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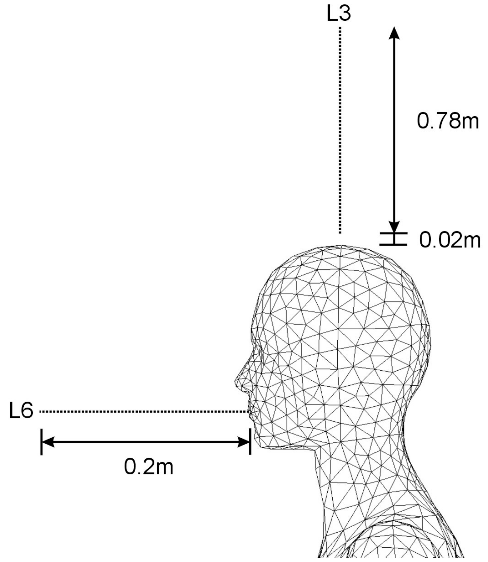
Benchmark

Benchmark Tests for a Computer Simulated Person



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Benchmark Tests for a Computer Simulated Person

by

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Introduction

Thermal manikins without and with breathing functions have been used for many years in full-scale experiments concerning indoor environment problems, see Brohus and Nielsen (1996), Bjørn and Nielsen (2002) and the proceedings of the International Meeting on Thermal Manikin Testing edited by Nilsson and Holmér (1999). The use of thermal manikins with breathing function makes it possible to measure the influence of ventilation and source location within healthy building problems and to measure the details of the processes involved in passive smoking, SARS infection, and many other details of the transport processes in the indoor environment.

Computational Fluid Dynamics (CFD) is an alternative to full-scale measurements. Research centres around the world have therefore developed different configurations (subroutines) to represent a Computer Simulated Person (CSP). The CSP´s can be very different in respect to size, form (rectangular grid or body-fitted grid), heat emission details, turbulence models, etc. The variations may reflect the different possibilities in the software but it may also be because of different standards for persons from country to country. Some examples of predictions made with CSP's are given by Murakami et al. (1995), Murakami et al. (1996), Murakami et al. (1998), Brohus and Nielsen (1996), Bjørn and Nielsen (2002) and Topp et al. (2002).

Figure 1 shows different thermal manikins for *experiments*. They also reflect the possibilities which can be obtained in a CFD prediction ranging from a simple rectangular geometry to a very detailed manikin.

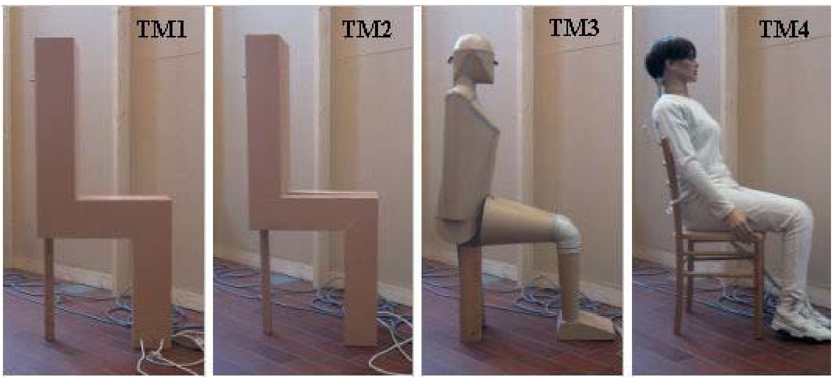

Figure 1. Four manikins for experiments.

This note introduces two different benchmark tests for a CSP. Both test cases have been, or will be, measured in full scale to get measurements for comparison with the predictions. The measurements

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will be made with the detailed manikin shown to the right in Figure 1. This manikin has been developed at DTU in Copenhagen, see Tanabe et al. (1994) and Madsen (1999).

One benchmark test will be related to mixing ventilation and another test to displacement ventilation. The mixing ventilation case has been developed by Aalborg University within the framework of the International Centre for Indoor Environment and Energy, and the displacement ventilation case has been developed at the University of Tokyo and Keio University.

Mixing Ventilation Case

The CSP considered in this case is seated and it is facing a unidirectional flow field that may be considered similar to the flow field a person is exposed to in a mixing ventilated room, as illustrated in Figure 2.

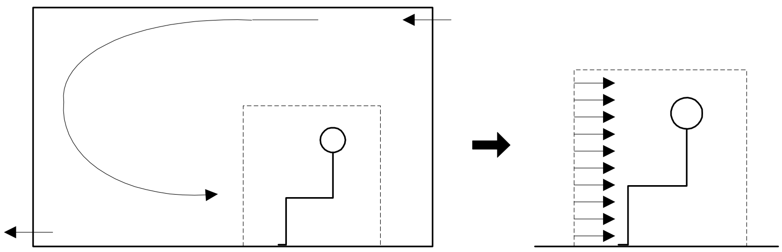

Figure 2. A person is exposed to a flow field in a mixing ventilated room that locally may be considered as a uniform flow.

The uniform flow field is simulated as a horizontal flow in a wind tunnel, see Figure 3. This geometry is equivalent to the set-up in the experiments discussed at the end of this note.

The width of the tunnel is 1.2 m. Both the CSP and the exhaust openings are centred on the *x*-axis. The circular exhaust openings have a diameter of 0.25 m and are located 0.6 m from the floor and the ceiling, respectively. Top, sidewall, floor and end wall should be simulated as solid surfaces.

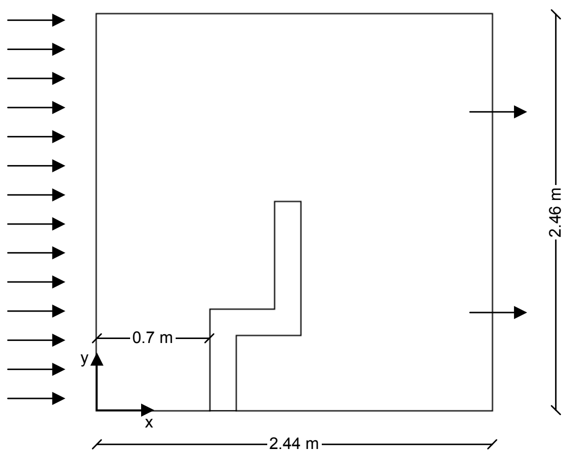

Figure 3. Plane outline at z = 0 of the tunnel and location of the CSP. The CSP is seated in the mixing ventilation case and facing the flow. The width of the tunnel is 1.2 m.

A uniform velocity u_o is applied at $x = 0$ (to the left in Figure 3), while the air leaves through the two circular openings at the opposite end (to the right in Figure 3). The two outlet openings may be simulated as partly squared openings if the CFD program is restricted to the use of Cartesian grid.

Numerical Methods and Boundary Conditions

The inlet boundary conditions have the following values:

	U_o (m/s)	T_o (°C)	k_o (m^2/s^2)	ε_o (J/kgs)
Case 1	0.05	22	6.0E-04	4.8E-06
Case 2	0.20	22	9.6E-03	3.1E-04
Case 3	0.50	22	6.0E-02	4.8E-03

The turbulent kinetic energy and the dissipation of turbulent kinetic energy have been calculated from

$$k_o = 1.5(u_o I_o)^2 \quad \text{and} \quad \varepsilon_o = C_\mu^{3/4} \frac{k_o^{3/2}}{l_o}$$

with turbulence intensity I_o = 40% (based on Nielsen 1990) and turbulent length scale l_o = 0.5 m (based on Gosman et al. 1980).

The boundary conditions at the floor are given as surface concentration c_s of 1000 mg/m^3 with a density of ρ = 1.2 kg/m^3.

CFD code

Turbulence model:	free
Algorithm:	free
Scheme	free
Grid (format, number):	free
Combined simulation of air flow and radiation:	free

Computer Simulated Person (CSP)

Posture:	seated
Geometry:	free
Heat flux:	76 W, corresponding to an activity level of 1 met. The feet are in contact with the floor but there is no heat flux from the feet to the floor. The Heat flux is 38 W if only convection is included
Breathing:	free

Grid

There are no restrictions on the grid. The specification of the grid should be indicated or reported.

Quality of the CFD prediction

Comments should be made on the quality of the predictions as:

- Order of accuracy of the numerical scheme
- Turbulence model

- Grid quality should be considered and studied i.e. in terms of different grid sizes or distribution of y^+-values

Results

The predictions must be made for the individual Computer Simulated Person used by the participants of the benchmark test.

It is convenient to report the simulations at the following locations:

- Vertical velocity profiles at different positions along the *x*-axis (*z* = 0): *x* = 0.19 m, *x* = 0.69 m, *x* = 1.19 m, *x* = 1.69 m and *x* = 2.19 m
- Three horizontal velocity profiles(m/s) close to the manikin. The first profile should be located 25 mm above the head. The second profile should be located at the centre of the mouth, and the last profile should be at the height of the torso (158 mm above the upper part of the legs)
- Concentration gradients (kg/kg) at different positions along the *x*-axis (*z* = 0): *x* = 0.19 m, *x* = 0.69 m, *x* = 1.19 m, *x* = 1.69 m and *x* = 2.19
- Horizontal concentration profile (kg/kg) at the centre of the mouth and inhaled concentration
- Average convective heat transfer coefficient ($W/m^2\,^oC$)

If combined simulation of air flow and radiation is considered, the convective and radiative heat transfer rate of each region should be reported:

- Area of each region (m^2)
- Convective and radiative heat transfer rate (W/m^2)

Displacement Ventilation Case

The CSP considered in displacement ventilation is standing and facing the supply flow as shown in figure 4. It is placed 5 cm above the floor to avoid heat conduction from the CSP to the floor.

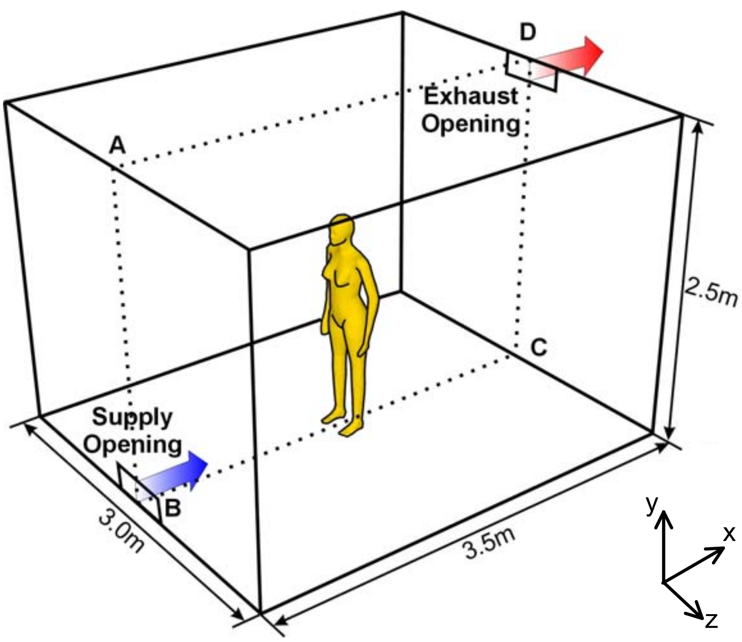

Figure 4. Set-up of the displacement ventilation case. The CSP is standing in this case in the mean planes of the room.

Air is supplied from an opening with dimensions 0.4 m (width) and 0.2 m (height) located at the floor and centred on the *x*-axis. The exhaust opening has the same dimensions and is located at the ceiling and centred on the *x*-axis.

Numerical Methods and Boundary Conditions

The inlet boundary conditions are as follows:

Velocity 0.2 m/s (air flow rate 0.016 m^3/s)
Temperature 22ºC
Turbulence intensity 30%
Turbulent length scale 0.1 m

The boundary conditions at the floor are given as surface concentration c_s of 1000 mg/m^3 with a density of $\rho = 1.2$ kg/m^3.

CFD code

Turbulence model:	free
Algorithm:	free
Scheme:	free
Grid (format, number):	free
Combined simulation of air flow and radiation:	free

Computer Simulated Person (CSP)

Posture:	standing, 5 cm above the floor
Geometry:	free
Heat flux:	76 W corresponding to an activity level of 1 met. The feet are free of the floor and there will be a heat flux from the soles of the feet. The heat flux is 38 W if only convection is include
Breathing:	free

Grid

There are no restrictions on the grid. The specification of the grid should be indicated or reported.

Quality of the CFD prediction

Comments should be made on the quality of the predictions as:

Order of accuracy of the numerical scheme
Turbulence model
Grid quality should be considered and studied i.e. in terms of different grid sizes or distribution of y^+-values

Results

The results should be reported at the following locations (see figure 5):

- Vertical velocity, concentration, and temperature profiles at L1, L2, L4 and L5 (m/s, kg/kg and ^{o}C)
- One vertical velocity ant temperatur profile above the head, L3 (m/s and ^{o}C)
- One horizontal velocity, concentration, and temperature profile located at the centre of the mouth, L6 (m/s, kg/kg and ^{o}C)
- Inhaled concentration (kg/kg)
- Average convective heat transfer coefficient (W/m^{2} ^{o}C)

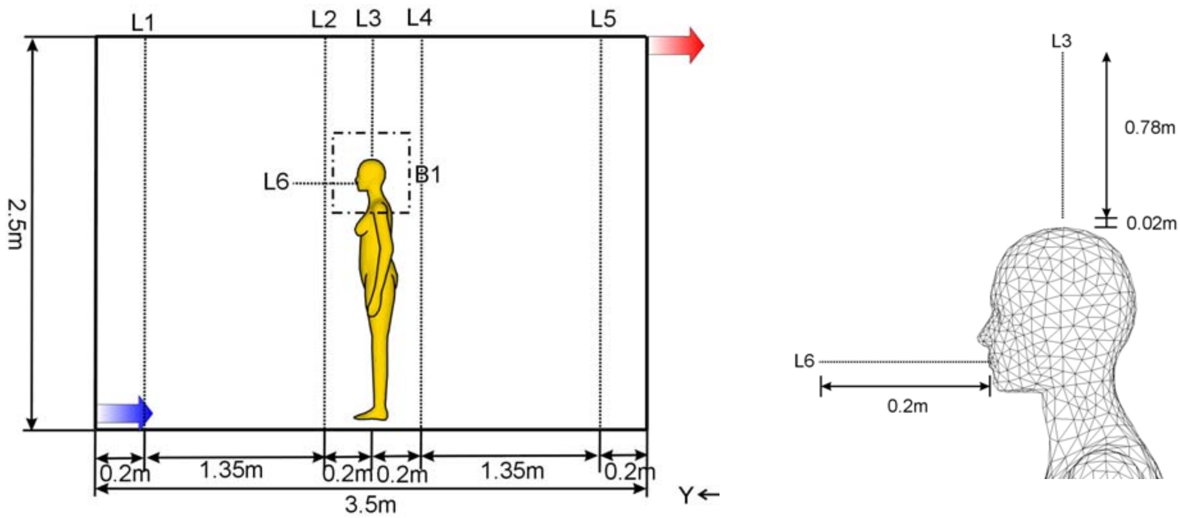

Figure 5. Locations of lines for reporting results.

If combined simulation of air flow and radiation is considered, the convective and radiative heat transfer rate of each region should be reported:

- Area of each region (m^{2})
- Convective and radiative heat transfer rate (W/m^{2})

Measurements for Comparisons in the Mixing Ventilation Case

Velocity measurements have been made in the mixing ventilation case and they can be downloaded in an Excel spreadsheet from www.civil.auc.dk/~i6topp/CSP.

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