Evaluation of the performance of the air cleaning device.

A Final Report prepared by

Dr Louise Fletcher

Pathogen Control Engineering Research Group
School of Civil Engineering
University of Leeds

30 April 2010

Objectives of the study

The objective of the study was to evaluate the performance of the air cleaning device operated at the four standard fan speed settings (700, 1100, 1500 and 3150rpm). The performance will be evaluated in terms of its ability to reduce the concentration of airborne *Staphylococcus aureus* (NCTC10399/ATCC13709) and *Clostridium difficile* spores in the test chamber.

Culture Preparation

The *Staphylococcus aureus* used in the tests was prepared by inoculating 100ml of sterile Tryptone Soya Broth (Oxoid, UK) with a 0.1ml aliquot of previously frozen cells (in 40% glycerol). The broth was then incubated at 37°C for 24 hours and shaken at 100rpm. After 24 hours incubation the culture is assumed to be at the boundary between the exponential and stationary growth phases. After incubation the culture was centrifuged and re-suspended in sterile ringers solution and 1ml of this suspension was used in the nebulizer as described below.

The *Clostridium difficile* spores used in the tests was prepared by inoculating 100ml of sterile Fastidious Anaerobe Broth (Oxoid, UK) with a 0.1ml aliquot of previously frozen cells (in 40% glycerol). The broth was then incubated anaerobically at 37°C for 48 hours and shaken at 100rpm. After incubation the culture was subjected to alcohol shock treatment to kill any vegetative cells and leave only spores.

Experimental Methodology

The experiments described in this report were carried out in the aerobiological test chamber at the University of Leeds, which consists of a 32.25m^3 hermetically sealed negatively pressurised chamber in which the air flow rate, temperature and relative humidity can be constantly controlled and monitored. The experiments were carried out with the ventilation system set at 1.5 AC/hr at ambient temperature (approx 20°C) and relative humidity (approx 50%).

During the microbiological experiments the bacterial aerosols were generated using a 6-jet Collison nebuliser operating at a flow rate of 12 l/min and at a pressure of 20 psi. This was connected to the room via a 25 mm diameter pipe which terminated in a plastic sphere containing twenty four 3mm diameter holes through which the aerosol was dispersed. Air samples were collected through a plastic pipe located as requested by the client which was opposite the wall on which the device was mounted. This pipe was connected to a six stage Andersen sampler loaded with sterile agar plates. During the sampling process air passed through the sampler and the bacteria were deposited onto the agar plates. The sampling time was varied depending upon the concentration of the bacterial culture with the aim of collecting between 200 and 300 colony forming units on the agar plates.

The air cleaning device was located on the wall with the top of the device approximately 30cm from the ceiling of the chamber. The power cable was plugged into one of the power sockets within the chamber and the control device was passed out through one of the access ports so the device could be operated from outside the chamber.

Test Procedure

The test chamber was set up as outlined above and allowed to stabilize for 30 minutes. The nebuliser was then connected to the inlet pipe and aerosolisation of the microbial solution began and during this time the air cleaning device remained switched off. After a period of 30 minutes the concentration of bacteria in the air inside the chamber reached steady state and sampling began. A total of ten replicate samples were taken at approximately 3 minute intervals using a six stage Andersen sampler containing sterile tryptone soya agar plates (Staphylococcus aureus) or Columbia Blood agar (Clostridium difficile) (on stages 5 and 6 only). Once all ten samples had been taken the device was switched on and operated at fan setting 4. A period of 30 minutes was then allowed for the concentration of bacteria in the air inside the chamber to reach steady state once again. A further ten replicate samples were then taken at 3 minute intervals as described above. Once the samples had been taken the device was then operated on fan setting 3 and another period of 30 minutes left before ten replicate samples were then taken at 3 minute intervals as described above. When the samples had been taken the device was then operated on fan setting 1 and a period of 30 minutes left before a final set of ten replicate samples were taken at 3 minute intervals as described above.

Once all the samples had been taken the agar plates were incubated at 37°C for 24 hours (staphylococcus aureus) or anaerobically for 48 hours (Clostridium difficile) after which the number of colonies on each plate were counted. All the counts were then subjected to positive hole correction in order to account for multiple impaction (Macher 1989). The corrected counts for each set of plates (stages 5 and 6) were added together to give a total count and multiplied to give a count per m^3 of test chamber air. Each set of samples represents ten replicates taken during steady state, the first ten being the concentration without any device and the other sets of ten with the device operating at the different fan settings. For each fan setting the mean was taken of the ten replicate samples to give a mean concentration with and without the device. This allowed the mean reduction in concentration to be calculated used to give an indication as to the efficacy of the device

In order to determine the statistical significance of the results a t-test was carried out on the two data sets (before and after). The purpose of the test is to determine whether the means of the two data sets are statistically different from each other. The test yields a p-value and the smaller the p-value the less likely the difference between the two data sets is the result of chance.

Results

Figure 1 shows the concentration of airborne *S. aureus* in the test chamber during the test and Table 1 shows a summary of the data. The concentration of *S. aureus* during the control period ranged from 29254.4 up to 34639.7 cfu/m^3 with a mean concentration of 31591.2 cfu/m^3. The concentration dropped dramatically when the air cleaning device was operated on it maximum fan speed setting of 3150rpm. The concentration ranged from a low of 4897.5 cfu/m^3 up to 6194.4 cfu/m^3 and had a mean concentration of 5654.4 cfu/m^3. This represents a reduction of 25936.8 cfu/m^3 which is 82.1%. When the fan speed was reduced to 1500rpm the device maintained its performance with an airborne *S. aureus* concentration of between 5395.8 cfu/m^3 and 6929.3 cfu/m^3 and a mean concentration of 6206.7 cfu/m^3. This represents a reduction of 25384.5 cfu/m^3 which is 80.4%.

When the fan speed was reduced further to 1100rpm the performance of the device started to drop off quite significantly. The concentration of *S. aureus* ranged from 13752.7 up to 16420.5 cfu/m^3 with a mean concentration of 15102.8 cfu/m^3. This represents a reduction of 16488.3 cfu/m^3 which is 52.2%. When operated on its lowest fan speed of 700rpm the performance of the air cleaning device dropped off once again with concentrations of *S. aureus* in the chamber of between 21272.1 cfu/m^3 and 25392.2 cfu/m^3 and a mean concentration of 22921.6 cfu/m^3. This represents a reduction of 8669.6 cfu/m^3 which is only 27.4%.

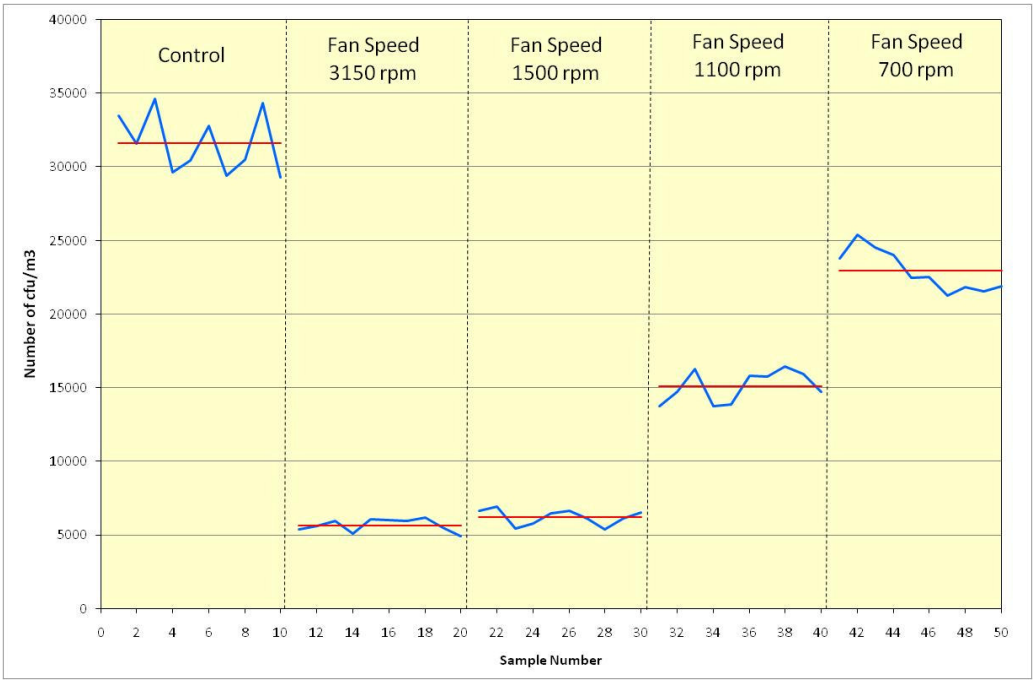

Figure 1 The performance of the air cleaning device at different fan speeds with bioaerosols of *S. aureus* – the blue lines represents the raw data from the ten replicate samples and the red lines are the mean concentrations over the ten replicate samples.

Table 1 Summary data for bioaerosols of S. aureus

Fan Speed (rpm)	*Concentration (cfu/m^3)*				*Reduction*		
	Before		After				
	Mean	SD	Mean	SD	cfu/m^3	%	Log
3150	61591.17	2063.77	5654.42	447.66	25936.8	82.1	0.75
1500			6206.71	532.55	25384.5	80.4	0.71
1100			15102.83	1060.28	16488.3	52.2	0.32
700			22921.55	1406.81	8669.6	27.4	0.14

Figure 2 shows the concentration of airborne *C. difficile* in the test chamber during the test and Table 2 shows a summary of the data. The concentration of *C. difficile* during the control period ranged from 9979.8 up to 13431.1 cfu/m^3 with a mean concentration of 11537.8 cfu/m^3. The concentration dropped dramatically when the air cleaning device was operated on it maximum fan speed setting of 3150rpm. The concentration ranged from a low of

1724.4 cfu/m^3 up to 3098.9 cfu/m^3 and had a mean concentration of 2426.5 cfu/m^3. This represents a reduction of 9111.3 cfu/m^3 which is 79%. When the fan speed was reduced to 1500rpm the performance of the device dropped only slightly with an airborne *C. difficile* concentration of between 1950.5 cfu/m^3 and 3583.0 cfu/m^3 and a mean concentration of 2997.9 cfu/m^3. This represents a reduction of 8539.9 cfu/m^3 which is 74%.

As was the case with *S. aureus* when the fan speed was reduced further to 1100rpm the performance of the device started to drop off quite significantly. The concentration of *C. difficile* ranged from 4565.4 up to 5523.0 cfu/m^3 with a mean concentration of 5100.0 cfu/m^3. This represents a reduction of 6437.8 cfu/m^3 which is 55.8%. When operated on its lowest fan speed of 700rpm the performance of the air cleaning device dropped off once again with concentrations of *difficile* in the chamber of between 7314.5 cfu/m^3 and 8240.3 cfu/m^3 and a mean concentration of 7809.5 cfu/m^3. This represents a reduction of 3728.3 cfu/m^3 which is 32.3%.

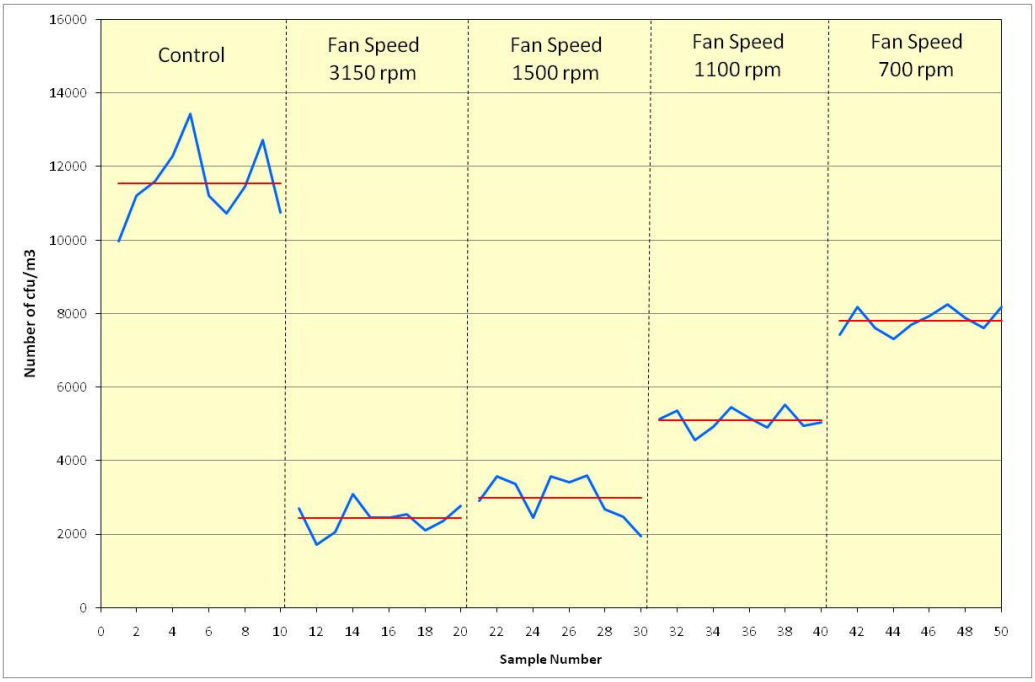

Figure 2 The performance of the air cleaning device at different fan speeds with bioaerosols of *C. difficile* – the blue lines represents the raw data from the ten replicate samples and the red lines are the mean concentrations over the ten replicate samples.

Table 2 Summary data for bioaerosols of *C. difficile*

Fan Speed (rpm)	*Concentration (cfu/m^3)*				*Reduction*		
	Before		After				
	Mean	SD	Mean	SD	cfu/m^3	%	Log
3150			2426.50	391.57	9111.31	78.97	0.68
1500	11537.81	1026.13	2997.88	589.43	8539.93	74.02	0.59
1100			5100.00	288.89	6437.81	55.80	0.35
700			7809.54	327.43	3728.27	32.31	0.17

Discussion

Overall the device performed extremely well in the chamber and achieved significant reductions in the concentrations of both airborne *Staphylococcus aureus and Clostridium diffcile* spores. The trend in performance at the different fan speeds was very similar for both bacteria aerosols.

It is clear from both test results that the level of performance was greatly influenced by the fan speed which is not surprising considering that the device will only remove the bacteria from the air passing through it. Therefore the more air that can be taken in and through the device the greater the reduction in the airborne bacterial concentration.

For both *S. aureus* and *C. difficile* the level of performance did not vary a great deal when the device was operated at fan speeds of 3150 and 1500 rpm with removals in excess of 80% for *S. aureus* and 74% for *C. difficile*. This is surprising given that there is more than twice the amount of air going through the device with only an extra 2-5% bacterial removal being achieved. The performance dropped off significantly only when the speed was reduced to 1100rpm and then again to 700rpm.

For *S. aureus* the performance in terms of the percent of the airborne bacteria removed dropped by 30% when the fan speed was reduced from 1500rpm to 1100rpm and by a further 25% when the speed was reduced from 1100rpm to 700rpm. For *C. difficile* the pattern was slightly different with a drop of only 18% from 1500rpm to 1100rpm and a further drop of 23% from 1100rpm to 700rpm.

It would appear from the results that there is very little advantage gained from operating the device on its maximum fan speed of 3150rpm in terms of the increased reduction in airborne bacteria count. The results suggest that the optimum operating speed of the fans in terms of reducing the bioaerosol concentration is 1500rpm.

Comments on the test procedure used.

The test procedure used has been standardized to allow a range of different devices to be tested under identical conditions. In this case the test carried out on this device is a continuous contamination test in which the space is subject to a continuous source of contamination as would be found within a clinical space containing an infective individual. However in reality the release of pathogens may be sporadic and at a much lower concentration than used during the test and therefore under real conditions it may be expected that the removal efficiencies of the device may be higher.

It is also important to note that the device is intended to be operated with fresh air introduction through a port on the rear of the device which is used to control the air currents within the space. However due to the nature of the testing procedure used this was not possible and therefore the effect this would have had on the results is difficult to predict. According to the manufacturer it is anticipated that when operated in this manner the removal efficiencies of the device would be enhanced.

Conclusions

The overall conclusions from the experiments carried out can be summarized as follows:

- The air cleaning device is capable of significantly reducing the concentration of airborne *S. aureus* and *C. difficile* within the test chamber.

- The performance of the air cleaning device is very dependent upon the speed at which the fan is operating.

- At fan settings of 3150rpm and 1500rpm the air cleaning device performed extremely well, reducing the airborne *S. aureus* concentration by in excess of 80% and the *C. difficile* concentration by more than 74%

- The performance of the device was significantly reduced at fan settings of 1100rpm and 700rpm.

- There appears to be little advantage gained from operating at maximum fans speed (3150rpm) in terms of the reduction in airborne bacterial concentrations.

- The optimum fan speed appears to be 1500rpm.