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Sensitivity analysis of personal exposure assessment using a breathing thermal manikin

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SUMMARY

The present work deals with the investigation of uncertainties related to personal exposure assessment using a breathing thermal manikin subject to a partly uniform velocity field in a wind channel. Several parameters are investigated: velocity level, thermal manikin heat flux, Archimedes number, incident flow angle, and contaminant source location. Substantial variance is detected and it is found that the parameters may influence the personal exposure substantially with a factor of approximately 10. Small variation of the contaminant source location (± 5 cm) may influence the result approximately $\pm 30\%$. In general uncertainty and sensitivity are substantial and should be investigated and reported.

KEYWORDS

Sensitivity analysis, personal exposure assessment, breathing thermal manikin, contaminant distribution, IAQ

INTRODUCTION

To assess ventilation effectiveness and personal exposure in ventilated enclosures an increasing number of studies have focused on 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 an investigation of uncertainties.

METHODS

Personal exposure measurements are performed in the partly uniform flow field generated by a wind channel, Figure 1. A breathing thermal manikin (BTM) is located in the wind channel as shown in Figures 1 – 2. CO₂ is applied as tracer gas to model contaminant transport. To investigate the uncertainty and sensitivity several factors are investigated comprising velocity distribution, heat flux from the thermal manikin, Archimedes number, incident flow angle, and relative contaminant source location. Tracer gas measurements are applied combined with velocity and temperature measurements and visual inspection by smoke.

RESULTS

In Figure 3 the influence of heat emission from the BTM is shown for total heat flux levels, i.e. combined convection and radiation heat output, ranging from 0 (unheated manikin) to 60 W/m² (activity level 1.2 met). The results are presented as box-and-whisker plot to include more information on the sample distribution (Ayyub and McCuen, 2002). Two different velocity levels are included. Figures 4 – 5 and Table 2 applies the dimensionless personal exposure, $c_e^* = (c_e - c_B)/(c_R - c_B)$, where c_e is the personal exposure, i.e. the concentration of inhaled contaminant, c_B is the background concentration and c_R is the return concentration. This means that the results become comparable, more universal, and that $c_e^* = 1$ corresponds to fully mixed conditions. Figure 4 shows results from measurements of dimensionless

personal exposure as a function of the Archimedes number, Ar (Brohus, 1997). Ar represents the balance between local inertial and buoyancy forces. Figure 5 presents measurements of personal exposure as a function of BTM incident angle relative to flow direction.

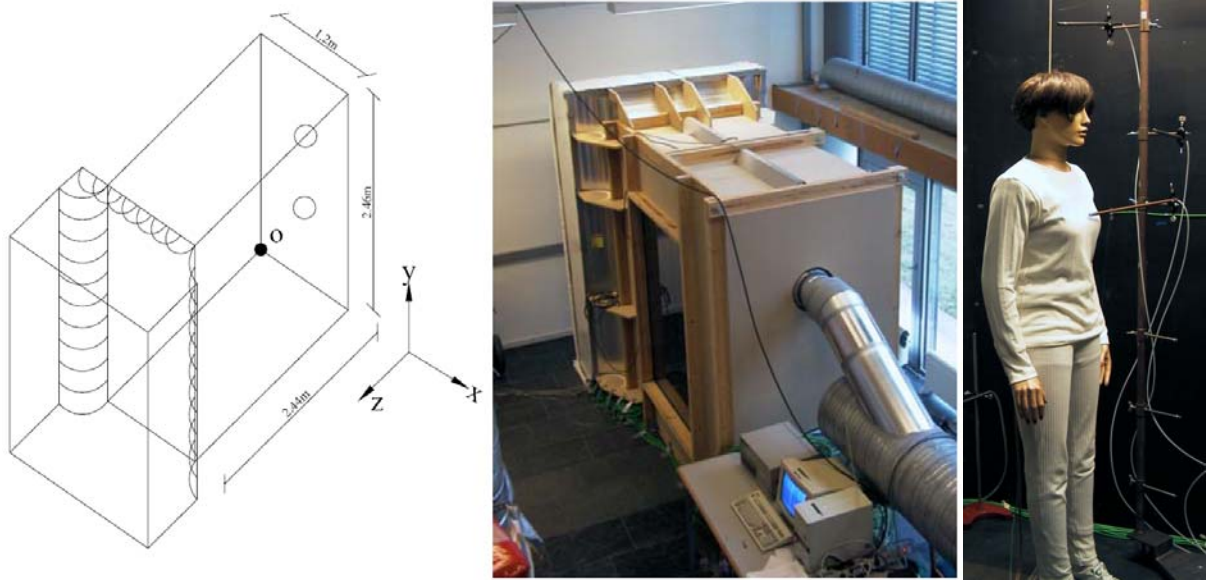


Figure 1. Sketch and photo of the wind channel and photo of the breathing thermal manikin.

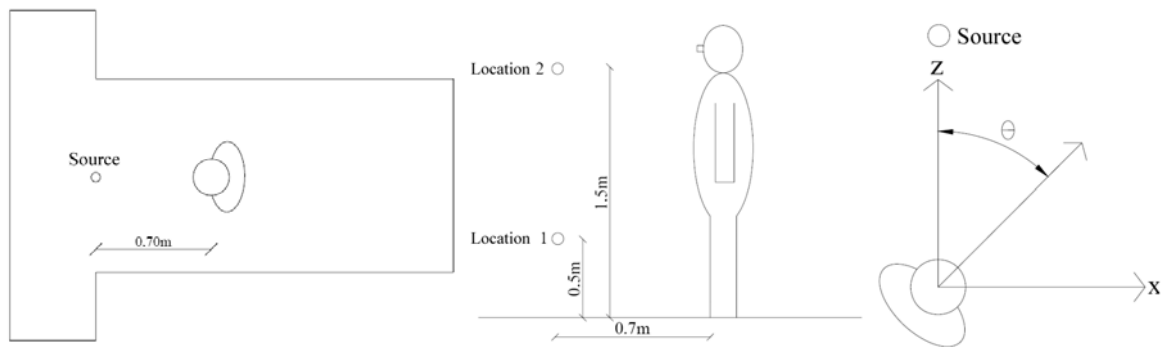


Figure 2. Location of breathing thermal manikin and contaminant source in the wind channel. Left: Top view, Centre: Vertical section, Right: Top view - rotation.

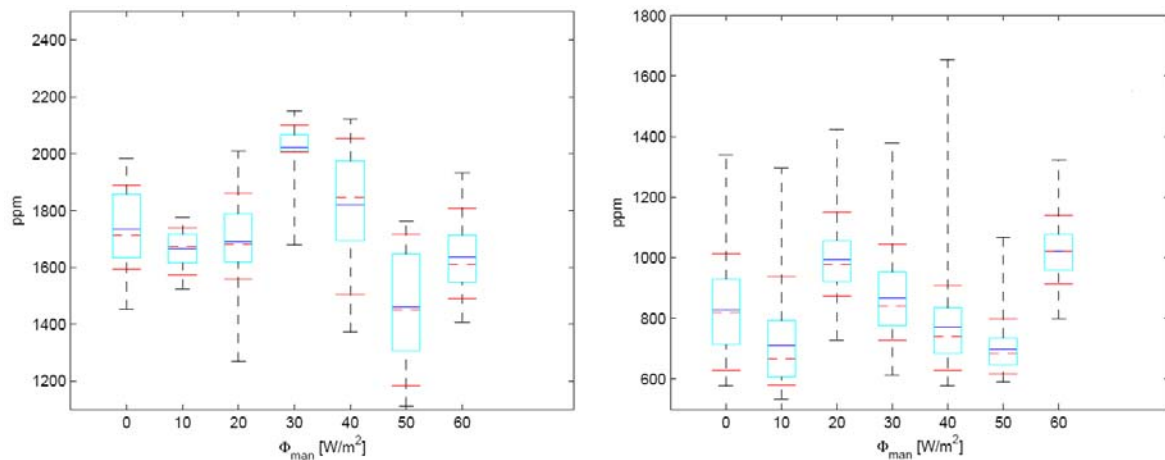


Figure 3. Box-and-whisker plot of personal exposure, c_e , as a function of manikin total heat flux, Φ_{man} . Contaminant source location $(x, y, z) = (0.6, 1.5, 2.44)$ m. Left: Nominal velocity 0.15 m/s, Right: Nominal velocity 0.3 m/s.

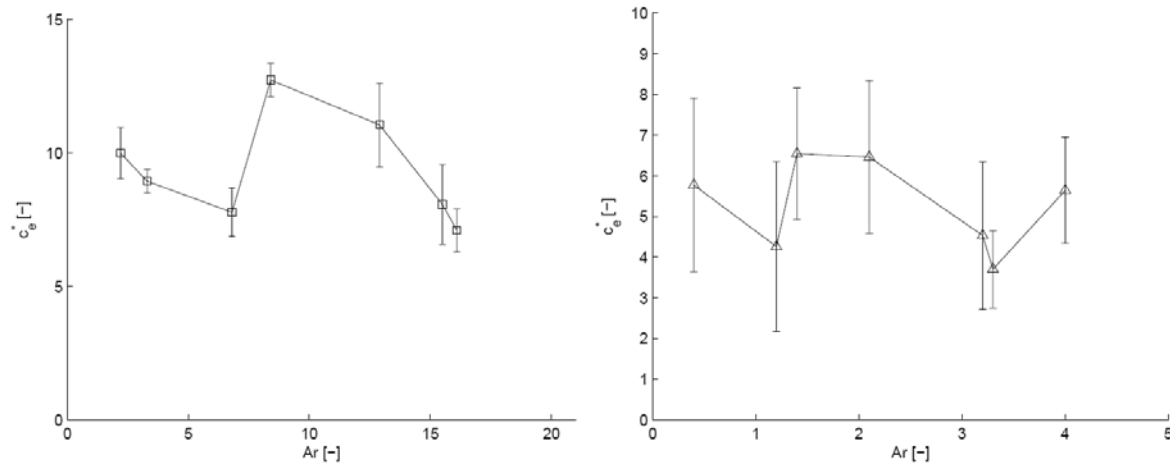


Figure 4. Dimensionless personal exposure, c_e^* , as a function of the Archimedes number, Ar . Contaminant source location $(x, y, z) = (0.6, 1.5, 2.44)$ m. Error bars: \pm one standard deviation. Left: Nominal velocity 0.15 m/s, Right: Nominal velocity 0.3 m/s.

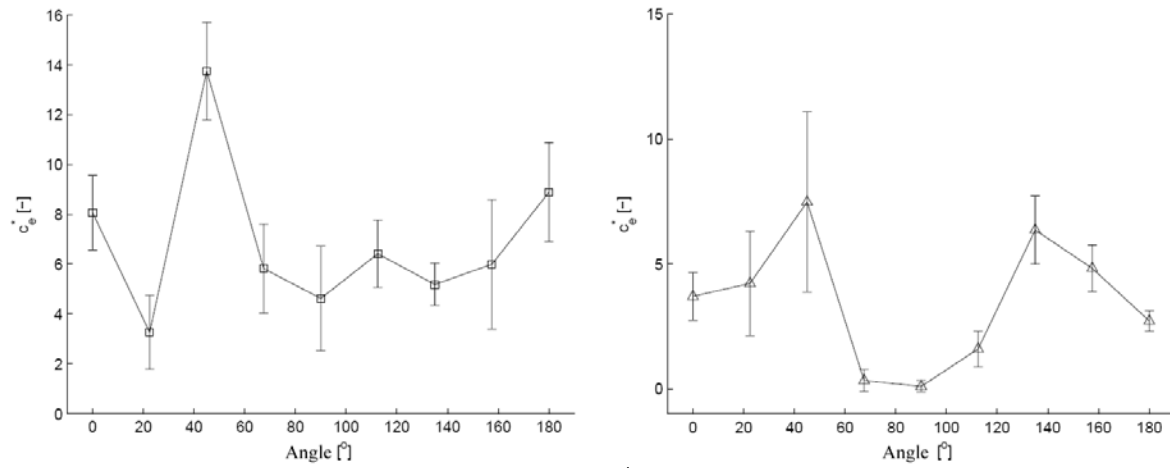


Figure 5. Dimensionless personal exposure, c_e^* , as a function of the incident angle, θ , see Figure 2. Contaminant source location $(x, y, z) = (0.6, 1.5, 2.44)$ m. Error bars: \pm one standard deviation. Left: Nominal velocity 0.15 m/s, Right: Nominal velocity 0.3 m/s.

To examine the personal exposure sensitivity to relatively small variations in the contaminant source location measurements are included for ± 5 cm variation, see Table 1.

Table 1. Influence of small changes in contaminant source location on personal exposure. Manikin total heat flux 50 W/m^2 . Velocity 0.15 m/s. Source location $(x, y, z) = (0.6, 1.5, 2.44)$ m (starting point). The source is moved 0.05 m (5 cm) in four directions. $z = 2.44$ m is fixed.

Movement	Δx	Δy	Relative deviation
Up	0 m	0.05 m	- 38 %
Down	0 m	- 0.05 m	27 %
Left	0.05 m	0 m	28 %
Right	- 0.05 m	0 m	7.5 %

To evaluate the relative influence of the different factors a simple sensitivity analysis is performed using the sensitivity index, $SI = (c_{e,\max}^* - c_{e,\min}^*) / c_{e,\max}^*$ where $c_{e,\max}^*$ and $c_{e,\min}^*$ are the maximum and the minimum output values, respectively. SI provides a one-at-a-time local sensitivity measure which may be useful for qualitative measures like ranking (Saltelli et al., 2000). The drawback is lack of consideration of nonlinearity and correlation.

Table 2. Sensitivity analysis with parameters ranked according to importance.

Parameter	Unit	Interval			Results		SI
		Base	Min	Max	$c_{e,min}^*$	$c_{e,max}^*$	
Vertical source location, y	m	1.5	0.5	1.5	0.44	8.07	0.95
Angle, θ	°	0	0	180	3.27	13.75	0.76
Nominal velocity	m/s	0.15	0.15	0.3	3.70	8.07	0.54
Total heat flux, Φ_{man}	W/m ²	50	0	60	7.10	12.73	0.44
Respiration	On/Off	On	Off	On	8.07	12.32	0.34
Clothing	On/Off	On	Off	On	5.87	8.07	0.27

DISCUSSION

The influence of the heat flux in Figure 3 reveals a substantial variance, however, no simple correlation is found. The specific contaminant source location, $y = 1.5$ m, may influence this conclusion as Table 1 indicates significant influence of vertical source location.

As to the Archimedes number significant influence on dimensionless personal exposure is found for the velocity level 0.15 m/s, Figure 4. This velocity level corresponds well with indoor thermal comfort requirements. A slight decline is followed by a sudden upward step and another decline. No obvious explanation on the step is found. It may be due to a change in the flow characteristics for increasing Ar.

The influence of the incident angle, Figure 5, reveals another significant yet rather complex behavior. A peak value is found for 40° which may be related to vortex shedding. Visual inspection using smoke visualization indicates substantial local change in the flow around the BTM and in the ascending convective boundary layer.

Overall it is found that the parameters included in the present study may influence the personal exposure substantially with a factor of approximately 10. Table 2 presents the ranking of six important parameters. As expected source location relative to the BTM exerts substantial influence which corresponds well with similar CFD simulation in Brohus and Jensen, 2009.

CONCLUSIONS

The sensitivity of a number of important parameters on the personal exposure assessment is investigated. Substantial general variance is detected even though simple correlations are difficult to establish. Overall it is found that the parameters included in the present study may influence the personal exposure substantially with a factor of approximately 10. Small local variation of the contaminant source relative to the breathing thermal manikin (± 5 cm) may influence the result approximately $\pm 30\%$. Uncertainty and sensitivity in case of personal exposure assessment are substantial and should be investigated and reported.

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