

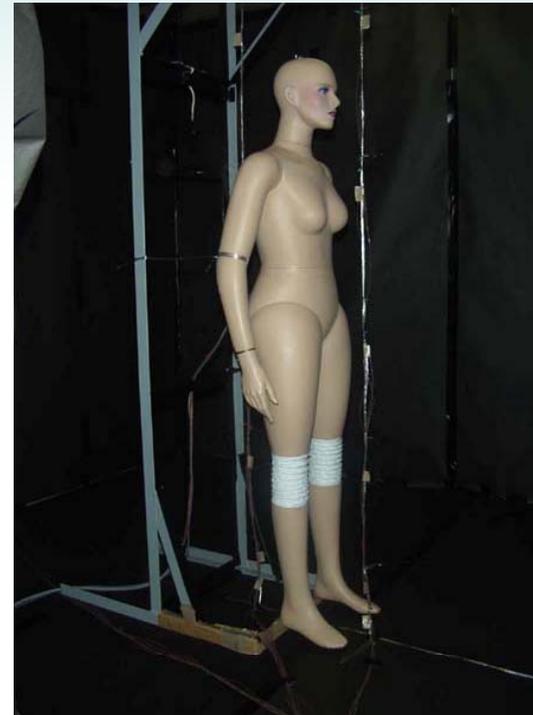
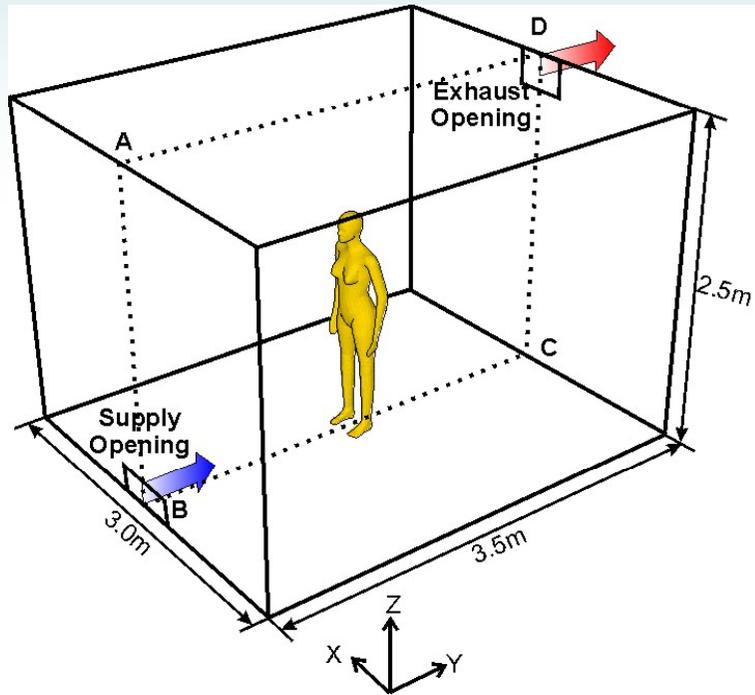
Benchmark Tests of CFD of Airflow around Human Body in a Room with Displacement Ventilation

Shinsuke KATO Jeong-Hoon YANG
IIS. The University of Tokyo

Outline

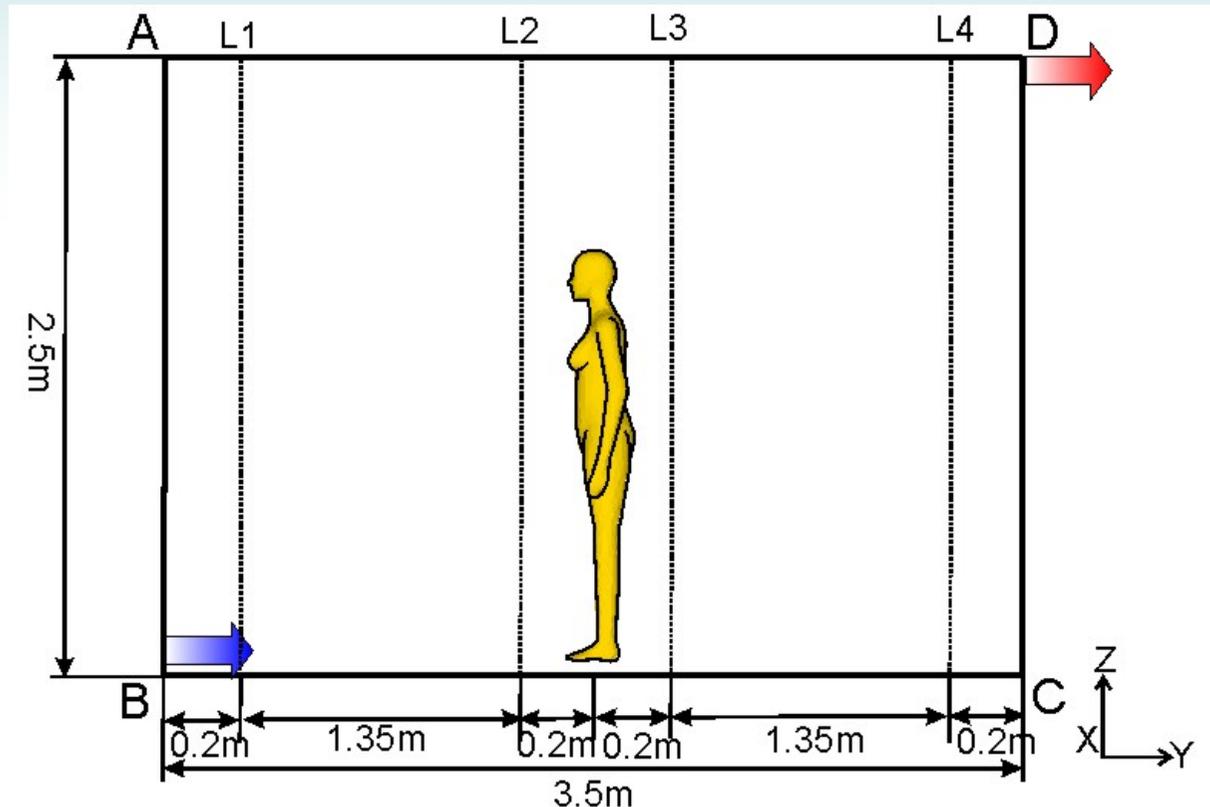
- Experimental Conditions
 - Displacement Ventilation
 - Thermal Mannequin
- Space Distributions of Velocity and Temperature
- Skin Temperature and Velocity around the mannequin
- CFD Conditions
- CFD Results
- Comparisons
- Conclusions

Experiment Condition



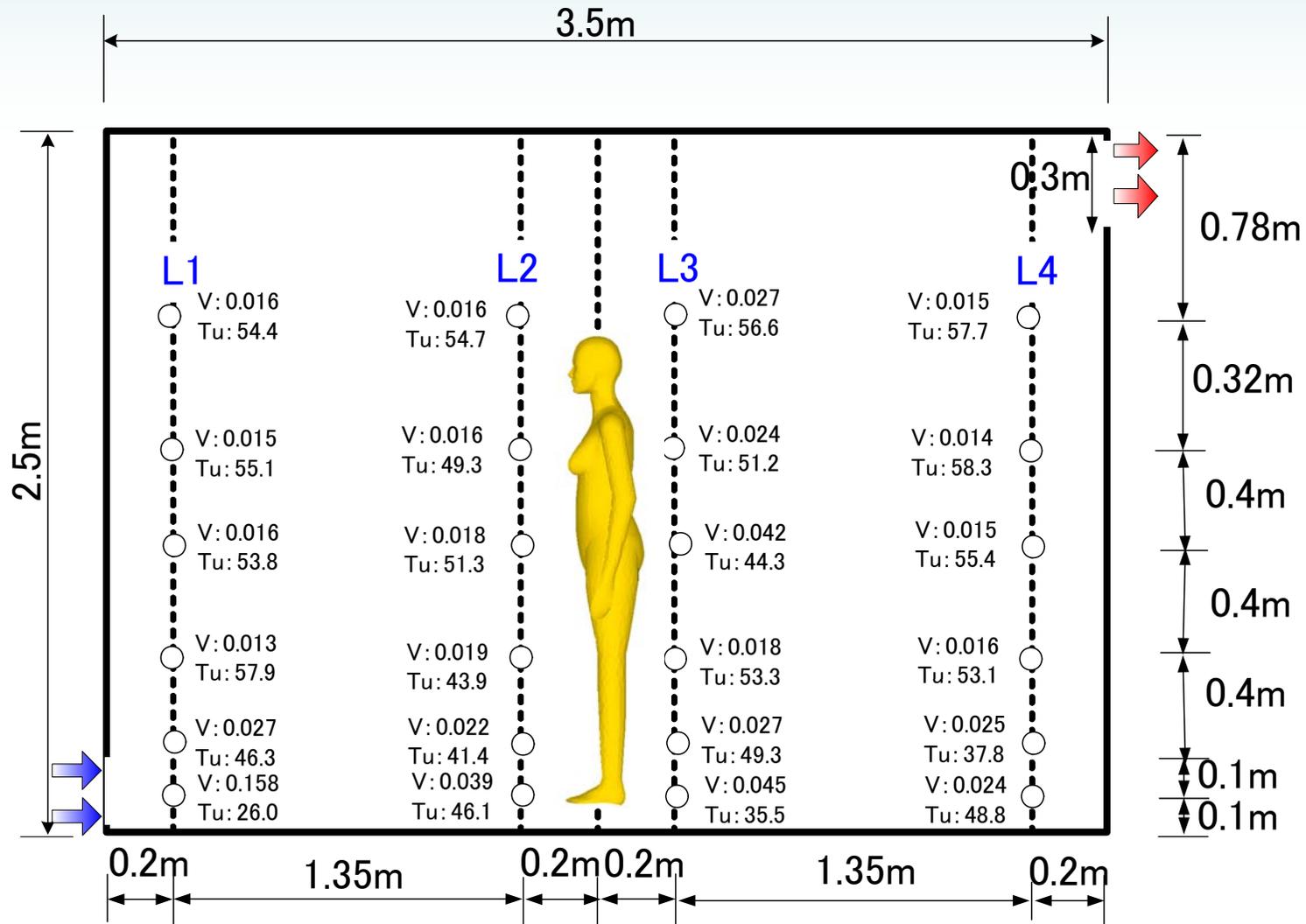
1. Test chamber size
0.3m X 3.5m X 2.5m
2. Supply Opening Condition
 - 1) Velocity : 0.182m/s
 - 2) Size : 0.4m(W) X 0.2m(H)
 - 3) Temperature : 21.8°C
3. Exhaust Opening Condition
Size : 0.3m(W) X 0.3m(H)
4. Thermal Manikin Condition
 - 1) Heat flux : 76W (Area : 1.471m², 51.6W/m²)
 - 2) Stable inhaled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

Measurement Position of Air Velocity and Temperature

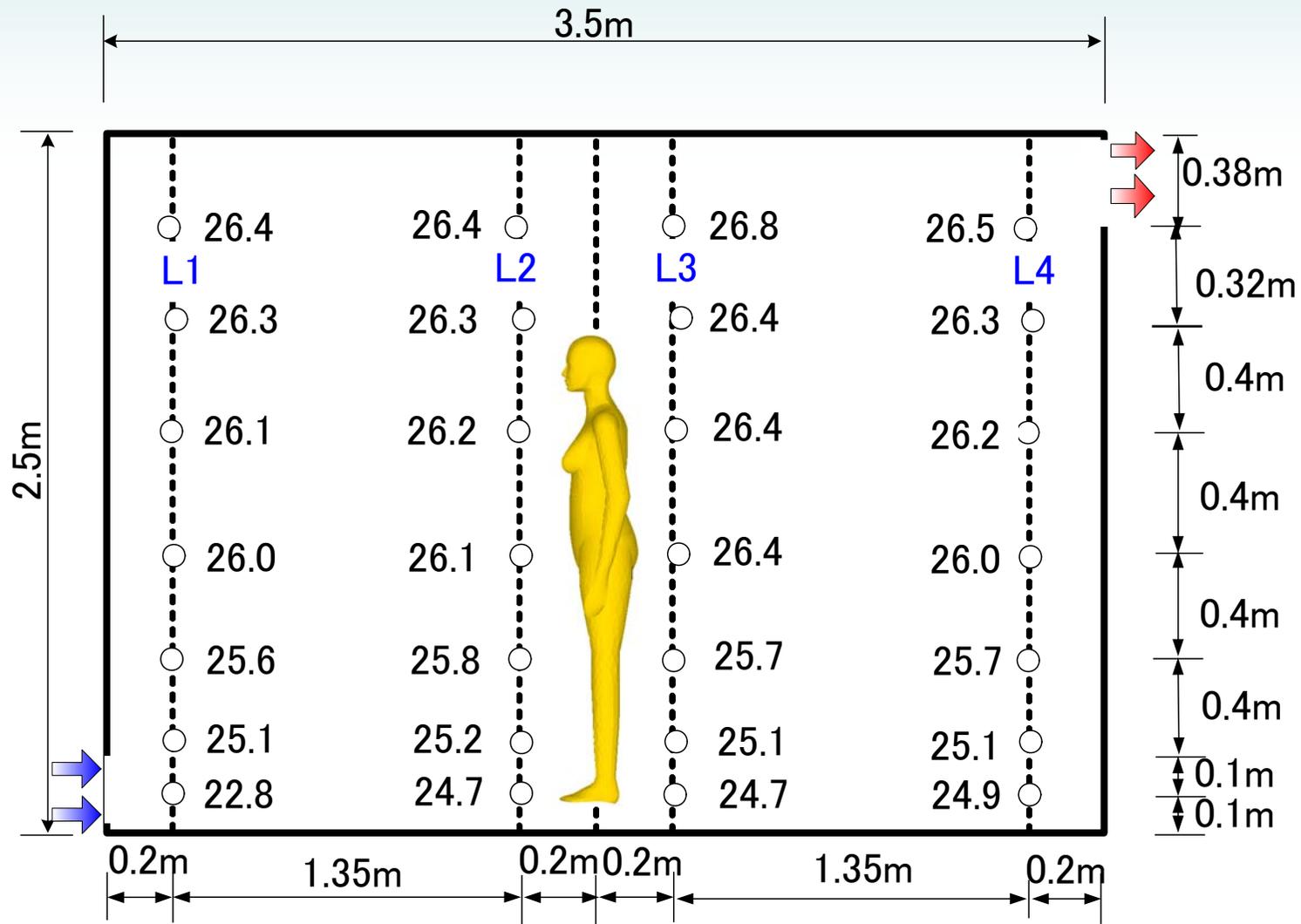


- ◆ Air Velocity : Ultrasonic anemometer (Average of 3 times, each time was measured 5 minute after stable air velocity)
- ◆ Air Temperature : T-type of Thermocouple (Average of 4 times, each time was measured 6 hour after stable air temperature)

Distribution of Air Velocity [V:m/s] and Turbulence Intensity [Tu:%]

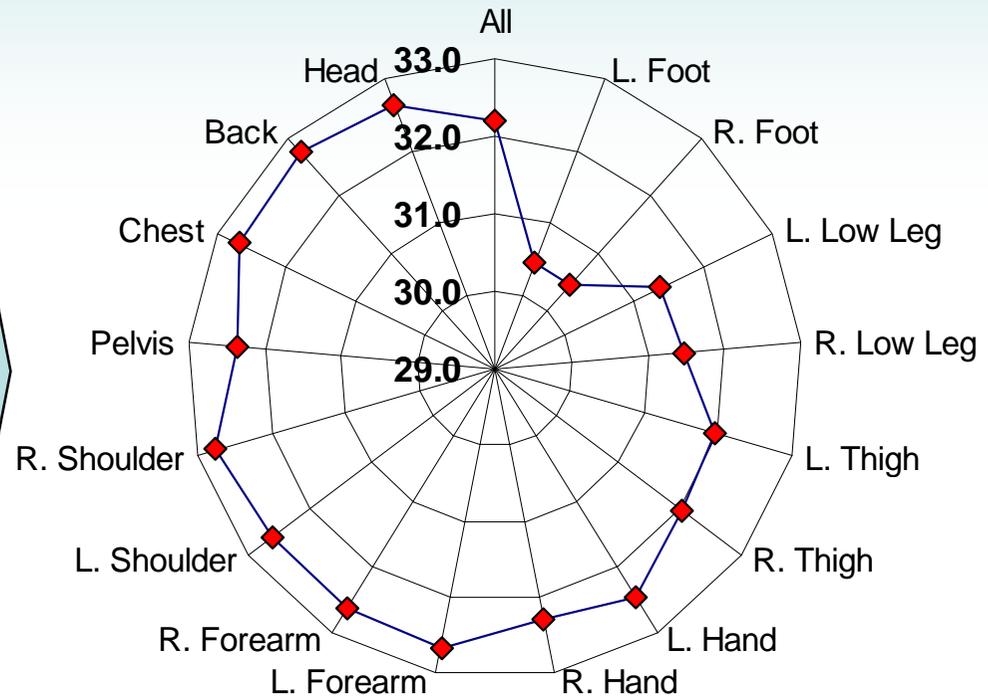
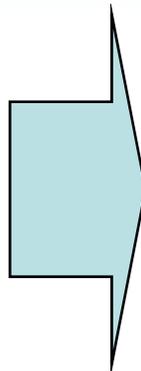


Distribution of Air Temperature [°C]



Skin Temperature of Thermal Manikin [°C]

Region	Temperature [°C]
All	32.2
L. Foot	30.5
R. Foot	30.5
L. Low Leg	31.4
R. Low Leg	31.5
L. Thigh	32.0
R. Thigh	32.0
L. Hand	32.5
R. Hand	32.3
L. Forearm	32.7
R. Forearm	32.6
L. Shoulder	32.6
R. Shoulder	32.8
Pelvis	32.3
Chest	32.7
Back	32.8
Head	32.7

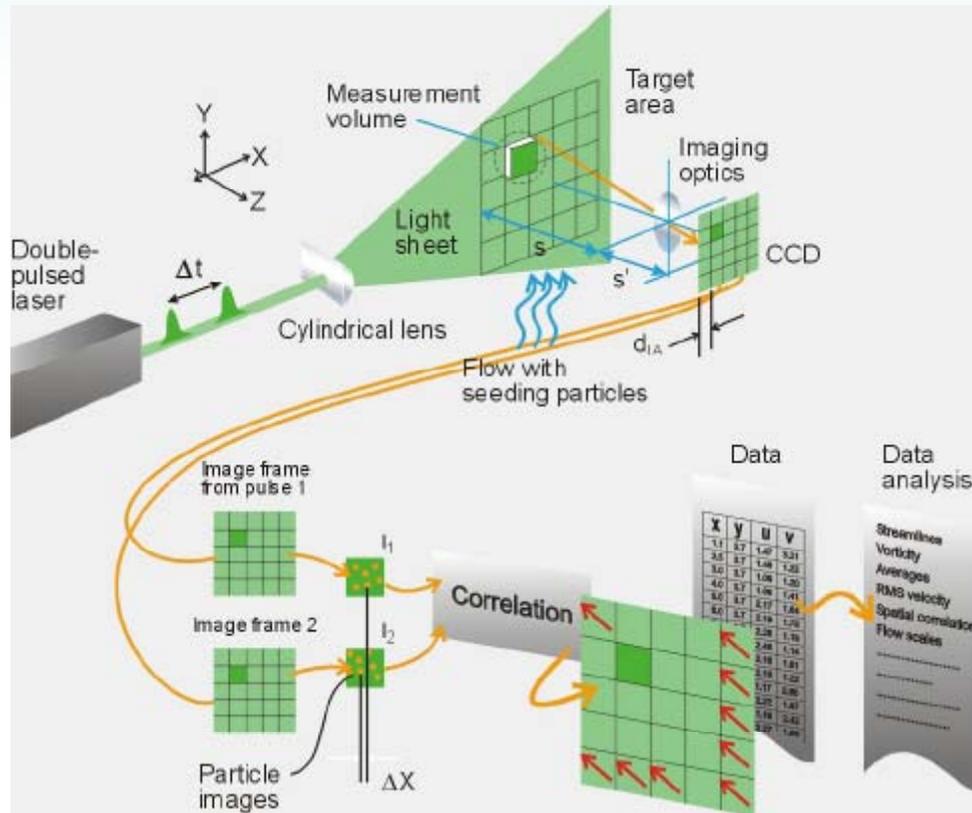


◆ Heat Flux : 76W (=51.6W/m²)

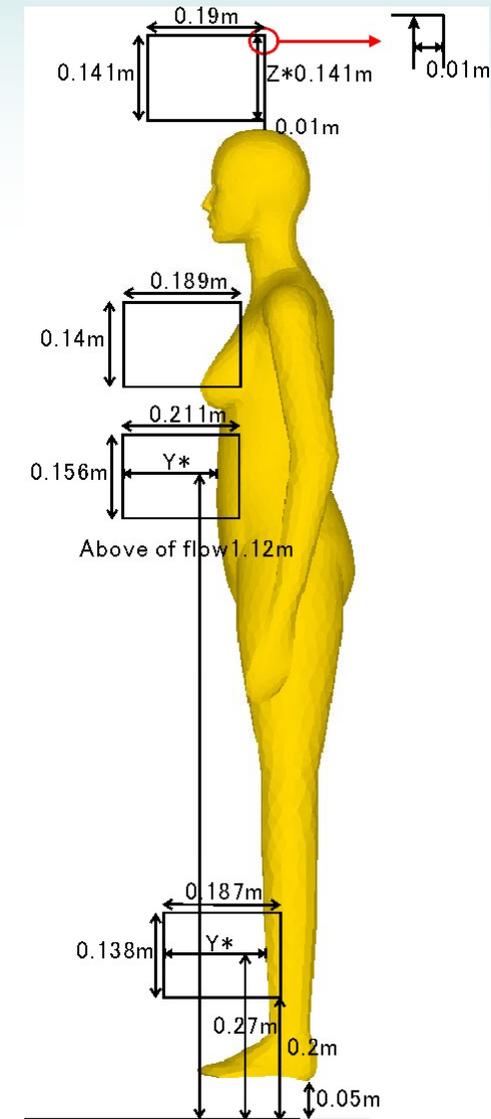
◆ Area : 1.471m²

◆ Measurement : Average of 4 times, each time was measured 6 hour after stable air temperature

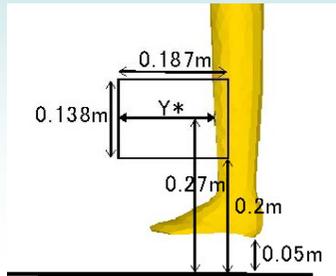
Measurement Velocity around Thermal Manikin using PIV



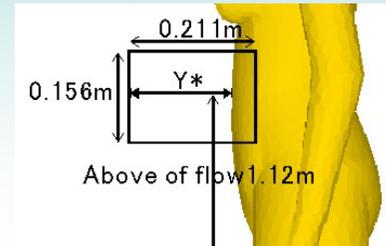
Measurement Principle of PIV
(by Dantec Dynamics)



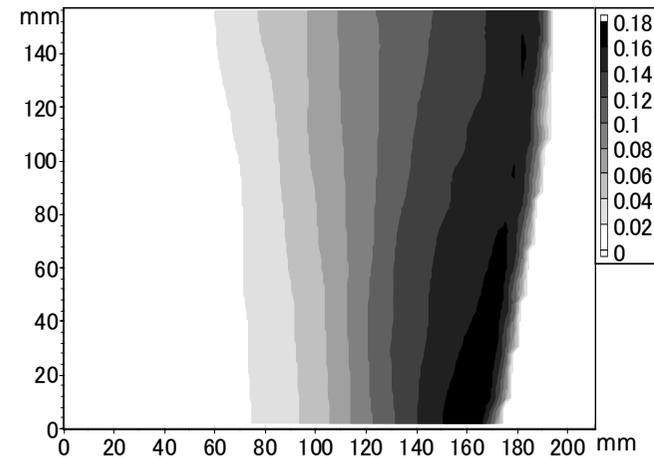
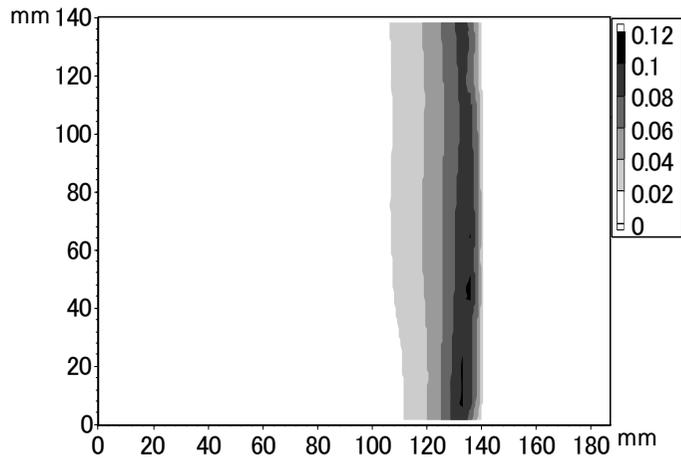
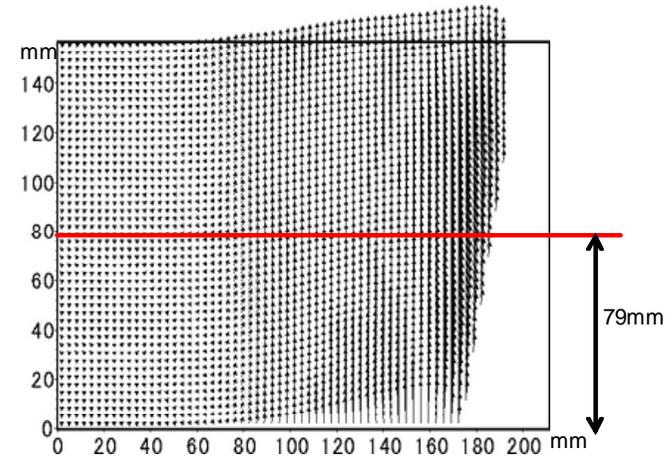
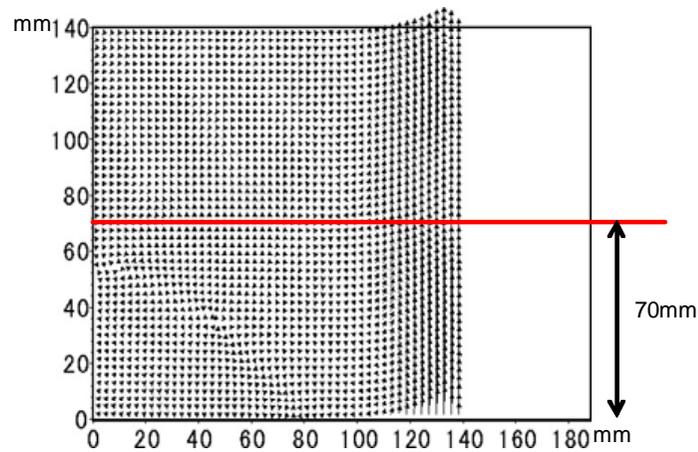
Air Velocity around each Region -1



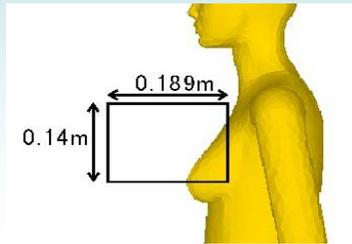
Low Leg



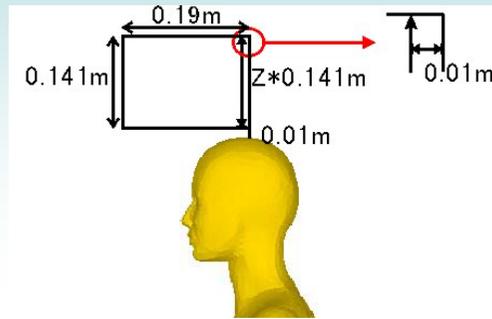
Pelvis



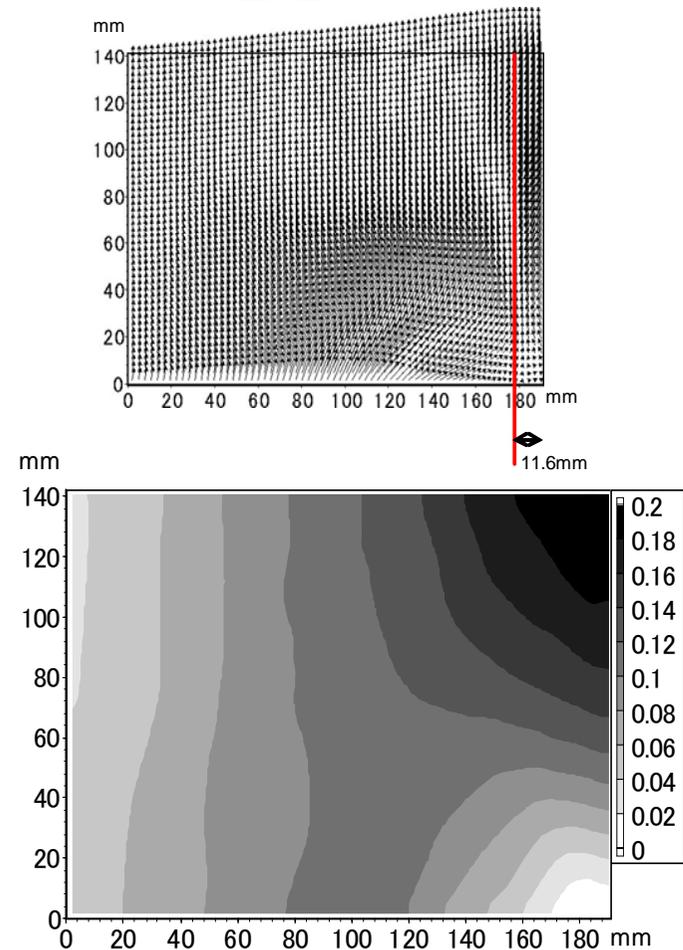
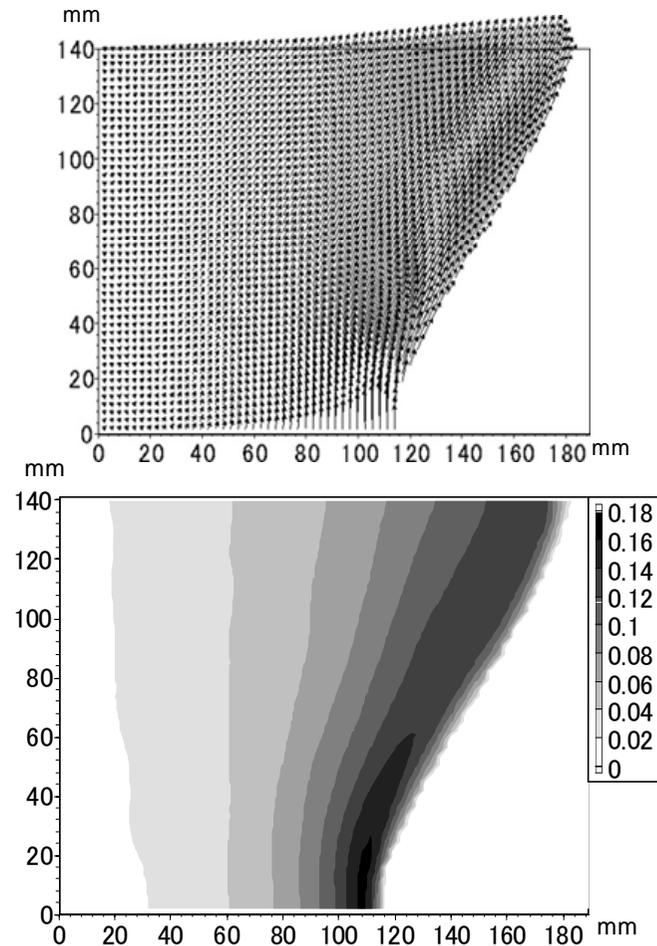
Air Velocity around each Region -2



Chest



Head



Analysis Cases

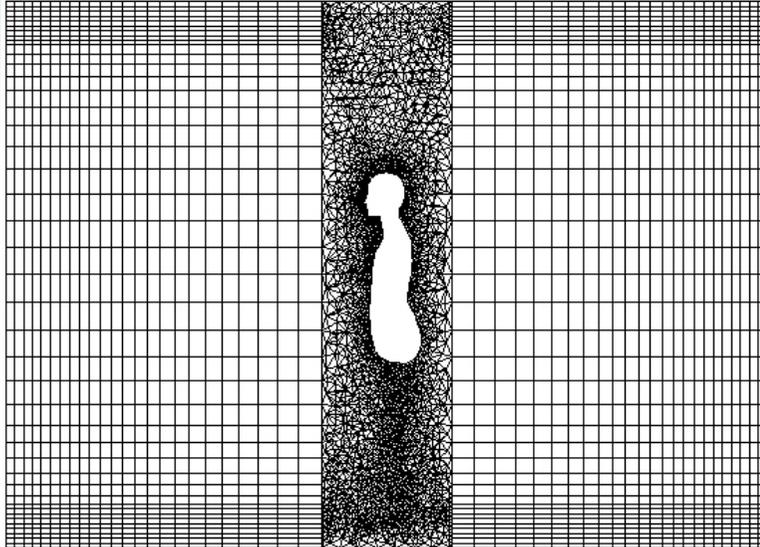
Case	Number of Grids		Radiation and Convection Couple Calculation	Scheme
	Space [Hundred Thousand]	Surface [Thousand]		
3CM	3	19	x (Only Convection Calculation)	First Order Upwind
3RU			○	MARS
3RM			○	
6CU	6	34	x (Only Convection Calculation)	First Order Upwind
6CM			x (Only Convection Calculation)	
6RM			○	MARS

Analysis Boundary Condition for CFD

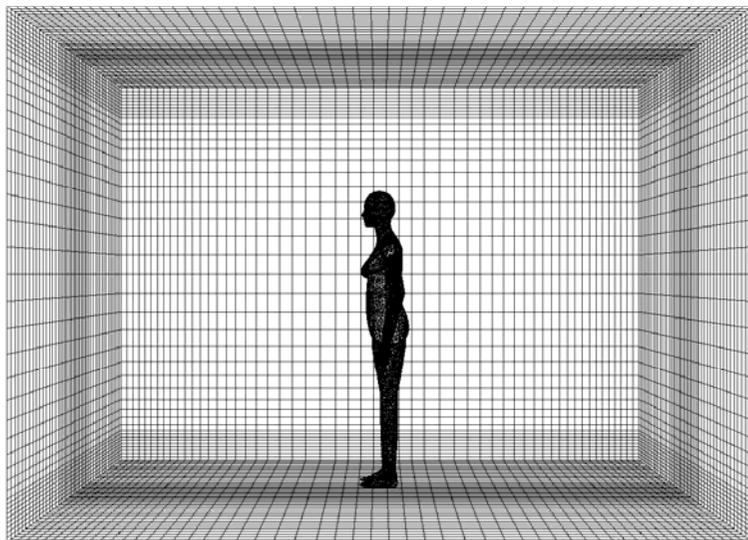
CFD	<ul style="list-style-type: none"> ● Software : Star-CD ● Unsteady State Analysis ● Algorithm : PISO ● Turbulence Mode : Non-Liner Low Reynolds Number K-e Model ● Scheme : ① UD (First Order Upwind) ② MARS (=MUSCL-TVD Method)
Supply Opening	<ul style="list-style-type: none"> ● Size : 0.4m(W) X 0.2m(H) ● Air Temperature : 22°C ● Air Velocity : 0.18m/s ● Airflow : 51.8m³/h ● Turbulence Intensity : 30% ● Length Scale : 0.1m
Exhaust Opening	<ul style="list-style-type: none"> ● Size : 0.4m(W) X 0.2m(H) ● free-slip
Computational Thermal Manikin	<ul style="list-style-type: none"> ● Heat Flux <ul style="list-style-type: none"> ① Radiation and Convection Coupled Calculation : 76W ② Only Convection Calculation : 38W (=27.02 W/m²) ● Surface : no-slip
Wall	<ul style="list-style-type: none"> ● Heat Flux <ul style="list-style-type: none"> ① Radiation and Convection Couple Calculation : Adiabatic Wall ② Only Convection Calculation : 38W (=0.712W/m²) ● Surface : no-slip

Analysis Grid

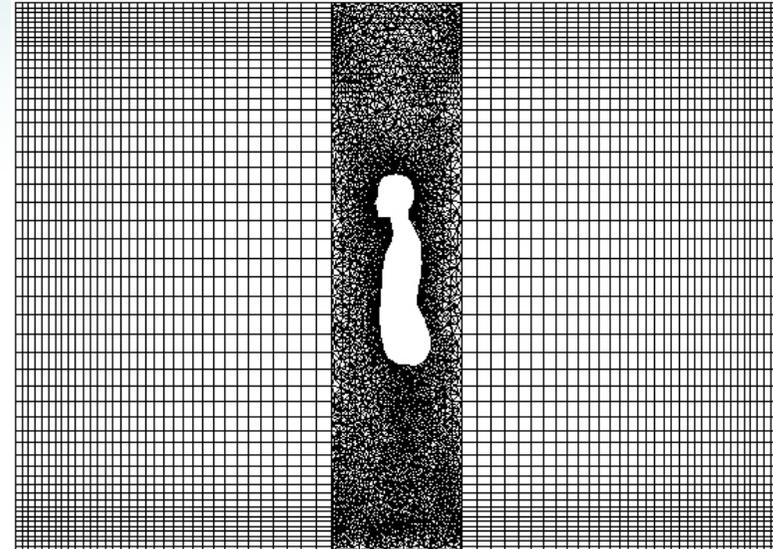
Space : 3 Hundred Thousand Grids



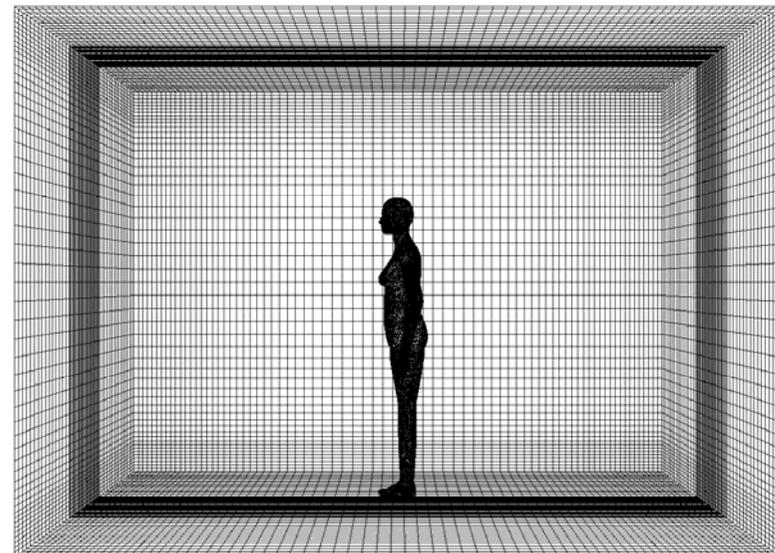
Surface : 19 Thousand Grids



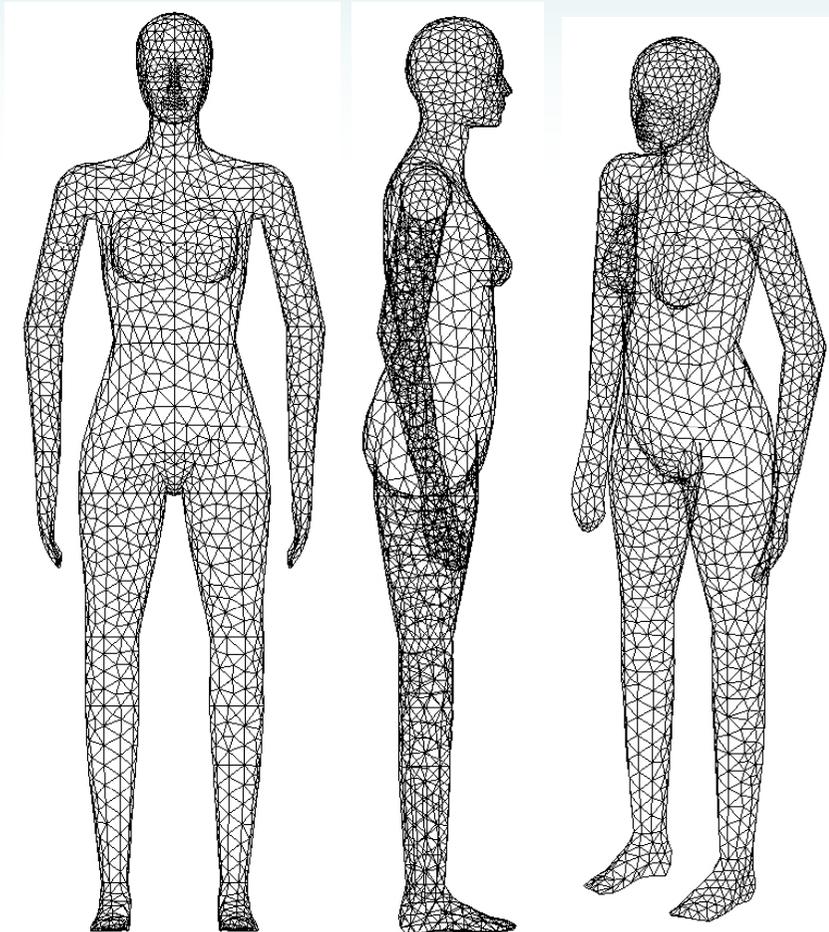
Space : 6 Hundred Thousand Grids



Surface : 34 Thousand Grids



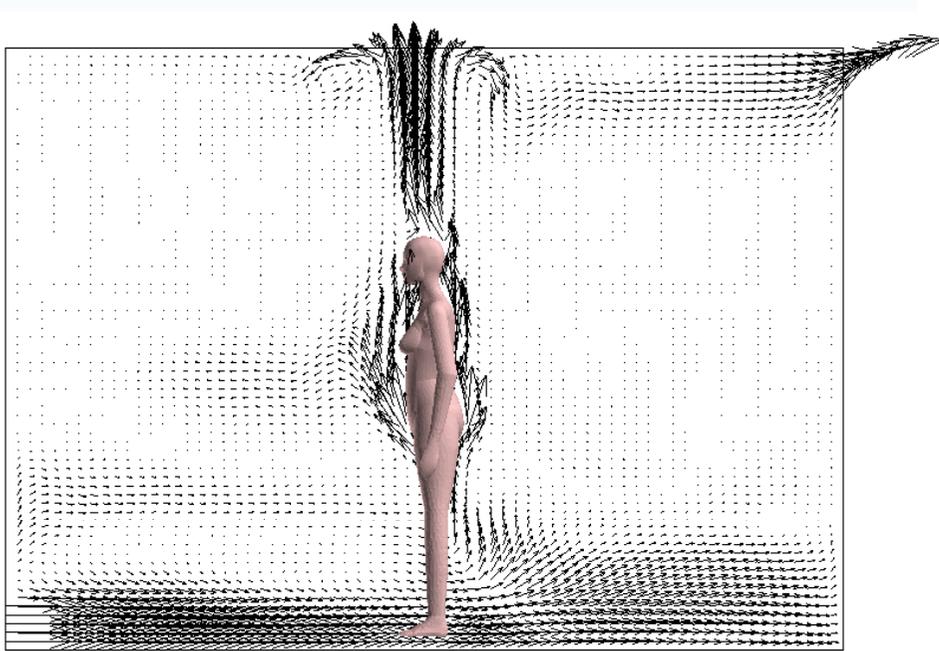
Computational Thermal Manikin



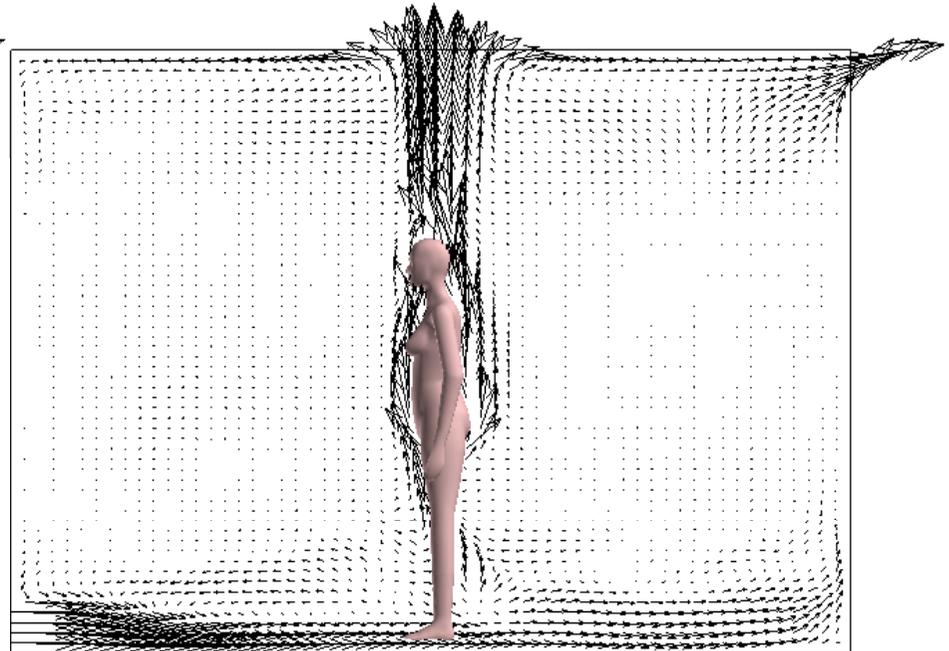
No.	Region	Area of Thermal Manikin [m ²]	
		Experimental	Computational
1	L.Foot	0.044	0.042
2	R.Foot	0.043	0.042
3	L.Low Leg	0.089	0.083
4	R.Low Leg	0.089	0.083
5	L.Thigh	0.163	0.164
6	R.Thigh	0.165	0.164
7	L.Hand	0.038	0.031
8	R.Hand	0.037	0.031
9	L.Forearm	0.050	0.047
10	R.Forearm	0.050	0.047
11	L.Shoulder	0.074	0.072
12	R.Shoulder	0.078	0.072
13	Pelvis	0.174	0.147
14	Chest	0.144	0.143
15	Back	0.133	0.122
16	Head	0.100	0.117
Total		1.471	1.407

* Height of Manikin : 1.65m

Airflow Field : Vector Velocity [m/s]

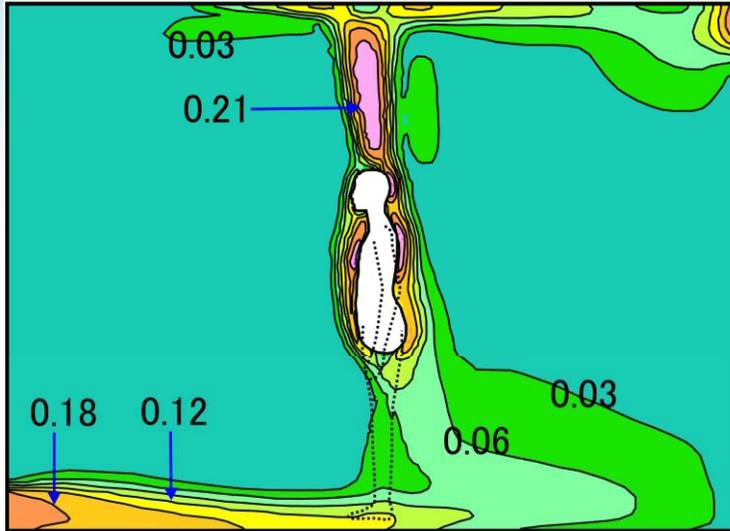


6CM

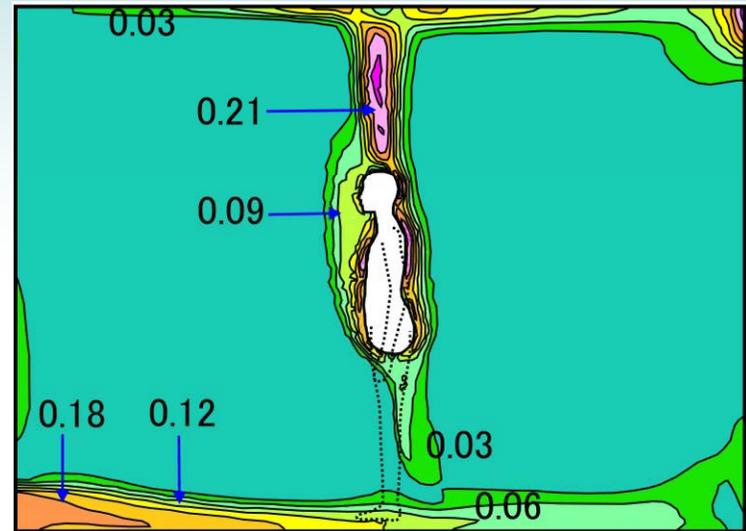


6RM

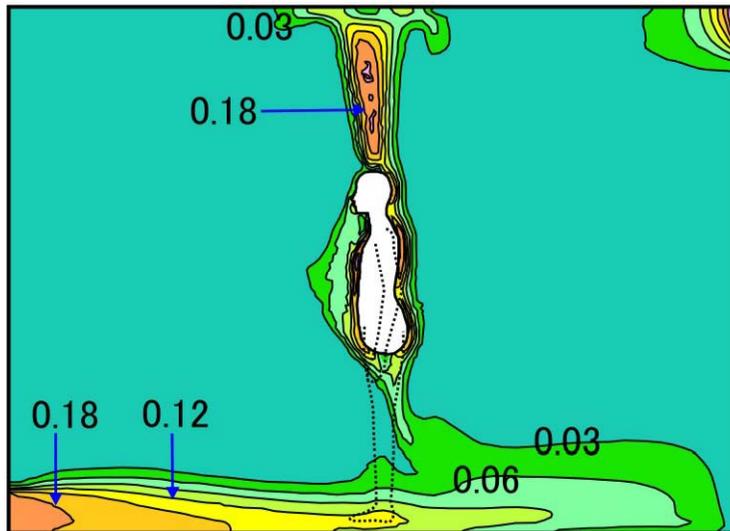
Airflow Field : Scalar Velocity [m/s]



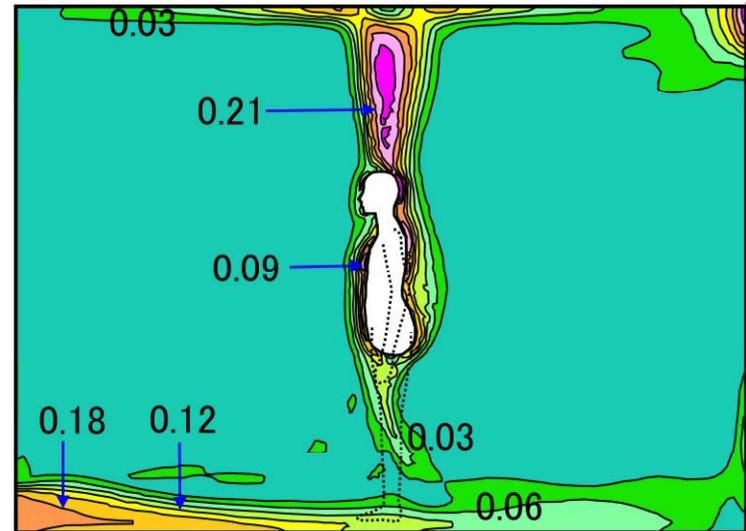
3CM



3RM

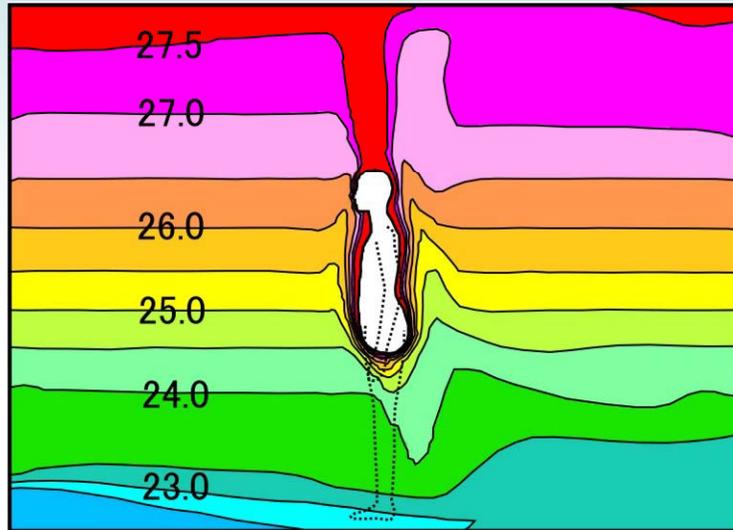


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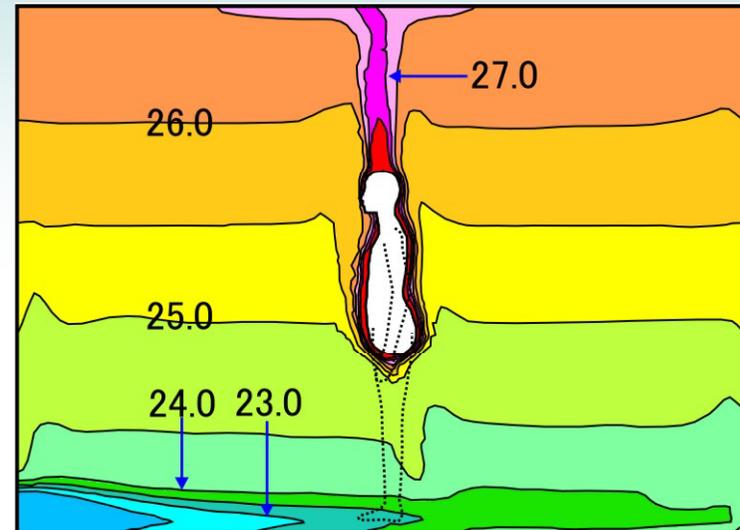


6RM

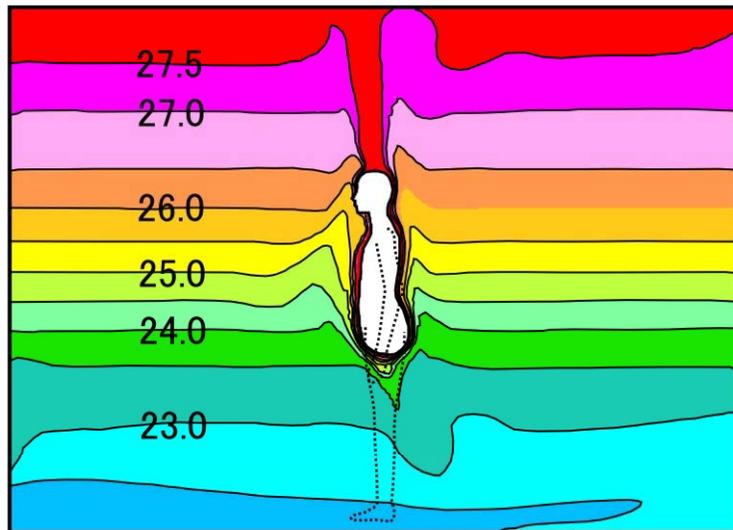
Air Temperature [°C]



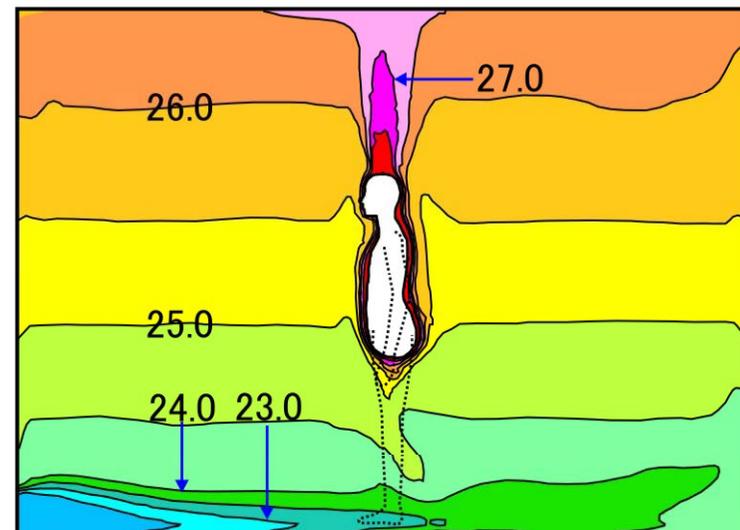
3CM



3RM

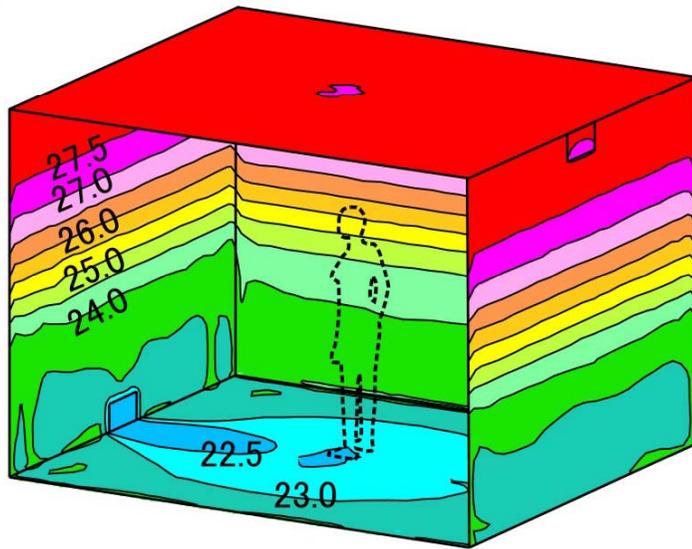


6CM

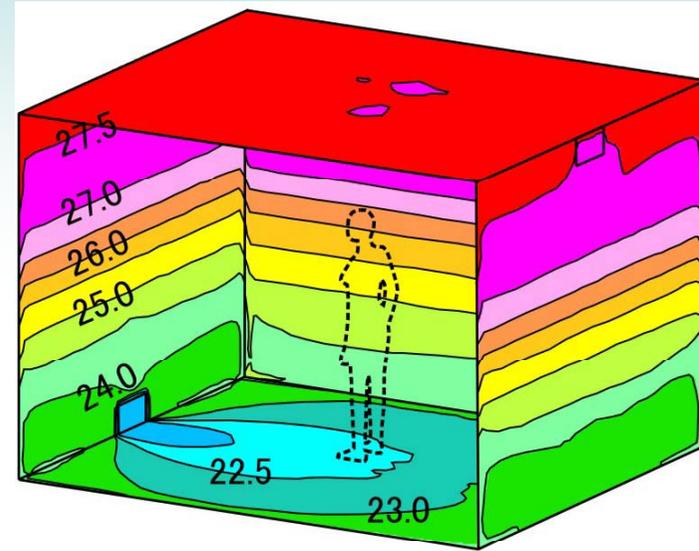


6RM

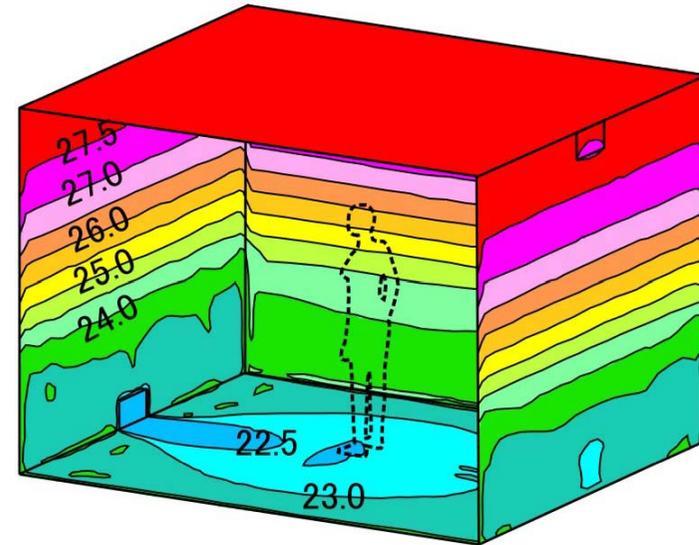
Wall Surface Temperature [°C] - 1



3CM

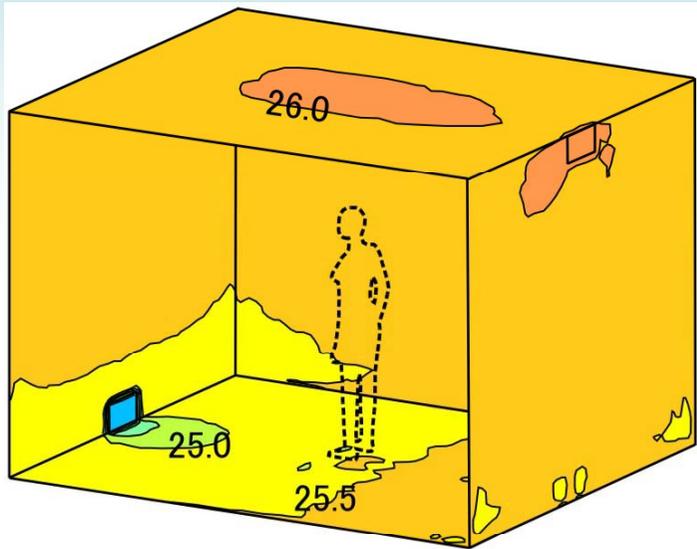


6CU

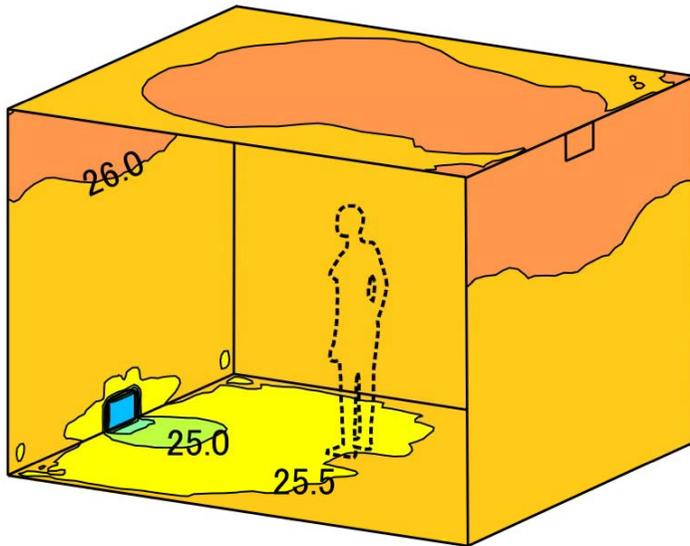


6CM

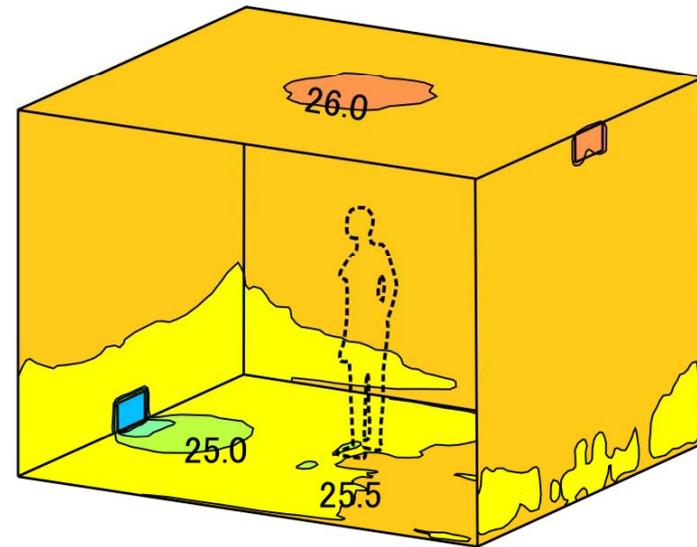
Wall Surface Temperature [°C] - 2



3RU

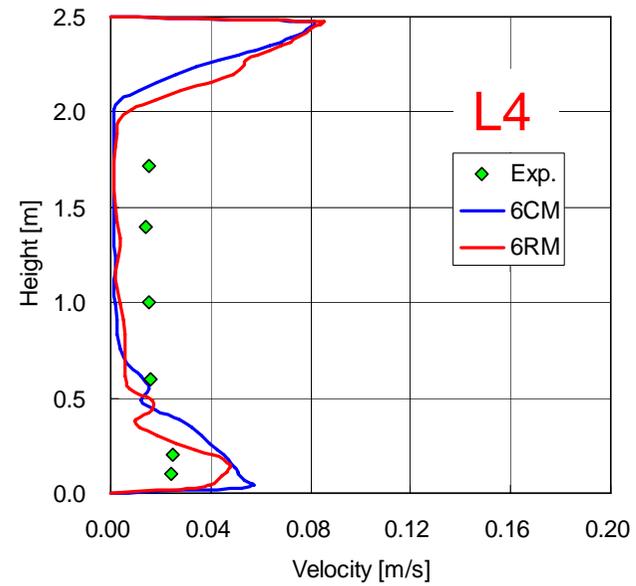
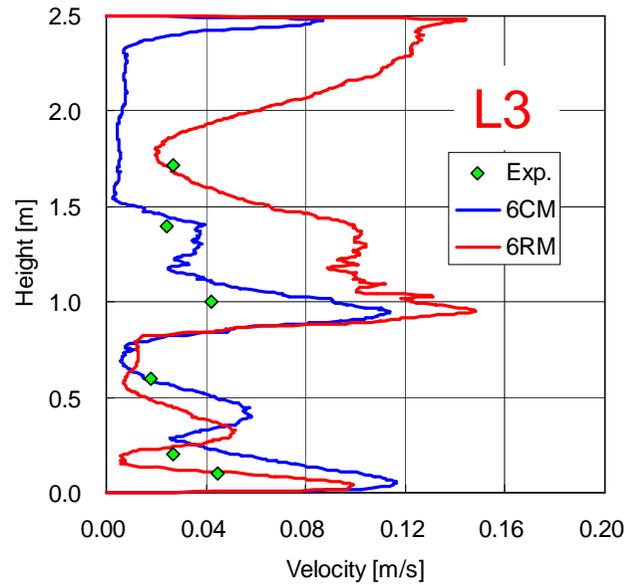
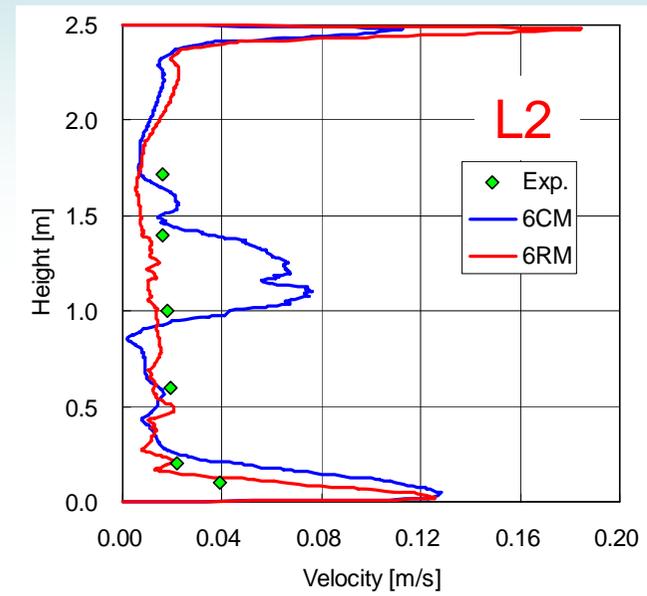
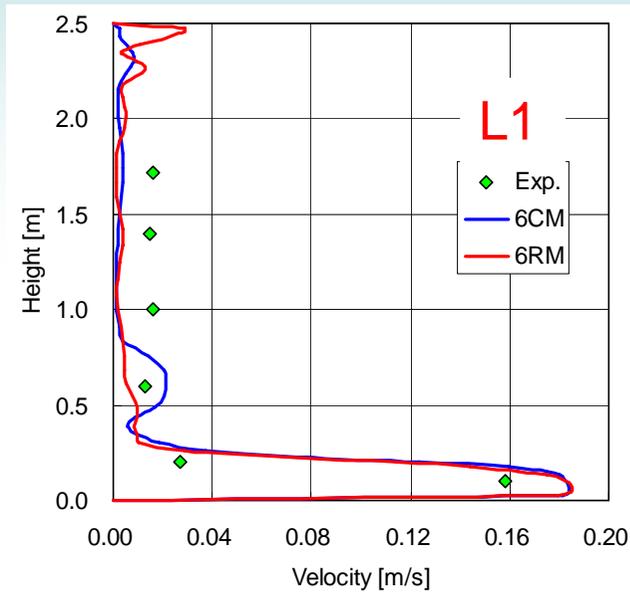


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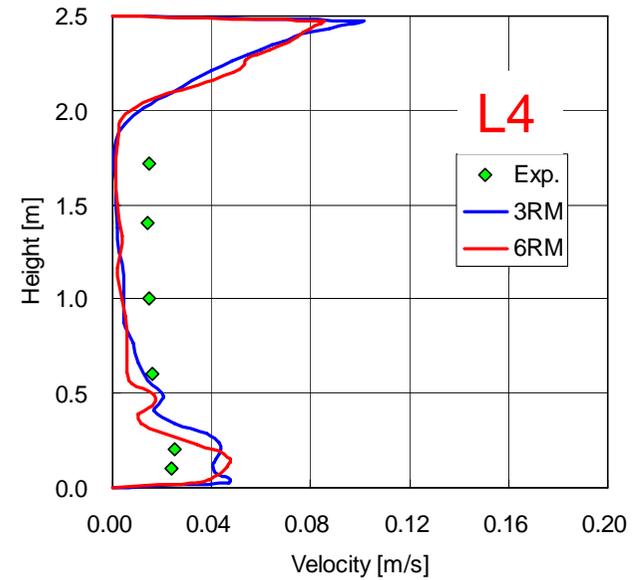
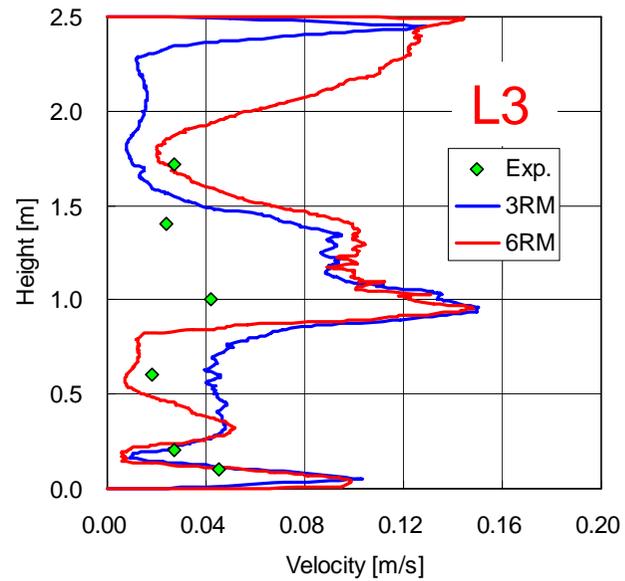
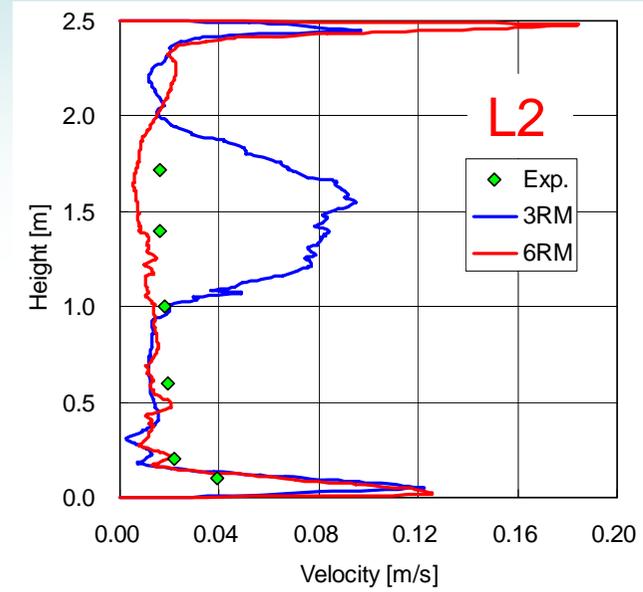
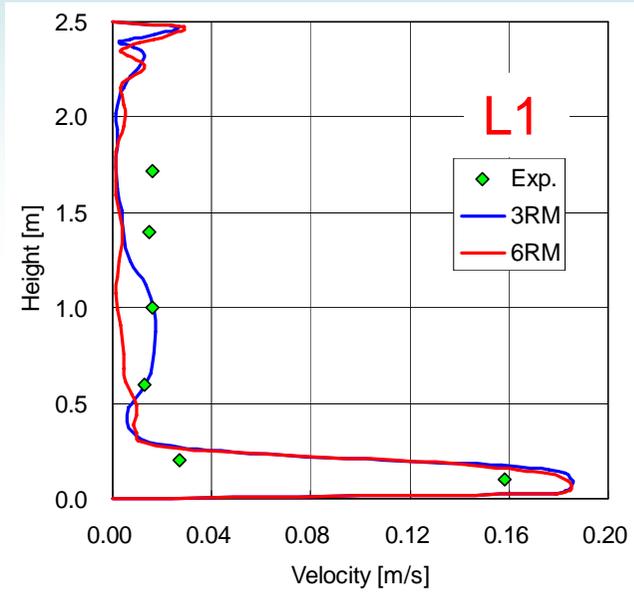


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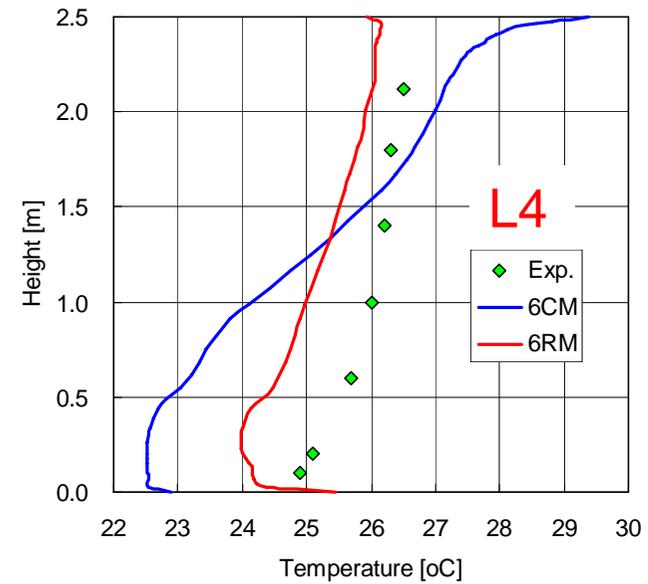
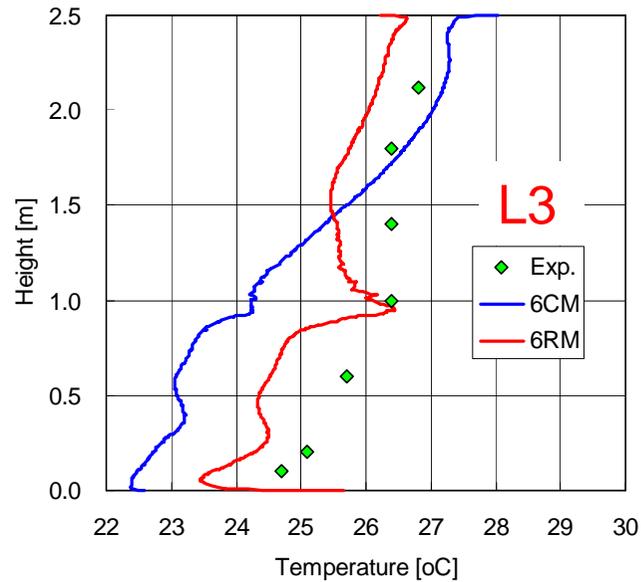
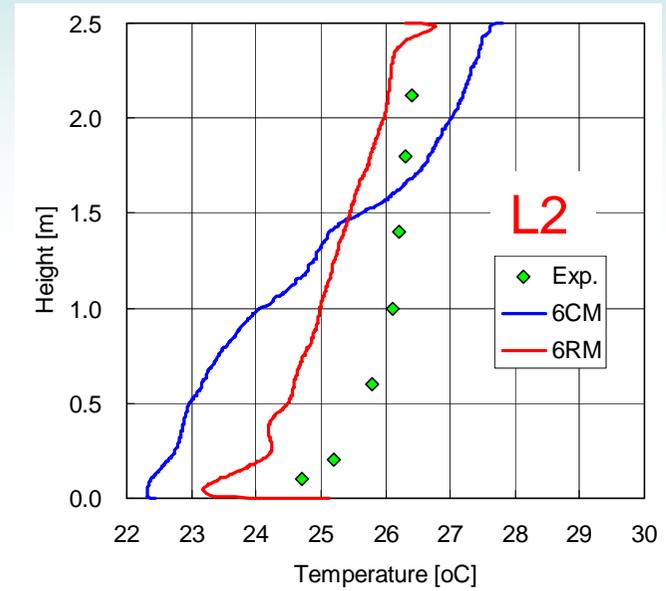
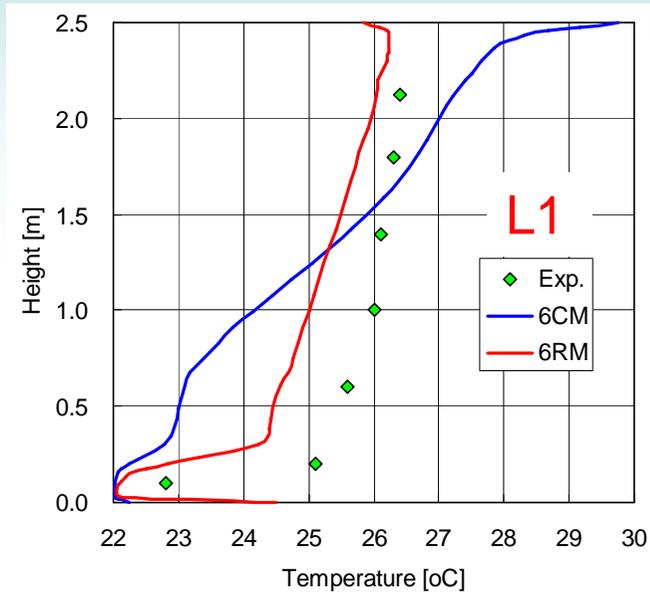
Distribution of Air Velocity in a Room [m/s] - 1



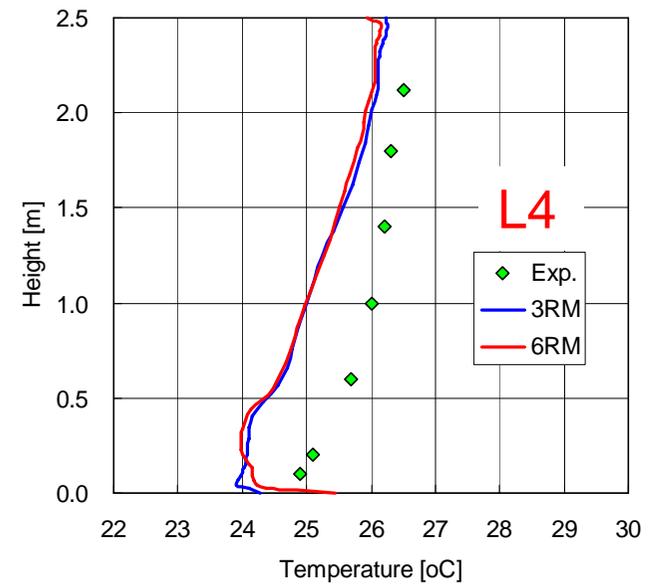
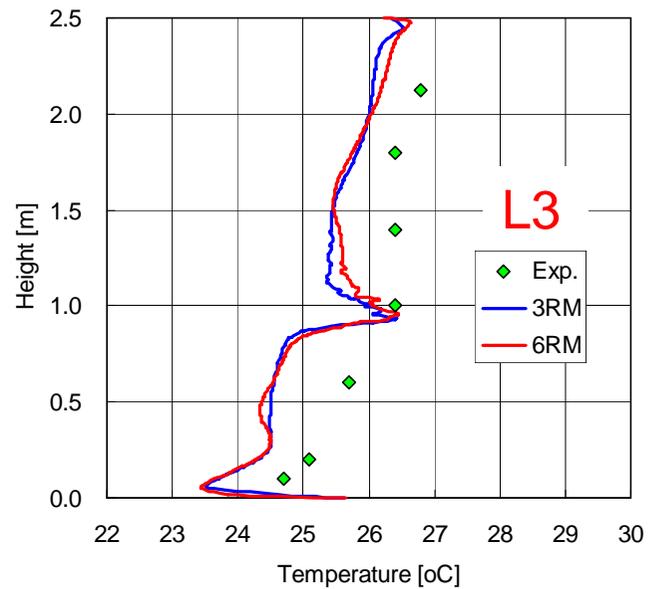
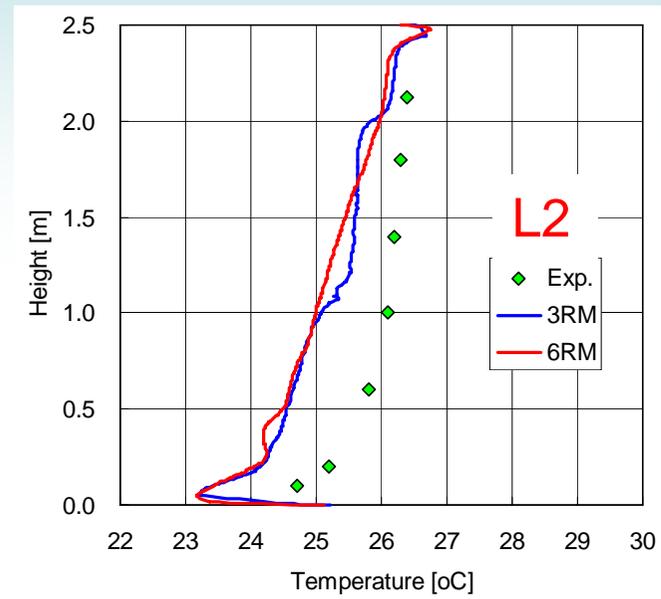
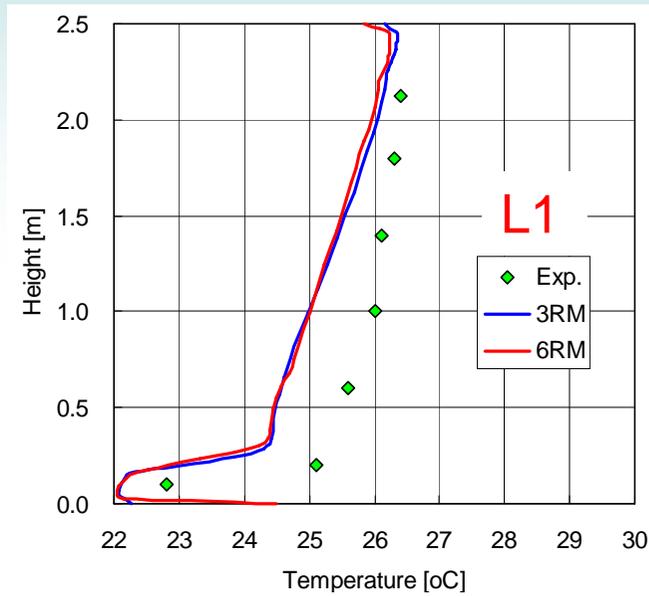
Distribution of Air Velocity in a Room [m/s] - 2



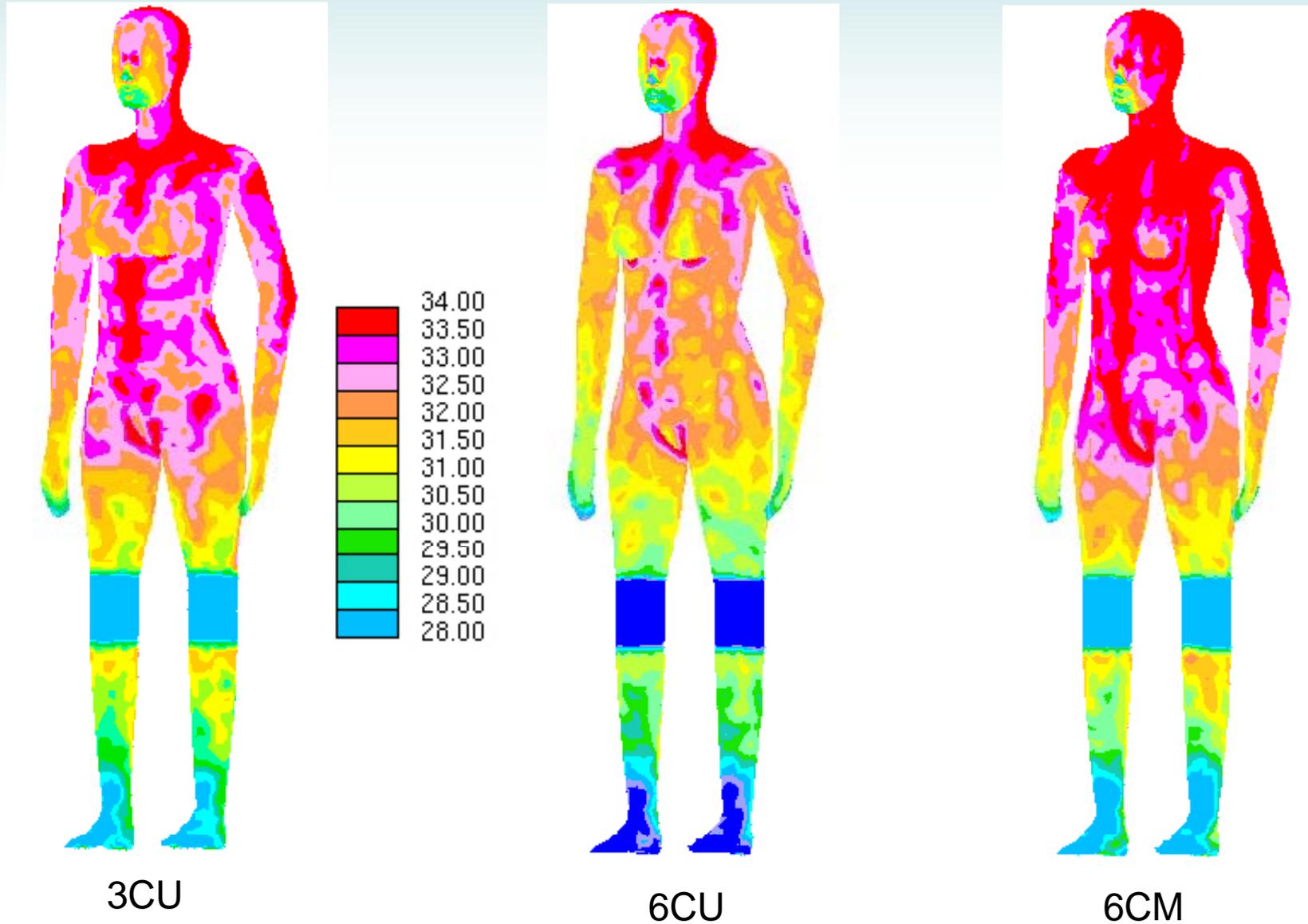
Distribution of Air Temperature in a Room [°C] - 1



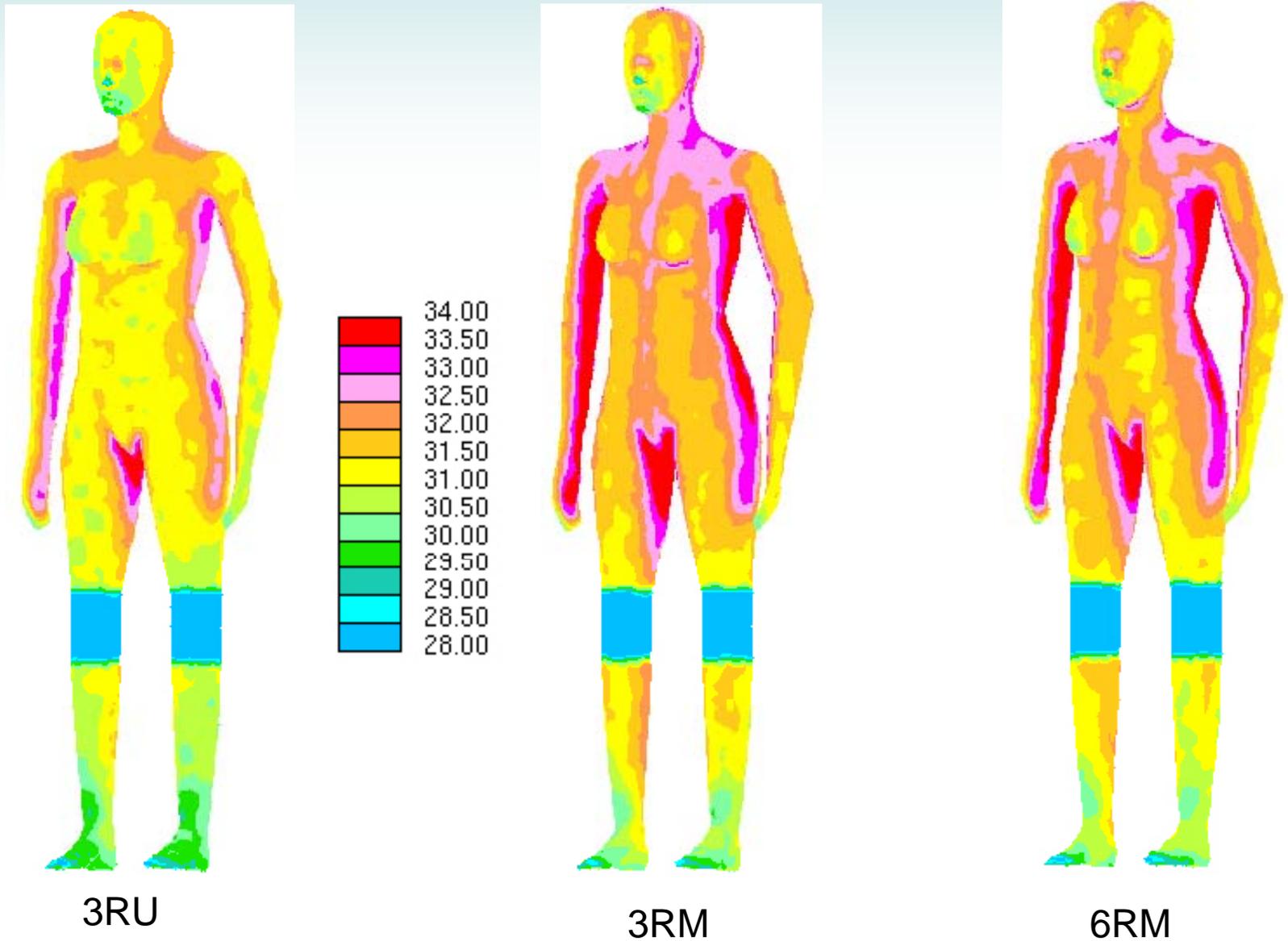
Distribution of Air Temperature in a Room [°C] - 2



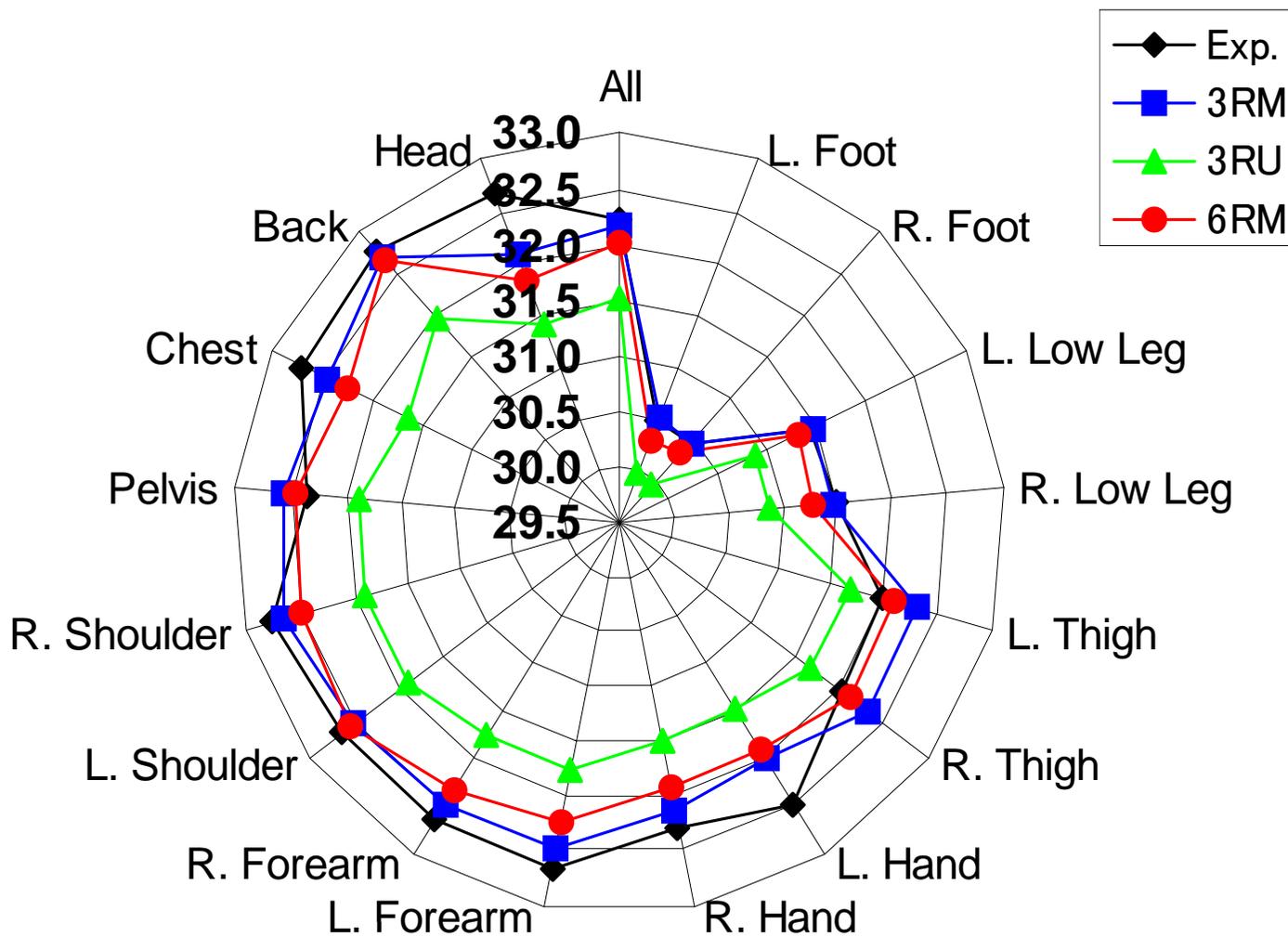
Distribution of Skin Surface Temperature [°C] - 1



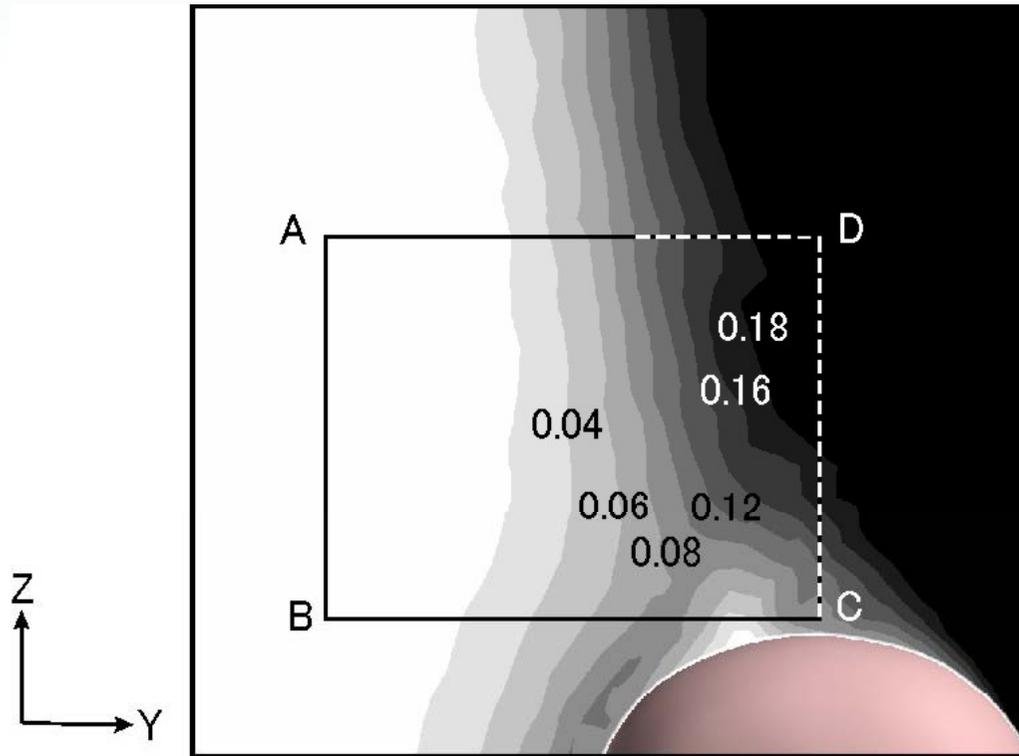
Distribution of Skin Surface Temperature [°C] - 2



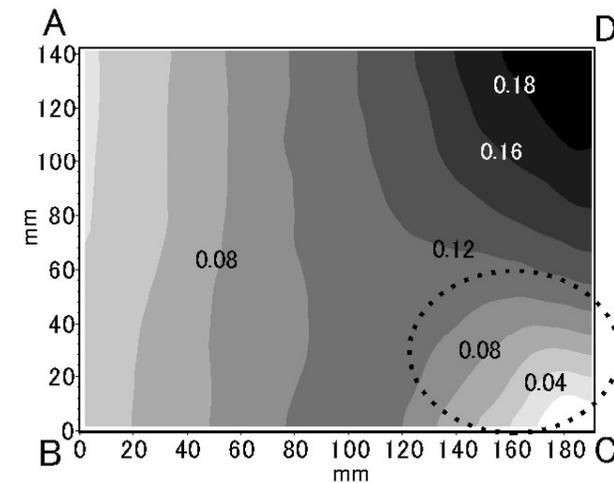
Distribution of Skin Surface Temperature [°C] - 3



Comparison of 2D Air Velocity of CFD and PIV above Head [m/s]

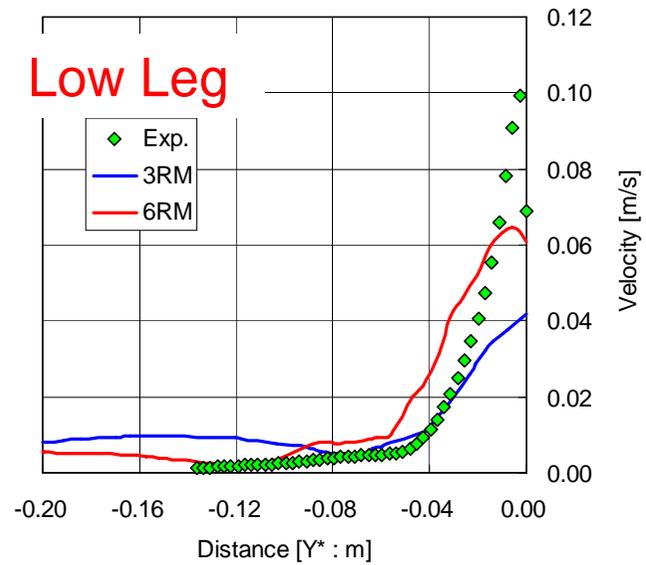
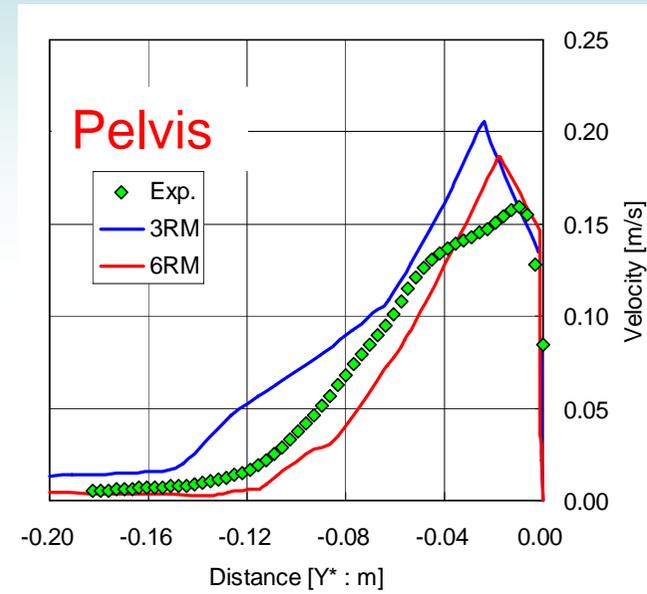
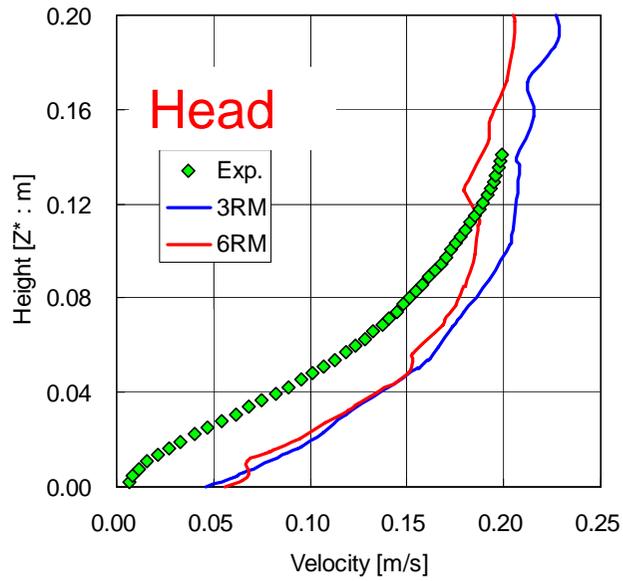


(1) Analysis result of CFD in Case 6RM

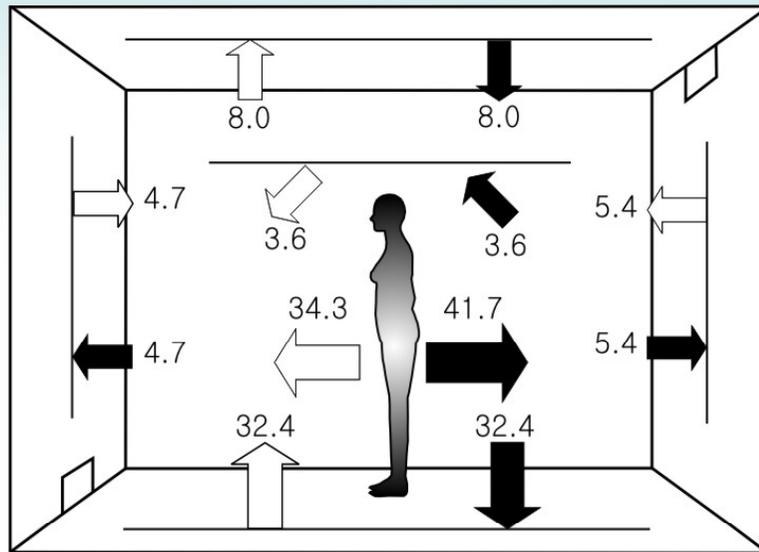


(2) Measurement result of PIV in area of ABCD

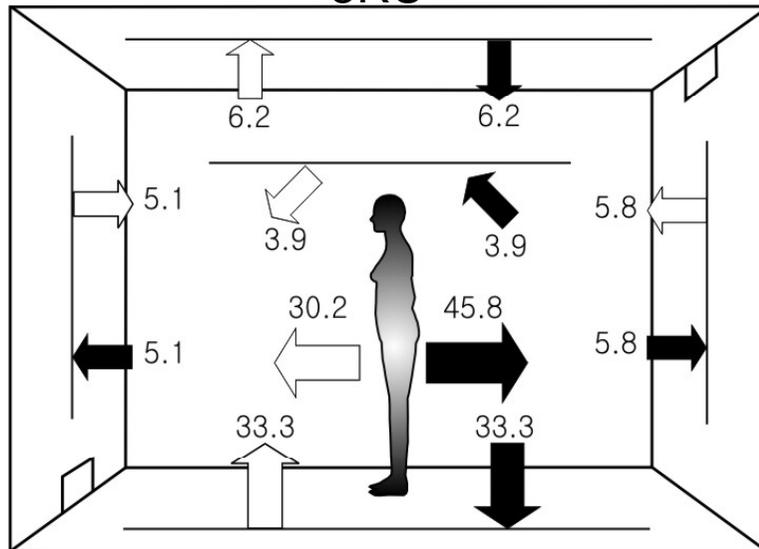
Distribution of 2D Scalar Air Velocity around each Region [m/s]



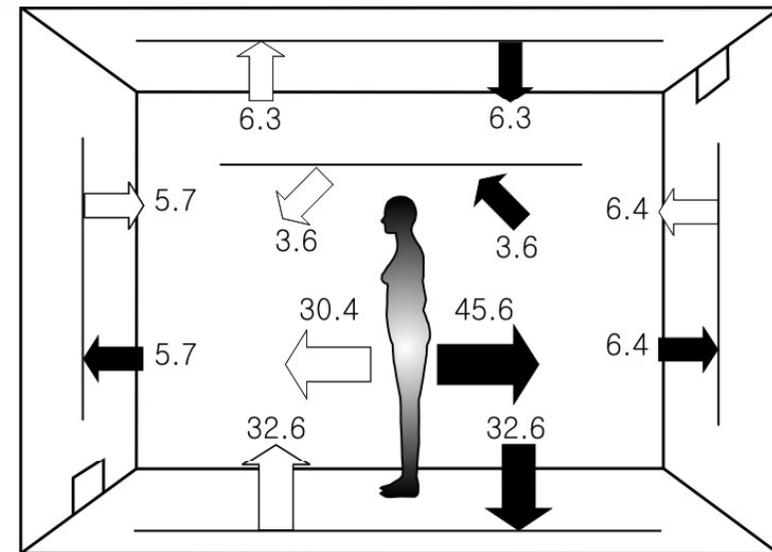
Heat Balance between Human Body and Surrounding Walls [W]



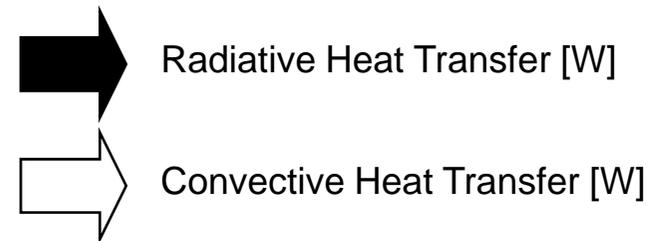
3RU



3RM



6RM



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 30cm/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