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# Computational Fluid Dynamics simulations of Personalised Ventilation: Sampling air quality in the breathing zone

Natalie A Gilkeson[1,*], M Amirul I Khan[1], Catherine J Noakes[1]

[1] University of Leeds, Leeds, UK
[*]Corresponding email: N.A.Gilkeson98@leeds.ac.uk

## SUMMARY

A complex relationship exists between building energy use, personal comfort, indoor air quality and health. Creating a micro-climate around an individual with a personalised ventilation (PV) system has the potential for lowering energy consumption increase sustainability, occupant productivity, indoor air quality and personal comfort. This research considers clean air delivery through a PV system to a seated computational thermal manikin (CTM) in a mechanically ventilated chamber, via computational fluid dynamics (CFD) simulations, using ANSYS Fluent. The mean age of air, used as a surrogate measure of air quality, is determined at the manikin's mouth and nostrils along with three sample volumes in the breathing zone for small variations in temperature of the PV flow and distance between the PV nozzle and breathing zone. Results show that location of the PV jet relative to the breathing zone is important as is the choice of sample size and analysis.

## KEYWORDS

CFD; indoor air quality; mean age of air.

## 1 INTRODUCTION

Close to half of the total energy consumed worldwide is the heating and ventilating of non-industrial buildings (Ward, 2004). Whilst increasing the air-tightness of the building and reducing ventilation rate can improve the thermal efficiency, it can also be detrimental to the indoor air quality (IAQ), which in turn can have a significant impact on human health (Sundell, 2004). Furthermore, poor IAQ can negatively affect productivity in office environments (Wargocki et al., 2000). Personalised ventilation (PV) systems modify the micro-climate around an individual which has great potential to positively impact the wellbeing of indoor occupants (Melikov, 2004) by improving personal comfort, air quality and productivity.

## 2 METHODS

Simulations were run with a simplified domain for a validated benchmark test case of PV (Russo et al., 2009). An unclothed computational thermal manikin (CTM) is centred in a computational domain (2.03m wide, 2.64m long and 2.49m high), which is split into a predominantly hexahedral mesh of 5.4 million cells with 166,000 cells on CTM, clustered around breathing zone with inflation layer ten cells deep. Air is supplied to the room at 16:5ls$^{-1}$ through a wall diffuser at 20.5°C with a turbulent intensity of 5%. The PV supplies air through a circular face of diameter 0.05m at a rate of 2.4ls$^{-1}$ at 21°C, 23.5°C and 26°C with a turbulent intensity of 1.7%. Air is exhausted through a pressure outlet on the ceiling. The CTM has a constant surface heat flux of 58:1Wm$^{-2}$, the walls and ceiling are set at 23:5°C and the floor at 22°C. As large areas of the room contain stagnant, non-turbulent air, the Transitional SST turbulence model is employed. Thermal, pseudo-transient steady-state simulations are run in 3D using the ANSYS Fluent double precision solver. Radiation is modelled with the Discrete Ordinates model, whilst the Boussinesq approximation accounts for buoyancy forces and second order discretisation schemes are used for the remaining CFD equations.

## 3 RESULTS AND DISCUSSION

With the CTM fixed, the PV tube is moved to six equally spaced horizontal locations in the range 0.086m to 0.636m from the CTM breathing zone. Mean age of air (MAOA) is used as a proxy for air quality and values are taken in symmetric data cloud samples located in the breathing zone: directly in front of the CTM face and in line with the centre of the PV nozzle. Data from the three sample volumes (2cm$^3$, 4cm$^3$ and 6cm$^3$) is compared with the values at the CTM mouth and nostrils.

The distributions of MAOA on the CTM mouth and nostrils show that very close to the CTM (when the breathing zone is located well inside the cone of establishment of the PV jet), the three PV temperature configurations exhibit very similar distribution functions, with air much younger (fresher) at the mouth than the nostrils, with a larger range of age of air at the nostrils. Moving the PV further slightly away, the cooler air is more likely to be older and the warmer air has a slightly smaller range of air ages. This trend continues until the end of the cone. Outside of the jet cone, the profiles of the distribution functions for each PV temperature become more distinct and their range of air ages reduces. The difference between the age of air at the mouth and nostrils becomes less pertinent as the PV jet flow becomes established and entrains local air from the bulk flow (mainly sourced from the wall diffuser and hence significantly older).

Statistical analysis on the data cloud samples highlight a wide variety in the mean, median and mode for the smaller PV distances within the cone of establishment, corresponding to the wide range of velocities found in these regions. Increasing the sample volume exacerbates this. The sample volume has less influence on the MAOA values (with the mean, median and mode becoming similar) as the airflow becomes more uniform (established) outside of the jet core. Within the jet cone there is little difference due to PV temperature, however this begins to have an influence outside of the jet cone with warmer air generally older. Comparison of the mean and mode MAOA in these sample volumes with the area weighted mean values on the CTM mouth and nostrils shows that within the jet cone (< 0.306m), 6cm$^3$ over-predicts, but 4cm$^3$ is a good predictor for nostrils and 2cm$^3$ for the mouth for all PV temperatures. Outside of the jet cone (> 0.416m), all the sample volumes predict the mean values found at the CTM mouth and nostrils well (the mean and mode at this distance are very similar).

## 5 CONCLUSIONS

The mean age of air was found to be more sensitive to the distance between the PV nozzle and breathing zone than small variations in temperature. The local flow physics can have an impact on variations in sample volume and hence incomplete statistical analysis may be misleading.

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