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Technology Review

UPPER ROOM ULTRAVIOLET GERMICIDAL IRRADIATION ELIMINATOR (UVGI)
AN UPDATE

HEALTH TECHNOLOGY ASSESSMENT UNIT
MEDICAL DEVELOPMENT DIVISION
MINISTRY OF HEALTH
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TABLE OF CONTENT

1. BACKGROUND

The Deputy Director General (Medical) from the Ministry of Health has asked for an update to the existing technology review by the Health Technology Assessment Unit on UVGI Virus Zone Eliminator (2004).

2. INTRODUCTION

The control of indoor air quality (IAQ) plays an important role in the prevention of infection in hospitals to protect both hospital staff and patients, especially immunosuppressed and immunocompromised patients, who are highly susceptible to the adverse effects of various airborne chemicals and microbes. Improper control of hospital IAQ may cause hospital-acquired (nosocomial) infections and occupational diseases (Leung & Chan 2006).

More recently the bioterrorism threat and the appearance of new pathogens with the potential for airborne spread, such as severe acute respiratory syndrome (SARS), have stimulated installations of upper-room irradiation systems (First et al 2005). Ultraviolet Germicidal Irradiation (UVGI) systems for air disinfection are coming into increasing use for indoor air quality and disease control (Bahnfleth et al 2005).

3. TECHNICAL FEATURES

Currently there are eleven distinct system of UVGI application available ranging from in-duct air disinfection for HVAC application, to upper air single-room systems, to surgical site surface disinfection refer to Fig 1. While there are certain common issues in the application of such systems, such as lamp performance and safety, the information and methods needed to design each type are quite different. The most common types of systems (in no particular order) are in-duct and cooling coil disinfection systems in HVAC applications, standalone recirculating units such as may be found in hospital isolation rooms, and upper air systems (Bahnfleth et al 2005).

It has been noted that the efficiency of disinfection depends on both the UV radiation field intensity and the residence time of microbes is exposed to the radiation field. Therefore, the mechanical ventilation system should maintain an air speed not exceeding the limit recommended by the UVGI system manufacturer for sufficient residence time (Leung & Chan 2006).

At present, the most well-developed areas of standards related to the application of UVGI are the rating of lamps (IESNA 2000; CIE 2003), electrical safety (certifiable by any of several laboratories), and safe human exposure limits (NIOSH 1972; ACGIH 1991; AIHA 2001; IRPA 1985; NEHC 1992).

Currently planned list of guidelines and standards for upper room UVGI and their status as of May 30, 2005 are as follows (Bahnfleth et al 2005):

- IUVA-G01A: General Guideline for UVGI Air and Surface Disinfection Systems (draft under internal IUVA review)

- IUVA-G02A: Guideline for Design and Installation of UVGI Air Disinfection Systems in New Building Construction (draft under internal IUVA review)
- IUVA-S04A: Standard for the Testing and Commissioning of Upper Room UVGI Systems (first draft pending)
- IUVA-S05A: Standard for the Testing of UVGI Surface Disinfection Systems (first draft pending)
- IUVA-S06A: Standard for Laboratory Testing of UVGI Air and Surface Rate Constants (draft under internal IUVA review)
- IUVA-S08A: Standard for Epidemiological Testing of Air Treatment Systems (first draft pending)

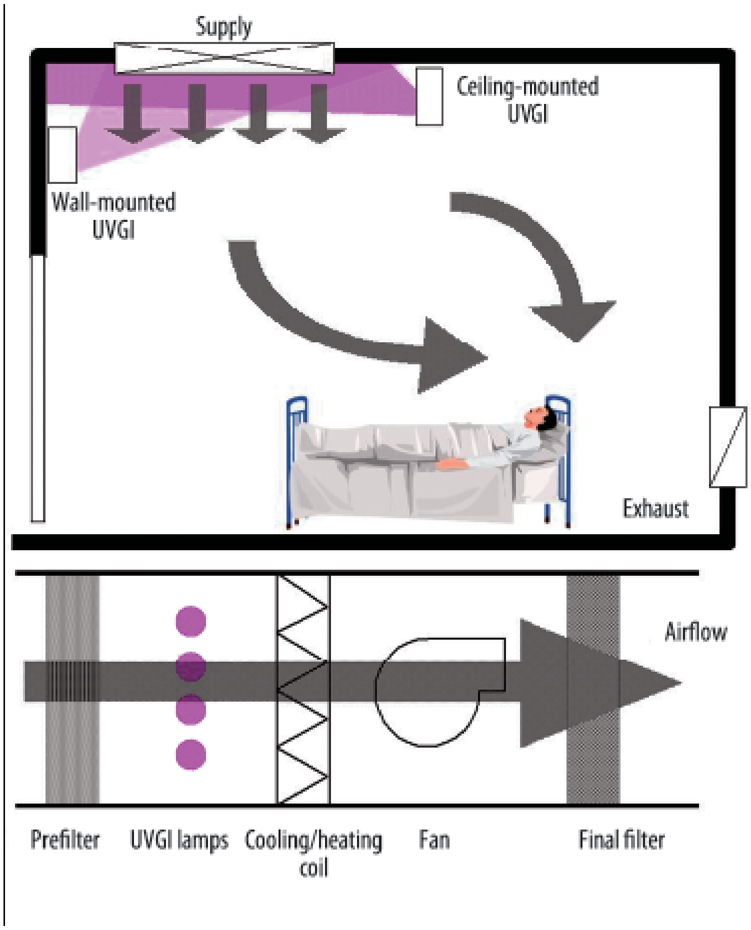

Figure 1. UVGI installation configurations: (**A**) Upper-room configuration and (**B**) Air-duct configuration.(Leung & Chan 2006)

4. OBJECTIVE

The aim of this paper is to update on the existing evidence with regards to upper room UVGI eliminator looking at aspects of safety, effectiveness and cost implications.

5. METHODOLOGY

Electronic search was carried out using various databases as included in Appendix 1. As this is an update, limits were applied and articles were retrieved from 2005-2006. The keywords used in the search include: ultraviolet germicidal irradiation; germicidal ultraviolet irradiation; UVGI; air disinfection; standards; guidelines; air sterilizer; hospital; indoor air quality; AND management.

Any article (including reviews) considered potentially relevant was included, and the bibliographies of publications were examined for additional relevant studies.

6. RESULT AND DISCUSSION

6.1 Safety

The issue of direct exposure to UV light resulting in kerato-conjunctivitis (so-called welder's eye), and skin cancer was addressed in our previous technology review report (2004). However recent studies revealed that the risk of kerato-conjunctivitis can be prevented by installing the fixtures within ventilation systems (duct irradiation), or by using wall- or ceiling-mounted fixtures with baffles to block rays directed downward so that only the air in the upper room is irradiated (upper room irradiation) (Tuberculosis and Chest Service Public Health Services Branch, 2006).

First et al (2006) also demonstrated (based on a limited number of observations) that by limiting the maximum lower room irradiance at every point to less than the continuous 8-hour time-weighted average threshold limit value the observed doses were one-third to a factor lower than the doses calculated from maximum eye-level irradiances measurements in the occupants' spaces.

6.2 Effectiveness

ASHRAE [9], AIA [11], and CDC [12] recommend that UVGI be used **to supplement** the essential engineering control methods, including mechanical ventilation, filtration, and differential pressure control and that UVGI cannot be used as a substitute to the above measures(Leung & Chan (2006); Tuberculosis and Chest Service Public Health Services Branch, (2006); NICE (2006).

Types of Airborne Organisms

(i) Bacteria

In an experimental study by Xu et al (2005), increasing the irradiance level of the UVGI lamps increased the effectiveness of inactivating Mycobacterium parafortuitum. However the relationship was linear up to a certain level. A further increase in the irradiance above this high level resulted in little increase in the inactivation of the airborne TB-like bacteria.

Whereas another experimental study demonstrated that the choice of suspending medium influenced both size and UVGI susceptibility of S. marcescens (Lai et al 2004).

These studies once again concurred with our previous report that the efficacy of upper room UVGI is effected by room ventilation rate, UV radiance levels and distributions, airflow patterns and relative humidity.

Mycobacteria tuberculosis
There are no recent studies that address the control of tuberculosis using UVGI application.

Most authorities believe the most important part of TB control measure is to get the infectious patient into the isolation room as soon as possible. Air changes per hour (ACH) of 6 to12 under negative pressure is pivotal for infection control in an isolation room. The other measures such as HEPA filter or UV irradiation are no replacement for a properly maintained respiratory isolation rooms, although they may serve as supplementary measures in selected settings (Tuberculosis and Chest Service Public Health Services Branch (2006); NICE 2006; Leung & Chan 2006).

More recent studies have once again demonstrated that germicidal effect of UV irradiation varies with relative humidity and intensity of the UV light (Xu et al 2005; Tuberculosis and Chest Service Public Health Services Branch, 2006). It has been recommended that for optimal efficacy of UV irradiation, the relative humidity should be maintained below 60% (Tuberculosis and Chest Service Public Health Services Branch, 2006). High relative humidity above 75 percent lowers the effectiveness of UVGI to inactivate the TB-like bacteria (NIOSH Update 2003).

Another concern raised in the Hong Kong Tuberculosis Manual is as the lamp gets old or covered with dust, the residence time for air sterilization increases therefore affecting the effectiveness of the device (Tuberculosis and Chest Service Public Health Services Branch 2006).

(ii)Fungal
Two studies conducted by Green et al (2004, 2005) noted that UVGI application was less effective against fungal spores.

6.3 Cost Implications

There are no available studies on the cost implications of upper room UVGI. However there was statement in the Tuberculosis and Chest Service Public Health Services Branch (2006) that “UV light are attractive because the fixtures are relatively cheap, and the maintenance and energy costs are low”.

7. CONCLUSION

The safety of UVGI is still a concern and UVGI should be installed and maintained properly to prevent both short term and long term complications.

Most recent epidemiological studies on the health benefits of air treatment using upper room UVGI are still few in number and limited in quality.

8. RECOMMENDATIONS

To ensure hospital indoor air quality and disease control, it is recommended priority lies in having good ventilation design. UVGI systems are only effective as supplementary measures for deactivating bacteria in selected settings.

Further research on the effectiveness of upper room UVGI are required.

9. REFERENCES

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Appendix 1

LITERATURE SEARCH

An electronic search of the HTA agency websites, Cochrane Database of Systematic Reviews via OVID, ACP Journal, Cochrane Controlled Trial Register and other EBM sites were initially carried out. Subsequently PUBMED database was searched and limits were applied (2004 to 2006). Various relevant guidelines on tuberculosis were also retrieved. The keywords used in the search either singularly or in combination were "UVGI; air disinfection AND ultraviolet; UVGI zone eliminator; UVGI lamps; upper room UVGI; safety; effectiveness; efficacy and cost.

Number of search: 8
Number of relevant abstracts: 7
Number of full text articles obtained: 2
Guidelines: 3

EVIDENCE TABLE: _ULTRAVIOLET GERMICIDAL IRRADIATION

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
EFFECTIVENESS ULTRAVIOLET GERMICIDAL IRRADIATION					
1	Leung M, Chan AH. (2006) Control and management of hospital indoor air quality. Med Sci Monit. Mar;12(3):SR17-23. Epub 2006 Feb 23.	Cross Sectional study literature review and conducted comprehensive IAQ assessments in nine hospitals in Hong Kong The control and mitigation measures cover mechanical ventilation, filtration, differential pressure control, directional airflow control, local exhaust ventilation, and ultraviolet germicidal irradiation (UVGI) disinfection. Their applications in critical environments, such as operating theatres, isolation rooms, and other typical units, such as outpatient departments and laboratories, are also considered UV radiation of wavelength 220–300 nm can penetrate cell walls and inactivate tiny airborne droplet nuclei by disrupting their reproductive mechanisms]..	Airborne pathogens, such as *multidrug-resistant Mycobacterium tuberculosis bacteria*, *Legionella bacteria*, and measles viruses, can be killed by UVGI [12,21]. However, UVGI is less effective against fungal spores. The efficiency of disinfection depends on both the UV radiation field intensity and the residence time of microbes exposed to the radiation field. Therefore, the mechanical ventilation system should maintain an air speed not exceeding the limit recommended by the UVGI system manufacturer for sufficient residence time. ASHRAE [9], AIA [11], and CDC [12] recommend that UVGI be used to supplement the essential engineering control methods, including mechanical ventilation, fi ltration, and differential pressure control, but UVGI cannot be used as a substitute for any of these methods.	Level 8	
BACTERIAL					
2.	Xu P, Kujundzic E, Peccia J, Schafer MP, Moss G, Hernandez M, Miller SL (2005)	Cross sectional evaluated the efficacy of an upper-room air (UVGI) system for inactivating airborne bacteria, which	Performance of the UVGI system degraded significantly when the relative humidity was increased from 50% to 75-90% RH, the horizontal UV fluence rate distribution was skewed to one side	Level 8	

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
	Impact of environmental factors on efficacy of upper-room air ultraviolet germicidal irradiation for inactivating airborne mycobacteria. Environ Sci Technol. Dec 15;39(24):9656-64.	irradiates the upper part of a room while minimizing radiation exposure to persons in the lower part of the room. A full-scale test room (87 m3), fitted with a UVGI system consisting of 9 louvered wall and ceiling fixtures (504 W all lamps operating) was operated at 24 and 34 degrees C, between 25 and 90% relative humidity, and at three ventilation rates. Mycobacterium parafortuitum cells were aerosolized into the room such that their numbers and physiologic state were comparable both with and without the UVGI system operating.	compared to being evenly dispersed, and the room air temperature was stratified from hot at the ceiling to cold at the floor. The inactivation rate increased linearly with effective UV fluence rate up to 5 microW cm(-2); an increase in the fluence rate above this level did not yield a proportional increase in inactivation rate.		
3	Lai KM, Burge HA, First MW (2004) Size and UV germicidal irradiation susceptibility of Serratia marcescens when aerosolized from different suspending media. Appl Environ Microbiol. Apr;70(4):2021-7. .	Experimental systems It is generally recognized that data from different laboratories might vary significantly due to differences in systems and experimental conditions In this study, the effect of the composition of the suspending medium on the size and UVGI susceptibility At low humidity (36%),.	S.marcescens suspended in water-only medium was the most susceptible to UVGI, followed by those in serum-only medium. The count median diameters (CMDs) for culturable particles from water-only and serum-only media were 0.88 and 0.95 micro m, respectively, with the measurements based on their aerodynamic behavior. The bacteria suspended in phosphate buffer, synthetic saliva, and phosphate-buffered saline had similar UVGI susceptibility and CMD at 1.0, 1.4, and 1.5 micro m, respectively. At high humidity (68%) the CMD of the particles increased by 6 to 16%, and at the same time UVGI susceptibility decreased, with the magnitude of decrease related to		

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
			the type of suspending medium. In conclusion, the choice of suspending medium influenced both size and UVGI susceptibility of S. marcescens. These data are valuable for making comparisons and deciding on the use of an appropriate medium for various applications.		
FUNGAL					
4.	Green CF, Davidson CS, Scarpino PV, Gibbs SG. 2005 Ultraviolet germicidal irradiation disinfection of Stachybotrys chartarum. Can J Microbiol. Sep; 51(9):801-4.	UVGI dose necessary to inactivate fungal spores on an agar surface and the efficacy of UVGI were determined for cultures of Stachybotrys chartarum This study employed a UVGI testing unit consisting of four chambers with a 9-W, Phillips, low pressure, mercury UVGI lamp in each chamber. The testing unit's apertures were adjusted to provide 50, 100, 150, and 200 microW/cm2 of uniform flux to the Petri dish surfaces, resulting in a total UVGI surface dose ranging from 12 to 144 mJ/cm2.	The UVGI dose necessary to inactivate 90% of the S. chartarum was greater than the maximum dose of 144 mJ/cm2 evaluated in this study. While UVGI has been used to inactivate several strains of culturable fungal spores, S. chartarum was not susceptible to an appropriate dose of UVGI. The results of this study may not correlate directly to the effect of UVGI on airborne fungal spores. However, this indicates that current technology may not be efficacious as a supplement to ventilation unless it can provide higher doses of UVGI to kill spores, such as S. chartarum, traveling through the irradiated zone.	Level 8	
5.	Green CF, Scarpino PV, Jensen P, Jensen NJ, Gibbs SG. Disinfection of selected Aspergillus spp. using ultraviolet germicidal irradiation. Can J Microbiol. 2004 Mar;50(3):221-	The efficacy of UVGI and the UVGI dose necessary to inactivate fungal spores on an agar surface for cultures of Aspergillus flavus and Aspergillus fumigatus were determined	The UVGI dose necessary to inactivate 90% of the A. flavus and A. fumigatus was 35 and 54 mJ/cm2, respectively. UVGI can be used to inactivate culturable fungal spores. Aspergillus flavus was more susceptible than A. fumigatus to UVGI. These results may not be directly correlated to the	Lev el 9	

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
	4.	A four-chambered UVGI testing unit with a 9-W, Phillips, low pressure, mercury UVGI lamp in each chamber was used in this study. An aperture was adjusted to provide 50, 100, 150, and 200 micro W/cm2 of uniform flux to the surfaces of the Petri dish	effect of UVGI on airborne fungal spores, but they indicate that current technology may not be efficacious as a supplement to ventilation unless it can provide higher doses of UVGI to kill spores traveling through the irradiated zone.		
6.	Griffiths WD, Bennett A, Speight S, Parks S (2005) Determining the performance of a commercial air purification system for reducing airborne contamination using model micro-organisms: a new test methodology. J Hosp Infect. Nov; 61(3):242-7. Epub 2005 Jul 11.	The performance of a duct-mounted air disinfection system, designed to reduce airborne pathogens in the hospital environment, was determined using a new testing methodology. The methodology places the equipment in a test duct, a microbial aerosol is generated and then sampled simultaneously before and after the test system. This allows a percentage efficiency value to be calculated. The air disinfection system is a novel chemical-coated filter and ultraviolet (UV) radiation air purification system, operating at a flow rate of 500 m(3)/h, against aerosols of MS2 phage and Mycobacterium vaccae (surrogates of viral and mycobactericidal pathogens).	A three UV lamp system was effective against airborne phages, removing an average of 97.34% of the aerosolized challenge. With the UV component switched off, the average efficiency dropped to 61.46%.This demonstrates that the chemical-coated filter component plays a more significant role than the UV radiation in destroying phages. When six UV lamps were used, the system was able to remove mycobacteria with an efficiency exceeding 99.99%. This test methodology can be used to assess manufacturers' claims of efficacy of equipment against airborne micro-organisms in the hospital environment.	Level 9	
7.	Tuberculosis and Chest Service Public Health Services Branch (2006).	UV light has been recommended for institutional TB control, because of its	Studies have shown that the germicidal effect of UV irradiation varies with relative humidity and intensity of the UV light:120 1. Increase in relative	Level 9	

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
	Tuberculosis Manual. Hong Kong: Department of Health	efficacy in eradicating airborne pathogens in experimental studies. With a room of 200 ft3 and 10 ft ceiling, installing a 30 W UV lamp was described as equivalent to adding 20 ACH.38 UV light is attractive because the fixtures are relatively cheap, and the maintenance and energy costs are low.	humidity reduces the efficacy of UV irradiation. It has been recommended that for optimal efficacy of UV irradiation, the relative humidity should be maintained below 60%. 2. As the lamp gets old or covered with dust, the residence time for air sterilisation increases. Due to these potential complications, low penetration power and slow onset of action of UV, the year round high humidity and unproven efficacy in practice, UV light is not so widely used locally.		
8.	NICE (2006) Tuberculosis Clinical diagnosis and management of tuberculosis, and measures for its prevention and control March 2006. Clinical Guideline 33	Evidence based guideline Search methodology given. Looked at combination with single formulation regimens.	Studies were searched for that focussed on measures directed at patients with infectious TB to prevent transmission to other patients or contacts. It was expected that these measures might include mask wearing by the patient, isolation in a single room, negative pressure rooms, germicidal ultraviolet radiation or air disinfectant at sites of transmission. Given the unexpected data on negative pressure facilities from the review of current service (see 9.3.2), and similar findings in other surveys, the recommendations spell out the three categories of infection control, and require simple steps to clarify which rooms meet the agreed standards. There can be conflicting guidance on whether staff should wear masks. It was agreed that masks are only required for MDR TB or during close contact in cough-inducing procedures, for example bronchoscopy and sputum induction. Patients are reassured by effective infection control measures, but are also often worried unnecessarily by masks or gowns, especially if these steps are not explained to them. The only role for patients wearing masks was within the first two weeks of treatment (when	Level 9	Still unclear of how the went on to base their recommendations based on two RCT

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
			the patient remains infectious) and when they are outside their single room, for example going for an X-ray (as they may come into contact with other, susceptible, patients). *The recommendations below deal with three levels of isolation for infection control in hospital settings:* ● *negative pressure rooms, which have air pressure continuously or automatically measured, as defined by NHS Estates105* ● *single rooms that are not negative pressure but are vented to the outside of the building* ● *beds on a ward, for which no particular engineering standards are required.*		
SAFETY					
7.	First MW, Weker RA, Yasui S, Nardell EA. (2005) Monitoring human exposures to upper-room germicidal ultraviolet irradiation. J Occup Environ Hyg. May;2(5):285-92.	The objective is to flood the entire volume of a room above 6.5 ft with high intensity ultraviolet germicidal irradiation, while minimizing unintentional irradiance below 6.5 ft to avoid eye and skin irritation. The method employed was to have subjects wear a small photometer that recorded total ultraviolet dose over the period of exposure while subjects went about their normal routine, and comparing this value with a hypothetical dose calculated from the highest measured eye-level irradiance.	Air exchanges between the upper and lower room result in air disinfection of the occupied space. Designers of these systems have adopted the practice of limiting the maximum lower room irradiance at every point to less than the continuous 8-hour time-weighted average threshold limit value, severely limiting the irradiation intensity in the upper room and thereby reducing one of the two major factors determining germicidal effectiveness, the other being room air mixing. The hypothesis of this study is that eye and skin exposure will be well below the recommended safe dose even when maximum eye-level irradiance levels in the room exceed the 8-hour continuous exposure threshold limit. The results of the study, based on a limited number of observations, confirmed the hypothesis. Observed doses were one-third to a factor of a hundred or more lower than the doses calculated	Level 8	

No	Author, Title, Journal, Year, Volume	Study design, sample size & Follow up	Outcome & Characteristic	Grade	Comment
			from maximum eye-level irradiances measurements in the occupants' spaces.		
2.	Tuberculosis and Chest Service Public Health Services Branch (2006). Tuberculosis Manual. Hong Kong: Department of Health	Consensus opinion	Direct exposure to UV light can result in kerato-conjunctivitis (so-called welder's eye), and prolonged direct exposure is associated with skin cancer. The risk of kerato-conjunctivitis is easily prevented by installing the fixtures within ventilation systems (duct irradiation), or by using wall- or ceiling-mounted fixtures with baffles to block rays directed downward so so that only the air in the upper room is irradiated (upper room irradiation).	Level 9	