GUIDELINES FOR THE UTILISATION OF ULTRAVIOLET GERMICIDAL IRRADIATION (UVGI) TECHNOLOGY IN CONTROLLING TRANSMISSION OF TUBERCULOSIS IN HEALTH CARE FACILITIES IN SOUTH AFRICA

Prepared for

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and the

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SUMMARY

Review and Guidelines for the Utilisation of Ultraviolet Germicidal Irradiation (UVGI) Technology in Controlling Transmission of Tuberculosis in Health Care Facilities in South Africa

In the 1940s and 1950s, both the potential and the problems of interrupting transmission of airborne infection with ultraviolet germicidal irradiation (UVGI) were demonstrated. William F. Wells and Richard L. Riley first introduced the concept of droplet nuclei as vehicles of airborne transmission and later showed that organisms suspended in these dried residua of larger droplets were highly susceptible to inactivation by ultraviolet irradiation of 254nm wavelength. Of the many airborne organisms that are susceptible to UV at this wavelength, most attention has been focused on tuberculosis because of its continued importance as the single greatest infectious cause of death in adults worldwide.

Ultraviolet germicidal irradiation (UVGI) is increasingly employed in high-risk institutions where transmission of tuberculosis (TB) is likely. As reviewed by Riley and Nardell,[1,2] and Macher,[3] UV air disinfection is supported by more scientific evidence of efficacy against tuberculosis than exists for room ventilation, air filtration, or the use of particulate respirators to prevent TB transmission. Research has demonstrated that UVGI is effective in killing or inactivating tubercle bacilli (*Mycobacterium tuberculosis*) under experimental conditions [4] and in reducing transmission of measles in a school, and influenza in a hospital. [5] Although a large field trial of UVGI to prevent TB transmission in homeless shelters in the United States is underway, the results are not yet available. Ventilation and air filtration may also be effective, but they have not been evaluated as thoroughly for the control of airborne infections, and they tend to be more costly.

The application of upper room UVGI fixtures requires careful planning and appropriate installation and maintenance to ensure that the technology is both effective and safe. UVGI intensity needs to be high enough in the upper room, above people's heads, to inactivate droplet nuclei, yet low enough at occupancy levels to avoid eye or skin irritation.

Based on the existing scientific evidence, and more than 50 years of practical experience, these guidelines have been developed to help reduce transmission of TB in health care facilities.

KEYWORDS

Ultraviolet-Germicidal-Irradiation (UVGI);
Tuberculosis (TB);
UV Disinfection;
Infection Control; and
Droplet Nuclei

GLOSSARY

This Glossary contains some of the terms and expressions used in these guidelines.

Aerosol: Droplets of various size expelled into the air when an infectious person coughs or sneezes, including droplet nuclei which may contain tuberculosis-causing bacteria. Droplet nuclei may remain airborne for extended periods of time.

Air changes: The ratio of the volume of air flowing through a space (usually a room) in a certain period of time to the volume of that space. This ratio is usually expressed as the number of room air changes per hour (ACH)

Air mixing: The degree to which air supplied to a room mixes with the air already in the room, usually expressed as a mixing factor. For effective upper room air disinfection, mixing between the upper and lower room is essential. Mixing is also necessary for effective air disinfection by ventilation or filtration.

Exposure: The condition of being subjected to infectious agents, irradiation, particulates, or chemicals that could have harmful effects.

Infection: The condition in which microorganisms enter the body and either cause disease or increase the probability of disease in the future.

***Mycobacterium tuberculosis* complex:** A group of closely related mycobacterial species that cause active tuberculosis in humans or animals.

Negative pressure: A room at negative pressure has slightly lower pressure than adjacent areas, which prevents air from flowing out of the room when the door is opened. Negative pressure is achieved by exhausting air from the room at a rate slightly greater than intake (if a ventilation system is in use). If there is no ventilation system, negative pressure relative to corridors can be achieved by using a window fan or other extractor fan.

Tubercle bacilli: *M. tuberculosis* organisms

Tuberculosis (TB): A clinically active, symptomatic infectious disease caused by an organism in the *M. tuberculosis* complex.

Ultraviolet germicidal irradiation (UVGI): The use of ultraviolet radiation (254 nm wavelength) to kill or inactivate micro-organisms.

Ultraviolet germicidal irradiation (UVGI) lamps: Lamps that kill or inactivate micro-organisms by emitting ultraviolet germicidal radiation, predominantly at a wavelength of 254 nm. UVGI lamps may be mounted on either the ceiling or located within the ducts of air ventilation systems.

Ventilation: An engineering control technique to dilute and remove airborne contaminants by the flow of air into and out of an area. Air that contains droplet nuclei is removed and replaced by contaminant-free air. Droplet nuclei become dispersed and their concentration in the air is diluted.

1. INTRODUCTION

Managers and staff of hospitals, clinics and other health care facilities are becoming increasingly aware of the need to prevent the transmission of tuberculosis (TB) among both employees and patients. Infectious particles, expelled by contagious individuals who are sneezing, coughing or even talking, may remain airborne for several hours, posing the threat of infection to any other persons in the environment. This is especially a concern in areas like South Africa where multidrug-resistant (MDR) TB are found.

In 1998, there were an estimated 180,000 new cases of tuberculosis in South Africa. Of these, at least 30% were associated with infection with HIV and 1% persons were harbouring MDR tuberculosis organisms. Should these trends continue in the absence of effective control programmes, 3.5 million new cases of tuberculosis will occur in South Africa over the next decade. However, employing effective tuberculosis and HIV control programmes and associated technologies should reduce the burden by half. At least 1.7 million cases and more than 50,000 tuberculosis deaths would be prevented and more than R2 billion would be saved over the next ten years. [6]

First and foremost, South Africa has adopted the WHO Framework for TB Control (the DOTS Strategy) which focuses on early detection of smear positive (infectious) persons, and ensuring their cure by directly observed treatment. It is essential that medical facilities adopt and implement this strategy. However, in medical facilities an additional responsibility exists for ensuring an environment free of risk of infection with tuberculosis. Environmental management provides one such possibility through engineering controls to prevent the spread and reduce the risk of exposure and transmission to HCW's and the general public by reducing the concentration of infectious droplet nuclei in the air.

This document provides an overview of engineering control measures and the rationale behind the general approach recommended for entire buildings. Particular emphasis is given to the implementation of ultraviolet germicidal irradiation (UVGI) in South Africa.

Successful application of UVGI requires an approach that "packages" the technology in the form of guidelines incorporating the appropriateness of the technology, and its installation and operation. In order for ultraviolet germicidal irradiation to contribute to tuberculosis control programmes in typical South African medical facilities - large older buildings that do not employ modern heating, ventilation and air conditioning systems - the engineering of room-mounted, upper room UVGI systems must to be clearly and accurately defined. The compilation of these guidelines has been largely based on the recommended practice outlined in two recently published technical documents.[13] In addition, reference is made in two documents from the United States Department of Health and Human Services, Public Health Service.[8,9] Updated versions of these documents are produced from time to time, and can be obtained by contacting the organisations directly and/or via the Internet at *www.cdc.gov/niosh/homepage.*

The scientific evidence supporting the use of UVGI can be divided into three categories:

1. evidence of susceptibility of airborne tubercle bacilli to UV radiation;

2. evidence of sufficient convective air mixing between the upper and lower-rooms in order to achieve the desired exposure;

3. evidence that UVGI is safe for room occupants.

The susceptibility of tubercle bacilli to UV radiation has been demonstrated under controlled conditions on both surfaces and in air. Because minute droplet nuclei are unprotected by fluid layers and other UV-absorbing matter, they are more susceptible than are organisms on surfaces. Riley and associates [15] aerosolised fully virulent tubercle bacilli in a bench-scale chamber specifically designed to control the duration and intensity of UV-C exposure under precise temperature and humidity conditions. The number of living organisms recovered without UV was compared to that after UV exposure at various doses. Knowing the dose of UV irradiation required to inactivate airborne tubercle bacilli was essential, but by itself was inadequate to predict the efficacy of upper-room UVGI where the intensity and dosage received by airborne organisms is unknown. In a sealed, unventilated, 18.5 m^2 room having only a radiator to assist with convective air mixing, a single 17 Watt UV fixture was capable of inactivating aerosolised bacilli at a rate equivalent to 10 additional air exchanges (that is, equivalent ventilation)[15]. Subsequent experiments showed that air disinfection in the lower room was increased when air mixing between the upper- and lower-rooms was improved by the use of low-velocity ceiling fans[17-19].

1.1 Environmental Controls For Tuberculosis: Rationale for Treatment of Whole Buildings

Exposure to tuberculosis (TB) exists in facilities where susceptible individuals are in contact with persons suffering from the disease. These settings typically include health care facilities in areas where tuberculosis is prevalent, correctional facilities and worker hostels. If any facility is identified as being potentially hazardous, environmental engineering controls, such as UVGI, may help reduce the risk of transmission.

The greatest risk of infection arises from the individual with undiagnosed or unsuspected tuberculosis. These individuals are unaware that they are infectious, but they pose a real threat of transmitting TB to others in the same enclosed area. Infectious droplet nuclei can rapidly disperse throughout the air of any enclosed room or area, transported by air currents in corridors, stairwells and through ventilation ducts that recirculate air.

There are three potential sites for air disinfection within buildings:

1. Room air;
2. Corridor air
3. Recirculated air through mechanical heating, ventilating, and air conditioning (HVAC) systems.

The approach to each of these sites differs, and each is reviewed separately.

1.1.1 Room Air

The air of individual rooms likely to be occupied by infectious patients should be disinfected. Air movement should be from corridor to room to exhaust to minimise contamination of corridor air. This strategy assumes that corridor air itself is not a source of contagion, and should be coupled with air disinfection in corridors, if possible.

Due to the unpredictable distribution of infectious sources and the droplet nuclei they produce, buildings likely to accommodate infectious people require air disinfection throughout. However, the economics of air disinfection suggest priority application in the highest risk areas.

In tuberculosis hospitals, for example, the highest risk areas would be wards for newly admitted and multidrug resistant patients, and rooms for indoor sputum collection. Other typical high-risk areas include waiting rooms, doctor's examination room in clinics, dining rooms or other areas where patients might congregate.

1.1.2 Corridor Air

Air in corridors and passageways need to be disinfected because patients who may be diagnosed or unsuspected move through them. Susceptible persons include medical staff, visitors, housekeeping and maintenance staff who are exposed to corridor air for extended periods daily.

In addition, corridors are conduits which allow air to move from one area to another within buildings. Disinfecting air in corridors is an efficient way to reduce transmission of contagion within buildings.

1.1.3 Recirculated Air

Many modern buildings have heating, ventilation and air conditioning (HVAC) systems to recirculate air throughout the building to maintain occupant comfort. These systems can also contribute to the distribution of airborne organisms throughout the building, thereby exposing all occupants in the HVAC circuit. Although airborne organisms are diluted in a larger volume of distribution within buildings, the total volume of infectious air respired collectively by exposed occupants is also greater. Examples of TB transmission throughout buildings have been reported[10]. In one circumstance, an office worker infected 27 or 67 (40%) of her co-workers over the month-long period that she worked before her TB was diagnosed. Infections were not clustered around the location of the infectious source, but fairly evenly throughout the two-story building[22]. On the positive side, HVAC systems can provide an opportunity to interrupt transmission by filtering or UV irradiating air within return ducts. However, while air disinfection within ducts should reducing the chance of recirculation of infectious droplets, it is theoretically less effective in preventing transmission among room occupants than upper room air disinfection within rooms

1.2 Conventional Air Disinfection: An Overview

There are essentially two conventional engineering methods to control the transmission of airborne infections within whole buildings: ventilation and filtration, or a combination thereof.

1.2.1 Ventilation

HVAC systems are designed primarily to provide good air quality (adequate oxygen and removal of respired carbon dioxide) and thermal comfort at reasonable energy costs. Ventilation dilutes and removes contaminated air, especially odours, and controls airflow patterns within rooms and entire buildings. Two types of mechanical ventilation systems are generally employed to achieve air dilution and removal: the single-pass and recirculation systems.

However, medical facilities in countries defined as middle- to low-income, generally do not employ mechanical HVAC systems. In the absence of central heating and ventilation systems, natural ventilation and ceiling fans are used. Ceilings are generally high, as buildings were designed to maximize patient comfort through natural lighting and dilution of odours. Unfortunately, natural ventilation provides unpredictable control for preventing the transmission of airborne infections within buildings. Ceiling fans help by facilitating dilution, but drafts limit their use, especially when temperatures fall. Except for exhaust fans used in isolation rooms, room fans generally lead to air mixing rather than to air replacement.

Other limitations:

- Unlike odour and temperature control, functions for which ventilation and other forced-air systems are designed, the removal of highly dilute (but still dangerous) infectious particles requires large ventilation rates in order for adequate protection to be achieved.

- Ventilation becomes progressively less and less efficient, since each doubling of the effective ventilation rate reduces the risk of infection by approximately half. There are practical upper limits to the ventilation rate, and consequently, there is almost always a residual risk of infection.

1.2.2 Filtration

Air filtration, using high-efficiency particulate air (HEPA) filters, removes air contaminants, including all airborne pathogens. Filtration may be used to supplement recommended ventilation. HEPA filters are air-cleaning devices that have a demonstrated minimum removal efficiency of 99.97% of particles $\geq$0.3 μm in diameter[12]. Since droplet nuclei carrying *Mycobacterium tuberculosis* organisms range from 1 to 5 μm in diameter, it is expected that HEPA filters will remove such droplet nuclei from contaminated air. In any application, HEPA filters must be carefully installed and maintained to ensure adequate functioning.

Filtration techniques are used in a number of ways to remove infectious droplet nuclei. Methods may include the placement of high-efficiency particle air filters in ventilation return ducts to prevent their recirculation, in ducts discharging isolation room air into the general (central) ventilation system (although discharge directly to the outside is much preferred), and in room-air cleaners.

Potential limitations of filtration:

- High volume airflow through filters is usually required in order to effectively protect room occupants. This may not be practical, or may generate unacceptable noise or drafts.

- Proper installation, maintenance, replacement, and meticulous monitoring of HEPA filters are important to successful transmission control.
- Tests of room air cleaners in removing airborne inert particles have shown considerable variability depending on design and placement.
- Re-entrainment of already filtered air (short-circuiting) are also limitations of room air cleaning devices.

An in-depth discussion of conventional engineering controls is presented in Appendix A.

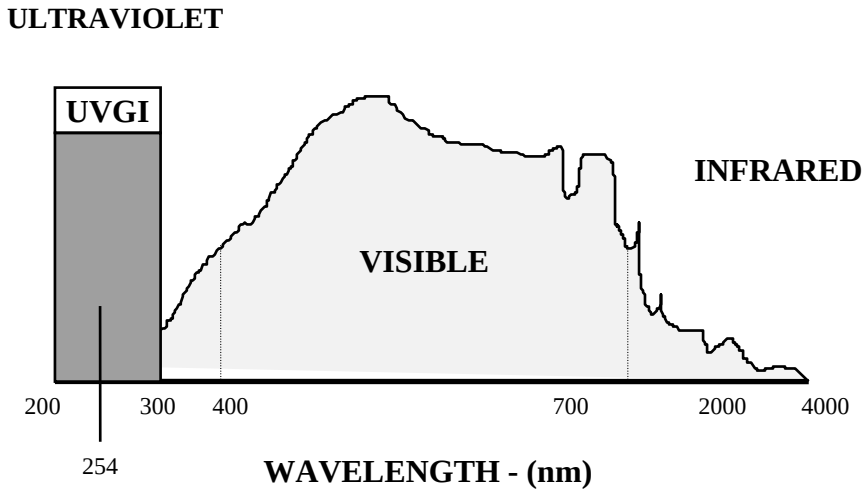
2. ULTRAVIOLET GERMICIDAL IRRADIATION (UVGI) TO CONTROL THE TRANSMISSION OF TB

2.1 Introduction

Ultraviolet radiation is non-ionising radiation and is that portion of the electromagnetic spectrum from 100 to 400 nm wavelengths. For convenience the UV spectrum has been subdivided into three different wavelength bands: UV-A (long wavelengths, range: 320 - 400 nm), UV-B (midrange wavelengths, range: 290 - 320 nm), and UV-C (short wavelengths, range: 100-290 nm). Commercially available UV lamps used for germicidal purposes are low-pressure mercury vapour lamps that emit radiant energy in the UV-C range, predominantly at a wavelength of 253.7 nm. The UV radiation associated with injurious and damaging sunlight is UV-A and UV-B.

UV-C, is unlike UV-A and UV-B, as it has extremely low penetrating ability. It is nearly completely absorbed by the outer layer of skin (stratum corneum), where little to no harm is experienced. Although listed as a potential carcinogen for man, UV-C is unlikely to be carcinogenic or to cause skin or eye irritation (keratoconjunctivitis) if applied correctly and within exposure limits as set out by the International Radiation Protection Agency (IRPA) and other international health bodies. (See Chapter 5 - Health and Safety Issues). UV-C safety issues are discussed in Appendix B.

Figure 1 - Electromagnetic Spectrum



2.2 UVGI Application Techniques

The approach adopted for ultraviolet germicidal air irradiation adheres to the “whole building treatment” concept and therefore relies on the following two areas of application: upper-room air irradiation and duct irradiation.

2.2.1 Upper-Room Irradiation

Upper-room UV air disinfection is employed to inactivate tubercle bacilli carried as droplet nuclei in the upper part of a room/area, while minimising the UV exposure to persons in the lower portion of that room. UVGI fixtures are suspended from ceilings or mounted on walls. The lamp fixture is equipped with louvers to direct the radiation horizontally and away from the lower part of the room, utilising the entire cross-sectional area of the upper room at a height above head level for air disinfection.

Upper-room UVGI relies upon good air mixing between the upper to the lower parts of the room. Natural convection currents, generated by body heat, ventilation, and occupant motion, normally provides air exchange rates between the upper and lower section of the room that may exceed room air exchange rates achieved by mechanical ventilation systems. Small temperature gradients between the upper and lower room, or low-velocity ceiling fans, are especially effective in improving upper and lower-room air mixing.

In room that lack adequate aire movement (i.e. complaints of stuffiness), the use of ceiling fans is a satisfactory solution [14]. Rooms lacking mechanical ventilation often have sufficient natural connective mixing to make upper-room UVGI an effective barrier to disease transmission[15]. Moreover, the lack of modern mechanical ventilation systems has been one of the principal attractions for the use of passive upper-room UVGI in health care facilities."**[13]**

Room-air disinfection has a twofold benefit:

1. It reduces transmission of airborne infectious bacteria within the room, and

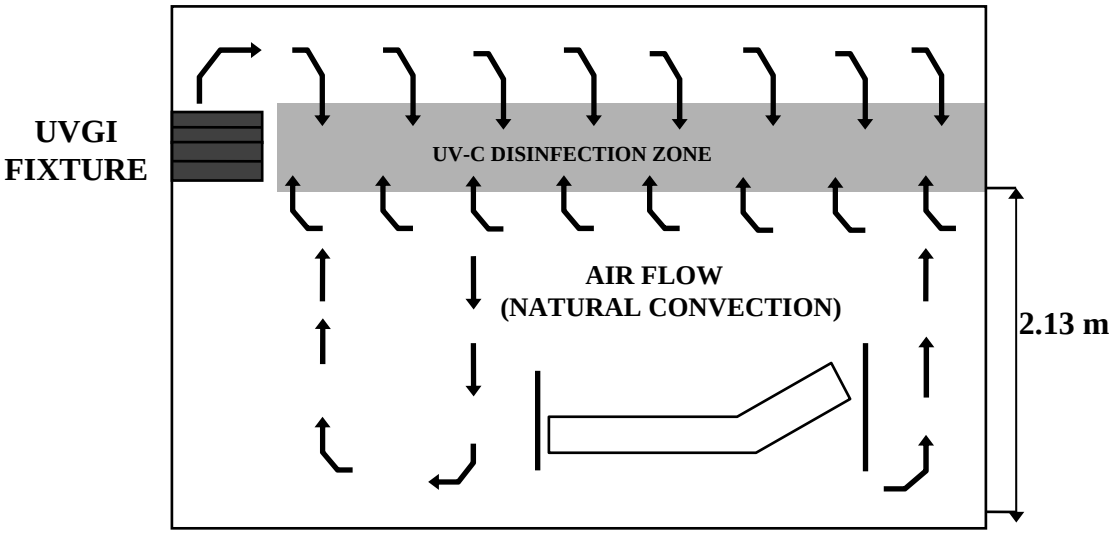
2. It reduces the probability of re-circulation of infectious bacteria within the building.

Reasons for utilising upper-room air disinfection in middle to low-income countries to control the transmission of TB rather than specialised ventilation or filtration systems include:

- They are passive devices, easily installed on existing walls and ceilings, readily accessible for inspection and maintenance, silent and inconspicuous, modest in cost, and energy efficient. In addition to medical facilities, they are applicable to all areas where people assemble such as schools, prisons, hostels, and transportation terminals and stations.

- They have advantages over other application modes related to effectiveness in preventing airborne infectious transmission within rooms. Infectious microbes are killed promptly because they are irradiated in the upper region of the room, very close to the locations where they are emitted into the air. This type of source control is comparable to locating dust and fume capture hoods at the sources of contaminants to be captured.**[13]**

Figure 2 - UVGI Upper-room Irradiation



2.2.2 Duct Irradiation

Where a central HVAC system exists, it is a potential conduit for the recirculation of infectious particles within buildings. It also provides an opportunity to disinfect air in a more central location, rather than in, or in addition to, room by room air disinfection. There are advantages and disadvantages to disinfecting air in central ventilation systems versus on a room-by-room basis. In hospitals that have well-functioning HVAC systems, it is possible to reduce transmission within buildings, especially when upper-room cannot be used due to low room ceilings, or other limitations. Fixtures are fitted into return ducts, the size, configuration, and UV power selected according to duct dimension and air flow. However, UVGI duct irradiation is generally not preferred over room UV, for the following reasons:

1. UVGI in return ducts disinfects air after it leaves the room. For room occupants sharing the same air with the infectious source, there is no protection provided by disinfection air after it leaves the room. Upper room air disinfection, or fan-driven room air disinfection units have the advantage of protecting occupants in the room with the infectious source.

2. UV lamps in ventilation ducts are out of sight and often out of mind. Although good maintenance of all air disinfection equipment is essential, in-duct lamps provide no reminders of their presence, and can be easily neglected. Upper room fixtures, and to some degree, room units, are less likely to forgotten.

3. UVGI in ducts is limited by the capacity and proper functioning of the ventilation system, whereas upper room UVGI, using room units, supplement room ventilation, provides desirable redundant protection should either system malfunction or fail.

The advantages of employing UVGI in ventilation ducts are as follows:

1. Although properly installed upper room UVGI has no significant harmful effects for occupants in the lower room, necessary fixture warning labels about direct, high-intensity UV exposure, and confusion with the more

harmful forms of UV irradiation (UV-A and UV-B) may cause safety concerns. UV in ventilation ducts and room units is not visible and avoids these concerns, however unjustified. Education of room occupants about upper room UV eliminates concerns in most facilities.

2. In facilities with properly installed and maintained upper room UVGI, UV in return ventilation ducts offers additional protection against recirculation of infectious particles. This might be particularly important if the ventilation circuit includes especially vulnerable occupants, such as young children or immunocompromised persons.

Table 1 - Theoretical 99% Disinfection of Air contaminated with *E. coli* at 26^{O}C in Reflective Duct Units (Cubic decimetres per second) - (Source: Commercial Lighting Design, Inc., USA)

	UV Watts Required								
Smallest side of duct (mm)	**2**	**5**	**10**	**20**	**36**	**40**	**50**	**75**	**105**
127	18	37	75	150					
152	22	45	85	171	271				
178	26	52	105	211	317	422			
203	30	60	120	241	358	483	604		
228	33	67	135	271	407	543	679		
254	37	75	151	302	453	604	755	1057	
381	56	113	226	453	679	906	1132	1585	2265
508	75	151	302	604	906	1208	1510	2114	3020
635	94	188	377	755	1132	1510	1887	2642	3775
762		226	453	906	1359	1812	2265	3171	4530
1270			755	1510	2265	3020	3775	5285	7551
2540				3020	4530	6040	7551	10571	15102
5080					9061	12081	15102	21143	30204

. Table 1 provides reference data for UV wattage necessary to disinfect air at various flow rates, based on the killing of ordinary bacteria. Generally it is advisable to use more UVGI in ducts than the tables suggest since room occupant exposure is not a concern. The installation of dust filtration upstream from the UV fixtures is recommended to decrease cleaning requirements and help maintain high levels of lamp performance.

3 INSTALLATION AND COMMISSIONING GUIDELINES

3.1 Upper-Room Installation

Parameters determining upper-room UVGI effectiveness include:

1. room configuration,
2. UV lamp placement, and
3. the adequacy of airflow in bringing contaminated air into the irradiated upper-room space.

UV fixtures must be appropriately placed, configured and spaced, and to accommodate the area, shape and height of the room to be disinfected in order to achieve germicidal irradiation levels (at least 10 UV Watts output per 218.6 m^2 floor space). Although the application of upper-room UVGI is not complicated, determining the optimal location and design for fixtures is best done by someone experienced in the field (see Appendix C: Generic Layout Showing Typical Wall and Ceiling Mounted Fixture Placing; and Appendix D: Typical Case Study Installations for Upper-Room UVGI).

Air mixing may be supplemented by the addition of ceiling fans where no mechanical ventilation exists, or by supplying cool air near the ceiling in rooms where warmer air is present below. However, no minimum air flow requirements exist for the application of upper-room UVGI as discussed in Chapter 2.2.1. The ceiling should be high enough (at least 2.44M) for a large volume of upper-room air to be irradiated, avoiding exposure of humans in the lower room to UV radiation.

3.1.1 Wall and Ceiling Mounted (Pendant) Fixtures

Layout - Final fixture locations may have to be adjusted to accommodate obstructions or interference by conduit pipes, lighting fixtures, sprinklers and so forth. Care should be taken to avoid reflection of the UV beam off smooth flat surfaces such as ductwork or plastered building finishes.

Fixtures - The manufacturer's manual should be consulted to ensure that UV-C output power ratings, irradiation intensity, fixture orientation, ideal fixture spacing, louver setting and any other required adjustments are adhered too during the installation.

Fixture mounting height - Ultraviolet fixtures are intended to irradiate the upper-room air. Although no UV-irradiation is intended to enter to the lower occupied space, reflected UV from surfaces occurs and is acceptable within exposure standards, as discussed below.

Wall mounted units should be installed with the bottom of the fixture no lower than 2.13 m above floor level to prevent unwanted exposure of occupants' eyes and skin to the UV-C radiation. A minimum ceiling height of 2.44 m is required for wall mounted fixtures. As ceiling height increases above the 2.44 m level, fixture mounting height may be raised to provide longer lines of UV energy flow for large rooms and long corridors (Table 2). Pendant or ceiling mounted fixtures are best employed where ceiling heights are above 2.89 m or higher, with the fixture at least 2.44 m above floor level.

Table 2 - Fixture Mounting Height Requirements

Ceiling Height	Mounting Height (bottom of fixture)
2.44 m	2.13 m
2.74 m	2.29 m
3.05 m	2.44 m

***Note*: No fixture should be mounted lower than 2.13m above floor level.**

Mounting - Installation of fixtures to be made neat and secure. Wall mounted fixtures should be securely fastened, level and plumb, to assure louver adjustment will not alter. It is desirable that cleaning and lamp replacement should not require dismounting of the fixture, breaking electrical connections or disturbing fixture beam alignment.

Safety - UV warning signs to be mounted at public sites in the facility. Installers should be careful not to look directly into illuminated UV fixtures nor leave newly installed fixtures powered until they have been metered and adjusted for safety compliance and in-service training has been provided for staff. Installers need to wear protective eye goggles if fixtures are on.

3.1.2 Commissioning

Measure - After the fixtures are installed and wired according to building regulation, output exposure limits need to be monitored to prevent occupants from excessive UV radiation. No fixture may be placed in service until tested with a calibrated UV meter and adjusted to ensure readings at eye level are not excessive. For a 8-hr workday, with continuous skin or eye exposure, the maximum UV-C exposure intensity is 0.2 $\mu W/cm^2$ [8]. However, most people are not continuously exposed due to movement within building, protection provided by ordinary eyeglasses and clothing, and shading provided by eyebrows and other barriers. Where exposure is brief, in a corridor, for example, UV intensity of 2 or 3 times that value is unlikely to cause eye or skin irritation, the most sensitive monitor of over-exposure. The actual exposure safety standard for an 8-hour day is 6.0 mJ/cm^2 [23], which can be reached by 8 hours continuous exposure at 0.2$\mu W/cm^2$, or 4 hours at 0.4$\mu W/cm^2$, or 2 hrs at 0.8$\mu W/cm^2$, etc. In the past, 0.2$\mu W/cm^2$ had been slavishly adhered to, disregarding variable exposure times, and variable risk of infection.

Based on experience in homeless shelters in the US over many years, an exposure irradiance of 0.4$\mu W/cm^2$ appears to be an acceptable goal at eye level in the lower room. Over-exposure is unlikely at this irradiance while upper-room UV should be effective.

Testing - Acceptance tests are to be conducted at a height of 1.75 m using a sensitive UV meter and a detector designed to measure 254 nm UV, not 260 nm, a common detector used in industry. As noted above UV-C intensity (254 nm) should not exceed 0.4 $\mu W/cm^2$. All areas covered by UV shall be surveyed and readings recorded accurately. UV sensors should be positioned to read direct and reflected radiation from fixtures, ceilings, walls and obstructions. Should the adjustment of fixture louvers fail to produce safe UV output levels, fixture manufacturers should be consulted for further recommendations or assistance.

Table 3 - Installation Summary

	Wall Mounted Fixtures *	Ceiling mounted Fixtures *

	Corner mount	Wall mount	Pendant	Pendant with Fan
Beam pattern	90^O	180^O	360^O	360^O
Minimum Ceiling Height	2.44 m	2.44 m	2.89 m	2.89 m
Fixture mounted height	2.1m	2.1m	2.4 m	2.4 m
Ideal UV-C intensity (mw/cm^2) for effective disinfection	> 10 $\mu W/cm^2$	> 10 $\mu W/cm^2$	> 10 $\mu W/cm^2$	> 10 $\mu W/cm^2$

* Appropriately designed UV fixtures are available for all locations. Only the most commonly used have been included in the table

3.2 In-duct Installation

Banks of UVGI lamps installed in ventilation ducts should safely house devices to minimize hazards to maintenance staff. The access door for servicing the lamps should be fitted with a window through which lamps may be visually inspected. The access door should be fitted with an interlock switch that trips the lamps off when the door is opened.

Layout - It should be noted that final fixture locations may have to be adjusted to accommodate UV duct units of standard sizes rather than re-fabricate duct sections. Inner surfaces of the duct should be reflective to provide higher operating efficiencies.

Fixtures - The manufacturer's manual should be consulted to ensure that UV-C output power ratings, irradiation intensity, fixture orientation and any other required adjustments are followed during the installation. Fixture output power requirements are determined by the volume and air flow of the duct (Table 1).

Fixture mounting - Ultraviolet in-duct units fit into existing duct systems and require careful fitting.

Mounting - Installation of fixtures to be made neat and secure. Cleaning and tube replacement will require dismounting of the fixture, without breaking electrical connections.

Safety - UV warning signs must be displayed at appropriate sites within the building. The signs should either be in a language used by maintenance personnel, staff and patients, or make use of universal symbols.

4. UVGI APPLICATIONS AND CONSIDERATIONS

For more than 50 years, upper-room UVGI has been employed safely in hospitals, clinics, correctional facilities and shelters around the USA and elsewhere without injuries more serious than an occasional transient skin or eye irritation caused from accidental direct exposure. However, until recently few studies have been conducted

to determine whether or not UVGI fulfils its intended purpose. Although most studies have shown efficacy, many engineering specifications are only now being defined.

4.1 UVGI Application in Low-Income Countries

This section serves to introduce some practical considerations relevant to the application of UVGIin low-income countries:

- there is a resurgence of TB within these countries which is also related to the spread of HIV
- the budgets of the health care industry, particularly the public sector, are limited and decreasing in real terms with respect to developed countries
- the infrastructure owned by the health care industry is often old, lacks maintenance and is in a poor state of repair
- there is a relatively high utilisation of the infrastructure by the community.

These realities indicate that an investment in UVGI by the health care industry in low-income countries must be maximumally cost effective. Cost will be a major consideration, along with ensuring the safe and effective application of UVGI for the benefit of health care workers and patients.

Although most public health buildings in low-income countries can be classed as old, they are sometimes perceived as ideal for preventing the transmission of tuberculosis because they have high ceilings and long corridors, i.e. plenty of open space for air to be transported and lots of windows to allow air in and out, and sunlight into the building. This perception may have been correct in the period when these buildings were designed and built, but current realities are very different.

It is not uncommon to find in larger general and tuberculosis hospitals that:

- the corridors are blocked with patients, either being treated or waiting to be treated
- overcrowding within the building creates a more humid environment in which ventilation is inadequate
- door and windows are normally kept closed at night to create a warmer environment for sleeping, and for security of the occupants.

4.2 TB Transmission Risk

To ensure the cost effective application of UVGI there are a number of key questions that need to be answered by the stakeholders concerned. The first one concerns the risk of tuberculosis transmission within the health care institution. Fundamentally, there is risk of contracting TB within any building in which there is an individual with TB in the presence of people who are not infected with the bacteria. Within a facility there are work areas and activities of health care staff where the risk of infection is relatively great compared to others. Attention should be focused on the highest risk areas for TB transmission within a facility.

Based on a review of the literature, environments may be classified according to their TB transmission exposure risk for the occupants, both health care workers or patients (see below). Please note this grading serves only as a general guide those interested in applying UVGI in a low-income country environment.

Grading of TB Risk Prone Environments

Higher Risk Environments: need for UVGI is essential

Facilities where TB is common:

- Sputum induction, bronchoscopy, and autopsy rooms
- Intake wards and clinics where symptomatic, undiagnosed patients are seen
- Waiting areas where symptomatic, undiagnosed patients gather
- Isolation rooms or wards for newly diagnosed TB patients
- Wards and clinics for immunocompromised patients
- Wards and clinics for patients with newly diagnosed multidrug resistant TB
- Corridors and common areas in high-risk facilities

Moderate Risk Environments: air disinfection strongly recommended

Facilities where TB is less common:

- General hospital wards and clinics where unsuspected TB cases may present for care
- Waiting areas for general wards and clinics
- Wards and clinics where TB patients are diagnosed and started on effective therapy
- Corridors and common areas for lower-risk patients

Lower Risk Environments: air disinfection may be useful to protect against occasional infectious cases

Facilities where TB is not common

- Wards and clinics where patients have responded to effective TB treatment
- Large, well-ventilated areas
- Areas where patients and staff spend short periods of time, such as toilets and showers.

Other High Risk Environments

It is well known that high rates of TB occur in prisons/hostels and environments of selected labour where the application of UVGI may also be considered.

4.3 Type of UVGI System Required

Once the TB transmission risk and corresponding requirement for the application of UVGI has been established, it is then necessary to determine the most appropriate system for installation. UVGI system selection is determined by the design and use of the building, and by the presence or absence of a mechanical ventilation system. As previously discussed, there are essentially two types of UVGI system that can be installed:

1. In-duct UVGI or

2. Upper-room UVGI

The pros and cons of these two approaches have been discussed previously. Under most circumstance, upper room UV is preferred, especially in South Africa, where most tuberculosis care facilities, hostels, and correctional facilities have no ventilation systems.

To date, the majority of UVGI installations in South Africa have been upper-room UVGI systems.

4.4 UVGI System Efficacy

UVGI system efficacy is ensured at two levels:

1. System Design
2. System Performance Monitoring

It is necessary that the consulting company selected to design and install UVGI have the necessary technical expertise. A minimum requirement would be the ability to design a system based on the guidelines provided in this document as well as the main reference documents listed [3,4]. Within the irradiated area, the intensity of UV-C should be greater than 10μW/cm^2. In the case of in-duct systems, it is more complex to assess the specific UV requirements, but this can determined using Table 1 in Chapter 2.

Effective design of UVGI systems entails the selection and positioning of the UVGI fixtures. In practice, designing an effective UVGI system could be an iterative process if there are constraints placed on the positioning of UVGI fixtures, in order to achieve at least the minimum criteria for effective reduction of TB-causing bacteria in the areas selected.

Once the system has been designed and installed, it is necessary to ensure the following:

1. Effective UV-C intensities are being generated by the UVGI system in the selected areas
2. The intensity of this UV-C irradiation will result in exposure at or below the minimum accepted 6mJ/cm^2 over an 8-hour limit. We recommend that the irradiance not exceed 0.4μW/cm^2 at eye level. These tasks should be performed by the installing consultant and confirmed by a third party organisation. This would constitute part of the commissioning of the UVGI system.

It is also recommended that these tests be performed on a regular basis, at least annually after routine lamp replacement, to ensure the continued effective and safe operation of the UVGI System.

Ideally, the consultant should have designed and installed UVGI systems previously, or have access to the necessary expertise and equipment.

4.5 Maintenance Requirements

Once a UVGI system has been installed and is performing safely and effectively, the continued performance within prescribed limits needs to be ensured. This should be achieved through regular maintenance and servicing of the system components. Resources invested in air disinfection equipment are essentially wasted if the system is not maintained in optimal working order. Maintenance capability must either be created in-house through the facilities' management , or contracted out to a qualified external maintenance service provider. During the design stage the Consulting Engineer can assist the process by reviewing the details of a service contract which can be put out for tender. The scope of the maintenance requirements should be clearly documented, with equal emphasis on safety and efficacy.

1. **Efficacy:** i.e. irradiate UV-C into areas above head height of the occupants of a room, at an intensity of greater than 10μW/cm^2 in the irradiated zone.

2. **Safety:** by ensuring that the exposure of UV-C at eye level in all irradiated areas is less than 6 mJ/cm^2 over 8 hours. For shorter exposures, the allowable irradiance is higher.

The testing component of maintenance is likely to be very similar to that performed during the commissioning of the UVGI system. However, the successful maintenance will also require regular cleaning and testing of the UVGI system. Thus the third consideration will be to stipulate the maximum intervals between cleaning of the environment. If initial re-testing with a sensitive UV meter after 6 months use shows a significant loss (> 25%) of UV output (compared to measurements taken after at least 100 hrs use - to allow for the expected initial drop-off in output) then a cleaning schedule once between annual lamp changes is appropriate. If UV output drops less than 25% at 6 months, then it is better not to clean fixtures until relamping at one year.

The reason for this is that cleaning fixtures, unless necessary, provides an opportunity for accidental exposure to high-intensity UV in the upper room if lamps are not turned off first, as required. It also can lead to damage to fixtures or louvers if maintenance workers are careless. Although the rated useful life of UV lamps varies by type, model and manufacturer, many models call for annual lamp changes. However, quarterly inspection of fixtures should be part of the maintenance program to identify premature failure of lamps so that they can be promptly replaced.

UVGI system maintenance does have cost implications, which should be included in the initial budget, but these do not have to be prohibitive if:

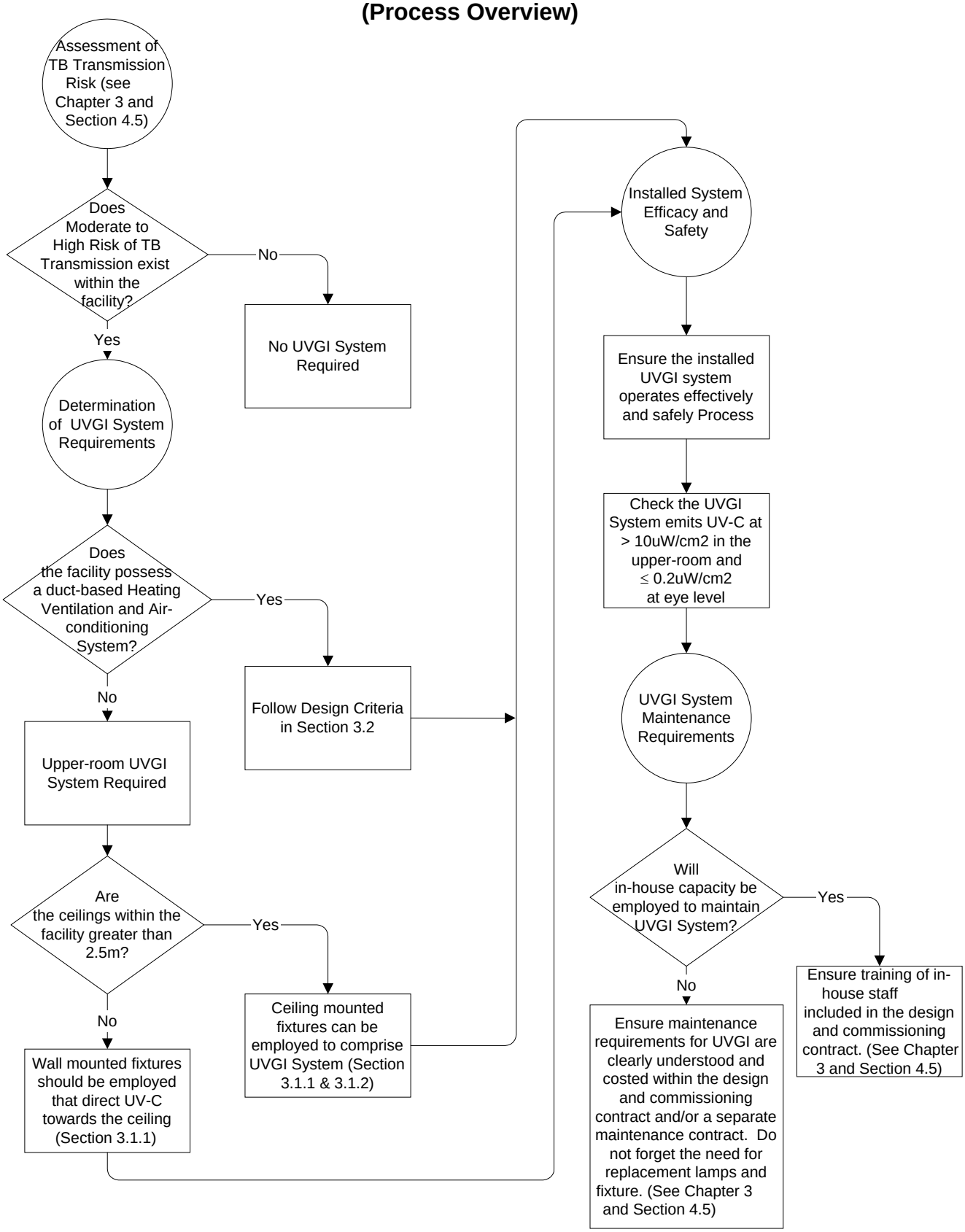
1. High quality components and materials are selected
2. In-house staff are trained to perform the maintenance and testing requirements
3. Maintenance is included in the design brief to the UVGI Consultant.

Note: the useful life of UV and other fluorescent lamps is shorted by turning them on and off frequently. For most installations, upper room UVGI lamps should be left on 24 hours a day both for effective air disinfection and to maximise lamp life. The practice of disinfecting air only after occupants have left a building has no basis in science and should not be done. Although tubercle bacilli in air have some persistent viability, the risk of transmission to others diminishes to near zero soon the infectious source leaves the building.

4.6 Applications Summary

The application of UVGI in low-income countries is summarised in a schematic diagram in Figure 4 below. The schematic diagram also contains references to other sections of this guidelines document which provide support to facilities considering the application of UVGI in a logical, process driven manner.

Figure 3 - Application of UVGI in Low-income Countries (Process Overview)



5. HEALTH AND SAFETY ISSUES

UVGI employs a “narrow band” (95% 253.7 nm wavelength) of the UV portion of the electromagnetic spectrum, also known as “short wave” UV, to inactivate airborne pathogens. This band of electromagnetic energy is lethal for airborne bacteria at intensity levels easily achieved in upper-room areas, above the heads of occupants. There are well-established safety criteria for UV-C in the lower room, determined primarily by the need to avoid eye and skin irritation. The 8-hour exposure limit for 254 nm UV is 6mJ/cm^2. The UVGI irradiance permitted within that standard varies greatly with the actual exposure of eyes and skin.

We recommend the irradiance should not exceed 0.4μW/cm^2 at eye level.

Longer wavelength UV-A and UV-B have greater penetrating capability than UV-C (short wavelength UV), and constant exposure to intensive, longer wavelength UV typically found in sunlight has been associated with skin cancer and cataracts. UV-C has more energy than UV-B or UV-A, and would have more damaging effects to tissue than UV in sunlight were it not almost completely (~ 95%) absorbed by the outer, dead layer of the stratum corneum (skin).

Direct exposure to high intensity UV-C lamps may cause temporary, painful, but superficial irritation of the eyes (photoconjunctivitis) or skin erythema (photokeratitis). Eye irritation is brief, as a result of the normally rapid turnover of the corneal epithelium. Intensive, direct skin exposure may cause erythema, and longer exposure may result in mild to moderate “sunburn” in sensitive individuals. (Also see Appendix B)

Before painters and maintenance personnel work in the upper section of rooms where UVGI is in use fixtures must be turned off to avoid injury.

Some concern was raised several years ago concerning the possibility that UV irradiation in sunlight, and possibly UV-C, could activate HIV virus which has been found in certain cells in the skin. This concern was based solely on experiments of the virus in the laboratory, not in people. However, since these concerns were raised there have been several epidemiological studies which have not shown any correlation between exposure to UV irradiation (sun exposure or treatment of skin conditions with UV-A) and the rate of progression from HIV infection to clinical AIDS. If there is no correlation with the more penetrating UV in sunlight or UV-A therapy, there is unlikely to be any effect of the very low doses of much less penetrating UV-C exposure in the lower room from upper room UVGI. According to the US Federal Drug Administration (FDA - personal communication), their initial concerns about HIV-infected persons being exposed to UV outdoors have been put to rest. There should be no concern about exposure to UV-C indoors.

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Appendix A

REQUIREMENTS FOR CONVENTIONAL AIR DISINFECTION TO CONTROL THE TRANSMISSION OF TB

1 VENTILATION

Ventilation may be used to achieve several desired effects, including diluting and removing contaminated air, controlling airflow patterns within rooms, and controlling the direction of airflow throughout the facility or building. Additionally, heating, ventilation and air conditioning (HVAC) systems are employed to provide good air quality (adequate oxygen and removal of respired carbon dioxide) and thermal comfort.

1.1 Ventilation rates

Recommended ventilation rates are typically expressed as ACH - air changes per hour. This is the ratio of the air volume entering the room per hour to the room volume, which is equal to the exhaust airflow (Q) divided by the room volume (V) multiplied by 60.

$$ACH = Q + V \times 60$$

Ventilation rates depend largely on the construction and operational requirements of the ventilation system such as energy requirements to heat, cool and move air. The expense and effort of achieving higher ventilation rates in order to achieve high removal efficiencies for new construction may be reasonable, whereas retrofitting an existing facility to achieve the desired ACH may be more difficult and costly.

The US Centers for Disease Control (CDC) guidelines for TB isolation rooms stipulates 6 air changes per hour for existing facilities and 12 in new or renovated facilities**.** These rates require high energy expenditures for cooling or heating air and may not be possible in either hot or cold climates in facilities that are resource-limited. In buildings without central ventilation systems, in addition to open windows during the day, simple roof ventilation systems can be used to promote air changes through convective and outside air movement. Air intake portals around the building perimeter permit continued air intake at night when windows may be closed. Simple window fans in isolation rooms can produce negative pressure in rooms, decreasing the spread of infectious droplet nuclei within the building.

Further information can be obtained from the WHO document “Guidelines for The Prevention of Tuberculosis in Health Care Facilities in Resource – Limited Settings”**

[1]

[1] ** http://www.who.int/gtb/publications/healthcare

Table 1A - Air Changes per hour (ACH) and time in minutes required for removal efficiencies of 90, 99 and 99.9% of airborne contaminants

	Minutes required for a removal efficiency of:		
ACH	**90%**	**99%**	**99.9%**
1	138	276	414
2	69	138	207
4	35	69	104
6	23	46	69
8	17	35	52
10	14	28	41
12	12	23	35
14	10	20	30
16	9	17	26
18	8	15	23
20	7	14	21
30	5	9	14
40	3	7	10
50	3	6	8

***Note*: This able does not take into account the ongoing production of contaminants by an infectious source in the room.**

A simpler approach to understanding the effectiveness of ventilation is to consider that, regardless of the existing ventilation rate, doubling the rate should reduce the concentration of contaminants (and risk of infection) by approximately half. After a second doubling, the contaminant is down to a quarter of the initial concentration, and after a 3rd doubling, the concentration is half of that, or 12.5% of the original. The problem is that, depending on the initial rate, it may or may not feasible to increase the rate by two times or more. Where ventilation is low or absent, increasing air flow by many fold may be relatively easy and the benefits substantial, even if still incomplete. However, where ventilation is already adequate for comfort, even doubling the rate may exceed the capacity of the HVAC system, and the benefits achieved relatively small. Thus, the CDC recommendation of 12 or more air changes, while likely to be effective in preventing transmission, if it is possible, is highly cost ineffective in terms of the energy costs required. The reason for the emphasis on upper room UVGI in resource-poor countries is that high levels of air disinfection can be achieved at much less cost.

1.2 Dilution and removal

This section, taken directly from the CDC Guidelines[9], applies to sophisticated care facilities such as could be found in and larger hospitals in South Africa.

The main objective of air dilution and removal is to achieve and maintain low concentrations of airborne contaminants. A major cost component of operating HVAC systems in institutional and commercial buildings is heating and cooling outdoor air. Recirculation of indoor air is, therefore, often adopted to reduce those costs at the expense of removing contaminates. Uncontaminated air (incoming air) is allowed to mix with contaminated room air and dilute the concentration of contaminants. The mixed diluted air leaves the room via the extraction system.

Two ventilation system arrangements are generally employed to achieve air dilution and removal: the single-pass and recirculation systems.

1. In single-pass applications, air from outside or from a central HVAC system is supplied to a specific area or room. This air is passed through the area prior to being exhausted from the building. The single-pass system is preferred in areas where infectious airborne droplet nuclei are known to be prevalent, such as TB isolation and treatment rooms, as it prevents contaminated air from being recirculated to other areas within the facility. Recirculated air can supply isolation rooms, but then needs to be exhausted to outside, or disinfected if it is recirculated.

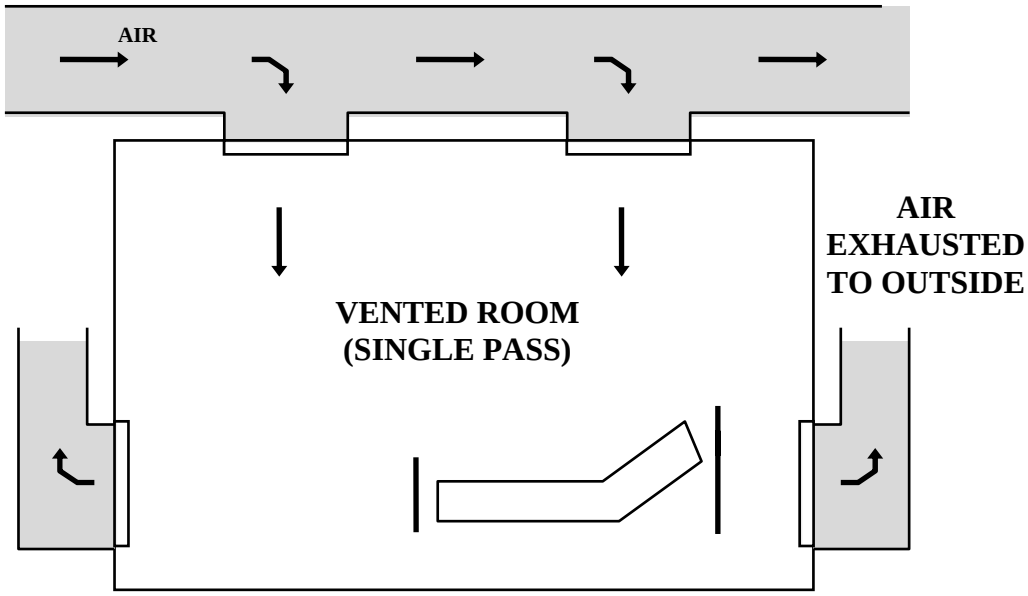
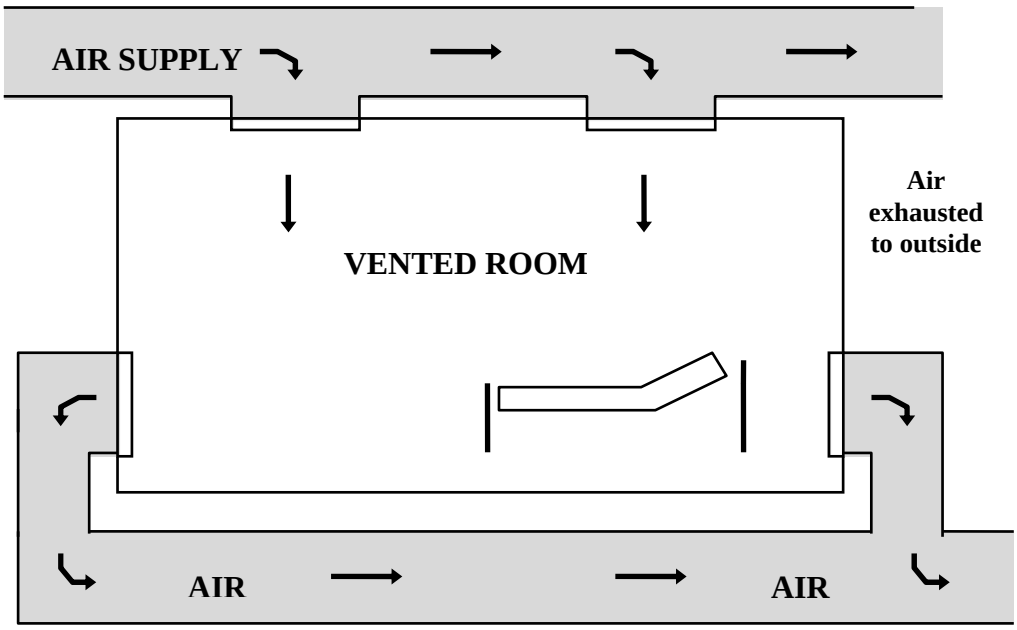


Figure 1A - Single-pass or Air Removal Ventilation System

2. In the more common recirculation systems, dilution occurs when contaminates which had been released into the air are allowed to mix with air supplied by the ventilation system. The resulting air mixture, containing portions of contaminated air, is recirculated to other areas serviced by the ventilation system. Industrial hygiene practice dictates that dilution ventilation be employed to control exposure only if the following criteria are satisfied:

   - small quantities of contaminants are released at uniform rates
   - there is sufficient distance between workers and the source of the contaminant
   - the contaminant has a low toxicity or concentration (≤ 100 PPM)
   - no air-cleaning device is required to remove contaminants before air is discharged to the outside environment or recirculated.

Figure 2A - Dilution or Air Recirculation Ventilation System



Possible limitations of ventilation:

- Unlike odour and temperature control, functions for which ventilation and other forced-air systems are designed, the removal of highly dilute (but still dangerous) infectious particles requires large ventilation rates in order for adequate protection to be achieved.

- Air ventilation becomes progressively less efficient since each doubling the effective ventilation rate reduces the risk of infection by half. This relationship of ventilation to protection is one of diminishing returns.

2 FILTRATION

Filtration techniques are employed to remove contaminants from the air, through the use of high-efficiency particulate air (HEPA) filters. Filtration may be used as a method of air cleaning that would supplement recommended ventilation measures.
HEPA filters are essentially defined as air-cleaning devices with a demonstrated and documented minimum removal efficiency of 99.97% of particles $\geq$ 0.3 μm in diameter.
Since *M. tuberculosis* droplet nuclei range from 1 to 5 μm in diameter, HEPA filters theoretically should remove droplet nuclei from contaminated air.
In any application, the installation of HEPA filters must be carefully conducted and they must be meticulously maintained to ensure adequate functionality is maintained (99%).

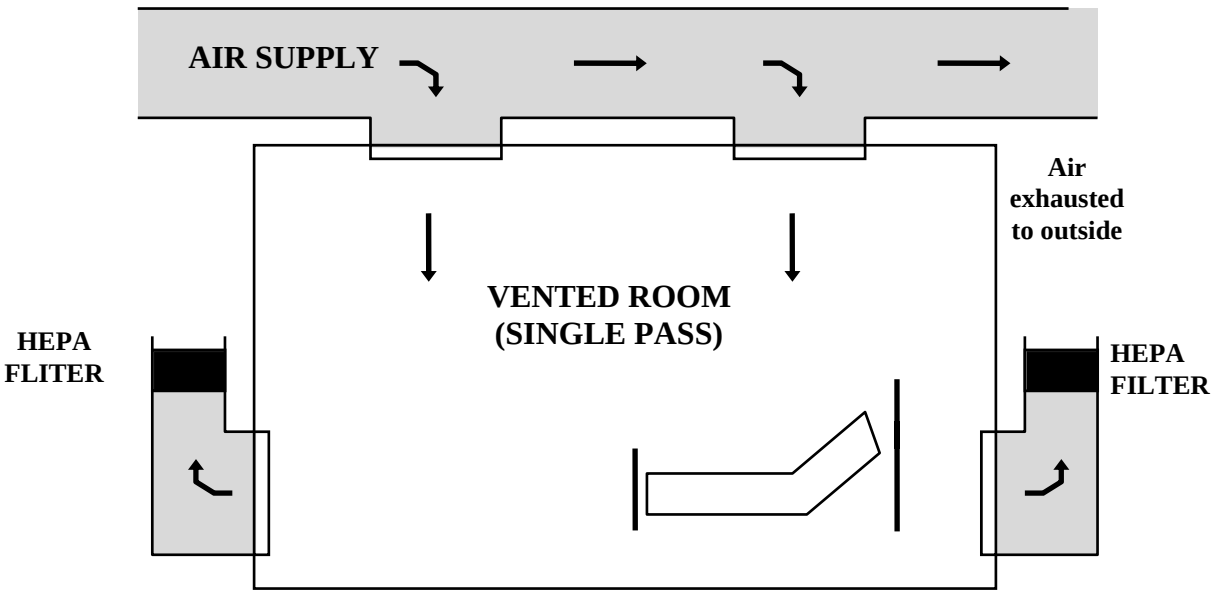
2.1 HEPA Filter Placement

Filtration techniques and filter placement may be used in a number of ways to remove infectious droplet nuclei from room or exhaust air. Favourable methods include the placement of high-efficiency particle air filters in extraction ducts to remove droplet nuclei from air prior to being discharged to the outside, directly or via ventilation equipment; in ducts discharging room air into the general (central) ventilation system; and in room-air cleaners.

1. *Exhausting HEPA-filtered air outdoors*

High-efficiency particle air filters may be used as additional safety measures by cleaning air from isolation rooms prior to direct exhausting outdoors. This precaution is usually not necessary, unless the room exhausts to an area where people congregate or where the risk of air re-entering the system is potentially high.

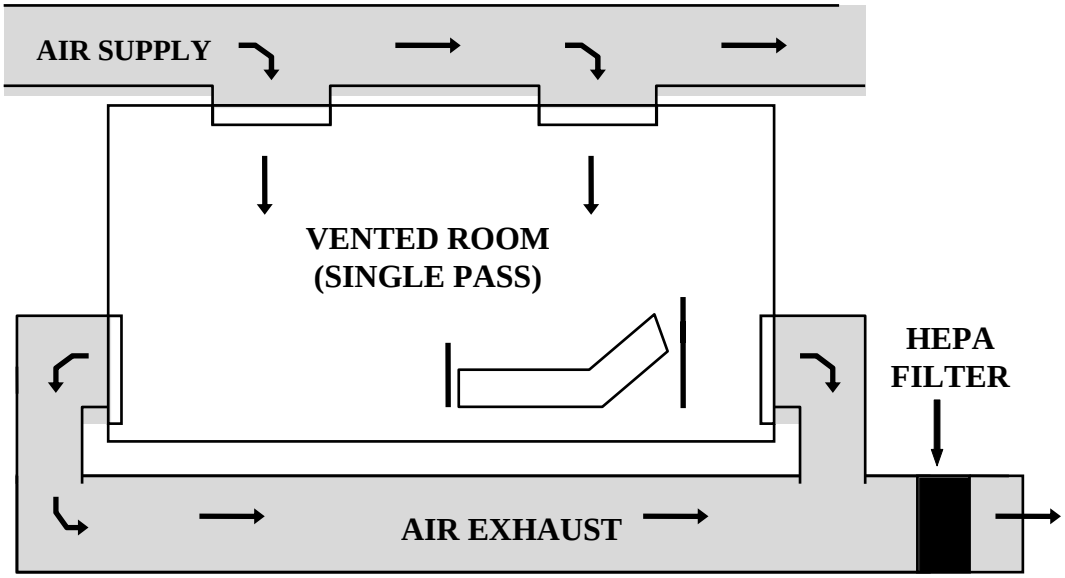
Figure 3A - Exhausting HEPA-filtered air outdoors



2. *Recirculating HEPA-filtered air to other areas of a facility*

Air from TB isolation and treatment rooms occupied by patients who have confirmed or suspected infectious TB should be ideally exhausted outdoors. However, in certain circumstances where recirculation of air into the general ventilation system from isolation rooms is unavoidable such as existing facilities with limiting ducting configurations, HEPA filters may be installed in the extraction ducting leading to the general ventilation system.

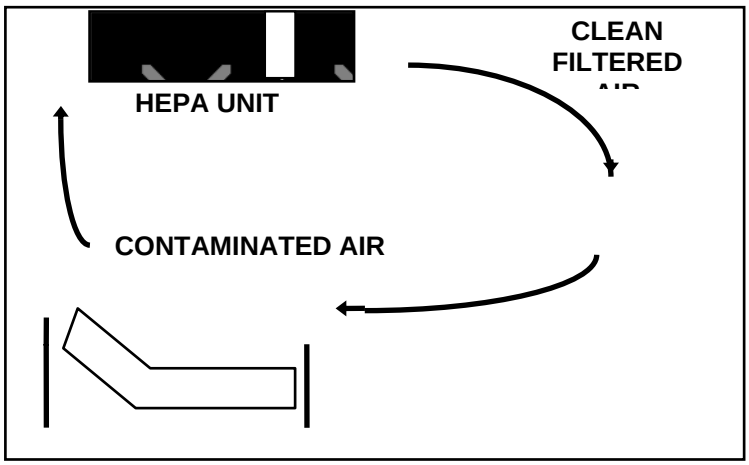
Figure 4A - Recirculating HEPA-Filtered Air To Other Areas of A Facility



3. ***Recirculation of HEPA-filtered air within a room***

The use of individual room-air recirculation may be employed where no general ventilation system is utilised, or where an existing system is not capable of providing adequate airflow. Recirculating air within a room may be conducted by exhausting air from the room, filtering it, and returning the air back to that individual room. Alternatively, air may be filtered by recirculation through free-standing systems or units mounted on the wall or ceiling of the room.

Figure 5A - Recirculation of HEPA-Filtered Air Within a Room



Possible limitations:

- The main limitation of filtration systems is the number of “effective” ACH that can be achieved with acceptable noise and draft.

- The proper installation, maintaining, replacement and monitoring of HEPA filters must be meticulous and are crucial to successful transmission control.

- The effectiveness of room-air cleaning units has not been evaluated adequately, and considerable variation in their effectiveness is inevitable.

Appendix B

UV FACT SHEET: Frequently asked questions on UV-C safety issues

Is UV harmful?

We are exposed daily to UV from sunlight. UV exposure may be harmful or harmless, depending on the type of UV, exposure intensity, exposure duration and the differing response of individuals to UV. There are essentially three types of UV:

1. UV-A - also known as black-light, the major type of UV in sunlight, responsible for skin tanning, generally not harmful, used medically to treat certain skin disorders.

2. UV-B - a small but dangerous component of sunlight. Most solar UV-B is absorbed by the atmospheric ozone layer. Prolonged exposure is responsible for some types of skin cancer, skin aging, and the clouding of the lens of the eye (cataract).

3. UV-C - also known as short-wave UV, not present in sunlight that reaches the surface of the earth, includes germicidal UV used for air disinfection. Over-exposure may cause transient skin redness and eye irritation, but does not cause skin cancer or cataracts.

Why is UV-B harmful while UV-C is not?

UV-C has an extremely shallow penetrating ability. It is essentially absorbed by the outer, dead layer of the skin (stratum corneum) where it does little harm. It does reach the most superficial layer of the eye, the cornea, where over-exposure may cause irritation, but it does not penetrate to the eye lens and cannot cause cataracts. The passage of UV-C is stopped by ordinary eye glasses and clothing.

How do occupants know they are not being over-exposed?

When UVGI is installed it must be checked with a sensitive and properly calibrated UV meter to ensure that reflected UV is less than the irradiance that will exceed the 6.0 mJ/cm^2 8-hour limit, taking into account anticipated actual exposure. Safety is assured if UV measurements at eye level meet ACGIH standards. Plants are far more sensitive to UV than are humans, and may wilt at levels of UV exposure that are considered safe for people.

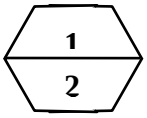
How much UC-C is considered to be safe?

The National Institute for Occupational Safety and Health (NIOSH) is the USA has established safe exposure levels for each UV type. These safe exposure level limits are set below those found to initiate eye irritation, the body part most susceptible to UV. See Chapter 5.

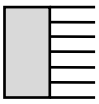
What precautions are required when working around or in close proximity of germicidal UV?

The principal precaution is that workers installing, dusting, inspecting or changing UV tubes, or working in the upper section of a room should turn fixtures off to avoid accidental direct UV exposure while they are in the upper room.

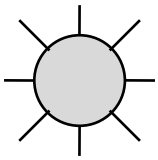
GENERIC LAYOUT SHOWING TYPICAL WALL AND CEILING MOUNTED FIXTURE PLACEMENT



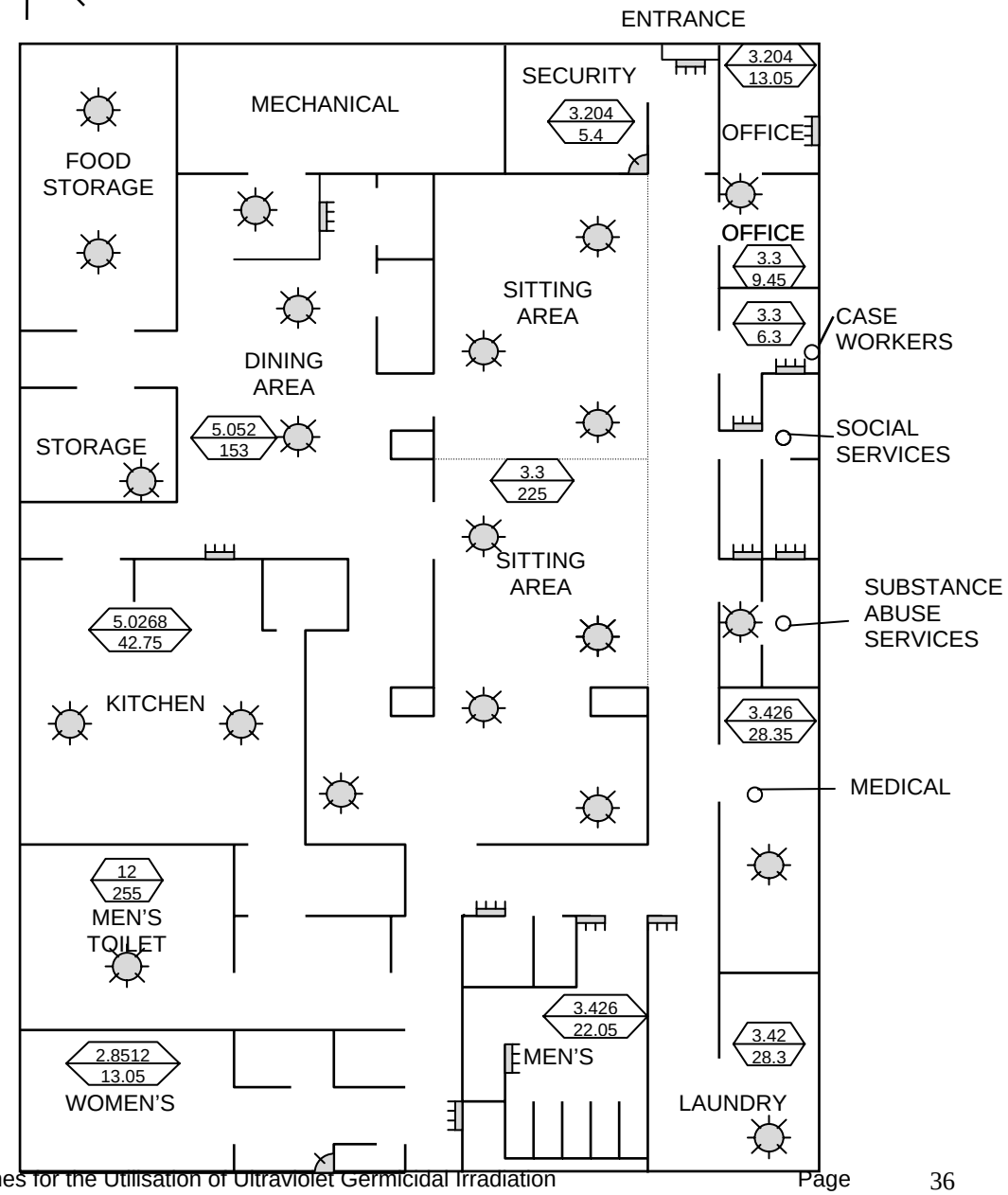
Value 1 denotes ceiling height (m)
Value 2 denotes room area (m^2)



Symbol denotes wall mounted fixture



Symbol denotes (pendant) ceiling mounted fixture



Appendix D

TYPICAL INSTALLATIONS FOR UPPER-ROOM UVGI

The following case studies have been sourced from:
First MW, Nardell EA, Chaisson W, Riley R. Guidelines for the Application of Upper-Room Germicidal Irradiation for Preventing Transmission of Airborne Contagion – Part II: 1998

In order to relate to typical facilities in South Africa, alternatives are quoted in brackets where applicable.

Case 1: A Medical Examination Room And Office

Room Parameters

Room dimensions: 4.2m x 3.1m
Floor area: 13m^2
Ceiling height: 2.7m

Recommended Installation

Fixture: Single high wall-mount
Power rating: 25W
Fixture UV output: 8.5W

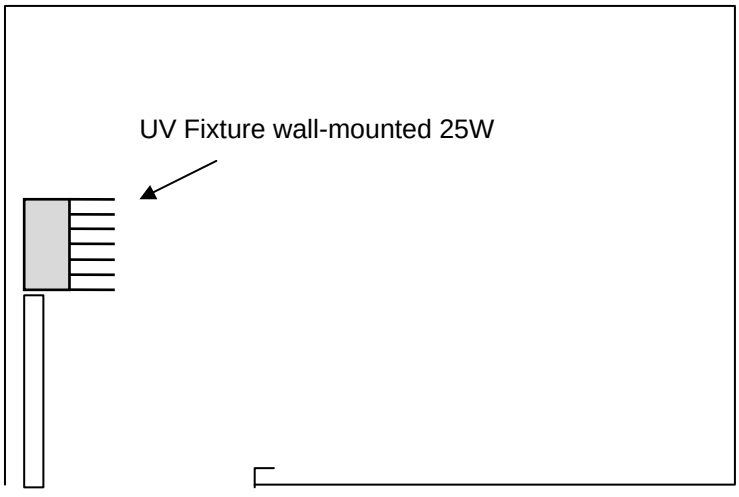


Figure E1 – A Medical Examination Room and Office

Case 2: A Homeless Shelter Dining Hall (Tuberculosis Hospital Communal or Dining Room)

Room Parameters

Room dimensions: 20m x 9.8m
Floor area: 180m^2
Ceiling height: 3.1m

Recommended Installation

Fixture: Ten (10) compact pendant fixtures
Power rating: 36W each – (360W Total)
Fixture UV output: 100W

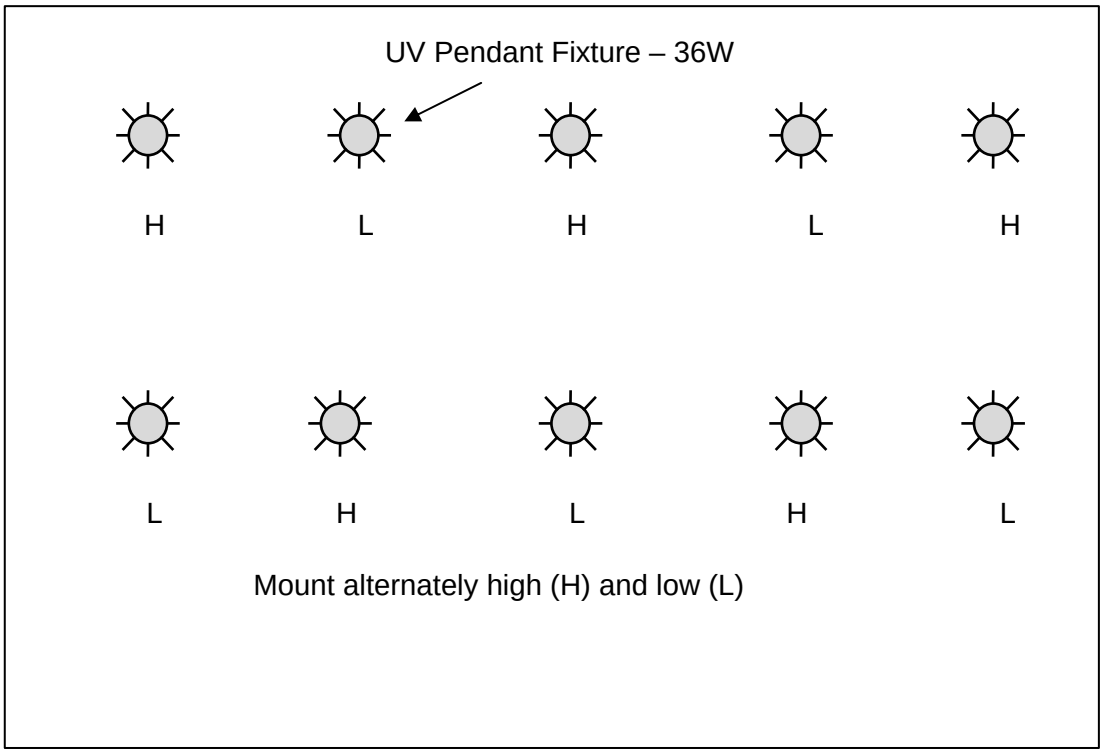


Figure E2 – A Communal Dining Hall

Case 3: A Small Security Station

Room Parameters

Room dimensions: 2.1m x 2.4m
Floor area: 5.04m^2
Ceiling height: 2.1m

Recommended Installation

Fixture: Single corner mount
Power rating: 18W
Fixture UV output: 5W

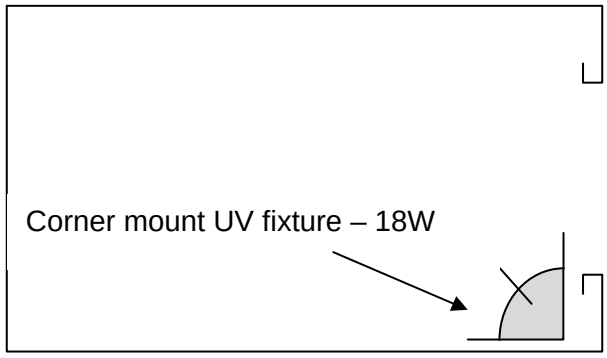


Figure E3 – A Small Security Station

Case 4: An Open Stairwell

Room Parameters

Ceiling height – landing: 3.9m

Recommended Installation

Fixture: Single pendant with fitted baffle
Power rating: 36W
Fixture UV output: 10W

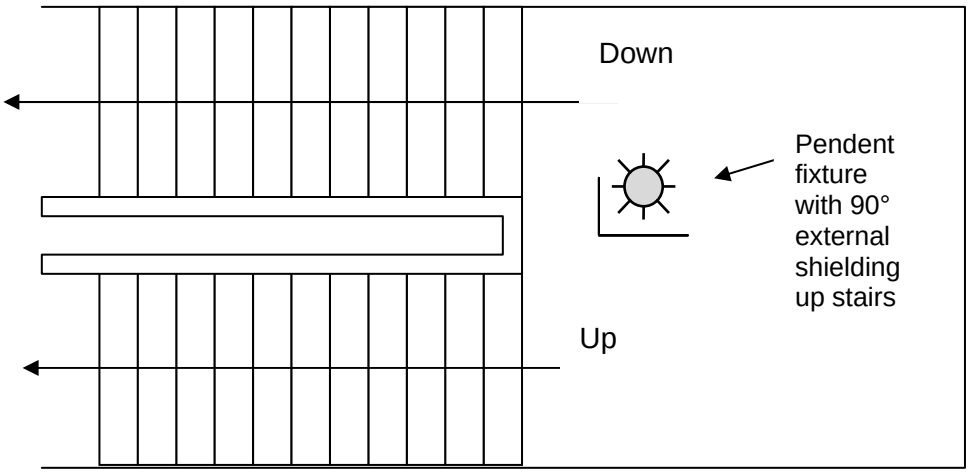


Figure E4 – An Open Stairwell

Case 5: A Hospital Isolation Room

Room Parameters

Floor area: 17.7m^2
Ceiling height: 2.5m

Recommended Installation

Fixture: Single wall mount, two (2) separate units should there be any obstruction
Power rating: 36W
Fixture UV output: 10W

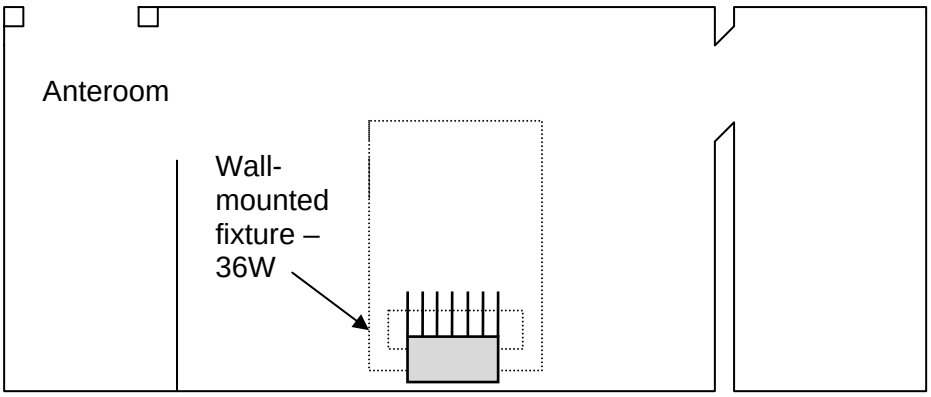


Figure E5 – A Hospital Isolation Room