Experimentally Evaluating the Effectiveness of an Air Disinfection Device

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1 Introduction

To conduct a reliable and repeatable experimental study, requires a knowledge and understanding of the various environmental and experimental parameters which can influence the results of that particular study.

This study aims to investigate some of the parameters which influence the assessment of how effective an air cleaning device is at eliminating indoor bioaerosols. The environmental parameters include: the room ventilation rate, the ventilation regime, and the device location. The experimental parameters include: the sampling locations, the number of samples and experimental repeats, the release mechanism, and the parameters specific to the biosampler.

The device employed was an upper-room ultraviolet germicidal irradiation (UVGI) system. UVGI disinfects by causing photochemical changes in the deoxyribonucleic acid (DNA) of a microorganism, thus destroying its ability to reproduce. An upper-room UVGI system is one where UV fixtures are used to create a zone of UV irradiation in the upper portion of a room, well above head height. In a well mixed room, the air and any microorganisms in the air, will enter the UV zone due to natural air currents and be disinfected

The results of this study will provide quantative data demonstrating the most effective ways to employ an air disinfection device. Furthermore, recommendations for experimental methodologies associated with the Andersen sampler will be made which will ensure repeatable, reliable results in future studies.

2 Materials and Methods

All experiments were carried out in a class 2 aerobiological test chamber (Figure 1), which has a volume of 32 m^3 and externally controllable temperature, humidity, ventilation rate and ventilation regime. The choice of ventilation inlet and outlet – one each low and high, facilitated the consideration of two ventilation regimes; A (in low, out high) and B (in high, out low).

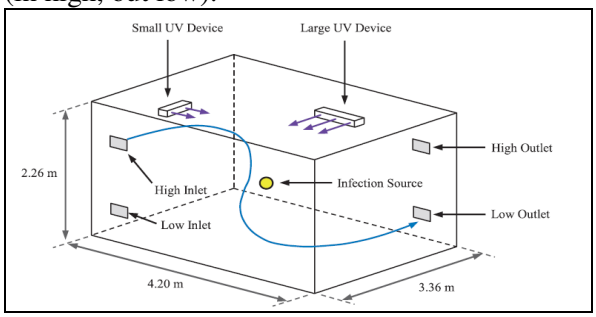

Figure 1. Schematic of aerobiological test chamber, showing ventilation regime B [1]

An upper-room UVGI system was set-up in the chamber using two wall mounted UV devices, mounted 0.5 m from the ceiling (Lumalier WM136 and WM236, Lumalier Corporation, Memphis, TN). Gilkeson and Noakes [1] detail the dose, intensity and field distribution of the resultant UV field, for a number of varying parameters.

Bioaerosols were generated by nebulising a solution of de-ionised water and a pure bacterial culture, into the centre of the chamber via a six-jet Collision Nebuliser (CN 25, BGI Inc, USA). The bacterium used were *Staphylococcus aureus* (*S. Aureus)* and *Bacillus Subtilis* (*B.Subtilis*).To determine the concentration of airborne microorganisms, a sample of the chamber air was extracted at 18 $Lmin^{-1}$, into a six-stage Andersen sampler (in the ante-room). The Andersen was loaded with agar plates, onto which the airborne particles deposited. The plates were then incubated at 27°C for 24hrs and the colony forming units (cfu's) were counted. The inactivity (I), is the fraction of airborne microorganisms inactivated by the UV irradiation. It can be experimentally deduced by determining the difference in the concentration

of airborne particles with and without the UVGI system, as a percentage of the average concentration of airborne particles without the UVGI system.

3 Results and discussion

Bioaerosol generation. The importance of maintaining the positioning of the T-nozzle in the nebuliser, was investigated by allowing the level of liquid in the jar to drop to where the nozzle was <0.5cm below the surface of the liquid, as opposed to the recommended level of 1cm. This resulted in a 51% drop in the detected mean airborne microbial concentration and a 33% increase in the variability between successively sampled plates.

Bioaerosol sampling. It is important that air sampling onto plates not start until the chamber has reached steady state conditions. To determine the fluctuation in airborne microorganism concentration with time, five, one minute samples were taken every 20 minutes, over a period of four hours. The results are shown in Figure 2, where the error bars represent one standard deviation above and below the mean. Preliminary results indicate that steady state conditions are not achieved until 40 minutes subsequent to the commencement of aerosol nebulisation.

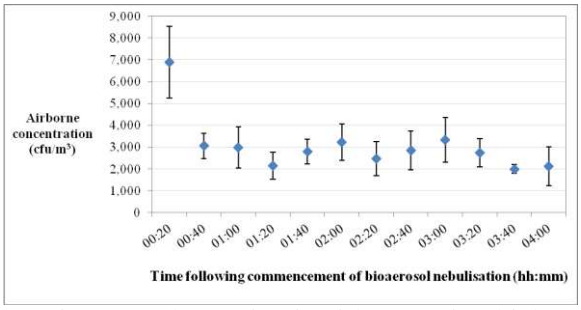

Figure 2. Fluctuation in airborne microbial concentration over time, with continuous bioaerosol nebulisation

It was investigated if the depth of agar in the plates inserted into the Andersen, had any effect on the resultant observed cfu's. A qualitative study using *S. aureus* indicated a 3-fold increase with deeper filled plates. In a quantitative study using *B. Subtilis*, 22 plates were filled with 10ml of agar and a further 22 with 30ml, resulting in agar depths of 0.42cm and 1.2cm respectively. There was a 1.5 fold increase in the number of observed cfu's for the deeper filled plates. Environmental parameters. A change in ventilation from regime A (in low, out high) to regime B (in high, out low), resulted in a lower inactivation percentage at all three ventilation rates examined (3, 6 and 9 ACH). This decrease in efficiency of the upper-room UVGI system, is attributable to a change in the airflow patterns, which determines the transport of the airborne microorganisms up into the UV field.

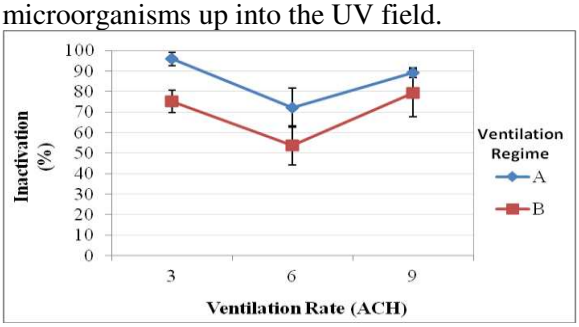

Figure 3. Inactivation of SA, with varied ventilation rate and ventilation regime

4 Conclusions

The importance of good, consistent experimental technique and design has been shown to be necessary in order to achieve reliable results. To ensure repeatable, reliable results in future studies which employ the above described procedures, it is therefore recommended that: (i) during aerosol production, the position of the nozzle tip in the liquid solution be continuously sustained at the manufacturers recommended depth of ~1 cm (3/8 of an inch), (ii) the depth of nutrient agar in sampling plates placed in Andersen sampler must be kept consistent, (iii) following a change in any experimental variable, a time period of 40 minutes must be allowed for the chamber to reach a steady state, before sampling the air.

The environmental conditions for which the above described upper-room UVGI system has been shown to be most effective are: a ventilation rate of 3 ACH and ventilation regime of in low, out high (which achieved 96.0 ± 3.2 % inactivation). Moreover, regardless of ventilation rate, a ventilation regime of A is recommended above a regime of B, as it resulted in an average of 16 % more microorganism inactivation.

Acknowledgements

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5 References

[1] CA. Gilkeson and CJ. Noakes. Application of CFD simulation to predicting upper-room UVGI effectiveness. Photochemistry and Photobiology (in press). DOI: 10.1111/php.12013