Efficacy of ultraviolet germicidal irradiation based portable air cleaning devices in built environments: Impact of environmental conditions

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1 Introduction

Portable air cleaning (PAC) devices are popular due to their low noise emission, high ergonomics and user friendly interface. Currently, a wide variety of PAC technologies exists (e.g. filtration, ionization, oxidation, electrostatic precipitation, ultraviolet germicidal irradiation (UVGI)). PAC devices based on UVGI have an impact on air hygiene and reduce the risk of aerosol disease transmission in different built environments.

Few studies have been carried out on their effectiveness under different environmental conditions. These studies, which employed models or were conducted within test chambers with controlled aerosol generation, have shown that variables such as particle size, air cleaner technology and position of the air cleaner in a room can affect air cleaner performance (Novoselac and Siegel, 2009; Zuraimi et al. 2011). However, real life built environments are not well mixed and often have considerable spatio-temporal variation in pollutant concentration and complex air flow patterns between different spaces or even within the same enclosed space.

This paper provides the preliminary results of a study that aims to use a UVGI-based PAC device as an example to demonstrate the impact of environmental conditions on the efficacy of disinfecting airborne bacteria in an environmentally controlled chamber using both experimental and mathematical (Computational Fluid Dynamics - CFD) models.

2 Materials and Methods

Initial experimental measurements were carried out in a secondary chamber (1m^3) constructed inside a stainless steel environmental chamber (43.2 m^3) and connected to a level II biosafety cabinet in an ante-chamber. A microbial solution (*Serratia marcescens*) was aerosolized into the chamber using a 6-jet nebulizer to test the efficacy of the UVGI-based PAC device. After aerosolization, an Andersen 6-stage viable impactor containing Tryptone Soy Agar plates was used to collect sequential air samples at predetermined time intervals (3 minutes each) to calculate the microbial decay rate over time. The colonies were enumerated and the total numbers of culturable colony forming units per cubic meter (CFU/m^3) were calculated for each stage of the Anderson impactor. Total counts for all the stages were also calculated. Experiments were carried out with the PAC device on and off under poor air mixing and well air mixing conditions. Total and size resolved clean air delivery rates (CADR) were computed by:

$$\text{CADR (m}^3\text{/h)} = V\,(K_{PAC} - K_n)$$

Where CADR is the clean air delivery rate (m^3/h), V is the volume of the chamber (m^3), K_{PAC} is the first order decay constant with PAC device turned on and K_n is the first order decay constant with PAC device turned off. CFD simulations carried out using ANSYS Fluent 14.5. 3D meshes with various degrees of refinement were used to model the small chamber with second order discretisation and a realizable k-ε turbulence model.

3 Results and discussion

The performance of the PAC device varied under different air mixing conditions and higher air cleaning efficacy was observed under well mixed air condition. Overall, the CADR for poor and well mixed air conditions were 16 m^{3}h^{-1} and

23 m^{3}h^{-1}, respectively. Figure 1 and 2 show the bacterial decay rates under poor and well mixed air conditions.

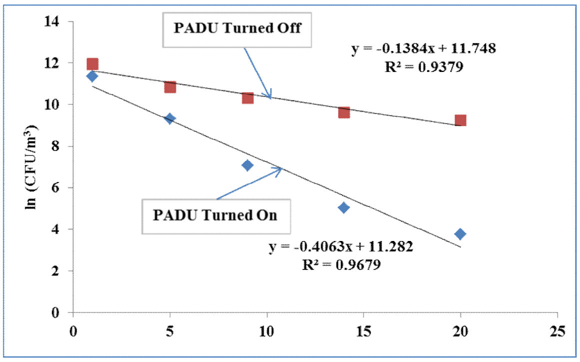

Figure 1. Bacterial decay rates with the PAC device turned on and with the PAC device turned off under poor mixed air conditions.

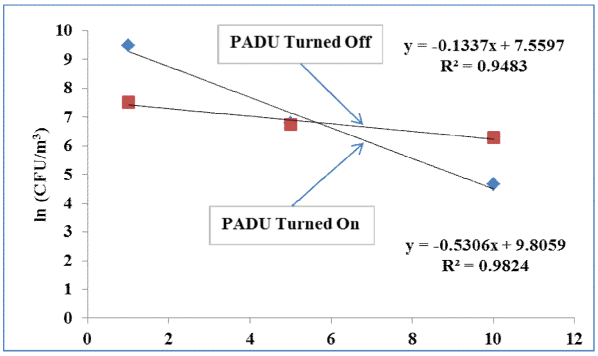

Figure 2. Bacterial decay rates with the PAC device turned on and with the PAC device turned off under well mixed air conditions.

With reference to size resolved efficacy, a trend of higher performance was observed in fine size fractions (in the size range of 1.1-2.1 μm and 0.65-1.1μm).

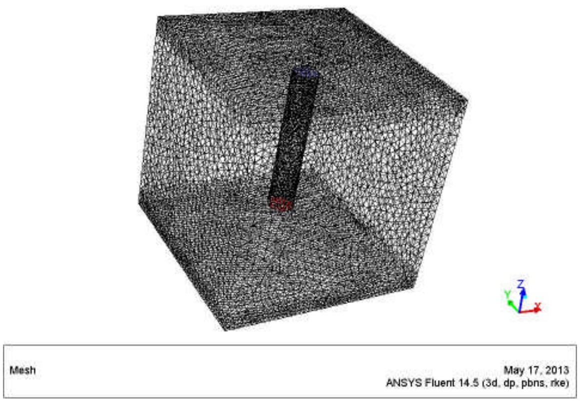

Figure 3. Initial computational mesh for the CFD simulations of the PAC within the secondary chamber.

Some preliminary runs of the CFD model were performed to assess its capabilities and extend the scope of the experiments. The simulations helped visualise the air pathlines, highlighting the complex flow established even within this small secondary chamber. Further analyses and more simulations are in progress which should highlight the difference in residence time of the particles.

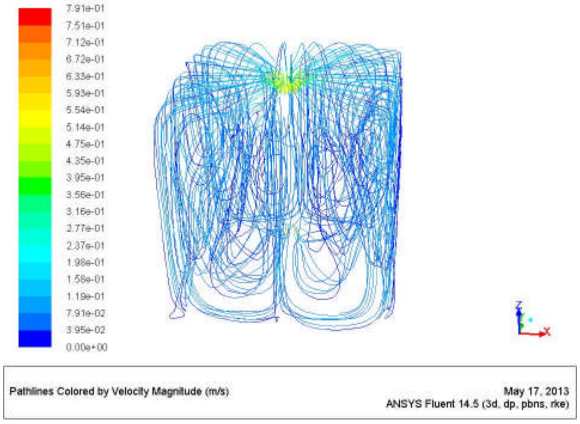

Figure 4. Air pathlines calculated by the CFD model, coloured by velocity magnitude.

4 Conclusions

Initial experimental results have shown a considerable variation in CADR under different air mixing conditions. The CFD simulations have highlighted the complex behaviour of air within the small chamber and will be used to investigate different environmental conditions and room sizes. The experimental measurements are currently being extended to main chamber under different air mixing conditions.

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5 References

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