# COMPARISON BETWEEN INDOOR ENVIRONMENT MEASURED WITH THERMAL MANIKIN AND COMPUTATIONAL FLUID DYNAMICS CALCULATION

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## ABSTRACT

With increasing demand for acceptable indoor environment it is necessary, already in the construction phase, to estimate what effect different environmental factors have on the occupants. Thermal sensation is affected by many factors of the indoor environment. Predictive models are available which describe overall thermal sensation as function of the most important factors. In this work reference environments have been investigated with a thermal manikin. The results from these measurements are then compared to CFD predictions. The heat loss and temperature of the manikin influence the air movements around the body. Thermal interaction with walls, ventilation and furniture are influencing the manikin. When this thermal information is linked together with models for the human thermal sensation, valuable knowledge about the thermal status of a room can be obtained. In the future this kind of calculations can enable consultants and engineers to make predictions and early statements in the design and construction process.

## INTRODUCTION

This investigation is a part of a larger project that will investigate why houses and working places are the source for unhealth. The background is defective designed or constructed buildings that causes many diseases, ruins the environment and consumes too much energy. The project is a co-operation between the National Institute for Working Life, the Centre for Built Environment at the Royal Institute of Technology and ABB Ventilation Products. To achieve the goal, to improve the indoor environment, computerised tools are going to be used and developed for assessment of good ventilation and indoor climate.

## METHOD

In order to investigate how well CFD calculations and measurements with a thermal manikin can predict the perceived climate in a room numerical calculations as well as full scale measurements where carried out. This study is the first step towards making computer simulations that will predict the effects of local climate disturbances that are well correlated with the thermal sensation experienced by subjects exposed to the same conditions

### The manikin method

Measurements with a thermal manikin yield a more complete, integrated and detailed information about thermal effects [1, 2, 3]. The manikin called AIMAN is a man-sized, sitting thermal manikin made of plastic foam The surface layer of the manikin is densely covered with resistance wires, embedded in a hard plastic shell. Manikin surface is divided into 33 independently controlled segments (Figure 1). Once heated the manikin responds to a step change and equilibrates at the new power consumption within approx. 20 minutes. The variation between double determinations in percent of their average value is less than a few percent.

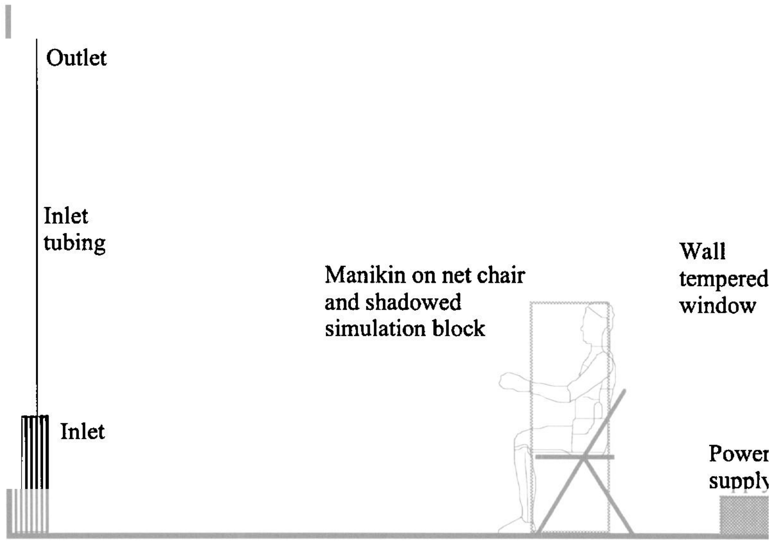


Figure 1. Schematic drawing of the segmented manikin inside the climatic room with deplacement ventilation.

**Measurement procedure**

The manikin was positioned in the environment that should be assessed. In this study a displacement ventilated empty room with air and wall temperatures close to 20°C was used (data see Table 2). Heat flow in $W/m^2$ from the different segments of the manikin surface was measured and controlled by a computerised system. Data for the actual conditions were recorded when manikin has reached heat equilibrium with the environment.

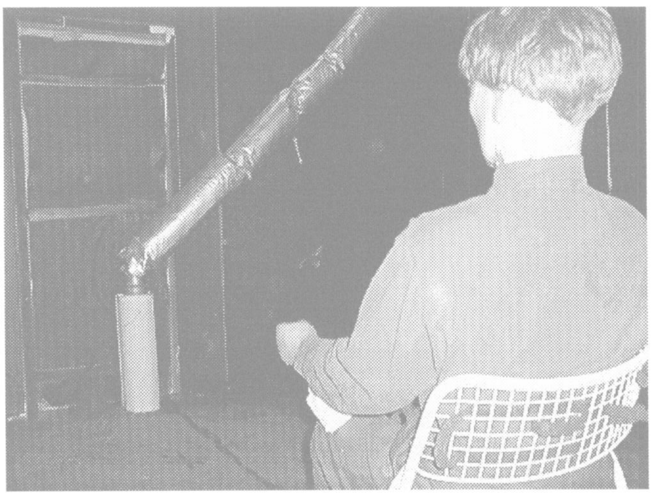

Figure 2. The thermal manikin AIMAN inside the climatic room.

The manikin technique has been validated in tests with subjects [4, 5]. The heat losses of the manikin as well as the subjective and physiological reactions of a panel of 10 subjects were obtained for altogether 20 different sets of climatic conditions. Measurements of local climate disturbances with a man–sized thermal manikin are well correlated with the thermal sensation experienced by subjects exposed to the same conditions. The manikin method represents a quick, accurate and reproducible technique for relevant, reliable and cost–effective assessment of many of the complex details of the climate and their integrated effects on humans.

**Calculation procedure**

The numerical methods used for air flow and heat transfer predictions are described in the manuals of the CFX-4.2 suit of software (AEA Technology, Harwell, OXON, UK). A side view of the room is shown in Figure 1. The manikin was positioned in front of the window with the same temperature as the walls. A rectangular block (x, y, z) (0.4 x 1.2 x 0.2 $m^3$) was representing the manikin. The manikin block had a free surface area of 1.52 $m^2$, giving a constant heat flux according to Table 2 to the surrounding air. The manikin power boxes (0.3 x 0.2 x 0.2 $m^3$) where positioned under the window and gave 10 $W/m^2$ heat load to the room. Ceiling, wall and floor conditions was adiabatic. The incoming air supply rate was kept constant at 3 different levels 10, 20 and 30 l/s. The supply air was distributed through a displacement air terminal (EMTEK). The supply-air temperature and normal velocity at the inlet was measured and set according to Table 1. The turbulence intensity and dissipation length scale at the inlet was set to 0.037 and 1.25 respectively. The outlet (0.5 x 0.2 $m^2$) was positioned at the same wall as the inlet but with the centre 2.5 m above the floor, see Figure 1 above. Boundary conditions for the CFD calculations are shown in Table 2 and 3. The isothermal incompressible flow field was calculated with three dimensional CFD. The turbulence model used was the low-Reynolds-number $k$-$\varepsilon$ model. The body fitted grid used had a global edge length of 0.1 m, consequently generating (40 x 27 x 34) 36720 cells. Calculations with more than 1000 iterations did not show any improvement of the residuals.

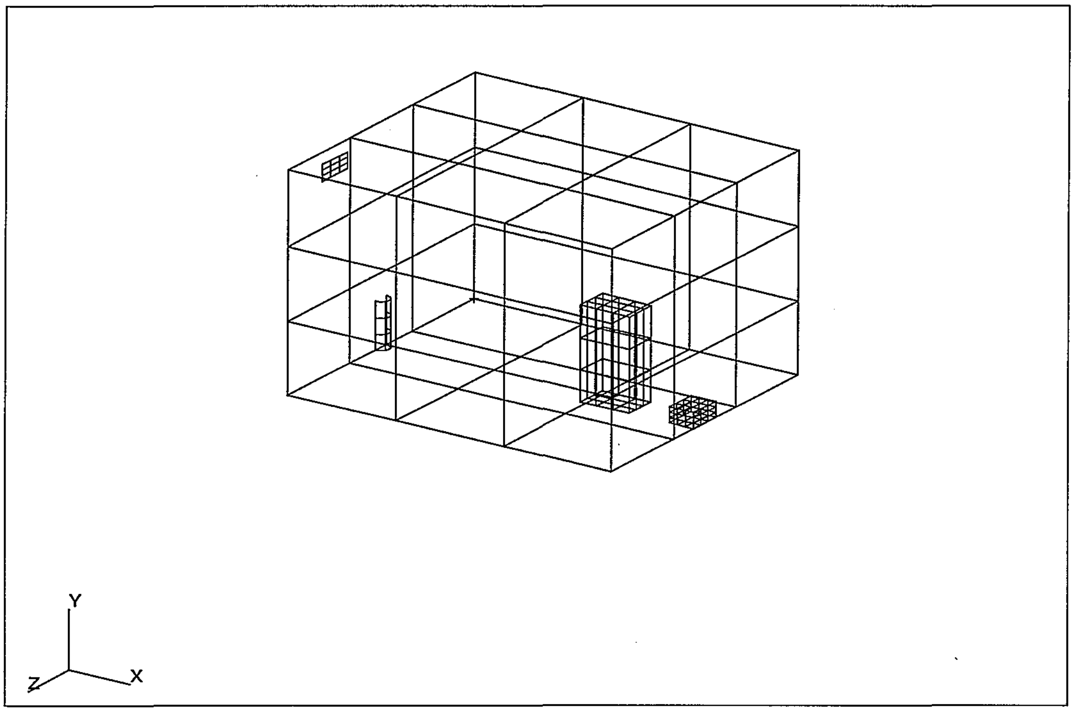


Figure 3. The geometry of the climatic room. The inlet and outlet are on the left wall.

## RESULTS

Three different cases has been studied both with the manikin and numerical simulations. The results from the numerical simulations are shown below. Temperatures in the middle of the room as well as at the inlet was measured continuously during the measurements (Table 1). The total heat loss from the manikin was measured for the three flow cases (Table 2).

Table 1. Heat loss data (W/m$^2$) from a selection of manikin segments during the exposure to the three different cases. (L = Left, R = Right)

| *Heat loss (W/m$^2$) Manikin segment* | *Air flow case (l/s)* 10 | 20 | 30 |
|---|---|---|---|
| ***Total*** | **66.2** | **68.4** | **68.9** |
| *Face* | 107.0 | 110.4 | 111.8 |
| *Chest* | 52.2 | 54.6 | 53.4 |
| *L hand* | 115.3 | 122.0 | 130.4 |
| *R hand* | 113.5 | 119.9 | 121.8 |
| *L foot* | 63.6 | 62.7 | 62.6 |
| *R foot* | 63.6 | 63.6 | 62.7 |
| ***Air temp.*** | **19.8** | **19.3** | **19.1** |

Table 2. The measured data together with data used in the CFD calculations.

| *Air flow case (l/s)* | *Room air Measured* | *Room air Calculation* | *Inlet air Measured* | *Inlet air Calculation* | *Heat loss Measured* | *Heat loss Calculation* |
|---|---|---|---|---|---|---|
| *10* | 19.8 | 20* | 16.6 | 16* | 66 | 66* |
| *20* | 19.3 | 20* | 17.1 | 17* | 68 | 68* |
| *30* | 19.1 | 20* | 17.8 | 18* | 69 | 69* |

* *input data*

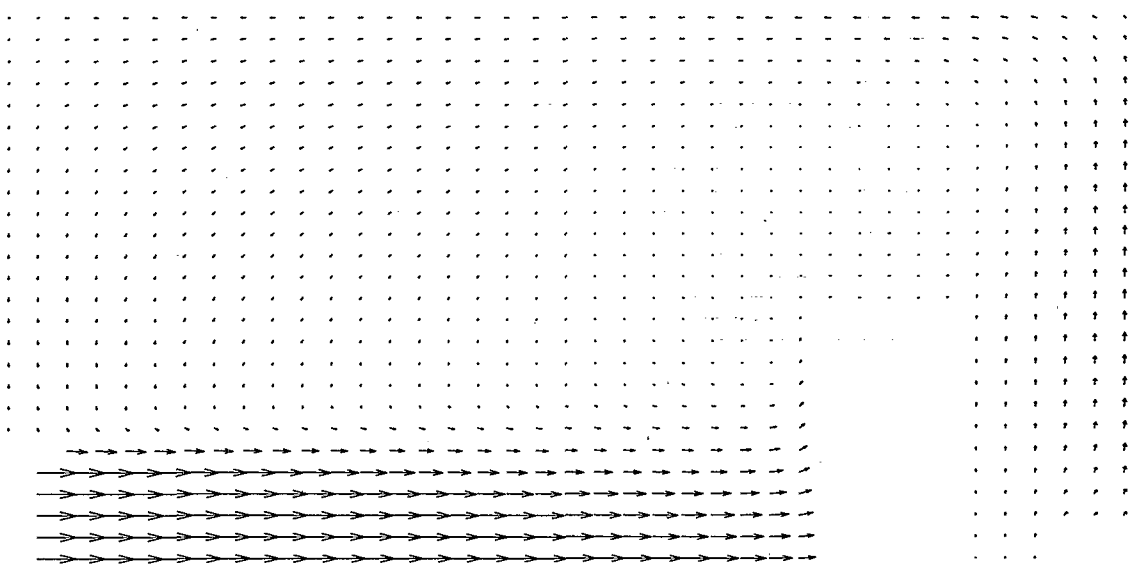

Figure 4. The flow patterns in the room shown in a plane at the inlet centre, se Figure 3.

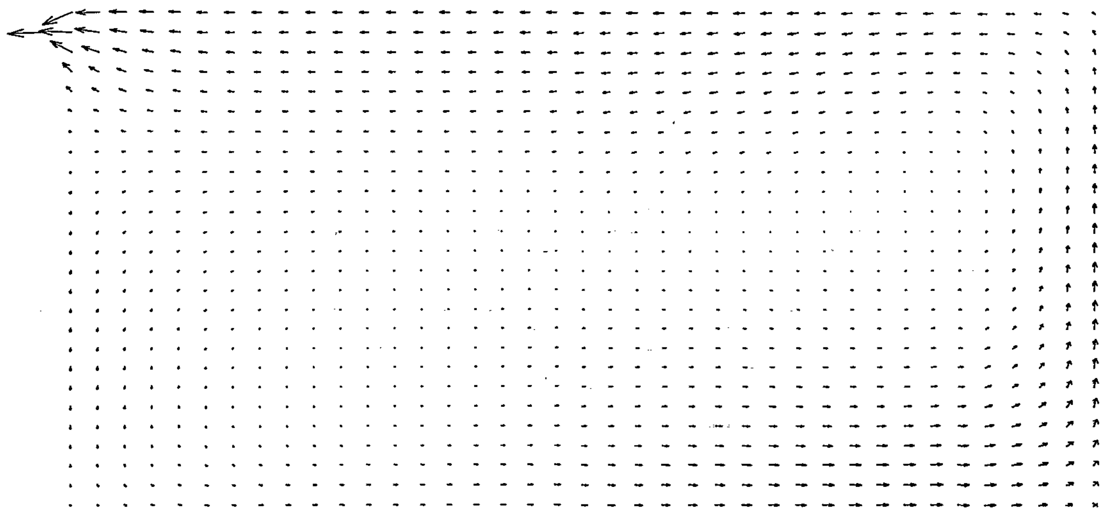

Figure 5. The flow patterns in the room shown in a plane at the outlet centre, se Figure 3.

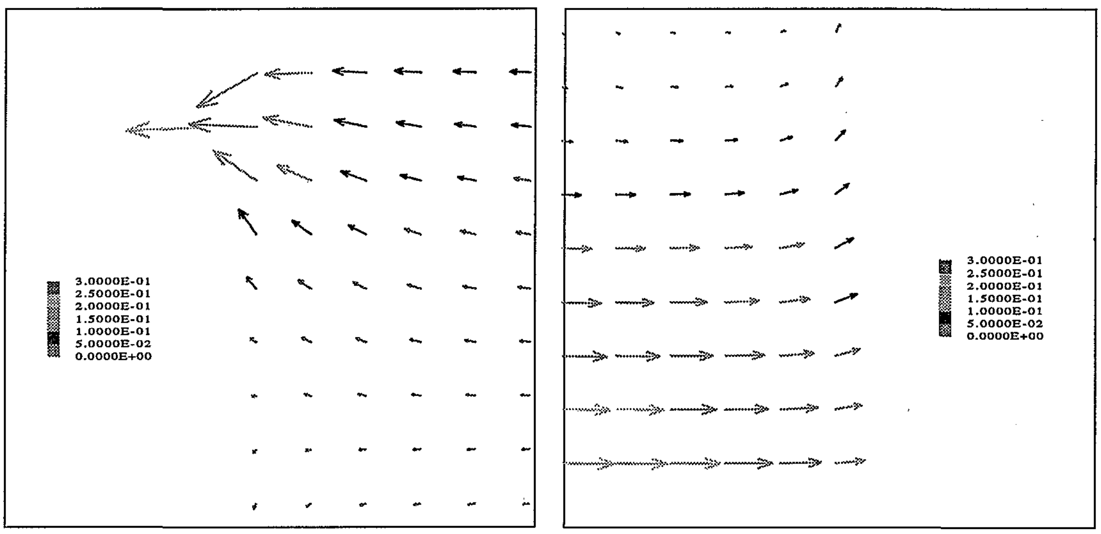


Figure 6, 7. The flow pattern, shown as magnifications of the manikin front area (right) and outlet area (left) shown in figure 4, 5. The values corresponds to the results shown in Table 3 below.

Table 3. The measured air speed (m/s) compared to data calculated with the CFD program.

| *Measurement* | *10 l/s* | | *20 l/s* | | *30 l/s* | |
|---|---|---|---|---|---|---|
| *position* | *Measured* | *Calculation* | *Measured* | *Calculation* | *Measured* | *Calculation* |
| *Inlet (0.2,0.3,1.7)* | 0.16 | 0.16* | 0.23 | 0.23* | 0.30 | 0.3* |
| *Outlet (0.0,2.5,2.5)* | 0.11 | 0.11-0.13 | 0.16 | 0.15-0.19 | 0.22 | 0.20-0.25 |
| *Manikin (2.0,0.6,1.7)* | 0.10 | 0.05-0.08 | 0.10 | 0.08-0.12 | 0.20 | 0.10-0.15 |

* *input data*

## DISCUSSION AND CONCLUSIONS

The results from this study show good agreement with the measurements made in the real environment. However, further development of the simulation of a human or manikin is needed. The model should include the right human geometry and the same thermal behaviour as the manikin. In more complex environments calculations including the influence of radiation from cold and hot surfaces has to be considered. Future research should aim at evaluating these results in order to find more accurate methods for evaluating ventilation and room design. CFD (Computational Fluid Dynamics) tools will be useful for this work.

## ACKNOWLEDGEMENTS

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