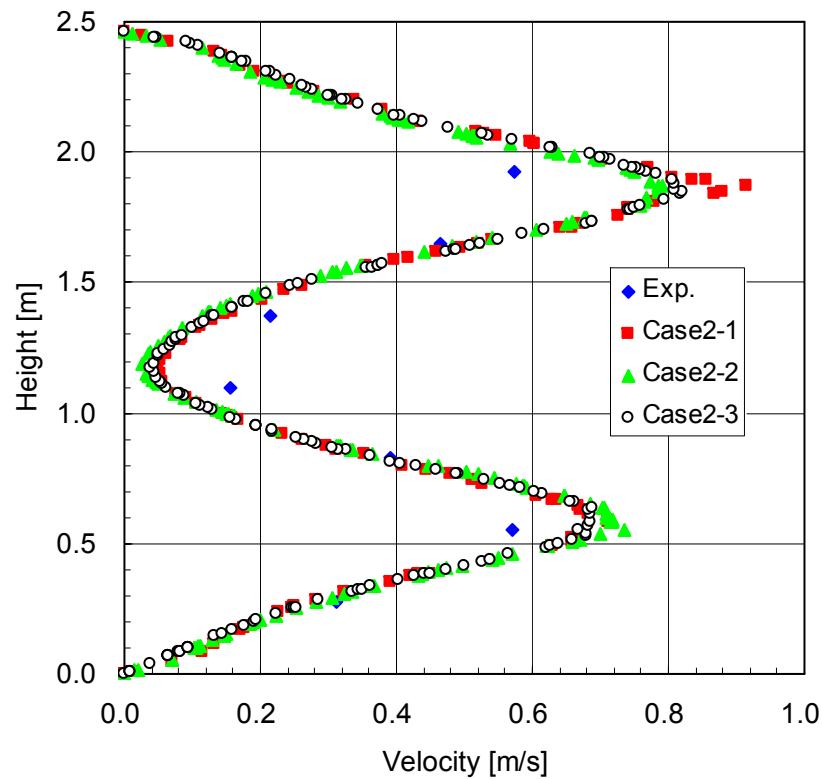
(a) $X: 0.19\text{m}$



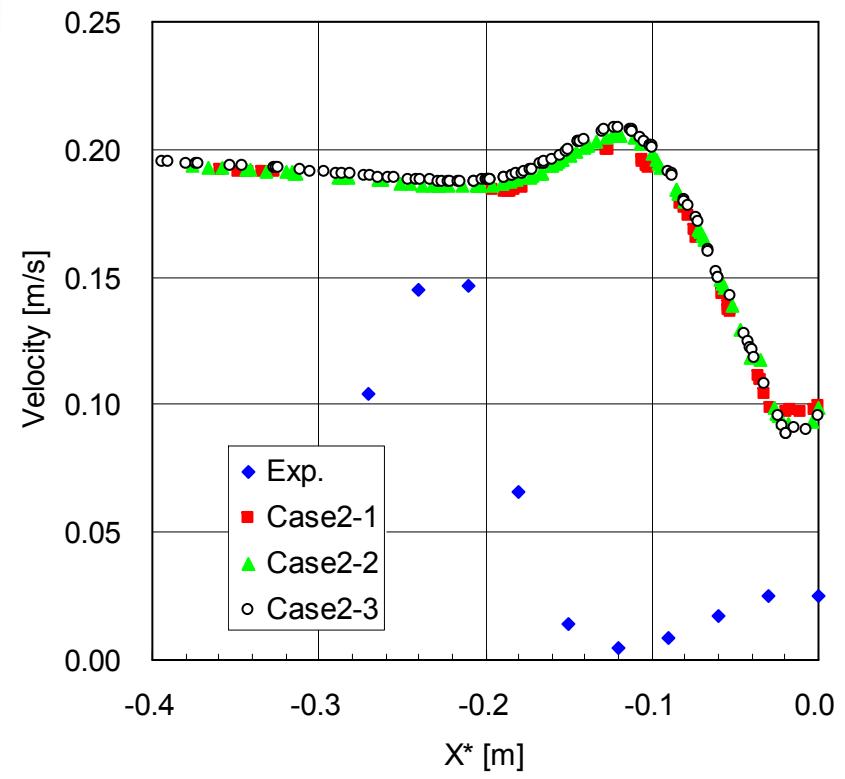
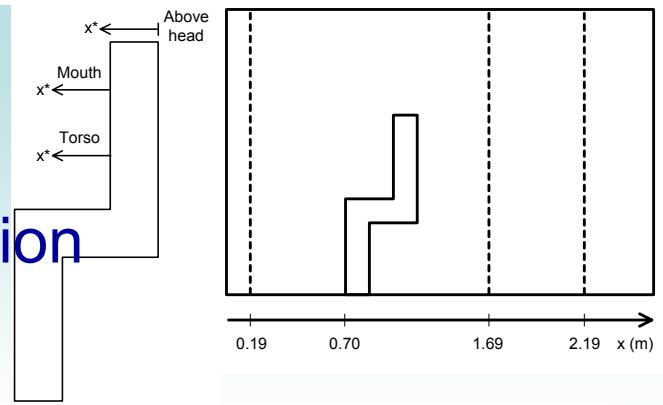
(b) $X: 1.69\text{m}$

Result of Case2

3) Vertical air velocity profile at each position



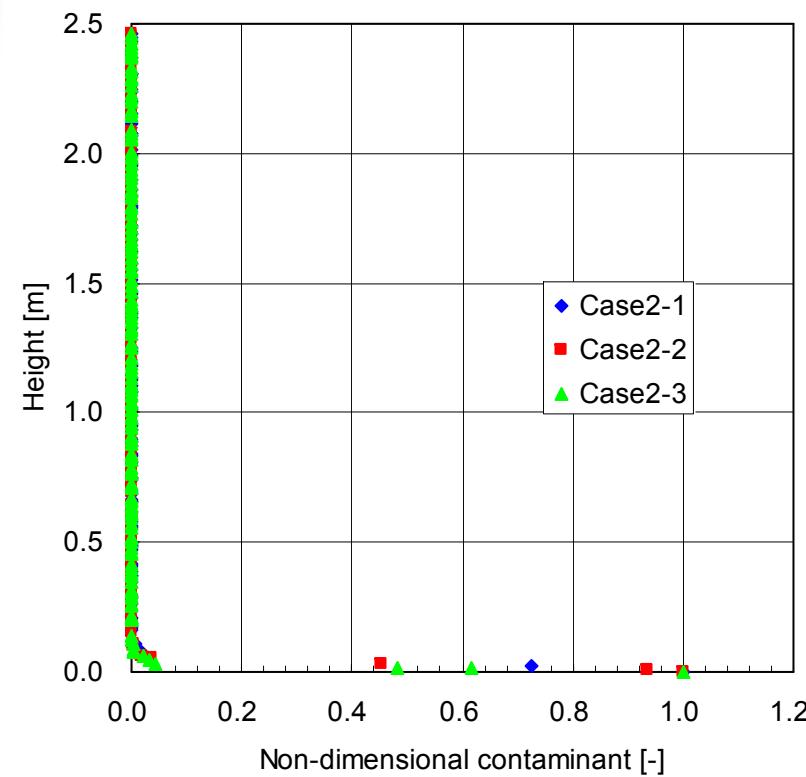
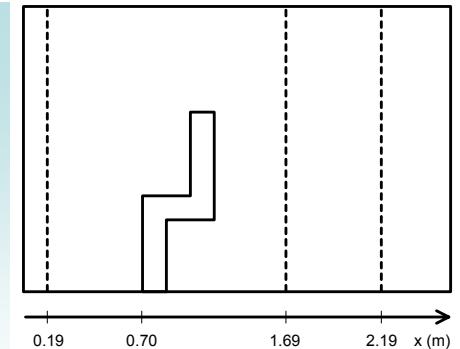
(c) $X: 2.19\text{m}$



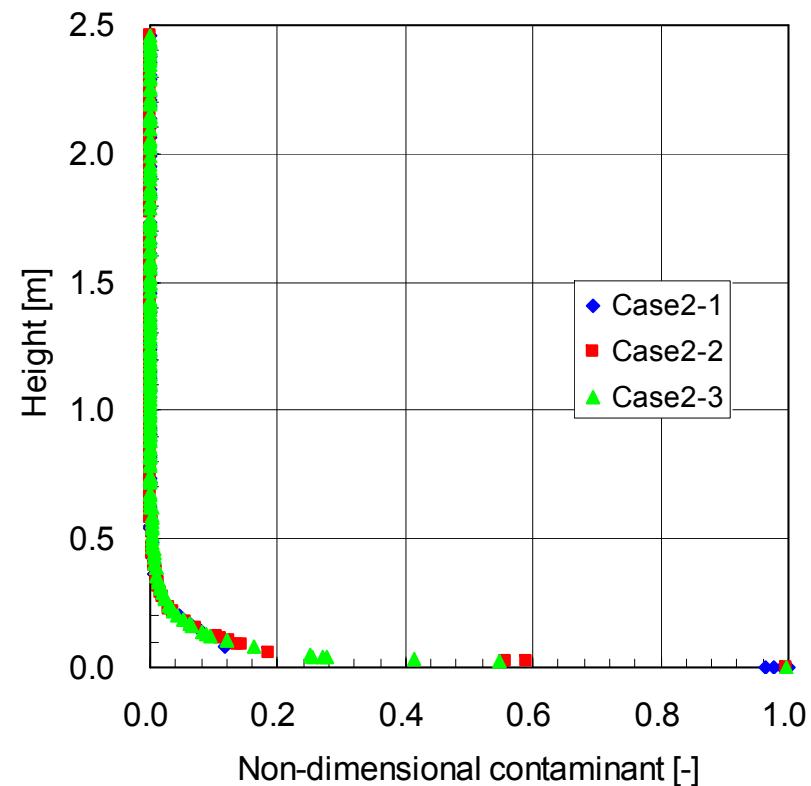
(d) Above head

Result of Case2

4) Concentration gradients at each position



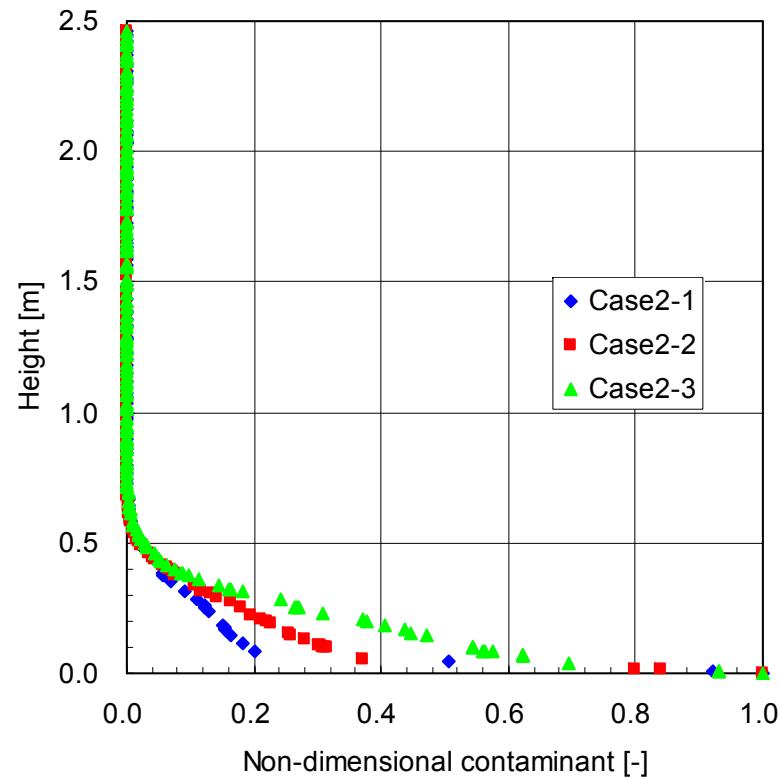
(a) X: 0.19m



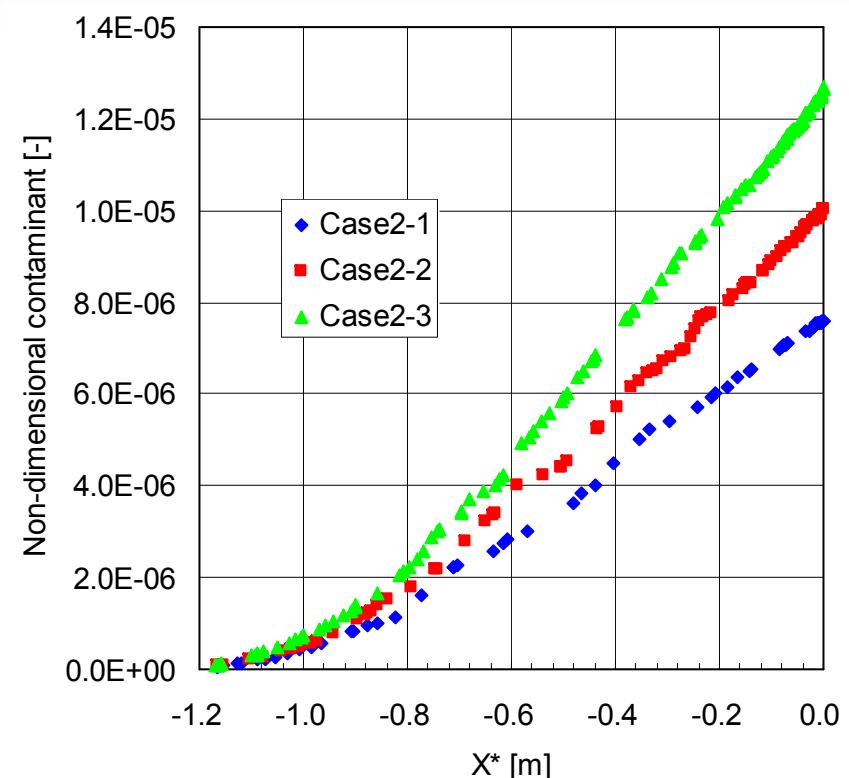
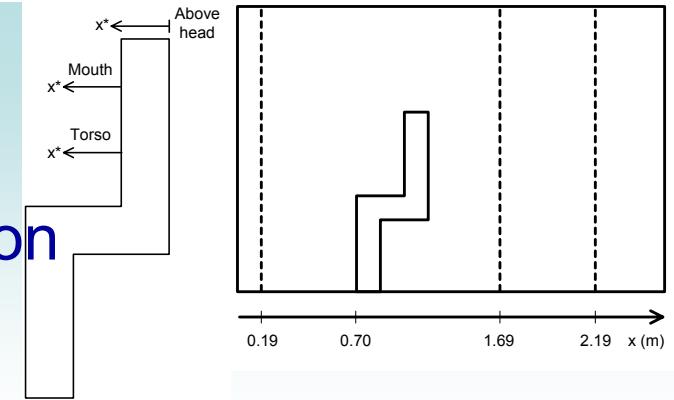
(b) X: 1.69m

Result of Case2

4) Concentration gradients at each Position



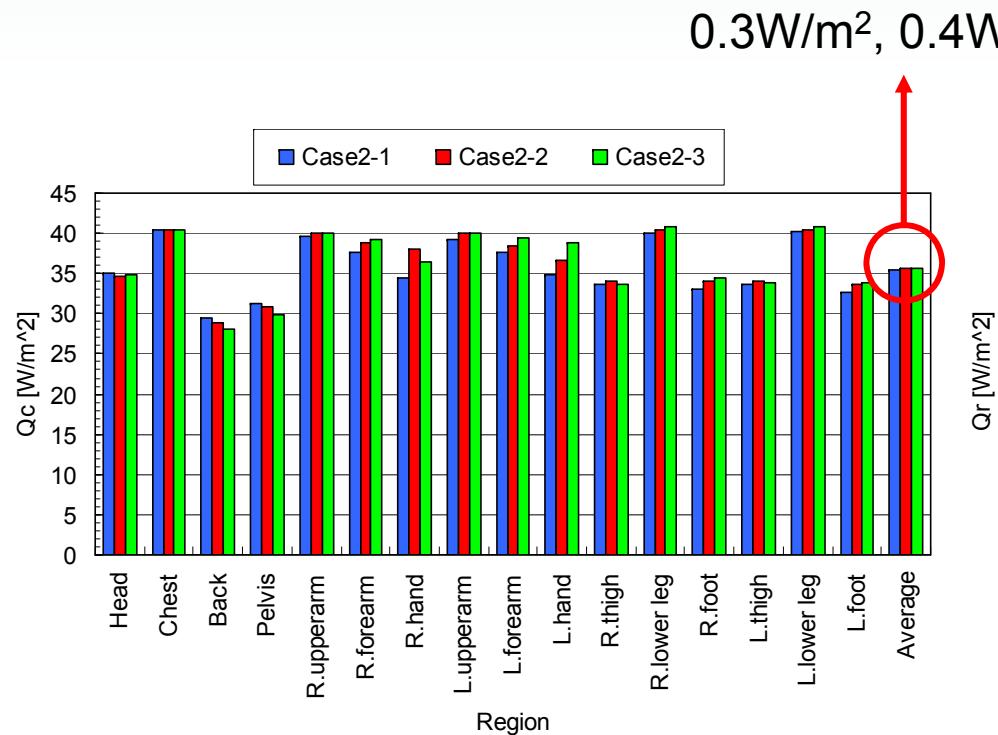
(c) $X: 2.19\text{m}$



(d) Mouth

Result of Case2

5) Result of radiation analysis

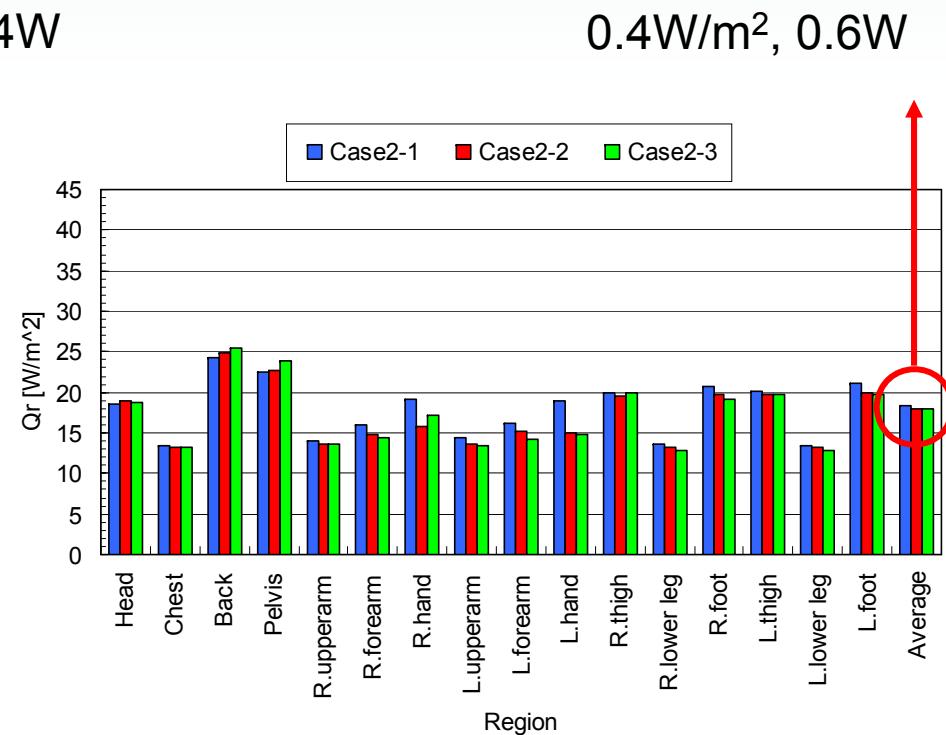


(a) Convective heat transfer rate [W/m^2]

*Case2-1:35.42

*Case2-2:35.7

*Case2-3:35.55



(b) Radiative heat transfer rate [W/m^2]

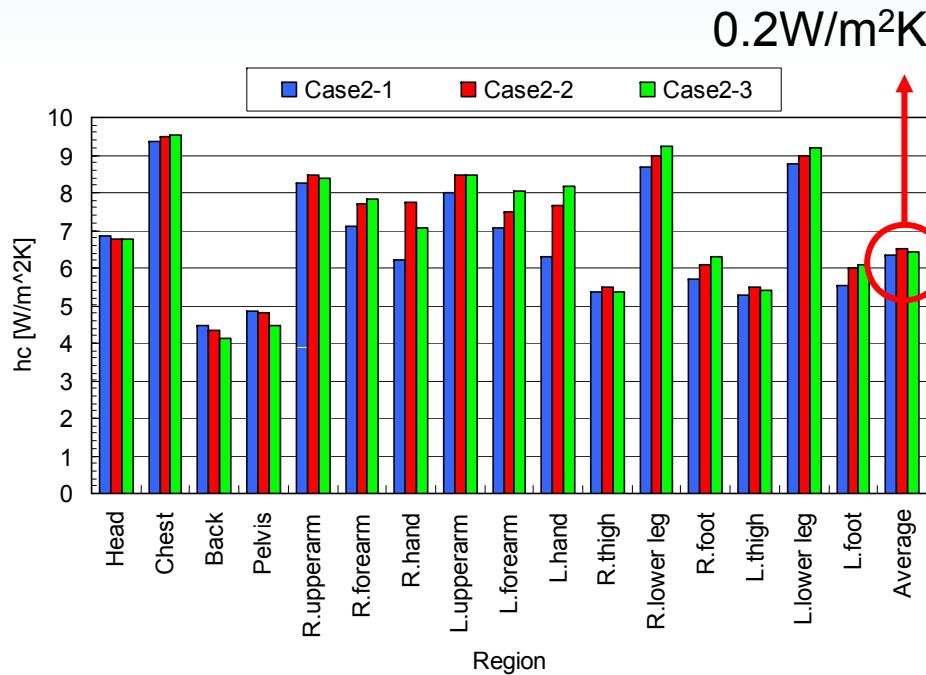
*Case2-1:18.28

*Case2-2:17.91

*Case2-3:18.03

Result of Case2

5) Result of radiation analysis

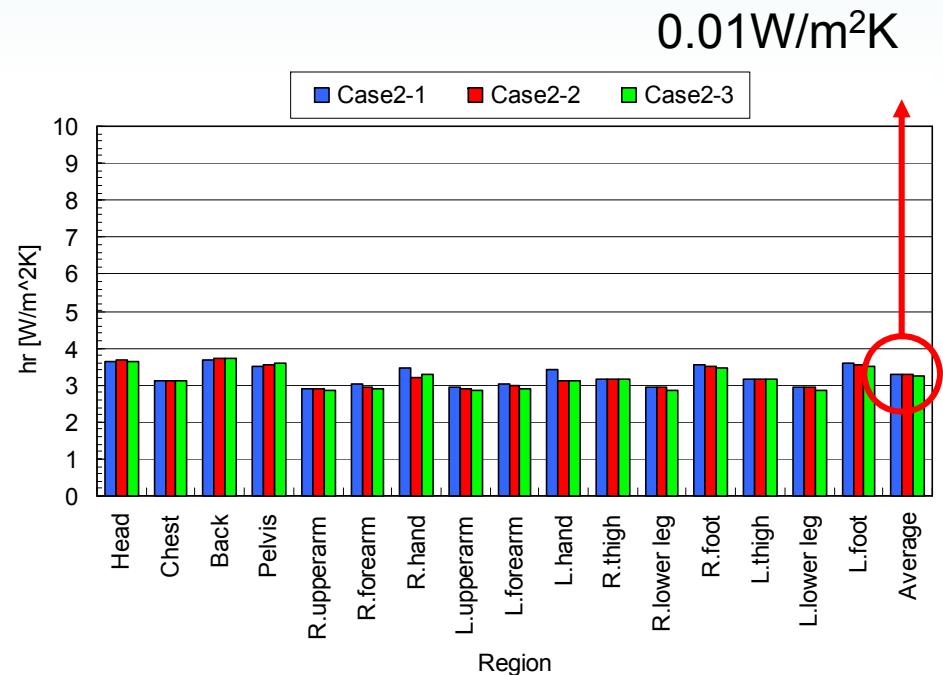


(c) Convective heat transfer rate coefficient
[W/m²K]

*Case2-1:6.35

*Case2-2:6.53

*Case2-3:6.44



(d) Radiative heat transfer rate coefficient
[W/m²K]

*Case2-1:3.28

*Case2-2:3.27

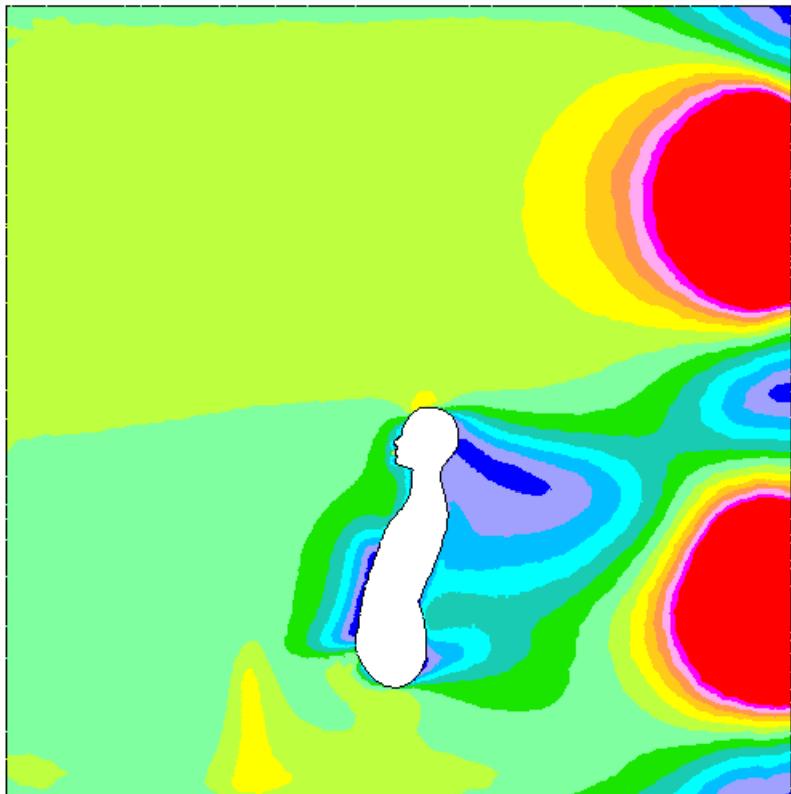
*Case2-3:3.27

Analysis cases

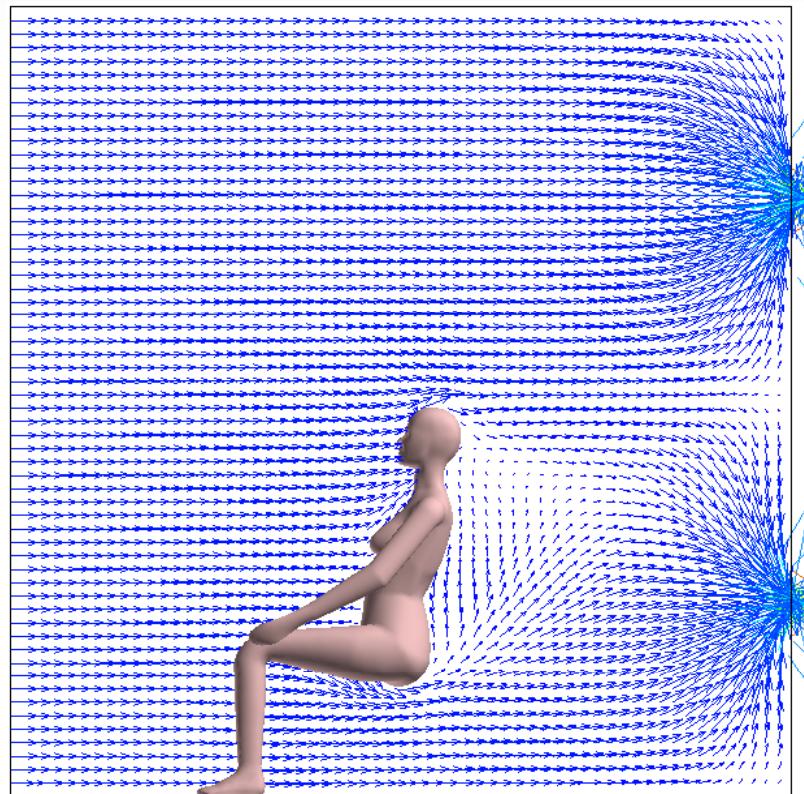
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| 1 | 1-1 | $U_o=0.05\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=6.0\text{E-}04$ $\varepsilon_o=4.8\text{E-}06$ | 0.25 |
| | 1-2 | | 1 |
| 2 | 2-1 | $U_o=0.2\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=9.6\text{E-}03$ $\varepsilon_o=3.1\text{E-}04$ | 0.25 |
| | 2-2 | | 0.5 |
| | 2-3 | | 1 |
| 3 | 3-1 | $U_o=0.5\text{m/s}$ $T_o=22^\circ\text{C}$ $k_o=6.0\text{E-}02$ $\varepsilon_o=4.8\text{E-}03$ | 0.25 |
| | 3-2 | | 0.5 |
| | 3-3 | | 1 |

Result of Case3

1) Distribution of air velocity: Case3-3



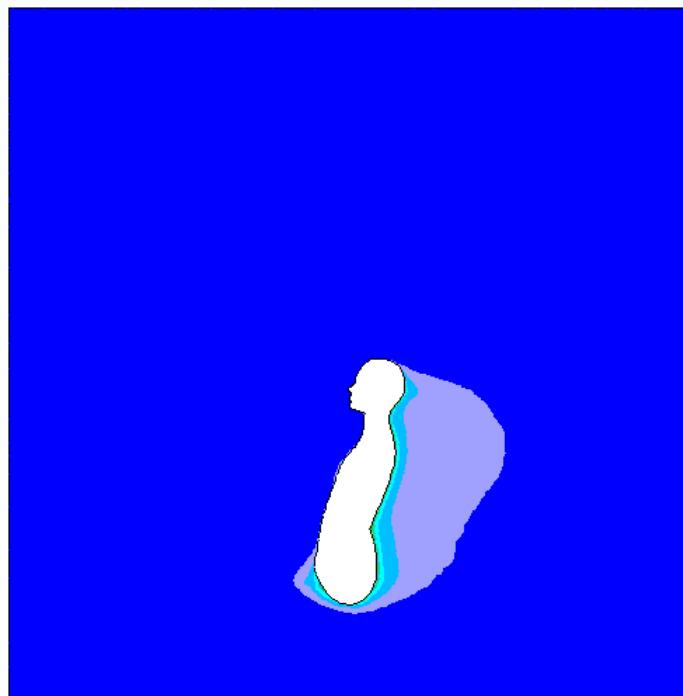
(a) Scalar air velocity [m/s]



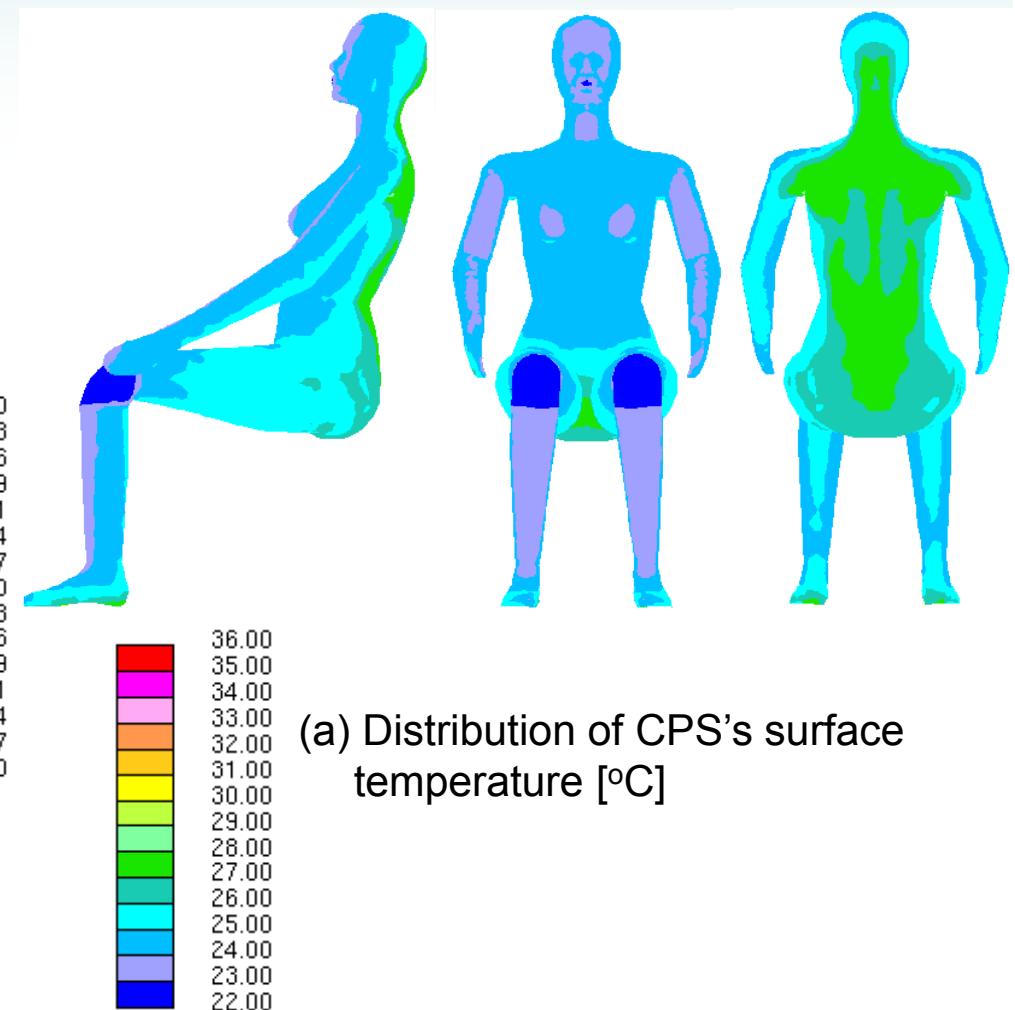
(b) Airflow pattern

Result of Case3

2) Distribution of temperature: Case3-3



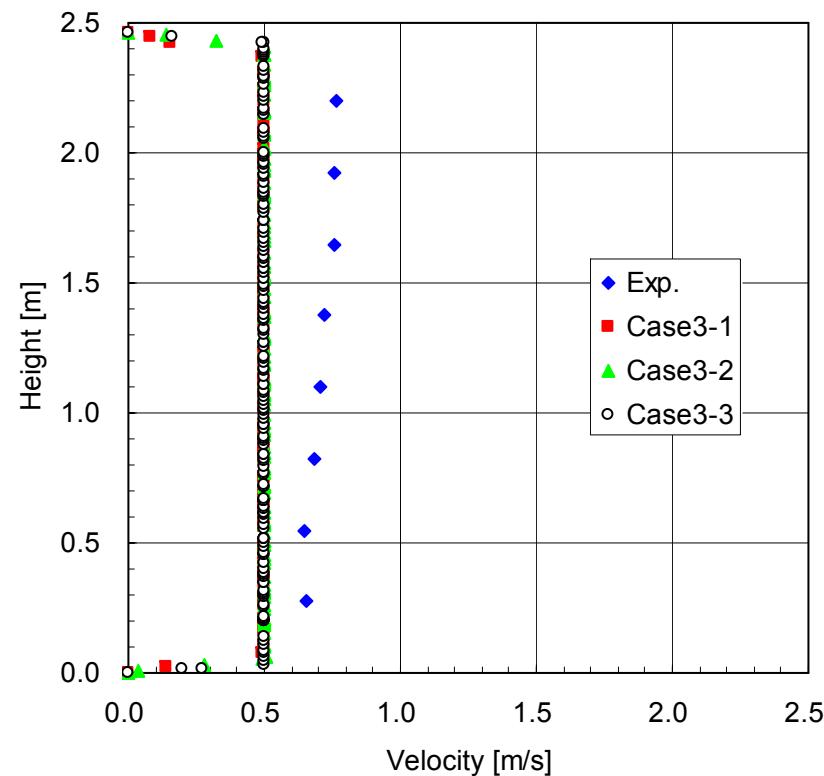
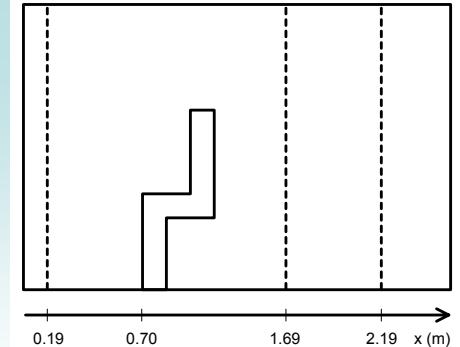
(a) Distribution of air temperature [°C]



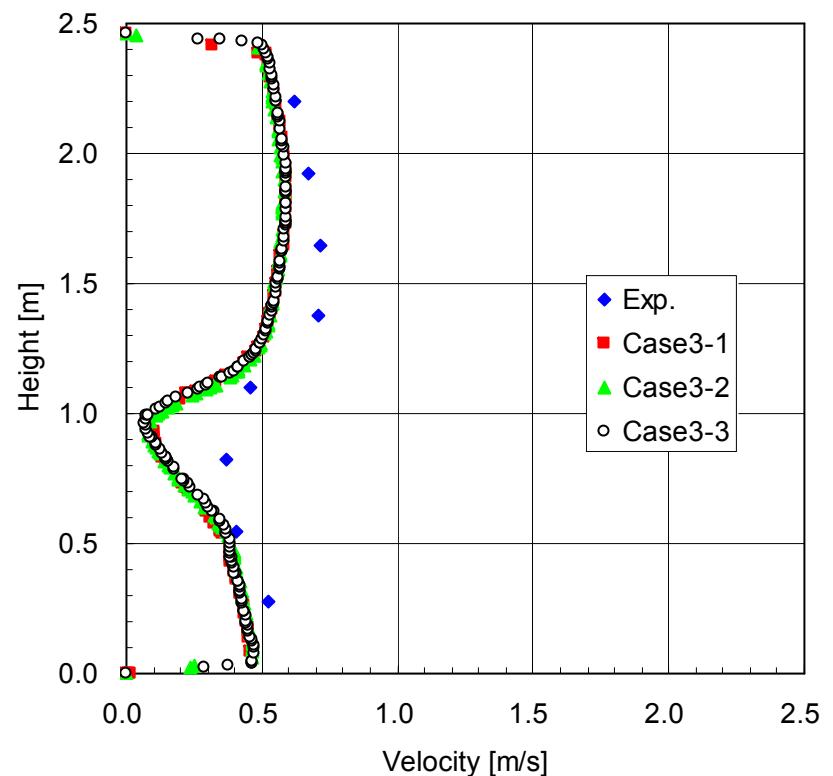
(a) Distribution of CPS's surface temperature [°C]

Result of Case3

3) Vertical air velocity profile at each position



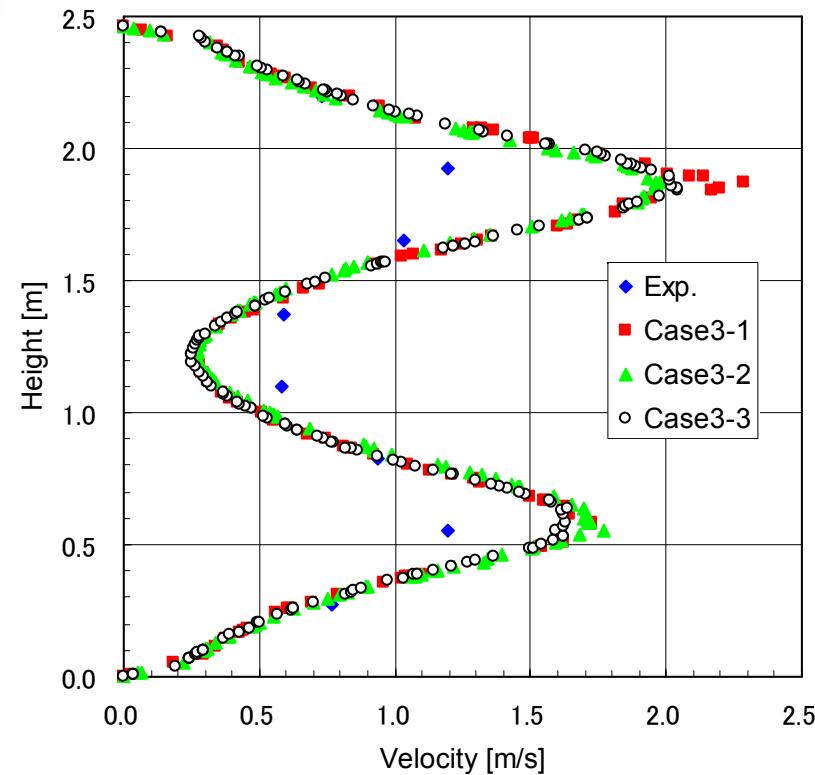
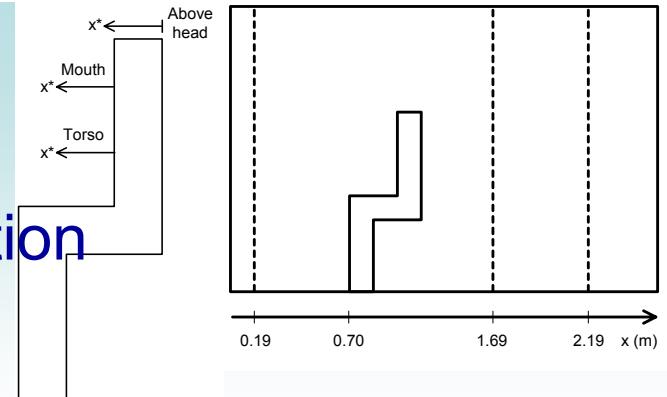
(a) $X: 0.19\text{m}$



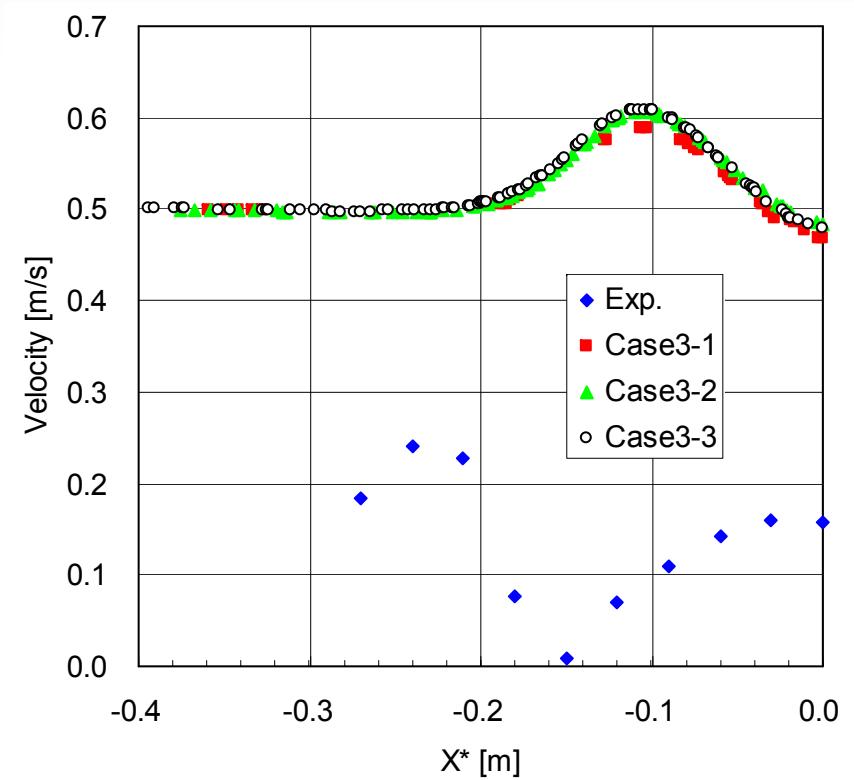
(b) $X: 1.69\text{m}$

Result of Case3

3) Vertical air velocity profile at each position



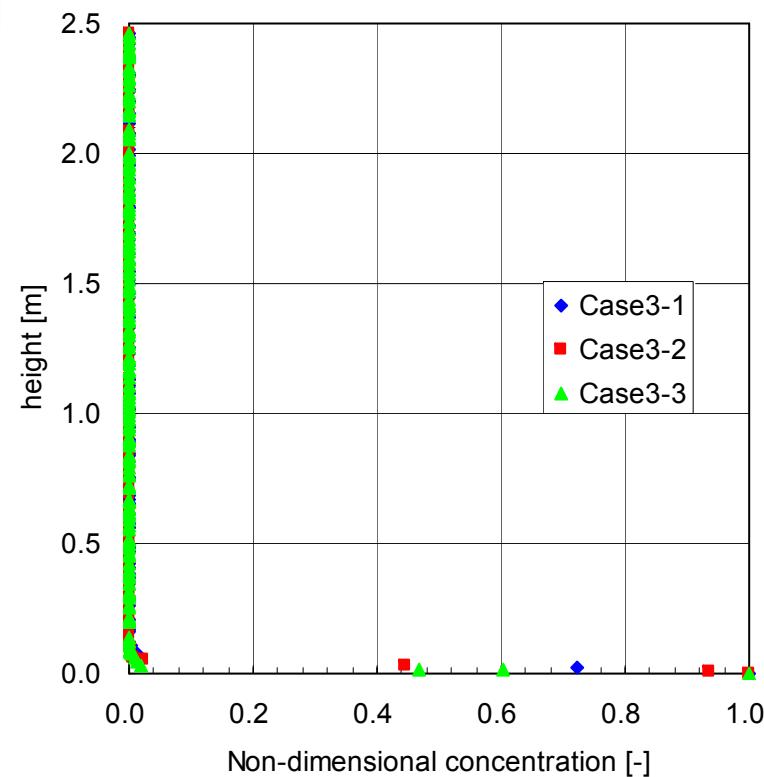
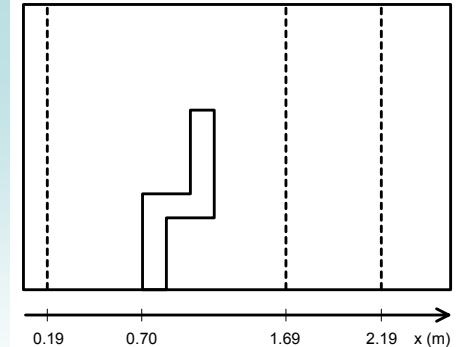
(c) $X: 2.19\text{m}$



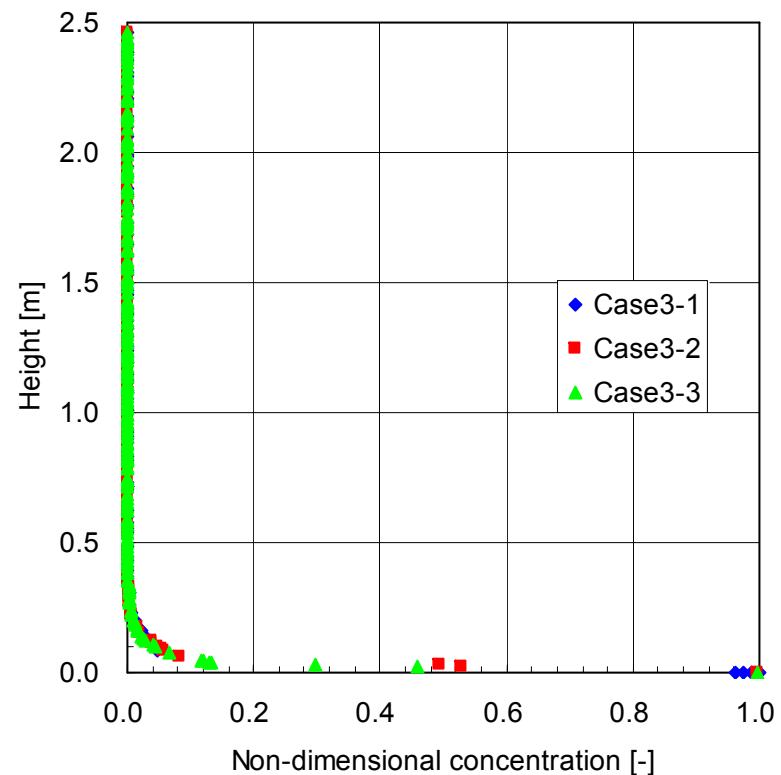
(d) Above head

Result of Case3

4) Concentration gradients at each position



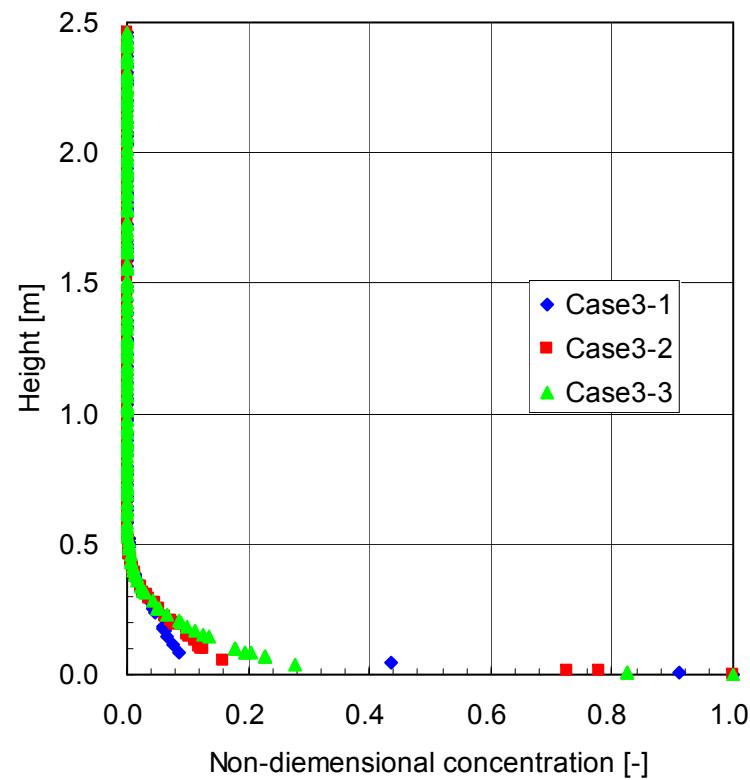
(a) $X: 0.19\text{m}$



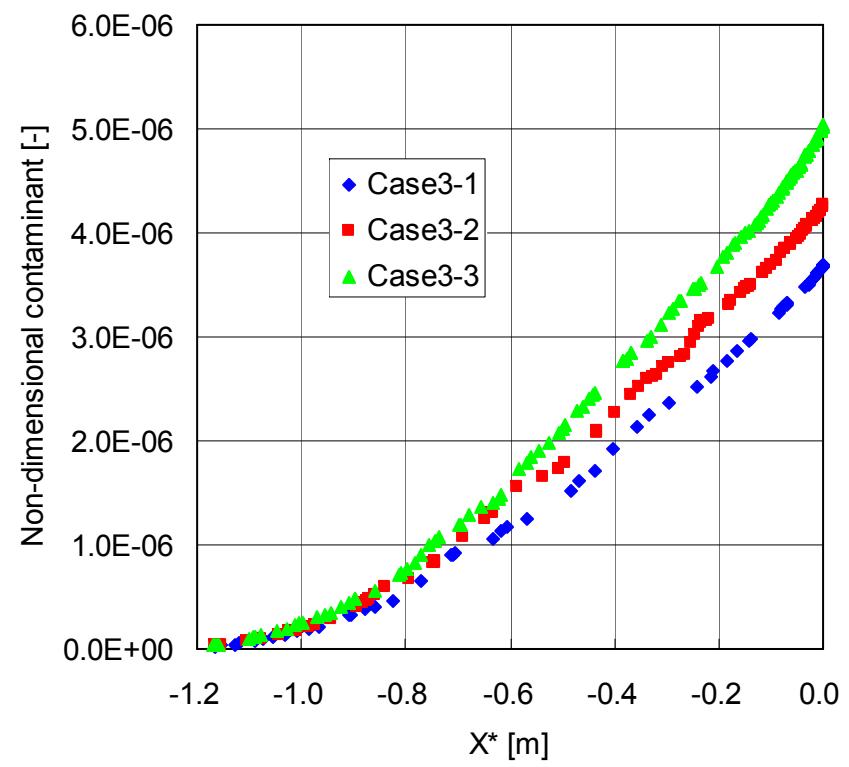
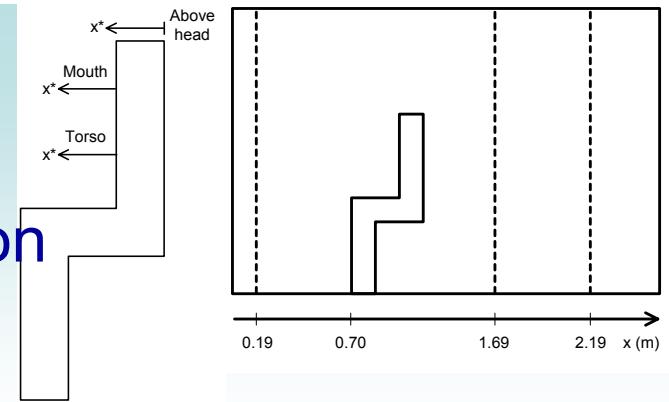
(b) $X: 1.69\text{m}$

Result of Case3

4) Concentration gradients at each position



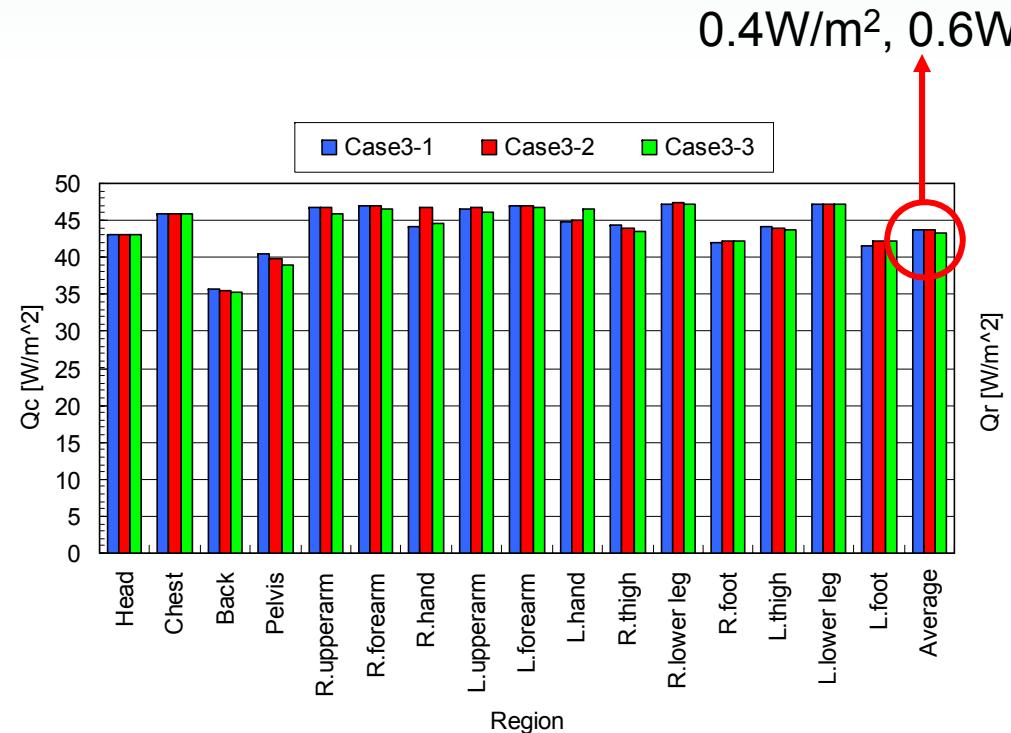
(c) $X: 2.19\text{m}$



(d) Mouth

Result of Case3

5) Result of radiation analysis

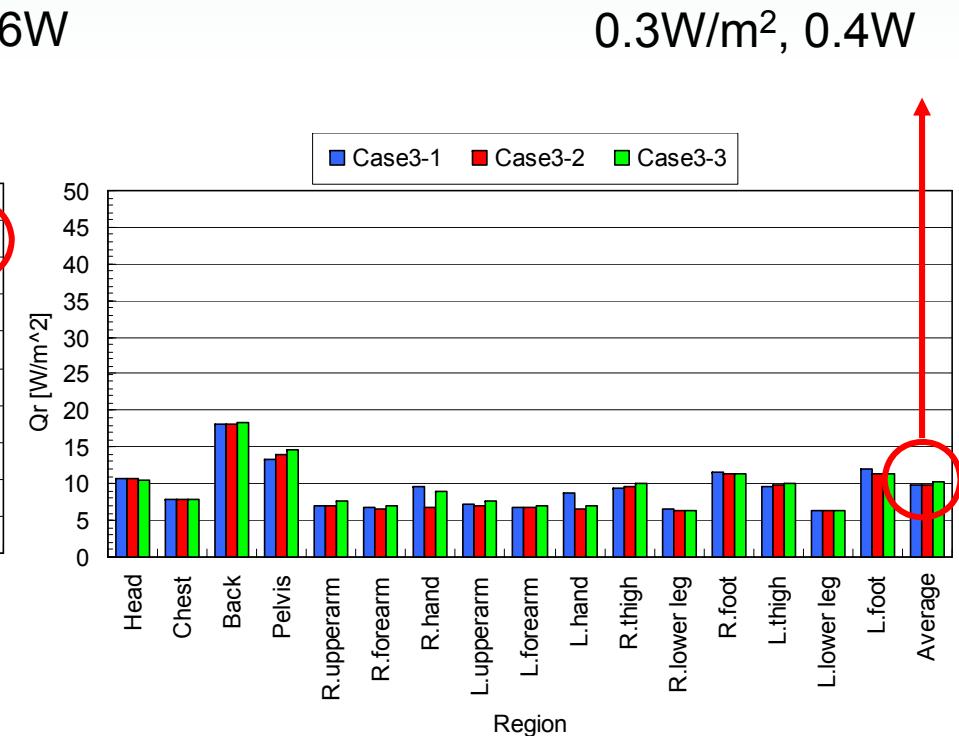


(a) Convective heat transfer rate [W/m^2]

*Case2-1:43.77

*Case2-2:43.69

*Case2-3:43.4



(b) Radiative heat transfer rate [W/m^2]

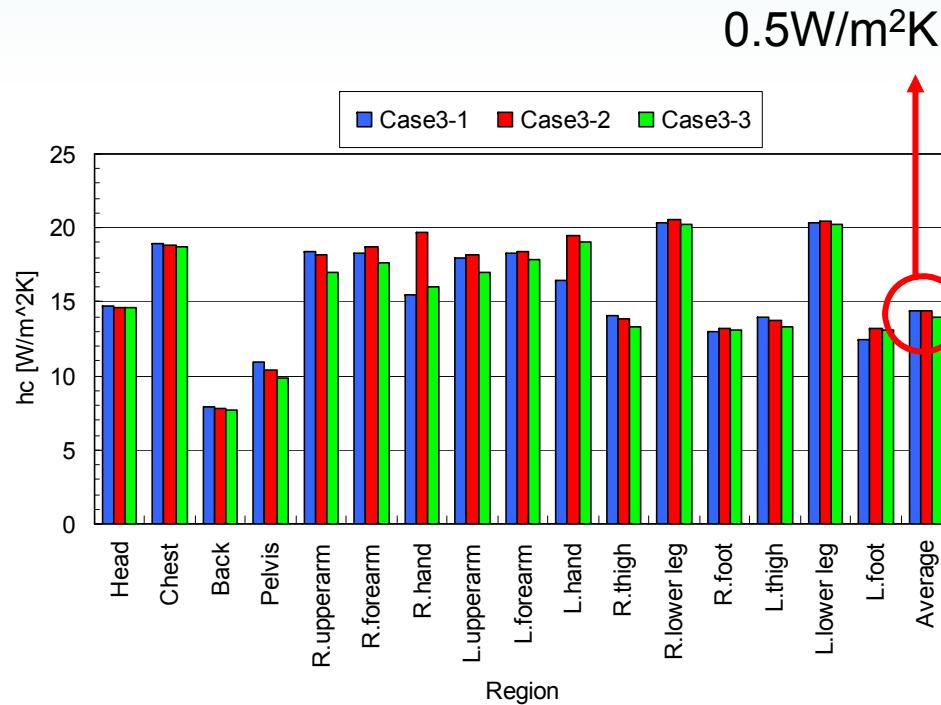
*Case2-1:9.93

*Case2-2:9.92

*Case2-3:10.18

Result of Case3

5) Result of radiation analysis

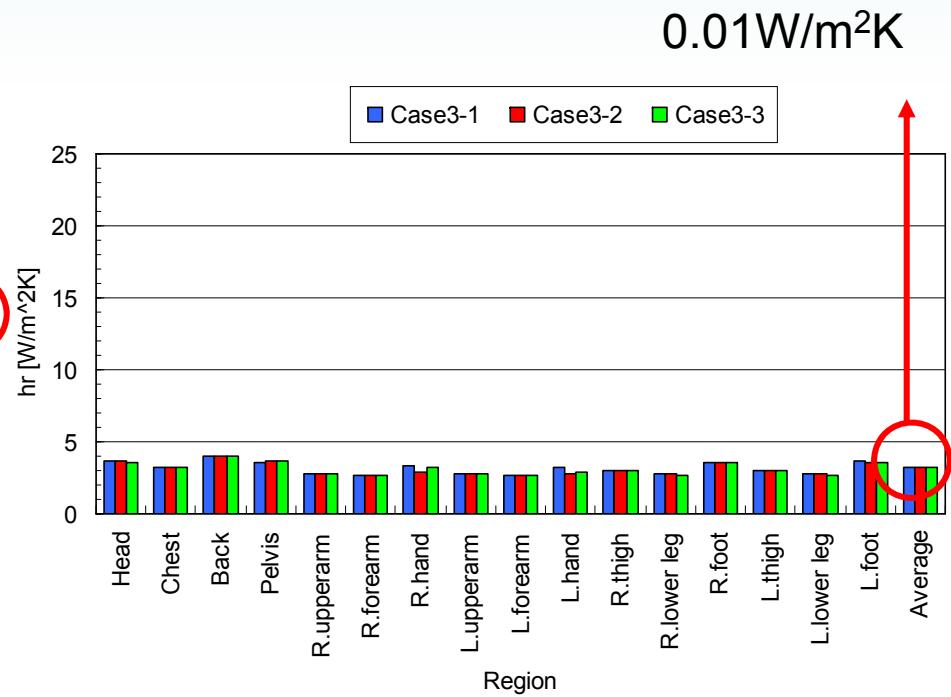


(c) Convective heat transfer rate coefficient
[W/m²K]

*Case2-1:14.4

*Case2-2:14.37

*Case2-3:13.91



(d) Radiative heat transfer rate coefficient
[W/m²K]

*Case2-1:3.27

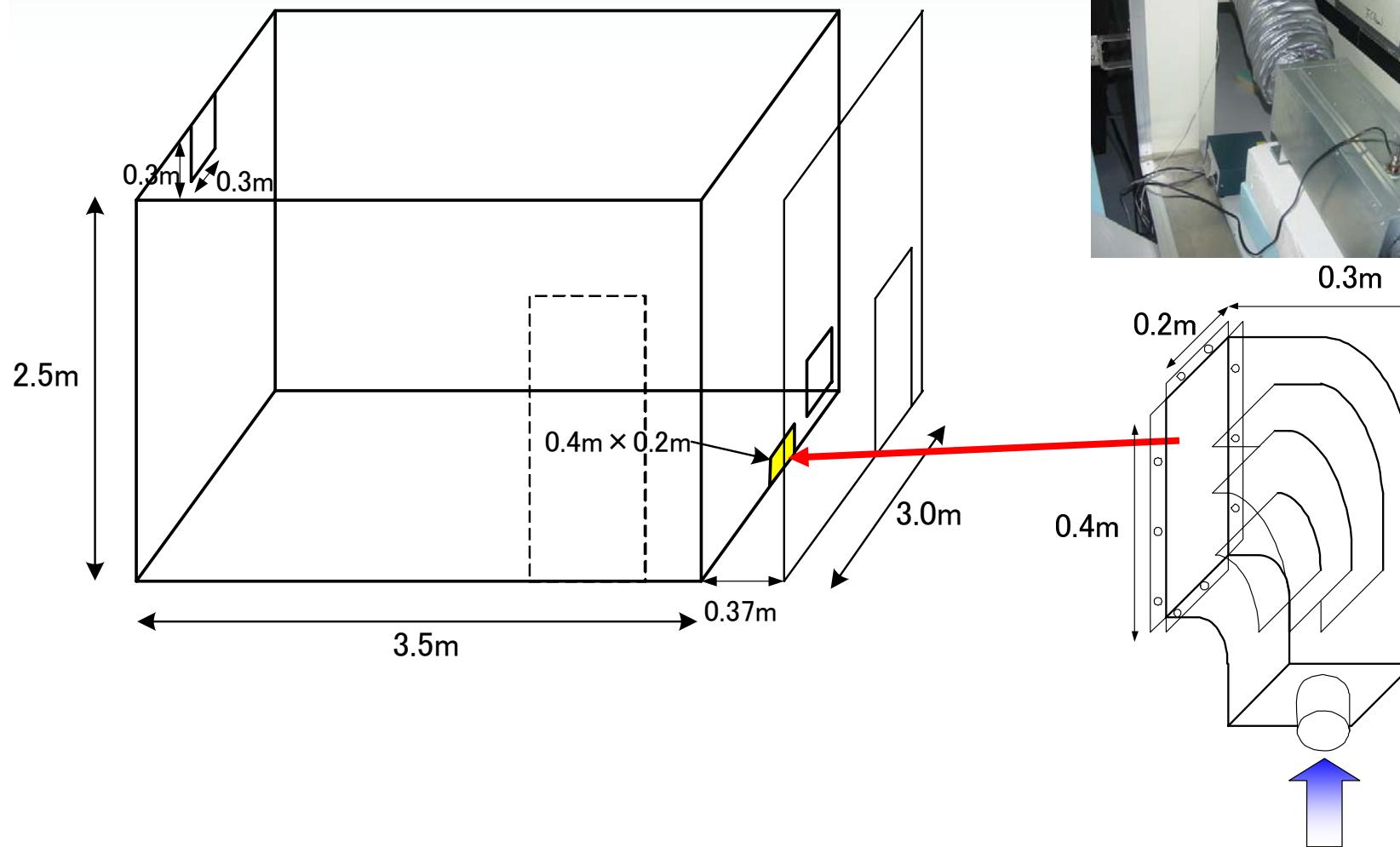
*Case2-2:3.26

*Case2-3:3.26

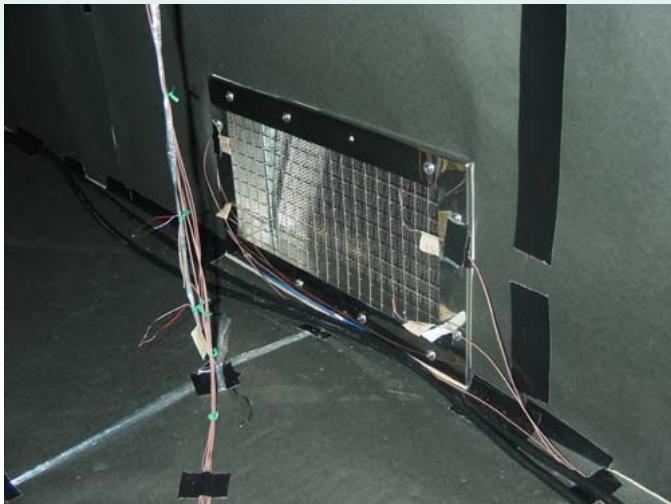
Benchmark Tests for Computer Simulated Person

- Experiment of Displacement Ventilation Cases-

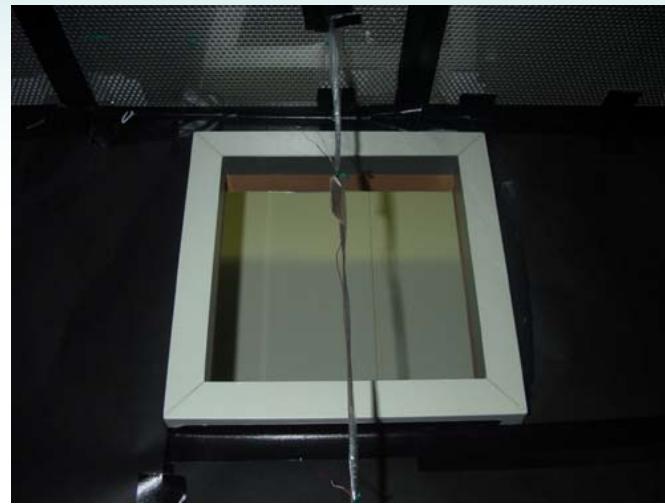
Outline of Test Room - 1



Outline of Test Room - 2



Supply Opening



Exhaust Opening



Control Temperature



Control Airflow Rate

Check the supply air velocity

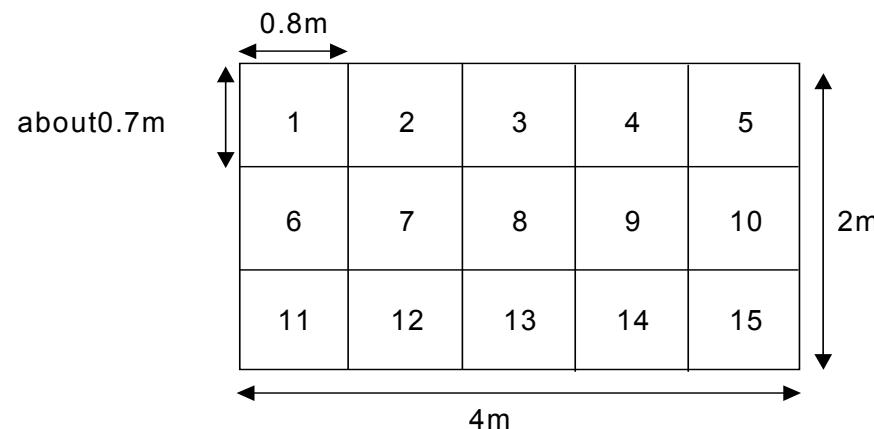
Average supply air velocity: 0.19 m/s

1st time, Each air velocity at measurement point[m/s]



| | | | | |
|------|------|------|------|------|
| 0.14 | 0.15 | 0.21 | 0.2 | 0.15 |
| 0.11 | 0.19 | 0.17 | 0.21 | 0.18 |
| 0.19 | 0.22 | 0.22 | 0.23 | 0.22 |

2nd time, Each air velocity at measurement point[m/s]

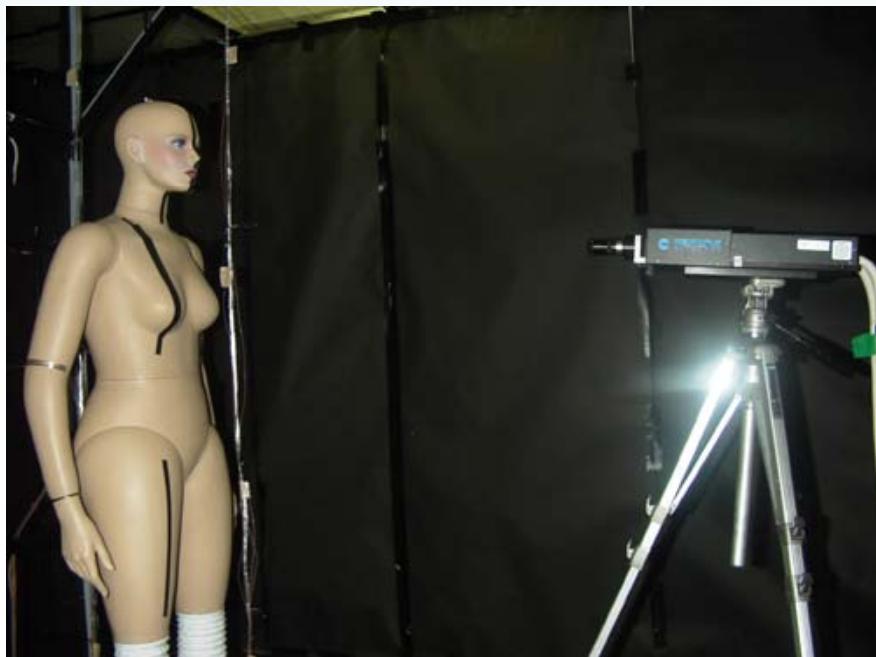


| | | | | |
|------|------|------|------|------|
| 0.19 | 0.16 | 0.22 | 0.19 | 0.19 |
| 0.12 | 0.17 | 0.15 | 0.17 | 0.18 |
| 0.15 | 0.17 | 0.19 | 0.21 | 0.2 |

Experimental Conditions

- a) Thermal manikin: 76W
- b) Average supply air velocity: 0.19m/s
(Average of 2times, thermistor anemometer)
- c) Average supply air temperature: 22.1°C
(Average of 5times, thermocouple of T-type)
- d) Air velocity of room was measured by using ultrasonic anemometer.
(Average of 3times, each time was measured 5minitue after stable air velocity)
- e) Air temperature of room was measured by using T-type of thermocouple.
(Average of 5times, each time was measured 6hour after stable air temperature)
- f) Air velocity of around of mouth and top of head was measured by using PIV.

Measurement of airflow around Thermal Manikin using PIV

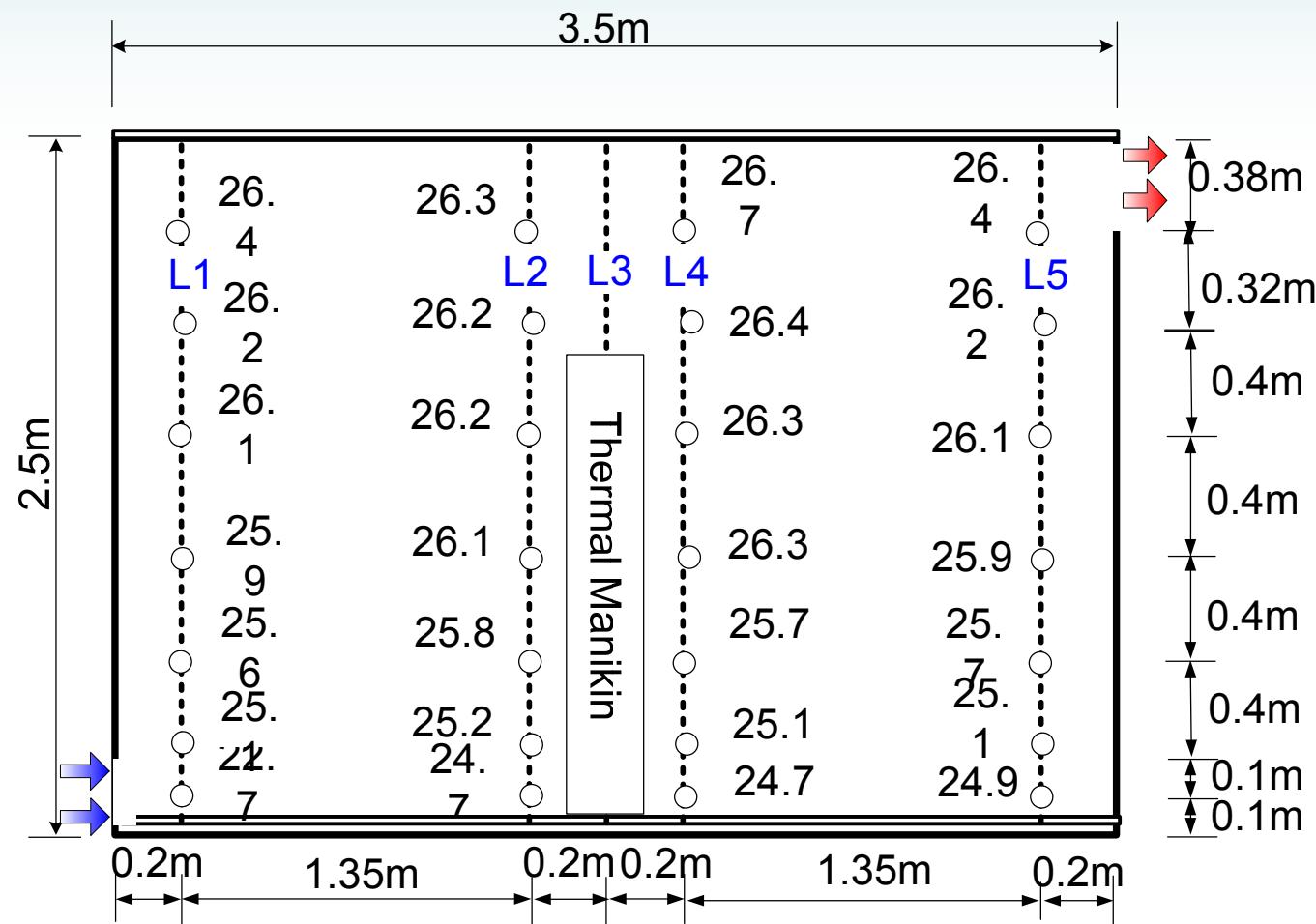


Appearance of measurement of airflow around thermal manikin

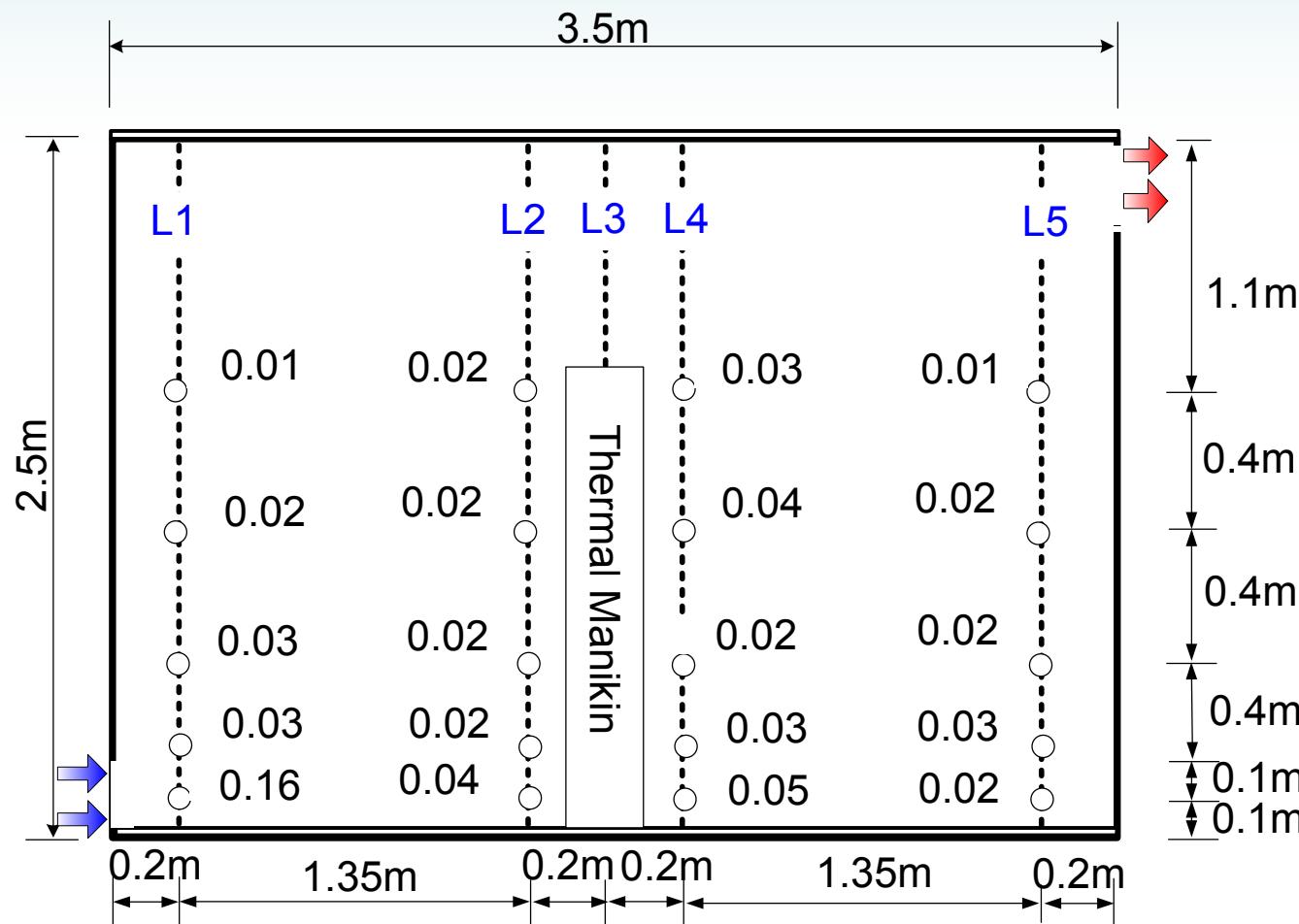


Equipments of PIV and controller of thermal manikin

Distribution of Air Temperature [°C]



Distribution of Air Velocity [m/s]



Open Data of Experiment

The result of PIV and all experiment data are scheduled to open from the Internet with Prof. Nielsen after ROOMVENT.