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Sensitivity analysis of personal exposure assessment using a computer simulated person

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SUMMARY

The paper considers uncertainties related to personal exposure assessment using a computer simulated person. CFD is used to simulate a uniform flow field around a human being to determine the personal exposure to a contaminant source. For various vertical locations of a point contaminant source three additional factors are varied, namely the velocity, details of the computer simulated person, and the CFD model of the wind channel. The personal exposure is found to be highly dependent on the relative source location. Variation in the range of two orders of magnitude is found. The exposure is found to be significantly sensitive to choice of model geometry, details of computer simulated person and velocity level. Modelling uncertainty and sensitivity should always be evaluated and reported.

KEYWORDS

Sensitivity analysis, personal exposure assessment, computer simulated person, CFD, IAQ

INTRODUCTION

To assess ventilation effectiveness and personal exposure properly in ventilated enclosures an increasing number of studies have focused on the application of personal exposure assessment in different ventilation settings like uniform airflow, mixing ventilation and displacement ventilation. Both experimental and numerical works have been undertaken using various models of a human being (Brohus, 1997). Most studies, however, lack a thorough investigation of uncertainties related to the investigation itself and to personal exposure assessment at large.

METHODS

CFD is used to simulate the uniform flow field around a person in a wind channel to determine the personal exposure to a contaminant source. The starting point is a full-scale wind channel and a breathing thermal manikin modelled by CFD, Figure 1. The case may resemble part of a mixing ventilated room or locally uniform flow field in industrial or hospital settings. The CFD code Flovent 4.2 is applied using the standard two-equation k-ε turbulence model and wall functions along all surfaces. The computational grid is checked for convergence. Two versions of a Computer Simulated Person (CSP) are modelled according to Brohus (1997). The models are kept very simple to be useful for practical engineering design. Despite the simple design the CSPs are found to provide useful results in several studies e.g. Topp et al. (2002) and Bjørn and Nielsen (2002).

The personal exposure is calculated for five vertical locations of the contaminant source, Figure 1. For each location three additional factors are varied in a 2^3 factorial design to investigate the influence, namely the velocity (0.05 m/s and 0.2 m/s), CSP details, and the CFD model of the wind channel (inlet opening detail with or without an extended filter box, Figures 1 - 2).

The computational grid is a rectangular structured mesh. The size varies between approximately 315,000 and 455,000 grid nodes depending on the inclusion of the extended filter box (for the grid dependency study half the size and twice the size are applied, respectively). The grid is refined close to the CSP and the contaminant source with a local mesh distance of 1 cm. As to the thermal boundary conditions the surface temperature is prescribed for all wind channel surfaces according to full-scale measurements (approximately 23 °C). For the CSP a constant convective heat flux of 25 W/m^2 is prescribed (corresponding to a human being in thermal comfort with an activity level of 1 met and a clothing insulation of 0.8 clo; Brohus, 1997). The supply temperature is 22.35 °C. No turbulence is assumed at the inlet opening.

Statistical analysis by 2^3 factorial design is applied to assess sensitivity and mutual correlation between the factors.

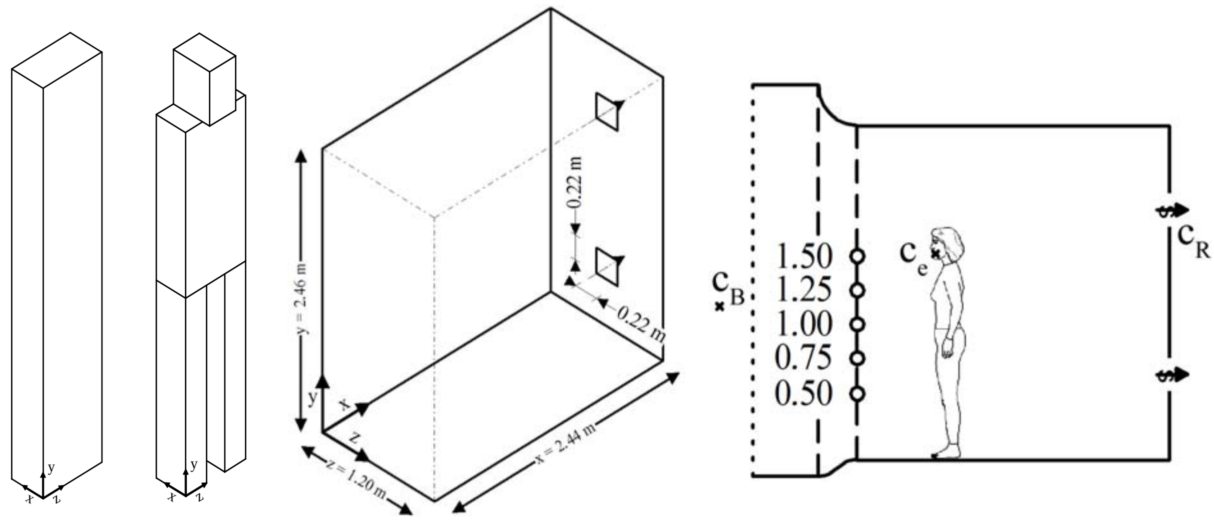

Figure 1. Left: The two Computer Simulated Persons, CSP 1 and CSP 2, respectively. Centre: Coordinate system. Right: The five different locations of the contaminant source. The personal exposure, c_e, is taken as the contaminant concentration at the first grid node along the CSP at the breathing zone height, i.e. 1.5 m above the floor (Brohus, 1997).

RESULTS

Figure 2 shows four selected examples of contaminant distribution in the centre plane of the wind channel for the point contaminant source at y = 0.75 m. The quantitative investigation of the three factors is found by means of sensitivity analysis using a 2^3 factorial design (Montgomery, 1997). In that way the main effect (first-order local sensitivity) of each factor is investigated and also the interactions, i.e. second-order effect (two-factor correlation) and third-order effect (three-factor correlation), Table 1.

For each source location Table 1 shows the mean value of the dimensionless personal exposure, $c_e^* = (c_e - c_B)/(c_R - c_B)$, for the eight possible combinations of the three factors. The remaining values in Table 1 are the local influences divided by the respective mean values. Thus, values close to zero means no sensitivity whereas values close to 1 indicate a variation of the personal exposure comparable with the mean value.

Table 1. Sensitivity analysis using 2^3 factorial design. v is velocity, G is wind channel geometry, C is CSP type. Values comprise factorial design main effects (1st order) and interactions (2nd and 3rd order) divided by the respective mean values.

Source	c_e^*	1st order			2nd order			3^{rd} order	Influence	
y [m]	Mean	v	G	C	vG	vC	GC	vGC	Max	Min
0.50	0.08	-1.62	0.08	-0.51	-0.44	0.12	1.01	-0.65	v	G
0.75	0.19	-1.54	-0.13	-0.91	-0.30	0.46	0.77	-0.36	v	G
1.00	0.60	-1.25	-0.37	-0.85	-0.27	0.37	0.34	0.06	v	vGC
1.25	2.65	-0.44	-0.34	-0.45	-0.45	0.16	0.07	0.11	C	GC
1.50	7.90	-0.12	0.11	-0.05	0.16	0.21	0.25	0.18	GC	C

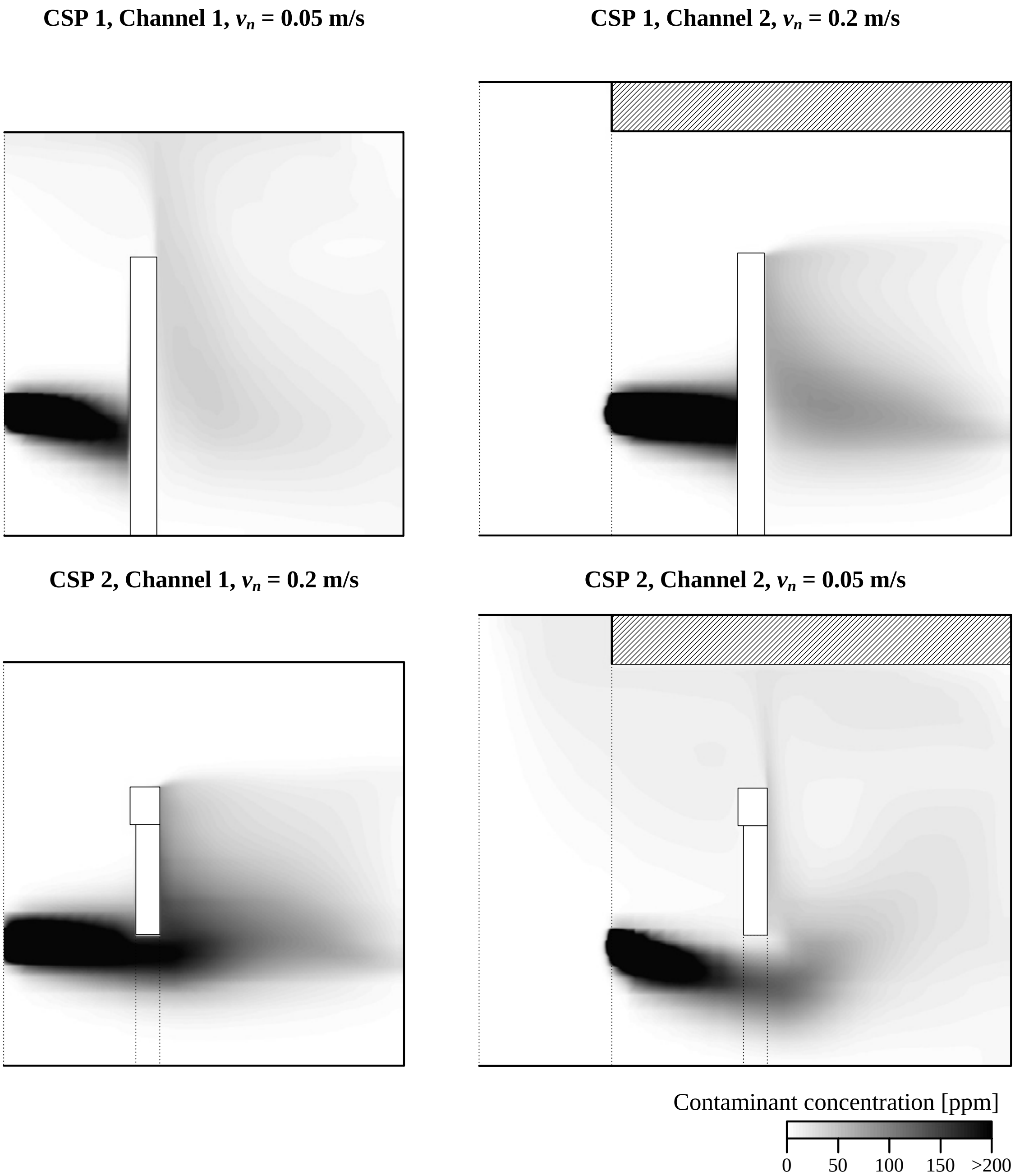

Figure 2. Samples of concentration distribution in centre plane. Source location z = 0.75 m.

DISCUSSION

As expected contaminant source location relative to the CSP is crucial to proper exposure assessment. Variation of mean dimensionless personal exposure over two orders of magnitude is found (approximate range 0.1 – 10). Compared with fully mixed conditions, i.e. $c_e^* = 1$, the actual exposure may be approximately 10 times lower or higher.

For each contaminant location significant influence of the three factors is found. As to flow pattern and contaminant distribution the factors are found to influence especially the area behind the CSP in the wake region and around the legs. Sensitivity is highest for lower locations of the contaminant source. This may be explained by the fact that for source location of y = 1.5 m the contaminant transport is "head on" from the source to the breathing area, whereas the lower location give rise to contaminant transport around and along the CSP before the contamination enters the breathing zone. Especially for the low velocity level, the ascending convective boundary layer around the heated body plays a crucial role.

For the low source location the personal exposure is most sensitive to the velocity level and not particularly sensitive to the wind channel geometry. Except for the highest source location, the exposure depends strongly on the CSP model. In that connection inclusion of legs may be seen both as an improved model but it may as well reveal the influence of standing with or without one's feet together. Significant sensitivity to interactions (2nd and 3rd order influence) is found for most source locations. For instance this means that the relative influence of the velocity level is influenced by the wind channel geometry. For low source locations significant third order influence is found.

Overall the results reveal a strong sensitivity to the choice of geometry and modelling details of the occupants in a ventilated room as well as the local velocity level. This fact points out the importance of critical evaluation of personal exposure assessment when CFD is applied. Furthermore, the need for sensitivity analysis to validate the assessment is clear. It is not sufficient to perform a "single" CFD simulation to get a quick result. The influence of important factors should be investigated and reported.

CONCLUSIONS

It is found that the personal exposure to a contaminant source in a uniform flow field is highly dependent on the relative source location. Variation in the range of two orders of magnitude is found. The exposure is found to be significantly sensitive to the choice of model geometry, choice of computer simulated person, and the velocity level. The results point out that it is not sufficient to perform a "single" CFD simulation. The uncertainty should be evaluated and reported. As part of this evaluation sensitivity analysis is an essential tool.

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