ULTRAVIOLET GERMICIDAL IRRADIATION: A UK HOSPITAL BASED PILOT STUDY

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1.0 INTRODUCTION

In recent years in the USA there has been renewed interest in the use of ultraviolet germicidal irradiation (UVGI) in healthcare facilities to protect patients and staff from TB infection (1,2). However, in the UK there has been very little interest in UVGI with the last major research study taking place in 1954 (3). In 1998 NHS Estates commissioned an 18 month pilot study to investigate the practical application of UVGI in hospital buildings. The pilot study took place in a pair of paediatric wards at the Leeds General Infirmary (LGI). The objectives of the study were to investigate the air disinfection capabilities of:

- UV lamps mounted in a hospital mechanical ventilation system; and
- shielded UV disinfection devices mounted in the ward space.

It was hoped that the pilot study would assist in the production of guidelines for the use of UVGI devices in hospital buildings and that it would also provide data for use in future research.

1.1 THE PILOT STUDY

A pair of adjacent paediatric wards (wards 51 and 52) at the LGI were selected for investigation. These wards are ventilated through separate supply and return air ducts which are fed from a common pair of rising ducts (see Figure 1). This ductwork system was selected because it was accessible, and also because the two wards are similar and share a common air handling unit (AHU),

The pilot study consisted of two planned experimental stages: Stage 1 which investigated the effectiveness of UV lamps placed in the ductwork of the mechanical ventilation system, and Stage 2 which investigated the effectiveness of shielded UV devices placed within the ward space. During both experimental stages the microbial bioburden in the ward space and in the ductwork was sampled, in order to assess the impact of the UVGI.

From the outset of the project, it was not anticipated that any *Mycobacterium tuberculosis* (MTB), or indeed any other pathogens would be encountered in air samples. The rationale behind the project was that if the UV lamps could disinfect a relatively benign microbial environment, then they should be able to kill the more harmful microbial pathogens, which are equally susceptible to UVGI. For example, it has been shown (4, 5) that pathogens such as MTB and *Staphylococcus aureus* are more susceptible to UV light than relatively benign bacteria, such as *Micrococcus sphaeroides.*

1.2 BACKGROUND MICROBIAL BIOBURDEN

Prior to commencement of the Stage 1 experimental work, the background microbial bioburden was determined for 10 sampling sites (as listed in Table 1 and shown in Figure 1) using 2 portable automatic air samplers (i.e. impactors) (Parrett Microbio MB2 and SAS Super 90). Tryptone soya agar (TSA) and Sabouraud dextrose agar (SDA) respectively were used for evaluations of total viable bacterial and fungal counts, respectively. In order to detect bacterial species of particular interest to the investigation (i.e. those of the genera *Staphylococcus* and *Acinetobacter*), two selective/differential media, mannitol salt agar (MSA) and Leeds Acinetobacter medium (LAM) were employed. TSA, SDA and MSA plates were incubated at 37°C in air; LAM plates at 30°C in air. For each medium, sampling was conducted over a period of two days. All ten sites were sampled in one day with 4 replicates at each site - one replicate being a sample of 1 m^3 of air. The mean corrected colony forming units per m^3 (cfu/m^3) of air was calculated for each site on each day.

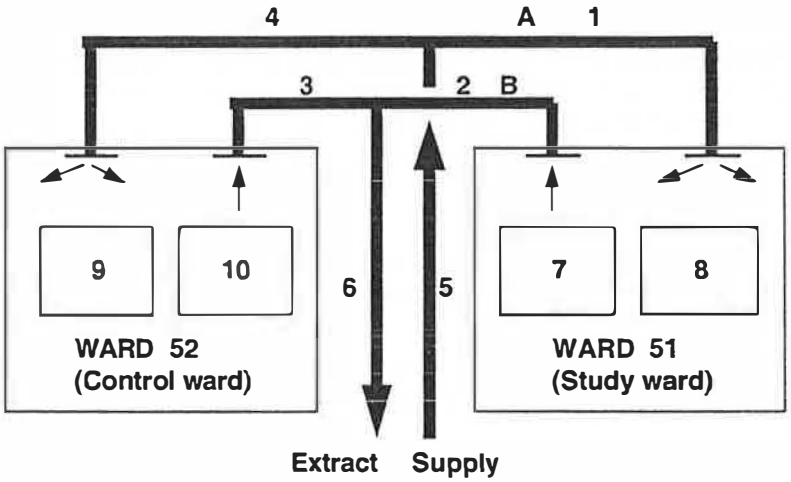

Figure 1 Schematic diagram of ductwork to the hospital wards and sampling sites

The results of the background sampling are shown in Table 1. All the values have been subjected to a 'positive-hole' correction transformation (6) and the mean cfu/m^3 of air has been calculated.

Site Ref. No.	1	2	3	4	5	6	7	8	9	10
Site	Ward 51 supply	Ward 51 return	Ward 52 return	Ward 52 supply	Supply	Return	Treat-ment room W 51	Bath-room W51	Treat-ment room W 52	Play-room W 52
SDA			0.25	0.25			1.00	0.25	0.25	
SDA		0.25	0.25				0.25	0.50	0.25	
LAM		0.25						0.50		
LAM										
LAM			0.25							
MSA	0.25	6.50	9.75		1.25	9.75	12.00	95.75	36.25	26.75
MSA	0.25	60.00	13.75		0.25	21.25	53.25	123.50	73.33	92.33
TSA	0.75	34.00	37.67	1.33	3.25	18.50	105.00	103.00	36.50	27.50
TSA	0.75	66.25	48.25	1.00	1.25	35.50	111.25	40.33	61.33	67.25

Table 1 Summary of corrected mean cfu/m^3 for all sampling sites

One isolate of *Acinetobacter* spp (*Acinetobacter junii/johnsonii*) was identified from the Ward 52 return air duct. Previous sampling of the ward spaces also yielded a single isolate of *Acinetobacter baumannii/calcoaceticus* from the corridor space in Ward 51.

From Table 1 it can be seen that the microbial bioburden was particularly high in the Ward 51 bathroom and relatively high in both treatment rooms and the Ward 52 play room. It should also be noted that although the supply air to the wards was clean, the return air duct contained a relatively high bioburden, which indicates that bacteria from the ward are being transmitted along the return air ducts. Although the ductwork system serving wards 51 and 52 is a full fresh air system (i.e. with no recirculation), this finding has implications for ductwork systems in which air is recirculated.

2.0 THEORETICAL WORK

In order to support the experimental work a computer based model (7) has been developed to simulate the UVGI of airborne pathogens. The model simulates the direct irradiation dose received by a spherical airborne particle passing over a UV lamp mounted in a ventilation duct. The model was used to predict the microbial 'kill' that would be achieved by a 'single pass' through a UV field.

In the model the *effective irradiation dose* H_{eff} (J/m^2), received by an airborne particle can be represented by the expression:

$$H_{eff} = E \times t \tag{1}$$

where: E = UV irradiance (W/m^2)
t = Duration of exposure to irradiation (s)

The steady state irradiance experienced by a spherical particle at a distance (h) from the UV lamp can be expressed as:

$$E = \frac{I_o(\sin\alpha_1 + \sin\alpha_2)}{(l_1 + l_2)h} \tag{2}$$

where: I_o = Radiant intensity from lamp (W)
h = Perpendicular distance of particle from UV source (m)
l_1 & l_2 = Partial UV lamp lengths (see Figure 2) (m)
α_1 & α_2 = Aspect angles (see Figure 2)

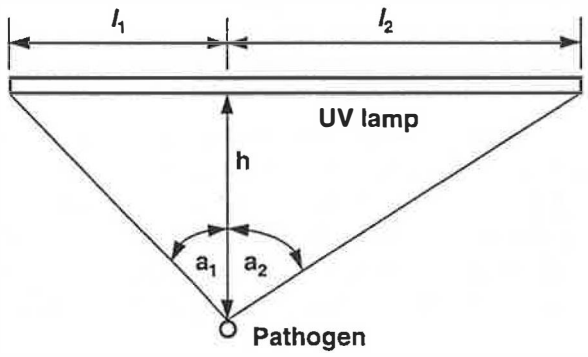

Figure 2 Plan view showing position of particle relative to UV lamp

In the model the effective dose, H_{eff}, is determined by integrating E with respect to time. This was achieved by dividing the field into a number of equal sections, each Δx long, with the time spent by the particle in each section being t_n . By multiplying the time, t_n , by the mean irradiation dose received in each sector it is possible to calculate the total effective dose received by the particle in that sector. The value for each sector may be summed to give an expression for the dose received by the particle as it moves through the whole field:

$$H_{eff} = \sum \left[t_n \left(\frac{I_o (\sin \alpha_{1n} + \sin \alpha_{2n})}{(l_1 + l_2) h_n} \right) \right] \tag{3}$$

where: h_n = Average distance of particle from UV source in segment (m)
t_n = Time spent by particle in segment for time step (s)

Finally, the percentage pathogen kill rate can be determined from the H_{eff} value by using equation 4:

$$\frac{N_t}{N_o} = e^{-kH_{eff}} \tag{4}$$

where: k = UV susceptibility constant for pathogen (m^2/J)
N_t = Number of pathogens at time t
N_o = Number of pathogens at t = 0 s

2.1 ROOM EFFECTIVENESS

The 'single pass' efficiency of a room mounted UV device (or indeed most air cleaning devices) should not be confused with its overall room effectiveness. Although a UV device may have a single pass efficiency in excess of 99 %, its overall room effectiveness may be much lower, simply because very little of the room air passes through the device. Therefore in order to increase the effectiveness of a UV device, it is important to maximise the air flow that passes through it. The background room ventilation rate also influences the extent to which a UV device will be able to reduce the microbial

bioburden. For a room mounted UV device the theoretical equilibrium microbial level that can be achieved in a room space can be determined by using equation 5.

$$C_e = \frac{Q_c}{(N_{vent} + \eta . N_{uv}) \times V} \quad (5)$$

where:

C_e	=	Equilibrium bioburden level (cfu/m^3)
Q_c	=	Rate at which microorganisms are introduced room space (cfu/h)
N_{vent}	=	Number of air changes per hour due to ventilation system (h^{-1})
N_{uv}	=	Equivalent number of air changes per hour due to UV device (h^{-1})
η	=	Single pass efficiency of UV device
V	=	Room Volume (m^3)

From equation 5 it can be seen that for a room with a background ventilation rate of 2 air changes per hour (ACH), the introduction of a UV device having an equivalent air change rate of 2 ACH, will result in a maximum theoretical reduction in the room bioburden of 50 % (assuming a single pass efficiency of 100 % and that complete mixing of the room air takes place). However, if the background ventilation rate were increased to 4 ACH, then the theoretical maximum reduction in bioburden due to the introduction of the UV device would be only 33.3 %.

3.0 STAGE 1 METHODOLOGY

The Stage 1 experiment was designed to investigate the effectiveness of UV lamps placed in a ducted mechanical ventilation system serving Ward 51. Samples were taken at regular intervals using an automatic air sampler at sites 1, 2, 7 and 8 in the supply air duct, the return air duct, the treatment room and the bathroom, respectively.

Four medium pressure UV lamps (manufactured by Hanovia Ltd.), each with a UV power of 276 W and an electrical power of 2.3 kW, were first installed at location B in the return air duct, and then at location A in the supply air duct (see Figure 1). At point A, the supply air duct had a diameter of 700 mm and the air velocity was measured at 4 m/s. At point B, the duct diameter was 775 mm and the air velocity was measured at 2.7 m/s.

On each day of testing the ducts were sampled with four replicates each of two media, TSA and SDA in the supply duct and TSA and MSA in the return duct. For the supply duct sampling SDA was substituted for MSA because of the higher prevalence of fungi in outdoor air. Air samples were taken with the turned lamps on and then with the lamps turned off. The four lamp settings were tested once in the supply duct and four times in the return duct. Percentage kill was calculated from the 'positive-hole' corrected mean cfu/m^3 values.

3.1 STAGE 1 RESULTS

The results of the supply duct experiment are presented in Table 2.

		Mean cfu/m^3			
Media	**On/Off**	**1 lamp**	**2 lamps**	**3lamps**	**4 lamps**
TSA	On	0	0	0	0
	Off	0.25	0.25	0.25	0.25
SDA	On	0.75	0	1.75	0
	Off	1.75	0	0.5	0.25

Table 2 Mean colony counts for the 4 lamp settings in the supply duct

The results shown in Table 2 are inconclusive, mainly because of the low levels of microbial bioburden present in the supply air. This means that a 100% reduction in bioburden represents, at most, a drop of 7 cfu/m^3 and the significance of such a result is uncertain. The low bioburden in the supply duct indicates that the filters in the AHU were removing most of the microorganisms from the incoming fresh air stream. Therefore, it would not be expected that the ultraviolet lamps would have a large effect when installed in a supply system.

Figure 3 shows the results of the return air experiment. The data presented are the average results for the lamps in the return duct. It is noticeable that the difference in % kill detected using two media is very profound with TSA giving higher rates of survival. It should be noted that in compiling the results for the lowest UV output (i.e. one lamp on), one data set has been omitted, because it's inclusion grossly distorted the results.

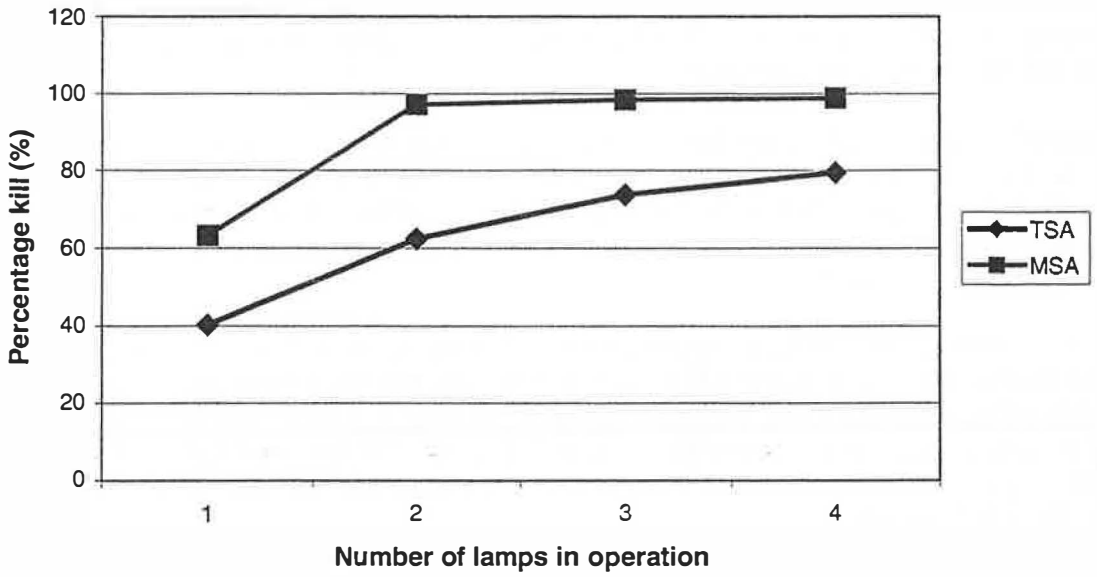

Figure 3 Results of the Stage 1 Return Air Duct Experiment.

It should be noted that the action of 2 lamps achieved a 97.19 % kill of those microorganisms which grow on MSA and with 4 lamps in operation, this value only increased to 98.88 %. By comparison using the TSA media, the action of 4 lamps resulted in an average kill of 79.53 %.

3.2 STAGE 1 DISCUSSION

The results in Figure 3 show that the greater the UV irradiance, the greater the reduction in bacterial numbers. This effect is seen on both media but is more pronounced on MSA. Although the latter finding is of particular interest as it suggests that *Staphylococci* spp. may be particularly susceptible to UVGI in this setting, it should be noted that MSA is a selective agar and may thus, impede the recovery of sub-lethally damaged bacteria.

On one occasion when the UV output was lowest (i.e. one lamp on) the number of organisms was found to be considerably higher than when the lamps were off. This was probably due to a local increase in organisms either from within the system, or being drawn in from the void space. Gram positive bacilli were mainly responsible for the extra growth on these plates and it is possible that spore germination was triggered by the lower dose UV, which would not necessarily affect the numbers of organisms appearing on the plates when the UV light was off. It should be noted that in Figure 3 this data set has been ignored.

The percentage kill results obtained during the Stage 1 experiment were lower than those predicted by the computer model. For example, the model predicted that a 100 % kill of *Staphylococcus aureus* should be obtained when 2 lamps (i.e. 552 W UV power) were in operation. However, the actual MSA results revealed an average kill of 97.19 %, although on a number of occasions a 100 % kill was achieved. The TSA results revealed an even greater difference between the actual and predicted kill levels. The model predicted that with 4 lamps (i.e. 1104 W UV power) in operation, 99.995 % of *Micrococcus sphaeroides* would be killed. The TSA results revealed that with 4 lamps on, the average kill rate was only 79.53 %, although for one set of data the average kill reached as high as 88.59 %. The reasons for these discrepancies are unclear and further investigation is required. However, the published UV susceptibility data for various airborne microorganisms can be notoriously inaccurate and it might be that inappropriate UV susceptibility constants were used in the computer analysis (i.e. 0.104 m^2/J for *Staphylococcus aureus* and 0.027 m^2/J for *Micrococcus sphaeroides*). It may also be the case that the microorganisms encountered were hardier than either of these two.

4.0 STAGE 2 EXPERIMENT

The Stage 2 experimental study was designed to investigate effectiveness of shielded UV devices placed within the ward space. Five fan driven shielded 'low pressure' UV devices (manufactured by BÄRO Technology) were installed at various locations within Ward 5 as shown in Figure 4. The background mechanical ventilation rate in Ward 51 was approximately 3.25 ACH.

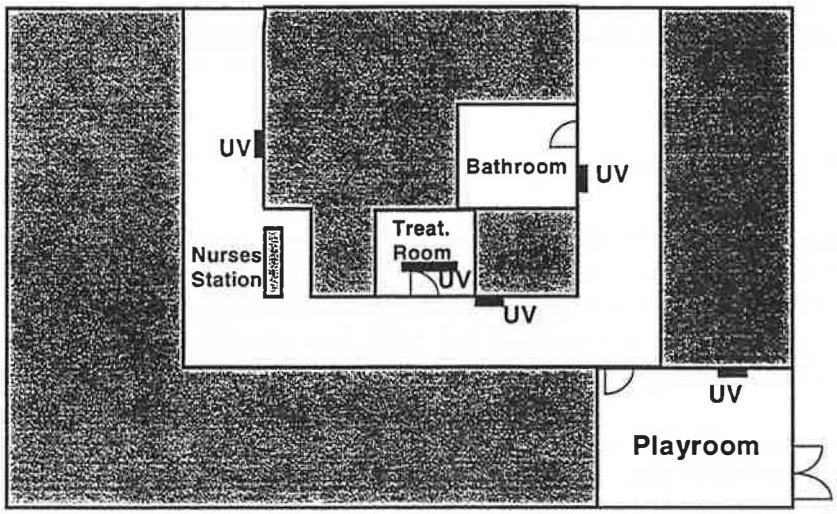

Figure 4 Location of shielded UV devices in Ward 51

UV devices were placed in the corridor space, the treatment room and the playroom in Ward 51. It was the original intention to place a UV device in the bathroom in Ward 51. Unfortunately, the hospital authorities decided to refurbish the bathroom during the Stage 2 experimental period. Consequently, it was decided to use the Ward 51 play room as a substitute during Stage 2.

Two types of fan powered UV device were used in the Stage 2 work; the BÄRO 'Damp-room' unit with a nominal discharge volume flow rate of 160 m^3/h and the BÄRO Model No. 8904 with a nominal discharge volume flow rate of 80 m^3/h. Table 3 presents the characteristics of the UV devices together with the rooms in which they were installed.

Room	**Room Volume** (m^3)	**Estimated Mechanical Ventilation Rate *** (ACH)	**Type of UV Device**	**Quantity** (No.)	**Position in Room**	**Equivalent Ventilation Unit of Device** (ACH)	**Total UV Power** (W)
Treatment Room	40.334	3.8	No. 8904	1	Ceiling	1.983	44
Play Room	75.774	Naturally Ventilated	Damp-room unit	1	Wall	2.112	68
Corridor & Nurses Station	224.258	6.0	Damp-room unit	3	Wall	2.140	204

* Based on data from mechanical ventilation system drawings

Table 3 Room and UV Device Data

4.1 STAGE 2 RATIONALE

It was intended in the Stage 2 study to place room mounted UV devices in two locations - the treatment room and the bathroom. These rooms were selected because they were accessible, had a relatively high bioburden and were enclosed, having no windows and only one door to the corridor. They were also both mechanically ventilated. In order to reduce the ingress of airborne microorganisms from the corridor space, it was decided to place 3 UV devices in the corridor. Preliminary air sampling had revealed the corridor space, in particular the nurses station, as being one of the locations in the ward with the highest bioburden level. UV devices were therefore placed in the corridor, in an attempt to 'cap' the bioburden and 'protect' the two study rooms.

When it was time to undertake the Stage 2 work it was found that the bathroom was unavailable and so the children's playroom was selected. This room was not as ideal as the bathroom, because it is natural ventilated and has a double door which is often opened in warm weather. However, the Stage 2 study took place from January to April 2000, a period in which the playroom double door would normally have been closed.

The Stage 2 experiment was designed so that the microbial bioburden in the ward space was sampled for a period with the UV lamps on and then for a period with the lamps off. The rationale behind this was that if the bioburden did not fluctuate greatly from week to week, then the 'lamps off' results could be used as a control for the 'lamps on' results. Unfortunately, in reality this appeared not to be the case and large daily fluctuations in the bioburden were observed, so an alternative method of obtaining a control had to be devised (see section 4.1).

The UV devices were sized to achieve a nominal equivalent ventilation rate of 2 ACH in the spaces in which they were located. With the exception of the unit in the treatment room, the devices were wall mounted, having an air inlet 1050 mm above finished floor level (FFL) and a discharge outlet 2510 mm above FFL. In the treatment room a smaller ceiling mounted UV device (BARO No.8904) was installed, because the room volume was smaller and wall space was unavailable.

4.2 STAGE 2 RESULTS

On each day of sampling during the Stage 2 experimental work, four replicates of TSA and MSA were taken at each of the five sites listed in Table 4, and the plates were incubated at 37°C in air. The lamps were switched on at least 72 hours before the first day of sampling. After ten sampling days the lamps were turned off for at least 72 hours before ten further sampling days were undertaken. The experiment was then repeated. The corrected mean cfu/m^3 values from ten days of sampling were then calculated. The results of both experimental runs are shown in Table 5.

Sampling Site Ref.	Ward No.	Sampling Site Location
A	51	In Ward 51 nurses' station
B	51	In Ward 51 treatment room
C	51	In Ward 51 children's play room
D	51	In supply air duct to Ward 51
E	51	In return air duct from Ward 51

Table 4 Air sampling sites

Experimental Run	Sampling Site Ref.	Corrected TSA Mean cfu/m^3 Lamps Off	Corrected MSA Mean cfu/m^3 Lamps Off	Corrected TSA Mean cfu/m^3 Lamps On	Corrected MSA Mean cfu/m^3 Lamps On
1	A	250.5	185.1	186.2	204.5
1	B	68.1	110.5	40.6	30.0
1	C	366.7	195.1	126.7	123.0
1	D	0.6	0.6	0.7	0.2
1	E	29.6	20.0	22.9	23.7
1	**Totals**	**715.5**	**511.3**	**377.1**	**381.4**
2	A	265.3	188.1	302.2	265.3
2	B	84.7	66.2	65.5	58.4
2	C	165.1	142.3	334.3	428.4
2	D	0.6	0.3	0.9	0.5
2	E	28.2	31.5	39.5	51.5
2	**Totals**	**543.8**	**428.3**	**742.3**	**804.0**

Table 5 Corrected mean colony counts for each site

It can be seen from the results presented in Table 5 that during the first experimental run the level of the bioburden in Ward 51 was generally lower when the UV lamps were in operation. However, during the second experimental run the situation was reversed, with the bioburden being generally higher when the lamps were off.

Figure 5 is a sequential plot of the 'positive-hole' corrected colony counts collected using MSA plates at the sampling points in Ward 51 during the Stage 2 experimental period. It can be seen that there are large daily fluctuations in microbial level. However, it is noticeable that many of the peak and troughs appear to occur at the same point in time.

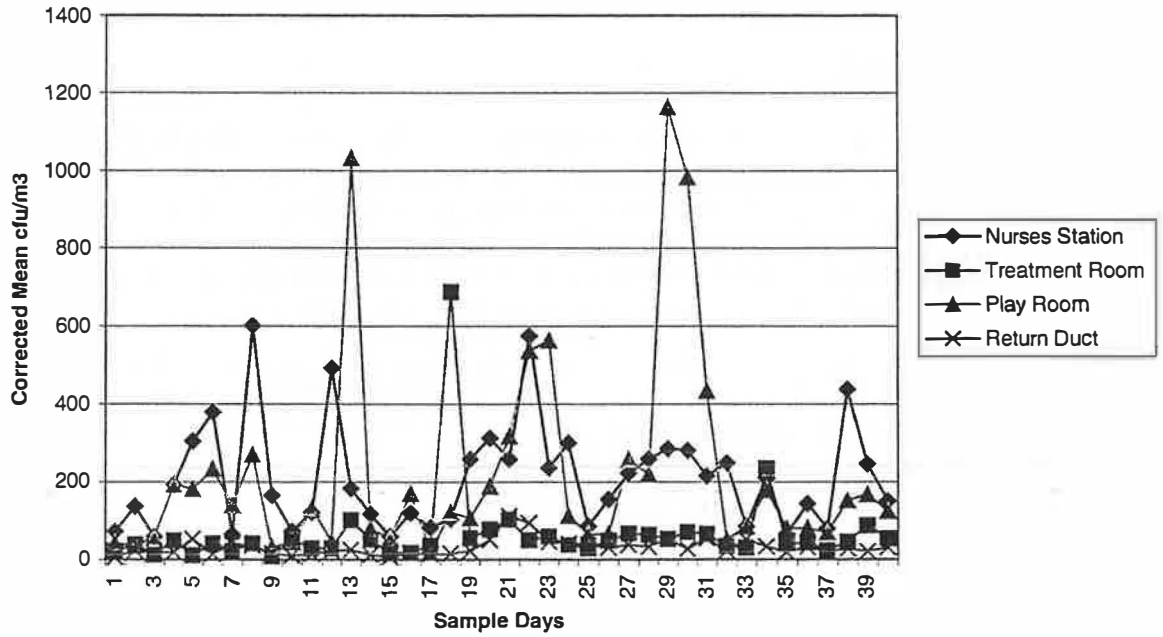

Figure 5 Stage 2 statistically corrected mean colony counts (MSA)

4.1 STAGE 2 DATA ANALYSIS

While the results from the Stage 1 experiment demonstrated that the intervention of UV lamps in the return duct significantly reduced microbial levels in the ducted air stream, the results of the Stage 2 experiment appear to be much less conclusive. During the first Stage 2 experimental run, a substantial reduction in the Ward 51 bioburden appears to have been achieved through the use of room mounted UV devices. However, during the second experimental run the operation of the UV lamps appears to have greatly increased the bioburden at the nurses station and in the playroom (see Table 5). This second observation was unexpected, since the action of the UV lamps should not increase the bioburden. One possible explanation for this unexpected result could be that the lamps were in fact reducing a very high ward background bioburden during the second experimental run. However, in order to establish whether or not this was indeed the case, it was necessary to determine the level of the bioburden which would have occurred in the ward on days 1 to 10 and 21 to 30 (i.e. the days when the UV lamps were on), had the UV lamps not been in operation. Therefore further analysis work was undertaken. In the analysis raw uncorrected data was used. It was necessary to use raw data because the 'positive-hole' correction technique is very non-linear in nature and distorts the results of any linear regression analysis.

The uncorrected sample mean colony counts on MSA, for the Stage 2 experimental period are presented in Figure 6. It should be noted that the UV lamps were switched on during days 1 to 10 and 21 to 30.

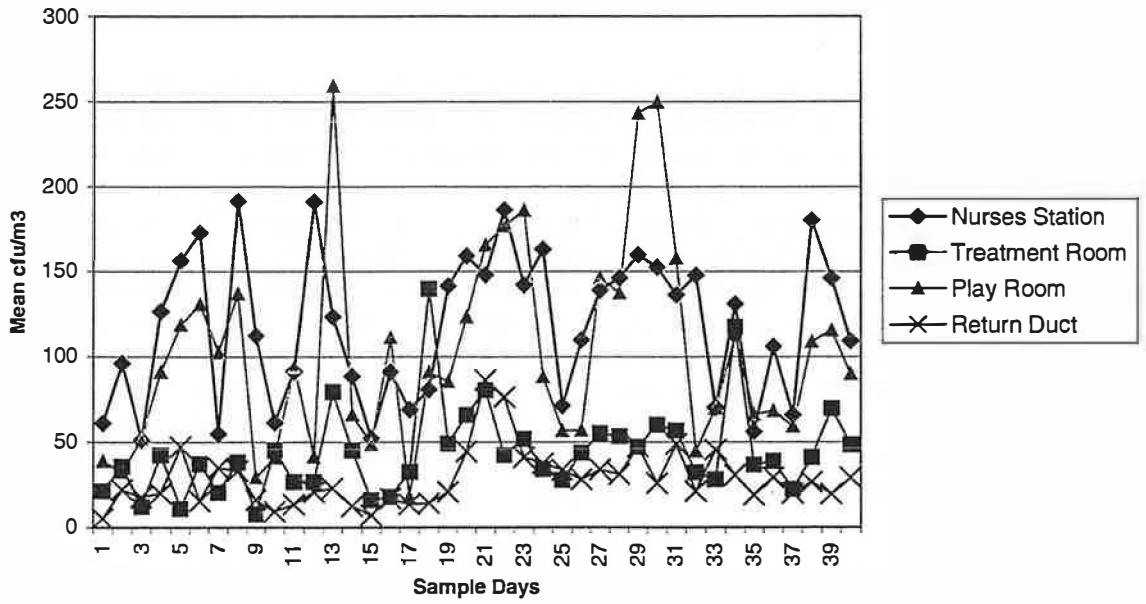

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Figure 6 Raw mean colony counts for Stage 2 (MSA)

From Figure 6 it can be seen that there appears to be some correlation between the data collected at the nurses station and the data for the play room; two locations which are at opposite ends of the ward. When the bioburden level peaks in the nurses station it also peaks in the playroom. This suggests that at any point in time the bioburden is fairly evenly distributed around the ward, so that when it increases in one part of the ward it also increases in the rest of the ward. Further evidence to support this view comes from Figure 7 which is a scatter plot of the bioburden in the playroom

against that at the nurses station for the period when the UV lamps were off. From Figure 7 it can be seen that there is general linear relationship between the two.

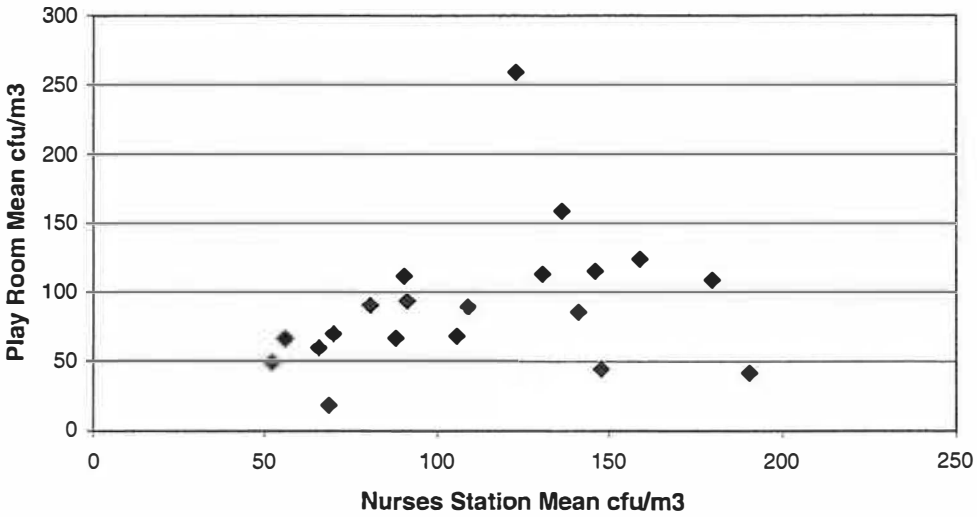

Figure 7 Scatter diagram of playroom colony count versus that from the nurses station (UV lamps off)

From Figure 6 it can be observed that the microbial level in the return air duct tends to reflect the general bioburden level in the ward space, with a similar pattern of peaks and troughs emerging. This is not surprising since part of the function of a ventilation system is to flush out and remove microbes from any room space. Since the average mechanical ventilation rate in Ward 51 is approximately 3.25 ACH it is to be expected that many of the microbes in the ward air will eventually end up in the return air duct. The level of the bioburden in the extract air will however, be lower than that in the ward air, because many microbes will be deposited on the ward and duct surfaces. This is reflected in the data, which shows the return air bioburden 'mirroring' the changes in the ward space, but at a much lower level. It should therefore be possible to use the microbial level in the return duct as an indicator of the general level of bioburden in the ward space. It should be noted however that the bioburden in the return air duct also reflects, in part, the intervention of the UV lamps in the ward space. However the impact of the UV lamps on the microbial level in the return air duct was relatively small since only 29.7 % (maximum) of the ward air was UV irradiated.

From Figure 6 it can be seen that the average bioburden in the return air duct was high during the periods when the UV lamps were on (i.e. days 1 to 10 and 21 to 30). Conversely, the average bioburden was lower during days 11 to 20 and 31 to 40. This suggests that during the periods when the lamps were in operation, the general background bioburden was relatively high, particularly so during the second test run. This may be one explanation of why the general ward bioburden appeared to be higher during days 21 to 30 (i.e. when the UV lamps were on) than for days 31 to 40 (i.e. when the UV lamps were off).

The results for the treatment room are of particular interest, since they represent the most 'enclosed' space in the study. It can be seen that the action of the UV lamps appears to have 'dampened' the bioburden level, so that the high peaks, experienced when the lamps were off, were eliminated. Because there is a relationship between the microbial level in the return air duct and the general

bioburden in the ward space, it is possible to derive a specific relationship between the microbial level in the return air duct and that in the treatment room. Figure 8 shows the relationship between these two locations. It should be noted that Figure 8 includes data collected during the Stage 1 experimental period and omits data from the 20 sample days when the UV lamps were in operation, so that the true relationship between the treatment room and the return air duct can be seen.

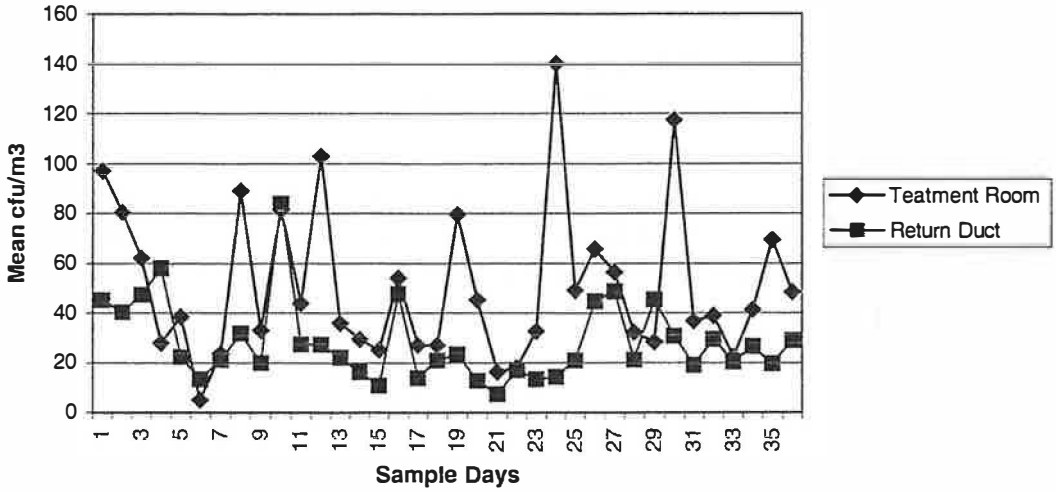

Figure 8 Bioburden in Treatment Room and in the Return Air Duct (MSA)

Since Figure 8 shows that there is, as expected, a relationship between the bioburden in the treatment room and that in the return air duct, it is possible to determine an expression for this relationship. Figure 9 shows a scatter diagram of the mean colony count in the treatment room bioburden versus that in the return air duct.

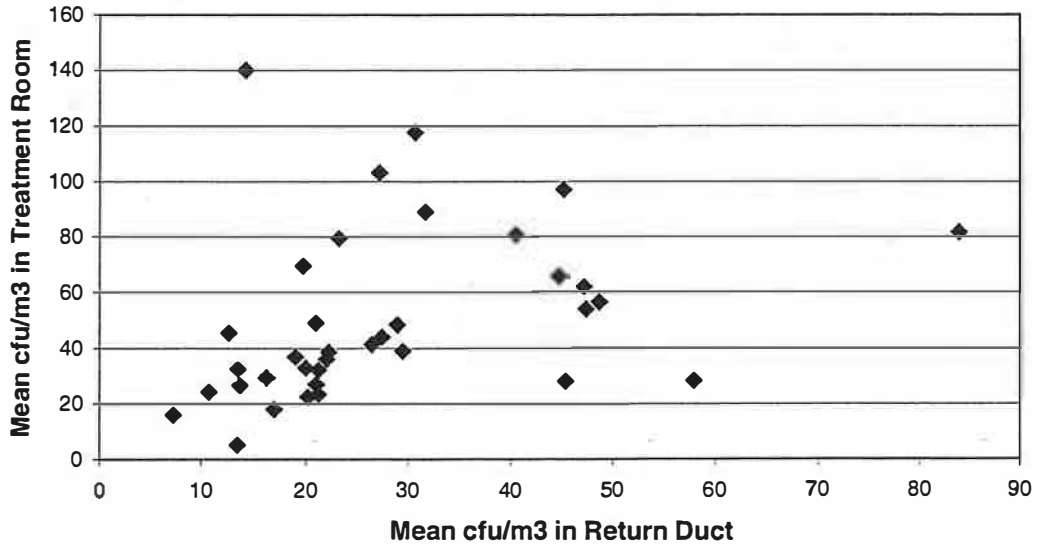

Figure 9 Scatter diagram of the treatment room bioburden versus return air duct bioburden

Linear regression analysis of the data in Figure 9 indicates that the relationship between bioburden in the treatment room and the microbial level in the return air duct can be expressed as:

$$y = 33.213 + 0.6177x \quad (6)$$

Where: x = Mean colony count in the return air duct (cfu/m^3)
y = Mean colony count in the treatment room (cfu/m^3)

By establishing the relationship between the two locations, it is possible to predict what the general bioburden in the treatment room would have been during sample days 1 to 10 and 21 to 30, had the UV lamps not been in operation. Figure 10 shows the results of this prediction.

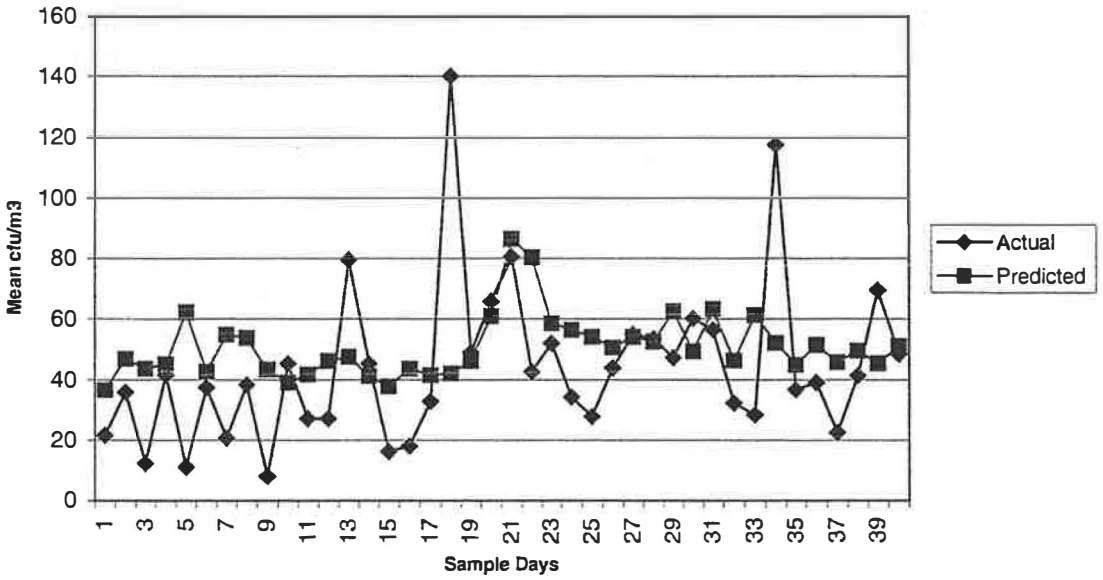

Figure 10 Predicted and actual colony counts in the treatment room during Stage 2

Figure 10 indicates that during days 1 to 10 and 21 to 30 the intervention of the UV lamps did reduce the bioburden in the treatment room. During the period 1 to 10 the average reduction was 41.93 % and during the period 21 to 30 the average reduction was 17.96 %.

By using all 56 data sets (i.e. both Stage 1 and Stage 2 data) for the treatment room and the return air duct, it is possible to perform a CUSUM analysis. In a CUSUM analysis the cumulative deviation from a 'baseline' relationship (i.e. the relationship established by regression analysis) is plotted against time. If the data follows the predicted relationship, then the 'trend' of the graph is horizontal. Any deviation from the baseline 'trend', either positive or negative, will however, alter the angle of the graph so that slopes either up or down. Figure 11 shows the results of the CUSUM analysis.

days 1 to 10 and 21 to 30 (i.e. when the UV lamps were on). It should be noted that the analysis assumes a 'single pass' efficiency of 100 % for the UV device.

	Predicted Mean Bioburden (UV Lamps Off) (cfu/m^3)	Predicted Bioburden Production Rate (cfu/h)	Theoretical Bioburden Equilibrium (cfu/m^3)	Actual Bioburden (UV Lamps On) (cfu/m^3)
First Test Run	46.79	7171.47	30.75	27.17
Second Test Run	60.55	9280.45	39.79	49.68

Table 6 Bioburden Equilibrium Analysis Results

It can be seen from Table 6 that the UV device in the treatment room achieved bioburden equilibrium levels that are in the region of the theoretical maximum value, the maximum theoretical reduction being 32.57 %. On the first experimental run the theoretical maximum was exceeded, with the calculated reduction being 41.93 %. However, on the second experimental run the calculated reduction was only 17.95 %, well short of the theoretical maximum value. The actual average reduction over the two experimental runs was 29.94 %.

5.0 CONCLUSIONS

The pilot study produced much useful data. It revealed that the bioburden was relatively evenly distributed around Ward 51 with peaks and troughs tending to appear at the same point in time at various disparate locations. It also revealed the bulk of the bioburden was being generated within the ward space and that microorganisms shed in the ward were being transported along the return air ducts. The Stage 1 experiment demonstrated that it is possible to kill many of the microorganisms that would otherwise be transported by the extract air stream by installing UV lamps in the return air duct. However, it was not possible to achieve complete air disinfection in the ducts, since some of the microorganisms sampled appeared to very resistance to UV light.

The results of the Stage 2 experiment were mixed. The UV device in the treatment room appears to have worked relatively well, capping the peaks in the bioburden which were observed when the device was not in operation. However, the results for the device in the playroom were inconclusive and those for the nurses station suggest that the impact of the UV devices in that location was minimal.

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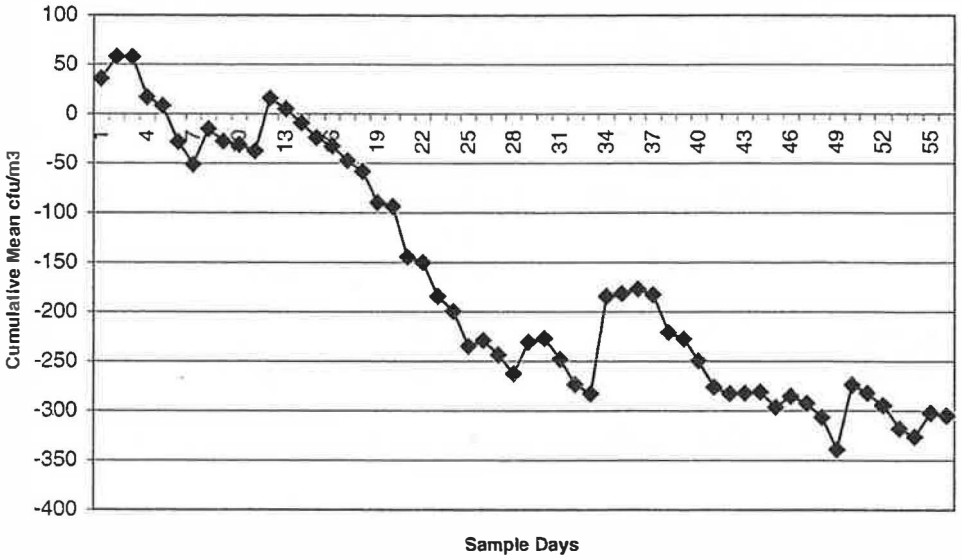

Figure 11 CUSUM plot of treatment room colony count

It can be seen from Figure 11 that when the UV lamps were switched on at point 17, there was an immediate steep decline in the treatment room bioburden and that this trend continued until point 27 when the UV lamps were turned off, at which point the CUSUM plot flattens out and indeed starts to increase. At point 37, when the UV lamps were again switched on, a steep decline in the bioburden is again observed and this continues until point 46 when the lamps were again switched off. After point 46 a horizontal trend is observed. The CUSUM plot demonstrates that, on both experimental runs, the UV lamps made a positive intervention and reduced the bioburden in the treatment room.

Unlike the treatment room, the results for the playroom and the nurses stations are far from conclusive. The UV devices appear to have had a minimal effect on the nurses station. This is not an altogether unexpected result, since the nurses station is a highly occupied and a congested space. In addition, it was not possible to install a UV device in the nurses station itself; the nearest UV device being approximately 5 metres away from the station. In the play room there is evidence that during the first experimental run the UV device did reduce the microbial level. However, during the second experimental run the impact of the UV device appears to be minimal. It was not possible to perform a CUSUM analysis on the playroom, because of insufficient data. Unfortunately, data had not been collected for the playroom during Stage 1 because at that time it was anticipated that the bathroom would have been used for the Stage 2 work.

4.2 THEORETICAL ANALYSIS

It is possible to determine the theoretical equilibrium microbial level for the treatment room by using equation 5. Since it is known that the ventilation rate in the treatment room is approximately 3.8 ACH and that the fan in the UV device produces an equivalent ventilation rate of 1.983 ACH, it is possible to calculate the theoretical equilibrium microbial level which should be achieved when the device is in operation. Table 6 shows the results of such an analysis for period covering the Stage 2 sample

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