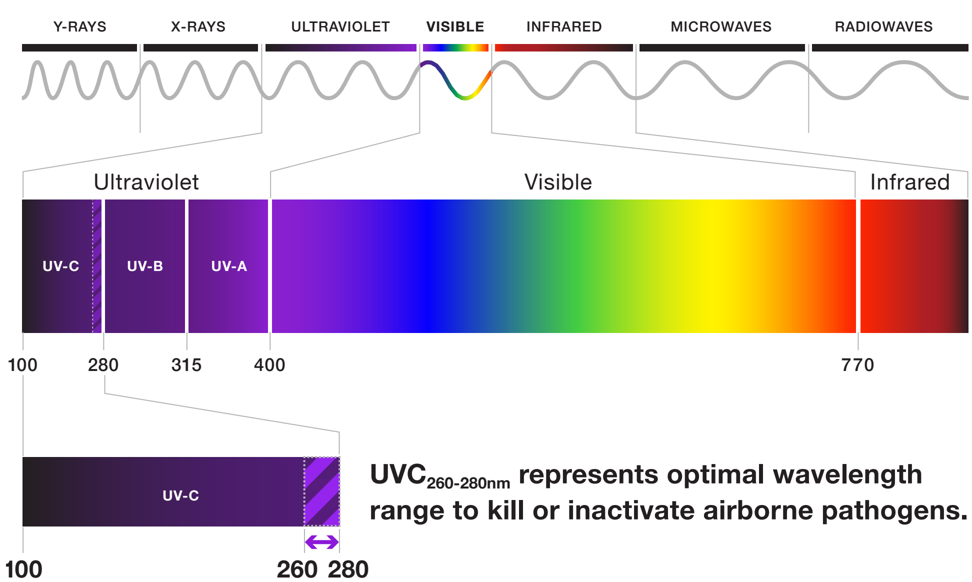
Environmental Controls: UVC

Using UVC to reduce TB transmission

What is UVC (UVGI)? And how do I apply it?

The term “ultraviolet” (UV) designates the region of the electromagnetic spectrum from 100-400 nm, which is not visible to the human eye (see **Figure 1**). The visible light spectrum runs from approximately 400-700 nm. The International Commission on Illumination (CIE) divides the ultraviolet region into three subregions: UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm). There are no photobiologic or photochemical reasons for the exact delineation between these three subregions. Ultraviolet Germicidal Irradiation (UVGI), Germicidal Ultraviolet (GUV), and UVC refer to the use of ultraviolet energy to kill or inactivate microorganisms. In this book, we will use UVC as a general term and use UVC_{254} when referring to the specific wavelength of 254 nm, in the UVC subregion, and fixtures that use this wavelength. UVC can be used to lower the risk of airborne transmission of *M. tuberculosis*, SARS-CoV-2, and other airborne pathogens.

FIGURE 1: **Ultraviolet region for optimal germicidal activity**



Germicidal range: $UVC_{260-280}$ (UVC in the 260-280 nm range) is considered the optimal range of wavelengths to kill or inactivate most bacteria, viruses, and fungi, by damaging deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and/or proteins. UVC in the 200-260 nm range is also germicidal, however not to same extent as $UVC_{260-280}$ (but may have a better safety profile with decreasing wavelength).

The UVC dose required to inactivate TB is generally highly effective against most viruses and other bacterial pathogens. Fungal spores are more UV-resistant but are not spread from person to person.

Sources for producing UVC

Historically, low-pressure mercury (Hg) lamps have been used in UVC fixtures as an efficient bactericidal source. These lamps primarily emit UVC at 254 nm (UVC_{254}) that can effectively kill or inactivate microbes of interest. Other UVC sources include Krypton-Chloride (primarily 222 nm), pulsed xenon (220-750 nm), and wavelength-specific light-emitting diodes (LEDs; primarily 260-280 nm). Some data suggest that LEDs that generate 405 nm blue light, which is outside the UVC region, may also be of use to inactivate some, but not all, microbes of interest. In general, the UVC output of UV-LEDs is relatively inefficient compared to other technologies.

In this chapter, we will focus on air disinfection with UVC_{254} sources.

A note about sunlight:

Older textbooks often discuss the ability of sunlight to effectively kill Mtb organisms, but this is misleading. Light generated by the sun does contain desired germicidal UVC wavelengths but most of this germicidal UVC is filtered out by the earth's atmosphere. At ground level, the amount of UVC in sunlight is not sufficient to effectively kill TB within a reasonable amount of time. The primary advantage of the use of outdoor space to reduce TB transmission is not because sunlight is disinfecting the air, but that dilution of organisms is significantly increased by the expansive natural ventilation.

Applications of UVC_{254} to decrease airborne transmission

UVC_{254} may be used to disinfect air, water, and surfaces; however, limitations exist and application should be tailored to the circumstances, site, and target pathogens. This chapter will cover details of use of UVC_{254} to disinfect air particularly for TB, but the same basic principles apply to other airborne pathogens.

The major applications of UVC_{254} to combat TB and other airborne pathogens include:

- Irradiation of air in the **upper, unoccupied portion of the room (upper-room UVC_{254})**
- Irradiation of air in an **HVAC** (heating, ventilation, and air conditioning) **system (in-duct UVC_{254})**
- Irradiation of air in a **room air cleaner (RAC)**
- Direct irradiation of a **whole room or space**

Most common applications of UVC_{254} as part of a TB environmental control strategy:

Upper-room UVC_{254} (more details pages 9-18)

- Upper-room UVC_{254} refers to the use of UVC_{254} fixtures with radiation directed in the upper portions of a room to disinfect the air while the room is occupied. UVC_{254} fixtures are mounted high on walls or suspended from the ceiling and positioned to avoid unsafe exposure to occupants in the room. The ventilation system and/or auxiliary fans mix irradiated air with the air in the lower part of the room (breathing zone), resulting in reduction of viable airborne microbes.
- Upper-room UVC_{254} is a useful environmental control for congregate, healthcare, public, and other settings with inadequate ventilation airflow rate, where susceptible people may have prolonged exposure to an unidentified infectious TB patient. Examples are homeless shelters, emergency department waiting rooms, houses of worship, and prison day rooms.

In-duct UVC_{254} (more details pages 18-20)

- In-duct UVC_{254} is the installation of UVC_{254} lamps inside of a return or exhaust air duct to kill any *M. tuberculosis* that may be in the airstream. If air is recirculated, UVC_{254} may be installed before or after the cooling coil and is a useful supplemental environmental control in recirculating air systems. In-duct UVC_{254} is not recommended as an alternative for cleaning of exhaust air from airborne infection isolation rooms (AIIR). Better options would be direct exhaust to the outdoors or HEPA (high-efficiency particulate air) filtration for AIIR exhaust air.

Effectiveness of UVC_{254}

UVC_{254} effectiveness will increase when the following are increased:

- **Irradiance:** a measure of radiant flux per unit area that is typically expressed in microwatts per squared centimeters ($\mu W/cm^2$). In simple terms, this can be understood as the brightness or intensity of the UVC_{254} lamp.
- **Length of pathogen exposure time:** duration the infectious particles containing the pathogen remain in the area of high irradiance. Exposure time will depend on how quickly air containing infectious particles moves past the lamp or through the disinfection (irradiated) zone.
- **Dose of UVC_{254}:** product of irradiance ($\mu W/cm^2$) x length of exposure (seconds) = microjoules per square centimeters ($\mu J/cm^2$)). Effectiveness and safety criteria for UVC_{254} are based on dose.

- **Output of the UVC_{254} fixture:** depends on the UVC_{254} wattage (UVC_{254} wattage may be a fraction of the stated lamp wattage), lamp, and fixture condition. Lamp intensity decreases with age and dust accumulation. Design of the UVC_{254} fixture may also reduce the functional output of UVC_{254}.
- **Proximity of infectious particles to the UVC_{254} lamp or fixture:** depends on placement and number of UVC_{254} lamps used. Adequate room air-mixing is needed to move infectious particles within the disinfection zone to effectively inactivate pathogens when using upper-room UVC_{254}.

UVC_{254} effectiveness will decrease with the following:

- **High humidity:** UVC_{254} dosing requirements increase when the humidity of the air is greater than 70%. In general, the UVC dose will need to be increased by up to two-thirds to compensate for constant humidity in this range.
- **Lower ambient temperatures:** UVC_{254} dosing requirements increase when the ambient temperatures are below 60ºF (15ºC).

The utility of UVC_{254} to disinfect room air and reduce the transmission of disease has been known since the late 1930s when first applied within schools to combat an epidemic of measles among children. Since then, much has been learned about the efficacy and safety of UVC_{254} to prevent TB transmission. A systematic review of current evidence, conducted by the WHO (World Health Organization), informed the 2019 guidelines that recommend use of upper-room UVC_{254} within healthcare settings to reduce TB transmission. Further details of the evidence base and recommendations can be found in the *WHO Guidelines on Tuberculosis Infection Prevention and Control: 2019 update* https://apps.who.int/iris/bitstream/handle/10665/311259/9789241550512-eng.pdf.

UVC_{254} Exposure, Safety and Maintenance Considerations

Ensuring safe radiation levels

Safety is a major consideration when using UVC_{254} as part of an infection control program. Exposure to UVC_{254} radiation can occur with direct or indirect exposure (for example, while cleaning a fixture with the lamp turned on, or if unexpected UVC_{254} is reflected off a UV-reflective surface on the ceiling and down to occupied areas). Overexposure to UVC_{254} can cause temporary, yet reversible, harm to the eyes (photokeratitis) and skin (erythema). Proper design, installation, and safety and maintenance protocols are essential to minimize the chances of overexposure.

Safety features built into the design of UVC_{254} equipment may include:

- UVC_{254} systems for upper-room, in-duct, whole-room, and RACs equipped with a "power cut-off switch" that automatically turns the UVC_{254} system off when a baffle, door, or hatch is opened that gives direct exposure to the UVC_{254} lamp.
- RACs designed with UVC_{254} lamps fully enclosed (minimal chance of overexposure).

- Upper-room UVC_{254} systems with motion detectors designed to automatically turn off the UVC_{254} fixtures when something moves above a certain height above the floor.

To ensure both efficacy and safety (particularly with upper-room UVC_{254}), **measure and record UVC_{254} irradiance after installation, after maintenance, annually, or in case of any reported complaints (UVC_{254}-related).**

- An industrial hygienist, health physicist, qualified engineer, or hired professional trained in measuring UV should be able to complete this task. Training and competency in taking UVC_{254} measurements should be established. A listing of expected competencies based on professional role is available in *ANSI/IES RP-44-2021: Recommended Practice: Ultraviolet Germicidal Irradiation (UVGI) and will also be available in ASHRAE GPC-37: Guidelines for the Application of Upper-air (Upper Room) Ultraviolet Germicidal (UVC) Devices to Control the Transmission of Airborne Pathogens* in 2023.

UVC_{254} radiometer

Irradiance[1] levels are measured with a device called a radiometer.

Take measurements to confirm:

1. **Performance:** Check that UVC_{254} source (lamp) is working properly. The radiometer should be calibrated specifically to measure the UVC radiation wavelength of interest (e.g., UVC_{254}) based on the lamp manufacturers' specifications.
2. **Safety:** Check that levels of effective irradiance in the occupied areas are safe for people in the room (when using upper-room UVC_{254}).

A broad range of possible irradiation levels (0.1-2,000 $\mu W/cm^2$) is needed to measure both the low end of the range to gauge safety levels in the occupied zone of a room and the upper end of the range to check lamp fixture performance. Proper radiometer and detector selection is critical to verify the expected irradiance levels. Depending on the type of radiometer, two separate devices may be needed to accurately obtain both sets of measurements.

1 The actual irradiance at each wavelength is referred to as the spectral irradiance. The total irradiance (for photobiologic activity) at each wavelength can vary and is different than the measured effective irradiance (except at 270 nm where they are the same). Most, but not all, radiometers are programmed to display results in total irradiance rather than effective irradiance. The relationship between effective irradiance and spectral irradiance for each wavelength requires a conversion factor. For UVC_{254}, multiply total irradiance by 2 to get the effective irradiance.

Choosing a UVC Radiometer

Radiometer manufacturers' websites and representatives can assist in procuring the proper meter.

Check the manufacturer specifications to determine if the radiometer has the following characteristics based on the UVC source being used:

Wavelength range: Choose a radiometer that measures wavelengths of 220-280 nm with a peak response at 254 nm for standard UVC_{254} low-pressure mercury lamps.

- If measuring sources other than UVC_{254} low-pressure Hg lamps, look for a radiometer calibrated to the peak output of the source you are using.
- If using more than one type of UVC fixture with different wavelengths, consider purchasing a radiometer that can be programmed to measure multiple wavelengths (rather than individual wavelength-specific meters).

Irradiance measurement range: Choose a radiometer that measures effective* irradiance within a recommended range of at least 0.1 - 2,000 µW/cm^2 for standard UVC_{254} low-pressure mercury lamps.

- The upper end of the range may need to be increased if high-output, unbaffled UVC fixtures are used.
- For wavelengths other than 254 nm, the range may need to be shifted up or down based on peak output of the lamp (check manufacturer's specifications or contact manufacturer directly).

Accuracy: May be referred to as "measurement uncertainty" under specifications. The radiometer should have an accuracy (measurement uncertainty) for both of the following criteria:

- Accuracy for measurements of UV irradiance >1 – 2000 µW/cm^2 should be: +/- 10% of the reading (Note: not +/- 10% of the upper end of the radiometer range) to measure irradiance and confirm performance of the source/lamp
- Accuracy for measurements of UV irradiance 0.05 to 1 µW/cm^2 should be: +/- 0.05 µW/cm^2 to measure safety levels for occupants

Some radiometers meet both required accuracy criteria as listed above. There may be radiometers that meet only one criterion, so a second radiometer that meets the other criterion will be needed. Reputable companies will disclose this information; if it is not listed online, speak with a manufacturer's representative.

Calibration instructions: The radiometer should be calibrated according to the manufacturer's recommendations. If none is provided, then an annual calibration is recommended.

Field of view (FOV) cone: A cone is a separate accessory for the radiometer that should be used for all safety measurements. The cone should be +/- 40 degrees (80 degrees total) and must be compatible with the radiometer model. If not listed in the model specifications, contact a manufacturer's representative to locate a compatible cone.

Note: The quality of radiometers or other tools (colorimetric cards or films) sold to measure UV output vary greatly and many do not measure the appropriate range of irradiance or meet the accuracy requirements for proper assessment of UVC safety and performance.
On average, the cost of a high-quality radiometer will be in the range of $2000-3000.

* Safety and performance standards presume dose measurements are calculated using effective irradiance. Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance).

What level of UVC_{254} is safe?

Safety recommendations are based on dose of exposure (mJ/cm^2) for an individual, i.e., the intensity of the radiation (irradiance, $\mu W/cm^2$) from the source that reaches the individual and the duration of exposure time (seconds). Two sets of recommendations exist and vary somewhat from each other:

Recommended Exposure Limit (REL): The CDC/National Institute for Occupational Safety and Health (CDC/NIOSH) published a recommended exposure limit for ultraviolet energy at the UVC_{254} wavelength in 1973.

- The REL for UVC_{254} is 6 mJ/cm^2 for an eight-hour exposure for both eye and skin exposure.

Threshold Limit Value (TLV®): In 2022, the American Conference of Governmental Industrial Hygienists (ACGIH) updated the TLV for ultraviolet radiation and designated separate values for eye exposure and for skin exposure by wavelength.

- The TLV for UVC_{254} for eye exposure remained unchanged at 6 mJ/cm^2 while the TLV for UVC_{254} for skin exposure is now 10 mJ/cm^2 (most UVC consultants currently recommend following the updated TLV).

A guide to calculating the UVC_{254} exposure dose to ensure proper safety levels can be found in **Appendix B**.

UVC_{254} safety education and signage

Staff and clients may have concerns regarding health hazards from UVC_{254}. To address these concerns, provide simple education on the purpose, benefits, and risks associated with upper-room UVC_{254}.

- Facility staff should receive appropriate state and federal OSHA-required education and training for safe UVC_{254} use, including hazards of UVC_{254} and use of Personal Protective Equipment (PPE).
- Consider posting a UVC_{254} information sheet on the wall of the room for occupants (staff and clients).
- Develop written site-specific protocols for testing, cleaning, maintenance, repair, and replacement of UVC_{254} fixtures and provide specialized training to appropriate staff.
- On/off switches for lamps should be accessible to appropriate staff members but not located where clients may turn off the fixtures. Consider lockable switches or placement of switches in staff-only restricted areas.

Take precautions to alert and protect the people using the room(s) in which the UVC_{254} is used.

Post warning signs, in all appropriate languages, on the UVC_{254} fixtures and other locations as appropriate (for example, overhead storage areas). The signs should carry the following (or a similar) message depending on type of UVC_{254} system used:

EXAMPLE. **Educational sign at occupant level**

FOR YOUR SAFETY

THIS BUILDING IS EQUIPPED WITH UPPER-ROOM UVC_{254} AIR DISINFECTION SYSTEMS

EXAMPLE. **Safety warning sign near areas needing precaution**

CAUTION

Ultraviolet Energy

Turn off UVC_{254} lamps before entering the upper part of the room

(space above the UVC_{254} fixtures).

Routine upkeep

Designate a staff member to be the in-house monitor for UVC fixtures. This person should be trained in the basic principles of UVC operation and safety and should be responsible for cleaning, maintaining, and replacing the lamps. This may include regular maintenance by the engineering department.

- Verify UVC output and clean UVC lamps and fixtures every 3 months (or more frequently depending on local conditions). Ensure that lamps are not burned out or broken. If working, the tubes will emit a violet blue glow (Note: this is not an indicator of the lamp's effectiveness which can only be confirmed by measuring output with a calibrated radiometer).
- Turn off the lamps before they are cleaned; clean with a lint-free cloth dampened with >70% alcohol.
- Check that the radiation level at each fixture meets the lamp manufacturer's recommendation. Most manufacturers will give a minimum irradiance[2] ($\mu W/cm^2$) value at 3 ft (0.91 m) from the UVC fixture, along the centerline. Tubes should be replaced once a year or as recommended by the manufacturer (or earlier if the irradiance levels are below the manufacturer's recommended minimum levels). Recycle used lamps as recommended by the lamp manufacturer and local or national regulations (see https://www.epa.gov/mercury/recycling-and-disposal-cfls-and-other-bulbs-contain-mercury). A written policy on proper clean-up of a broken lamp should be included in the maintenance instructions (see https://www.epa.gov/mercury/cleaning-broken-cfl).
- Eyewear does not need to be UV specific; any clear glass or plastic eye shields will block UVC.

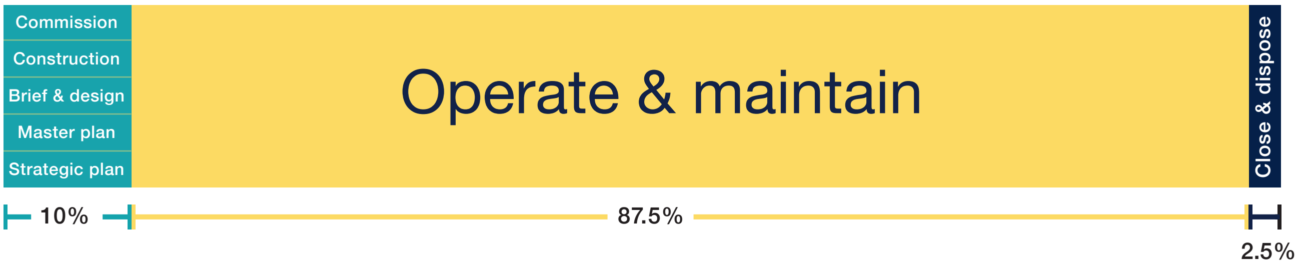
Keep a record of all maintenance and monitoring, including radiometer readings, dates, and remedial action taken if needed. This will help determine the average life of the lamps. Lamps should be purchased close to your planned replacement time because prolonged storage may result in a loss of radiation intensity.

2 Most manufacturers give irradiance based on effective irradiance. Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance).

Cost considerations

Over the lifetime of an UVC_{254} system, the majority of the costs are typically for long-term operation and maintenance (**Figure 2**). As a general rule-of-thumb, the average annual cost of operating and maintaining upper-room UVC can be 10-20% percent of the initial acquisition cost. This represents a new annual budget line for operation and maintenance. See **Appendix D** for a more detailed breakdown of cost considerations.

FIGURE 2: **Estimated Life Cycle Cost for UVC_{254} system:**



Applications of UVC

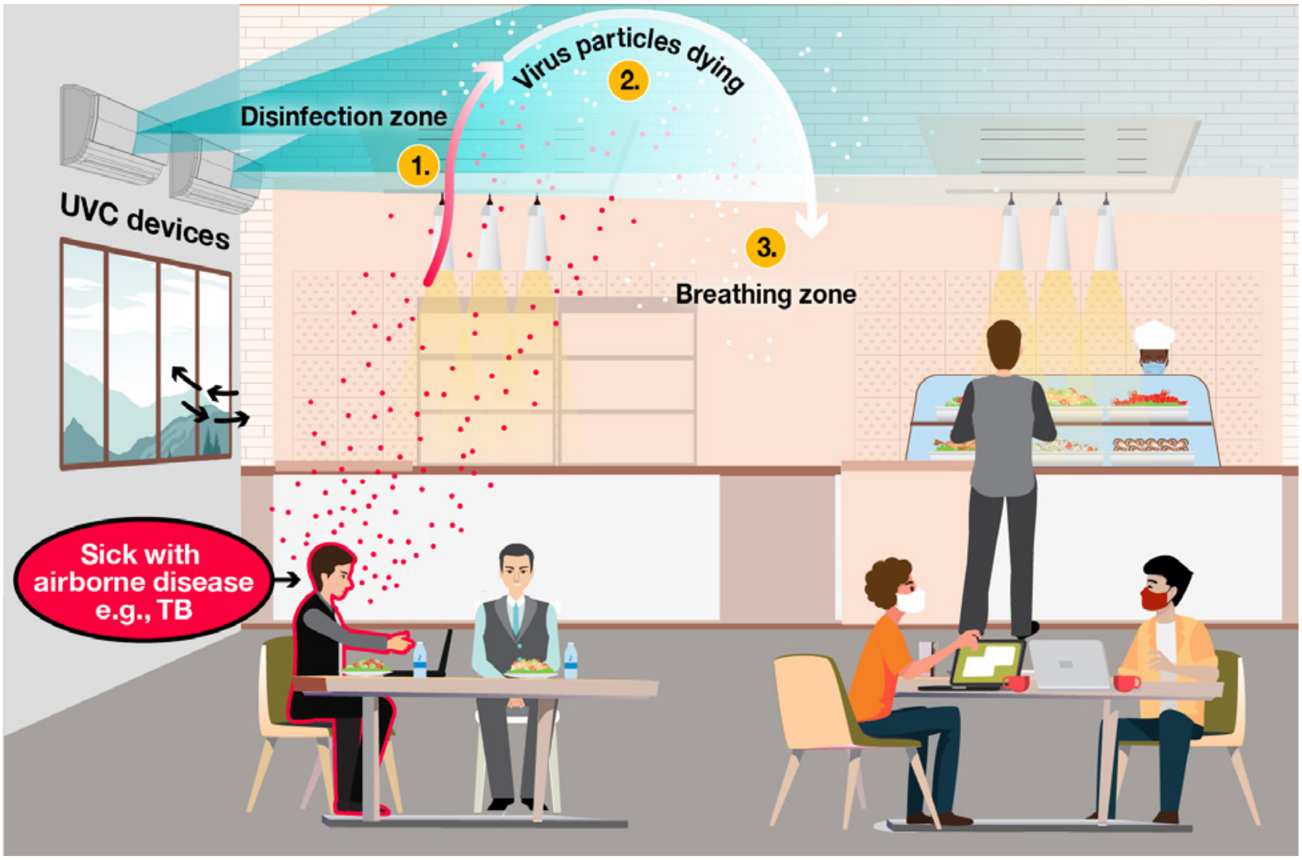
Upper-room UVC

Upper-room UVC refers to the creation of a UVC disinfection zone located above the people occupying a room to reduce the risk of disease transmission by infectious pathogens in the air (**Figure 3**). Airborne pathogens are killed or inactivated as they pass through the disinfection zone. Upper-room UVC may be considered as a supplement to ventilation strategies in high-risk areas, particularly those where unidentified infectious cases may be present. These settings may include emergency departments, waiting rooms, AIIRs, isolation areas, congregate settings, or homeless shelters.

HVAC systems in congregate areas can reduce, but not necessarily eliminate airborne pathogens/exposures. Adding more ventilation could help reduce the amount of time required to remove these particles; however, it may also be expensive to install and operate systems to further increase ventilation. If poorly designed or installed, ventilation systems may cause objectionable noise and drafts. In this case, consider using upper-room UVC to supplement ventilation. It can be added on a room-by-room basis without affecting the existing building ventilation system.

- The degree of disinfection achievable using upper-room UVC is based on UVC dose, room geometry, room air mixing, and other factors.
- Appropriate installation of upper-room UVC has been shown in some studies to achieve up to an equivalent of 24 air changes per hour (eACH).

FIGURE 3. **How upper-room UVC_{254} works**



Adapted from https:/www.cdc.gov/coronavirus/2019-ncov/community/ventilation/uvgi.html#

Airborne pathogens, e.g., TB, may be released by individuals occupying a room.

1. Airflow patterns move infectious pathogens up to a disinfection zone produced by the UVC lamps. Airflow may be produced by HVAC systems, fans, and/or open windows.

2. The airborne infectious pathogens are inactivated once they receive an appropriate amount of UVC dose. The particles remain in the air, but they are no longer infectious.

3. The best airflow strategy maintains continuous air movement upwards to be disinfected and then back down to the occupied breathing zone.

- For upper-room UVC_{254} systems to optimally disinfect the air, the air from the breathing zone must pass through the disinfection zone (upper-room) and return back to the breathing zone[3].
- Pathogens must either receive enough dose to be inactivated while in the disinfection zone during one pass or they must pass through the disinfection zone multiple times, until they receive sufficient cumulative UVC dose to be inactivated.
- Adequate "air mixing" to move potentially infected air upwards to be disinfected and move cleaner air downward into the breathing zone is a key component in an upper-room UVC design plan. Existing ventilation systems may need to be supplemented with ceiling or wall fans, or different supply-air diffusers to accomplish adequate airflow patterns for this purpose. In the latter case, consider keeping the ventilation system fan operating at all times (i.e., constant air volume setting) during building occupancy to ensure adequate air mixing.
- Ideally, UVC in the upper room should be uniformly distributed for best efficiency and occupant safety.

Determining if upper-room UVC_{254} is suitable for the setting

A room must meet the following criteria for upper-room UVC to be used:

- Ceiling height at least 8 ft (2.4 m)
    - Note: For many commercially available UVC fixtures, a minimum ceiling height of 8.5-9 ft (2.6-2.7 m) is recommended by many manufacturers.
- The UVC_{254} fixtures must be installed at a height of at least 7 ft (2.1 m) above the floor. Many manufacturer's instructions recommend installation at a height of at least 7.5 ft (2.3 m). The goal is that people cannot look directly into the lamps or bump into the fixtures.
- In congregate settings such as homeless shelters and dormitories, bunk beds should not be used unless the rooms have very high ceilings and the appropriate UVC_{254} fixtures are installed at a height above the bunk bed to ensure someone sitting on the top bunk is not overexposed.
    - If the ceiling height (and thus lamp placement) is too low, a client who is sitting on the top bunk may be inadvertently overexposed to radiation in the upper room by direct and reflected UVC_{254}.
- In rooms with high ceilings ($\geq$3 m or $\geq$10 ft) and minimal structures in the upper room, UVC_{254} fixtures may be installed higher than 7 ft (2.1 m) and may be an open-style design (see section on **Choosing fixtures for upper-room UVC**) provided that the TLV for UVC_{254} exposure is met.
- Room air mixing fans or appropriate ventilation diffusers are recommended to help enhance airflow patterns from the occupied space to upper room and from the upper room and back to the occupied space. The room air fans or HVAC system fans should be operated continuously while the building is occupied.

3 ASHRAE defines the breathing zone as "the region within an occupied space between planes at 3 and 72 in (0.08 and 1.8 m) above the floor and more than 2 ft (0.6 m) from the walls or fixed air-conditioning equipment."

Note: When assessing suitability of a room, consider architectural details as well as utilities and other engineering features in the upper room that can potentially alter efficiency of UVC coverage. Ceilings and walls may need to be repainted to reduce reflection and improve UVC_{254} safety. UVC energy can damage plants, degrade plastic, and fade wood or wallpapers, particularly in upper areas of a room (e.g., plants on tall shelving).

In rooms that already meet standards for air changes per hour (ACH) or clean air delivery rate (CADR) recommendations, upper-room UVC can still provide supplemental reduction in airborne disease transmission and should be considered on a site-specific basis.

Preparing for an upper-room UVC_{254} installation

Specialized expertise and equipment are needed to establish an effective upper-room UVC_{254} system. Only a qualified UVC contractor, working closely with a UVC fixture manufacturer's representative, should design, install, and test an upper-room UVC_{254} system.

- Ask for the manufacturer's proof of Environmental Protection Agency (EPA) registration https://www.epa.gov/sites/default/files/2020-10/documents/uvlight-complianceadvisory.pdf and a listing of completed UVC installation projects.
- Ask potential consultants or contractors about their experiences with previous UVC installations and confirm they are familiar with CDC/NIOSH and ASHRAE upper-room UVC_{254} guidelines.
- Ask to arrange a visit to a successful installation within a similar building or space. This will provide an opportunity to see an existing installation and to talk with another person about their experience with upper-room UVC_{254}.
- Ask the contractor about the possibility of a service contract for UVC_{254} monitoring, maintenance, and lamp replacement after the installation (some facility managers have negotiated up to 5 years of service into the initial purchase agreement). Maintenance generally includes lamp, reflector, and baffle cleaning. Ensure components are replaced with like components. UVC_{254} lamps should emit UVC_{254} and not produce ozone.
- In the installation contract, include requirement that irradiation levels be measured after installation by an independent contractor who can verify that the UVC system meets desired safety and performance specifications (final acceptance testing) before the installation is accepted as complete.
- Require a written report of the final acceptance testing.

Installation design and considerations

Design solutions are generally customized and unique for each setting.

Dose of UVC_{254} needed: The target UVC_{254} dose required to effectively disinfect for TB can be calculated using the size in **volume** (height x width x length) or **area** (width x length; assumes a maximum functional ceiling height of 10 ft [3 m] or less) of a room.

- The minimum dose criteria for upper-room UVC_{254} will also inactivate most airborne bacterial and viral pathogens of interest (e.g., SARS-CoV-2, influenza, and others [notable exceptions are fungi and some adenoviruses]).
- See **Appendix A dosing worksheet** for how to calculate a required UVC_{254} dose for a room/space.

Room/space Dosing Criteria for Upper-room UVC_{254}

- Volumetric Dosing Criterion is 0.34 mW/ft^3 (12 mW/m^3)
- Area Dosing Criterion is 0.0033 mW/ft^2 (0.035 mW/m^2);
  assumes a maximum functional ceiling height of 10 ft (3 m) or less

- Note: While the UVC_{254} dose criteria are used to gauge effectiveness of the UVC_{254} system to inactivate TB, separate exposure dose criteria are used to ensure safety for room occupants. See **What level of UVC_{254} is safe?**, page 7.

Placement and number of fixtures: Locate UVC_{254} fixtures so that radiation in the upper room is relatively uniform, continuous, and complete.

- The number of fixtures needed to reach the target effective dose depends on how big the room is based on room volume (ft^3 or m^3), area (ft^2 or m^2), room shape, and the UVC_{254} output of the fixtures.
- See the section on **Choosing fixtures for Upper-room UVC_{254}** and **Appendix C** for a worksheet and examples on how to calculate the number and output of fixtures needed based on room dimensions.
- **Airflow pattern requirements with UVC_{254}:** Adequate room airflow patterns (room-air mixing) from the breathing zone to the disinfection zone and back should be assured through the addition of mixing fans (ceiling- or wall-mounted) or proper selection of ventilation diffusers. The ventilation fans should be operated continuously while the space(s) are occupied. Ideally, the tests should be performed in various scenarios: high density of occupants (might enhance vertical air movement due to body heat generated), no occupants (no added air currents due to occupants), and HVAC on vs. off (assessing with or without added airflow from HVAC).
- The simplest way to check airflow patterns is with ventilation "smoke tubes" to visualize the air movement. The goal is to see the smoke moving up to the

disinfection zone and back to the breathing zone in several locations. The critical criterion is the direction of the smoke movement and not the speed of smoke movement.

- In a typical HVAC system, air may enter and exit near the ceiling. For some systems, air may enter near the floor and exit near the ceiling or vice versa (referred to as displacement ventilation). If air from the room exits near the ceiling and is recirculated to other parts of the building, upper-room UVC_{254} will help to disinfect the return air before it is recirculated. The pattern of airflow created by an HVAC system and the use of recirculated air (vs. direct exhausting of air to the outside) will influence UVC design planning.
- Room airflow patterns are also influenced by temperature gradients (i.e., hot air rises). The use of heating or cooling systems, or simply the presence of many warm bodies together in a room, can influence air movement.
- If there is insufficient air movement when the mixing fans or HVAC systems are off, program the HVAC fans to operate continuously while the building is occupied.
- See the section on **Ventilation** for more details.

Where do you measure irradiance levels in a room with UVC_{254} to ensure safety for occupants?

Since each room/space is different, one must evaluate where occupants will be in relation to potential upper-room UVC_{254} exposure. Are they standing 100% of the time? Sitting? Constantly moving within a space?

- Once fixtures have been placed:
  - Until readings of irradiance levels in the occupied zone are verified below the NIOSH REL or ACGIH TLV criteria for UVC_{254}, the installation is not complete, and the lamps should not be used.
  - Take irradiance readings with a calibrated radiometer at 3 ft (0.91 m) from each lamp or at a "witness point" on the wall, opposite the fixture, in the upper room, to ensure that the UVC_{254} radiation intensity meets the manufacturer's specifications.
- In general, a radiometer, calibrated to the wavelength of interest, is used to take irradiance measurements at **standing height 71 in (1.8 m), at sitting height 51 in (1.3 m)**[4] and at any other height above the floor deemed appropriate for the location and how the space is used. Examples of location-specific measurements to consider in addition to standing and sitting heights include:
  - Sleeping and sitting levels of beds in shelter dormitories, particularly upper bunkbeds
  - Floor levels in a children's play area of a waiting room
- More specific "eye height" measurements may be used to assess potential eye exposure of occupants in the room based on standardized guidelines for specific workplaces (anthropometry guides).

4 Chengalur (2004), Kodak's *Ergonomic Design for People at Work,* and ASHRAE GPC-37 Proposed Guideline (*Guidelines for the Application of Upper-Air (Upper Room) Ultraviolet Germicidal (UV-C) Devices to Control the Transmission of Airborne Pathogens*, 2022 draft) provides additional information on eye height measurement.

- If there are more than one UVC_{254} fixtures in a room, additional measurements should test the space for potential "hot spots" of irradiance. Hot spots can form if there are overlapping areas of irradiance from two separate fixtures or due to reflection of UV rays off reflective surfaces such as metal equipment or reflective paint.
- Some ceiling paints can reflect too much radiation down to the occupied room below, while others may be absorptive of UVC. If meter readings indicate excessive radiation in the occupied area, the ceiling may need non-reflective paint. This should be included in the budget for the planned installation.
  - Paint containing titanium dioxide is recommended for reducing reflection from surfaces. It is the paint ingredients, not the color (white vs. dark colors), that impact UV reflection.
- If irradiation levels are too high in any location, turn off the lamp or lamps causing the high irradiation levels and repeat measurements. To correct the problem, it may be necessary to adjust, relocate, or replace the fixtures and/or add non-reflective paint to the ceiling and walls.

Irradiance measurements are only the first step in calculating the safety risk for room occupants. Ideally, dose estimates would be made using the irradiance levels and the duration of exposure based on occupant activities (time sitting, standing, looking toward or away from lamp sources, etc.). These estimates are important because a worker could be exposed to a very high irradiance level for a short time and then to low irradiance levels for the remainder of an eight-hour work shift and the cumulative dose will still be below the UVC_{254} REL and TLV safety limitations.

- **Time-motion assessment:** This formal analysis tracks the actual movement and activities of those exposed to UVC_{254} within a room and can give a more comprehensive picture of UVC_{254} exposure risks. There are different methods for completing a time-motion assessment. One acceptable method is to have the person who spends the most time in the room keep a diary/log of their activities during a usual work shift and have irradiance measurements taken that correspond to their activities to allow an exposure dose calculation. A time-motion assessment is desirable for staff, residents, and clients in high-risk situations where prolonged periods of exposure are anticipated.
  - **Appendix B**, example #2, tracks a nurse's 8-hour shift with a description of activities and total dose calculation for exposure. This example also shows how a high irradiance reading for brief periods may be acceptable as long as the average exposure for the total 8-hour period stays within the safety limits.
- An alternative method is to have the person in the room wear a UVC_{254} dosimeter and keep a diary/log of their activities. A description of this methodology may be found in the paper by First (2005).

Time-weighted average (TWA) exposure: In a simplified approach, the UVC_{254} eye TLV dose limit of 6 mJ/cm^2 for an 8-hour period can be generalized as being equivalent to **an average irradiance level of 0.21 $\mu W/cm^2$ over the entire 8-hour period.** If the continuous UVC_{254} exposure was over a 4-hour period, with no other UVC_{254} exposure, the average irradiance level would be 0.42 $\mu W/cm^2$. This is called the time-weighted average (TWA) irradiance.

- Using TWA values can be a simple and practical way to assess safety in an area with UVC, particularly if exposure time for occupants is generally low.
- **Important:** the TWA does not represent the "maximum limit" of irradiance at any location in a space.

As an example of applying TWA measurements, consider a waiting room where visitors are primarily occupying the room for periods less than 8 hours.

- If visitors using the room are primarily seated, take the measurements at eye height when seated. If the irradiance measurement at a seated eye level of 1.3 m (51 in) is 0.21 μW/cm^2 or less, an occupant could be seated in the room at that location for 8 hours and not exceed the TLV for UVC_{254}.
- If measurements are taken throughout the room (standing, sitting, etc.) and all results are 0.21 μW/cm^2 or lower, the TLV_{254} would not be exceeded for an occupant moving throughout the room for 8 hours.
- Important: Based on how a room is used, finding an occasional irradiance measurement greater than 0.21 μW/cm^2 in a space can still be acceptable for maintaining exposures below the TLV_{254}. In many common scenarios the occupants of a room are moving through areas of variable exposure within a space (some higher or lower than 0.21 μW/cm^2) resulting in a TWA exposure below the TLV_{254}.
  - Under these circumstances, a general rule-of-thumb is that an irradiance[5] level of $\leq$0.4 μW/cm^2 or less, measured at eye height in the occupied space should not exceed the TLV_{254}

See **Appendix B** for examples on how to calculate exposure dose for upper room UVC_{254}.

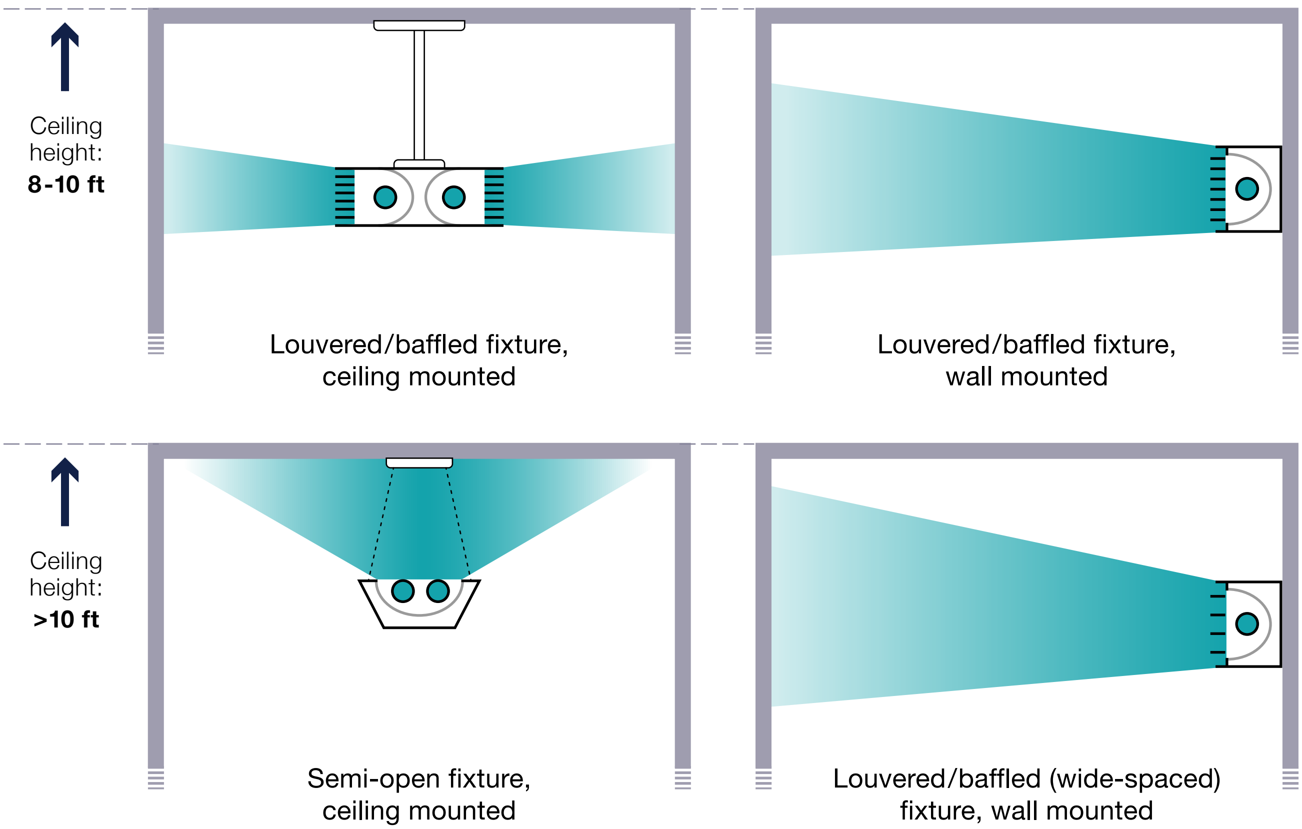
5 Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance) to compare against the ≤0.4 μW/cm^2 or less rule.

Choosing fixtures for upper-room UVC

For rooms with lower ceilings (8-10 ft or 2.4-3 m), a louvered or baffled UVC fixture is needed to ensure stray light does not overexpose occupants in the room/space (see **Figure 4**). In rooms with higher ceilings (≥10 ft or 3 m), UVC fixtures with wider spacing between baffles or open UVC fixtures may be used.

If the ceiling height is less than 8 ft (2.4 m), upper-room UVC cannot be safely used while the room is occupied. Consider the architectural features and finishes in the room when planning for upper-room UVC, as they may block, absorb, or reflect the UV radiation.

FIGURE 4. **Types of Upper-room UVGI fixtures best suited for room height**



The worksheet in **Appendix B** demonstrates **how to calculate the minimum UVC_{254} fixture output needed to disinfect a particular room/space.** Larger rooms/spaces may require more than one UVC_{254} fixture. This worksheet also includes three examples of different room sizes and considerations for:

1. Whether upper-room UVC_{254} can be used based on ceiling height (and architectural details).
2. Choosing between lamp intensity options and number of fixtures needed based on the calculated UVC_{254} output required for the room (UVC_{254} dose criterion based on normal vs. high-humidity conditions).
3. How lifecycle costs may impact choice.

Advantages and Disadvantages of Upper-room UVC Systems

ADVANTAGES	DISADVANTAGES
• Inexpensive to buy and operate compared to a new HVAC system, and to a lesser extent, room air cleaners. • Can be implemented room by room. • Limited impact on structure and mechanical systems. • Do not cause noise or drafts (except for air flow needed for air-mixing).	• If improperly installed or maintained, potentially hazardous to people within the rooms in which they are located. • Requires specialized expertise to install and monitor. • Each installation is site-specific. • Only addresses TB and airborne pathogens; does not remove dust and other particles nor does it provide outside ("fresh") air. • Hard to tell if working appropriately without a specialized meter. • Not as effective under humid conditions (>70% relative humidity). • Glow from lamps may bother individuals who are trying to sleep. • Staff and/or clients may be concerned about radiation exposure.

Irradiation of air in an HVAC System (In-duct UVC)

UVC_{254} lamps have been used in HVAC systems for years to reduce or eliminate biofilm from growing on heat exchange coils, in condensation pans, and on other surfaces within the HVAC system. Similar systems have also been used to disinfect the air flowing through the duct. However, the UVC dose required to maintain clean HVAC surfaces is quite low because the surfaces are generally irradiated all day, every day. The UVC dose required to disinfect the moving air stream will be considerable higher. The faster the air moves through the duct, the higher the amount of UVC needed to inactivate airborne pathogens.

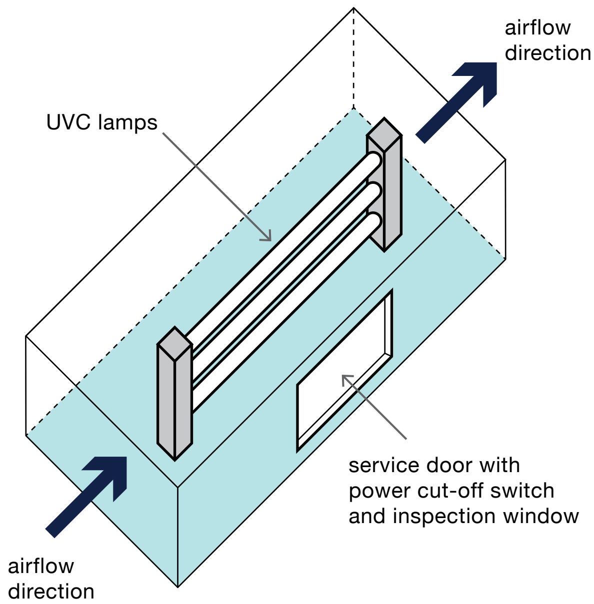
An in-duct UVC system can be effective for reducing the concentration of viable TB organisms in the airstream. For TB control purposes, a properly designed, installed, and maintained UVC_{254} system would be nearly equivalent to a 100% outside air system or HEPA filtration. UVC_{254} will inactivate susceptible microbial organisms, but does not provide dilution or removal of other contaminants in indoor air (e.g., odors, carbon dioxide, etc.) nor would it meet the requirements of the current CDC guidelines (2005) for containment.

Installation and monitoring

An in-duct UVC system should be designed and installed by an experienced professional, such as a UVC lamp or fixture manufacturer representative, HVAC engineer, mechanical engineer, or mechanical or electrical contractor.

- To disinfect air, UVC_{254} lamps are installed parallel to the airflow direction (in-duct UVC_{254} lamps used to disinfect the cooling coil and drip pan surfaces are installed perpendicular to the airflow direction). The number and spacing of the lamps should be selected to ensure that all air is exposed to the UVC radiation. Detailed calculations and measurements based on airflow and duct size will be required. **Figure 5** shows a sample installation. See **Appendix E** for examples of UVC dosing calculations.

FIGURE 5. **Schematic of in-duct UVC_{254} system**



- The UV intensities (irradiance) used inside a duct can be, and should be, greater than the UV intensities for upper-room UVC because the lamps are mounted inside the ductwork, thereby reducing the risk of UV exposure to room occupants. The required intensity of the lamps will depend on air speed in the duct and the cross-sectional area of the duct.
  - Generally, the average irradiance for a typical in-duct UVC_{254} system is about 1,000 to 10,000 µW/cm^2 over an 8 ft (2.4 m) length of duct, with air moving at an average velocity of 500 fpm (2.5 m/s).
  - If the UV sources are located downstream of a cooling cable or in cold air, additional UVC_{254} lamps (sources) will be needed because of reduced UVC efficiency at temperatures below 60°F (15°C). This is similar to the noticeable effect on fluorescent lamps (similar technology) which do not work well in cold rooms and outdoors when the temperature is low.
  - In some laboratory studies, the efficacy of UVC_{254} has been shown to decrease at relative humidity greater than 70%. While the mechanism is not well understood, it is hypothesized that airborne water molecules, as well as the aqueous layer around airborne pathogens, absorb UVC_{254} (requires increase dosing by two-thirds to compensate).
- Install a duct access door, with a glass viewing window (UVC does not penetrate normal glass or polycarbonate glass), so that the lamps can be cleaned, checked, and replaced. The duct access door should be electrically linked to the lamps' power supply so that the lamps are switched off when the access door is opened ("power cut-off switch"). This will protect maintenance staff from accidental exposure to UVC. Post a warning sign adjacent to the viewing window to alert staff of the danger to the skin and eyes from direct exposure to the bulbs. Anyone working in the vicinity of UVC-generating equipment should wear personal protective equipment (clothing and eyewear).

- Monitoring and maintenance are crucial because the intensity of lamps will fade over time.
- Most lamps will provide at least one year of continuous operation with effective irradiance inside a duct (many UVC system manufacturers offer lamps that last two years).
- Dust collection on lamp surfaces also leads to decreased UVC_{254} output.

- Be wary of in-room, stand-alone heating or cooling units (window, wall, or ductless units) that purport to use UVC_{254} for air disinfection. UVC within these units can be less efficient at disinfecting air because of the limited UVC_{254} dose received by the airborne pathogens while passing through the unit (i.e., the airborne pathogens are not exposed to the UVC long enough to inactivate them).

As previously mentioned, air-changes per hour (ACH) and clean air delivery rate (CADR; or clean airflow rate, CAR) are two parameters used to quantify the potential benefit of an environmental control. In a properly designed and maintained in-duct UVC system, assume that the equivalent mechanical airflow rate (eQ) is approximately the same as the CADR. To calculate the equivalent ACH produced using an in-duct UVC system, use the same ACH equation in **Ventilation** section. The same limitations with respect to directional airflow apply to a system with in-duct UVC as to a system with in-duct filtration. Airflow patterns in the room must be such to allow infected air from the breathing zone to reach the in-duct UVC inside the ventilation system.

Advantages and Disadvantages of In-Duct UVC

ADVANTAGES	DISADVANTAGES
• In-duct UVC lamps, unlike HEPA or other filters, do not cause a significant resistance to airflow in the system. Therefore, they can inactivate most infectious particles in the air but do not significantly reduce the amount of airflow. • In-duct UVC_{254} is usually less expensive to install and operate than a 100% outside air supply system.	• UVC lamps are a more specialized type of equipment than almost all other components of a mechanical HVAC system and require specialized expertise to install and maintain. • Higher output of UVC_{254} lamps (than those used for upper-room UVC_{254} systems) places greater potential risk to maintenance staff if safety measures are not followed, not operational, or inadequate.

Irradiation of air in room air cleaners (RACs)

As with RACs with filtration, RACs with UVC may be used to supplement an existing HVAC system. While the UVC calculations and dosing requirements are the same for RACs and HVAC systems, a more powerful UVC lamp is needed to inactivate the pathogen. This is due to the short UVC exposure time of the pathogens passing through a RAC system. Before purchasing a RAC with UVC, ask the distributor or manufacturer for independent testing results showing the efficiency of the RAC to remove and/or inactivate pathogens.

Direct irradiation (Whole-room irradiation)

Whole-room application of UVC in the United States is primarily used as a method to disinfect surfaces. The application of UVC_{254} (low-pressure mercury-vapor lamps) or $UVC_{260\text{-}275}$ (UV-LEDs) generally do not allow people to be in the directly irradiated room/space while in use, and therefore, is usually applied only for a fraction of a day when the space is unoccupied.

- Surface disinfection is limited by the thickness and composition of the material containing the pathogen of interest (e.g., if mixed in expectorated sputum on a surface) as well as the inability of UVC_{254} to efficiently disinfect shadowed or non-smooth surfaces.
- Recently, UVC_{222} (222 nm) has been promoted as means to irradiate a whole room safely while occupied. In addition, UVC_{222} is absorbed by proteinaceous material and is less penetrating than UVC_{254}. To date, no epidemiologic or observational studies have been conducted to confirm the utility and safety of UVC_{222} for this application, and current expert consensus on its utility is mixed. There are a number of studies on the horizon.

Note: Additional applications of direct UVC for purposes beyond air cleaning and surface disinfection are outside the scope of this document and will not be covered.

APPENDIX A:

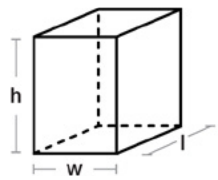
Upper-Room UVC_{254} Dosing Worksheets and Selection of Fixtures

UVC_{254} Volumetric Dosing Worksheet

Room Name, Location and Function: ____

Step 1: Measure room dimensions

Important:
If height is less than 8 ft (2.4 m) do not use upper room UVC_{254}.



- If any architectural or physical obstructions are noted and are lower than the measured "ceiling" height, use the floor to ceiling height of these structures in the decision to use upper-room UVC_{254} and for dose calculations below.
- If suspended ceiling, it may be possible to raise or remove to safely install upper-room UVC_{254}.

Room Height (h) ________ ft or m

Room Width (w) ________ ft or m

Room Length (l) ________ ft or m

Step 2: Calculate room volume (V)

Volume (V) = (h) x (w) x (l) ________ ft^3 or m^3

Step 3: Calculate required room UVC_{254} output (mW)

UVC_{254} volumetric dosing criterion: 0.34 mW/ft^3 or 12 mW/m^3

(V) x UVC_{254} dosing criterion = Required room UVC_{254} output (mW)

- Note: If natural room ventilation with high humidity, consider using up to 0.566 mW/ft^3 (20 mW/m^3).
- Remember – this is the dose required for TB pathogen inactivation. Separate safety requirements (UVC_{254} exposure dose limits) for occupants must be verified after installation.

Room V (ft^3) x 0.34 mW/ft^3 =

________ mW required*

or

Room V (m^3) x 12 mW/m^3 =

________ mW required*

* Small rounding difference between calculations in feet vs. meters

Step 4: Calculate type and number of UVC_{254} fixtures

a. Determine type of fixtures based on ceiling height.

b. From manufacturer testing data, find the total UVC_{254} output (mW) emitted per fixture for the selected model.

c. Calculate number of UVC_{254} fixtures needed by dividing UVC_{254} dose required for the space (step 3 above) by the manufacturer UVC_{254} output (mW) emitted per fixture (step 4b).

If full gonioradiometry data for selected UVC_{254} fixtures are available, a UVC CAD program may be used to estimate the UVC_{254} volumetric dose and required number of fixtures needed.

Type of UVC_{254} fixture based on floor to ceiling height (✔ choice):

a. ___ If 8-10 ft (2.3-3 m) use **louvered/baffled** UVC_{254} fixtures

___ If 10 ft (3 m) use **open (or louvered/ baffled)** UVC_{254} fixtures

b. ___ mW emitted per fixture

c. ___ mW required ÷ ___ mW emitted per fixture

= ___ # UVC_{254} Fixtures

Step 5: Appropriate air mixing should be installed/verified.

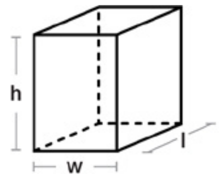
Step 6: Safety exposure for occupants should be considered during design and installation, then verified after installation.

UVC_{254} Area Dosing Worksheet

Room Name, Location and Function: ____

Step 1: Measure room dimensions

Important:
If height is less than 8 ft (2.4 m) do not use upper room UVC_{254}.



- If any architectural or physical obstructions are noted and are lower than the measured "ceiling" height, use the floor to ceiling height of these structures in the decision to use upper-room UVC_{254} and for dose calculations below.
- If suspended ceiling, it may be possible to raise or remove to safely install upper-room UVC_{254}.

Room Height (h) ________ ft or m

Room Width (w) ________ ft or m

Room Length (l) ________ ft or m

Step 2: Calculate room area (A)

Area (A) = (w) x (l) ________ ft^2 or m^2

Step 3: Calculate required room UVC_{254} output (mW)

UVC_{254} area dosing criterion: 0.0033 mW/ft^2 or .035 mW/m^2

(A) x UVC_{254} dosing criterion = Required room UVC output (mW)

- Note: If natural room ventilation with high humidity, consider using up to 0.058 mW/ft^2 (.0054 mW/m^2).
- Remember – this is the dose required for TB pathogen inactivation. Separate safety requirements (UVC_{254} exposure dose limits) for occupants must be verified after installation.

Room V (ft^2) x 0.0033 mW/ft^2 =

________ mW required*

or

Room A (m^2) x .035 mW/m^2 =

________ mW required*

* Small rounding difference between calculations in feet vs. meters

Step 4: Calculate type and number of UVC_{254} fixtures

a. Determine type of fixtures based on ceiling height.
b. From manufacturer testing data, find the total UVC_{254} output (mW) emitted per fixture for the selected model.
c. Calculate number of UVC_{254} fixtures needed by dividing UVC_{254} dose required for the space (step 3 above) by the manufacturer UVC_{254} output (mW) emitted per fixture (step 4b).

If full gonioradiometry data for selected UVC_{254} fixtures are available, a UVC CAD program may be used to estimate the UVC_{254} volumetric dose and required number of fixtures needed.

Type of UVC_{254} fixture based on floor to ceiling height (✔ choice):

a. ___ If 8-10 ft (2.3-3 m) use **louvered/baffled** UVC_{254} fixtures

___ If 10 ft (3 m) use **open (or louvered/baffled)** UVC_{254} fixtures

b. ___ mW emitted per fixture

c. ___ mW required ÷ ___ mW emitted per fixture

= ___ # UVC_{254} Fixtures

Step 5: Appropriate air mixing should be installed/verified.

Step 6: Safety exposure for occupants should be considered during design and installation, then verified after installation.

APPENDIX B:

UVC_{254} Exposure Dose Calculation

Units of Measurements

UVC Irradiance

flux of radiant energy per unit area

1 µW/cm²	=	0.001	mW/cm²
	=	0.01	W/m²
	=	10	mW/m²

UVC Dose

UVC irradiation absorbed, Irradiance multiplied by exposure time

1, 000 µJ/cm²	=	1	mJ/cm²
	=	10	J/m²
	=	10,000	mJ/m²

UVC Output

flux of radiant energy

1 Watt = 1 J per second

[Watt (W) = unit of power or radiant flux at rate of one joule per second; joule (J) = unit of energy]

Threshold Limit Value (TLV)

Maximum allowable UVC254 dose over an 8-hour shift (ACGIH)

- Eye exposure: 6 mJ/cm²
- Skin exposure: 10 mJ/cm²

Standardized/ergonomic eye-level heights

(ANSI/IES RP-44-2022)

- Sitting height: 51 in (1.3m)
- Standing height: 71 in (1.8 m)

Steps for Calculating UVC_{254} Exposure Dose

1 Measure irradiance for eye level and orientation of person(s) occupying room using a calibrated radiometer with a field-of-view cone properly attached to the sensor.

- **a.** Choose positions of expected use (ex., sitting at desk or waiting room chairs, standing at counter).
- **b.** Inspect room for possible "hot spots."
- **c.** Record all measurements documenting level above floor and orientation.
- **d.** Confirm if radiometer is measuring effective (weighted for safety) vs total (unweighted) irradiance*. If measuring total irradiance, multiply all values by 2 to convert to effective irradiance UVC_{254}.

2

- **a.** Determine expected duration of exposure at each measurement point (if multiple).
- **b.** Convert exposure time from hours/minutes to seconds.

3

- **a.** Calculate UVC_{254} dose at each measurement point (irradiance x time in seconds).
- **b.** Convert units to mJ/cm^2.

4 Add together all UVC_{254} dose estimates for total cumulative UVC_{254} dose (see Examples 1 and 2 below).

5 Compare total cumulative UVC_{254} dose to TLV maximum daily exposure safety limits.

Note: the TLV for UVC_{254} represents the **maximum running 8-hour exposure limit** for individuals exposed to UVC, whether moving through different rooms with UVC exposure or if longer than 8-hour shifts/day.

6 While the TLV UVC_{254} dose does not change, the TWA UVC_{254} allowable irradiance changes with exposure time. For instance, if one is only exposed to UVC_{254} for four hours, the TWA UVC_{254} dose remains 6 mJ/cm^2 for eye exposure and the TWA UVC_{254} irradiance is 0.42 $\mu W/cm^2$. If one is exposed to UVC_{254} for a 12-hour shift, **the UVC_{254} dose remains 6 mJ/cm^2 in any running 8-hour period and the TWA UVC_{254} effective irradiance may not exceed 0.21 $\mu W/cm^2$.**

For more detailed discussion, see section covering **What level of UVC_{254} is safe?**, page 7.

See the following three case scenario examples:

Example 1: Calculating UVC_{254} exposure dose for upper-room UVC_{254}.

Example 2: Time-motion assessment for UVC_{254} exposure dose.

Example 3: Time-motion assessment using running ("rolling") 8-hours for UVC_{254} exposure dose.

* Safety and performance standards presume dose measurements are calculated using effective irradiance. Most UVC254 radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance)

Example 1: Calculate UVC_{254} exposure dose for upper-room UVC_{254}

Calculate for a clinic waiting room with rows of visitor chairs facing forward (east). Average wait time for visitors is 0.5-1 hour. Choosing the 1-hour duration as representative value for calculating UVC_{254} exposure dose to determine if the exposure is below the TLV for UVC_{254}.

Step 1:	Radiometer measurement of irradiance at seated eye level of 51 in (1.3 m) is 0.2 μW/cm^2 and measures the same in all rows of seats facing forward (east). Radiometer is measuring total irradiance (multiply value by 2 to convert to effective irradiance)	Irradiance = 0.4 μW/cm^2
Step 2:	**a.** Expected duration of exposure = 1 hour **b.** Convert time to second	Exposure time = 1 hour = 60 minutes = 3600 seconds
Step 3:	**a.** UVC_{254} dose = irradiance x time (seconds) **b.** Convert units to mJ/cm^2	UVC_{254} dose = Irradiance x time = 0.4 μW/cm^2 x 3600 s = 1440 μW • s/cm^2 = 1440 μJ/cm^2 = 1.44 mJ/cm^2
Step 4:	Cumulative UVC_{254} dose for visitor would remain the dose for 1 hour (would not expect visitor to return and sit in waiting room again after appointment)	Total cumulative UVC_{254} dose = **1.44 mJ/cm^2**
Step 5:	Compare total cumulative UVC_{254} dose calculation to UVC_{254} TLV maximum daily exposure safety limits	Total cumulative dose is safely below the maximum allowable UVC_{254} dose for eye-level (6 mJ/cm^2) or skin-level exposures (10 mJ/cm^2). Calculate as % of TLV_{254}: = (1.44 mJ/cm^2 ÷ 6.0 mJ/cm^2) × 100% = **24% of UVC_{254} TLV**

Example 2: Time-motion assessment

A nurse kept track of her time and exposure during her eight-hour shift throughout facility with upper-room UVC_{254} to assess her individual risk based on usual work shift activities. She kept a diary/log of her activities and took eye-level irradiance measurements and recorded results accordingly.

Log of activity locations with irradiance measurements and time spent per location x 8-hour shift:

Corridor: .... 0.5 μW/cm² for 10 minutes ...... (600 s)

Nurse's desk: .... 0.05 μW/cm² for 3 hours .... (10,800 s)

Patients' rooms: ...... 0.10 μW/cm² for 3 hours .... (10,800 s)

Records area: .... 0.125 μW/cm² for 1.5 hours .... (5,400 s)

Break room: .... 0.15 μW/cm² for 20 minutes ...... (1,200 s)

What was her total UVC dose during her shift?

Step 1: Radiometer measurement of irradiance (eye level) in usual position/orientation during activities.

Radiometer is measuring total irradiance (multiply value by 2 to convert to effective irradiance)

Step 2:

a. Record duration of exposure at each position/activity.

b. Convert time to seconds.

Step 3:

a. UVC_{254} dose = irradiance x time (seconds); calculate sum of UVC doses for total shift

b. Convert units to mJ/cm²

Cumulative UVC_{254} dose = ∑ (Irradiance x time)

	IRRADIANCE	X	TIME (sec)	=	UVC_{254} DOSE
Corridor:	1.0 μW/cm²	x	600 s	=	600
Nurse's desk:	0.10 μW/cm²	x	10,800 s	=	1,080
Patients' rooms:	0.20 μW/cm²	x	10,800 s	=	2,160
Records area:	0.25 μW/cm²	x	5,400 s	=	1,350
Break room:	0.30 μW/cm²	x	1,200 s	=	360

Total = 5,550 μJ/cm²

Convert units = 5.55 mJ/cm²

Step 4: Cumulative UVC_{254} dose for this nurse during 8-hour shift

Total cumulative UVC_{254} dose = **5.55 mJ/cm²**

Step 5: Compare total cumulative UVC_{254} dose calculation to UVC_{254} TLV maximum daily exposure limits

Total cumulative dose is below the maximum allowable UVC_{254} dose for eye-level (6 mJ/cm²) or skin-level exposures (10 mJ/cm²)

Calculate as % of TLV_{254}:

= (5.55 mJ/cm² ÷ 6.0 mJ/cm²) × 100%

= **93% of UVC_{254} TLV**

Example 3: Time-motion assessment using running ("rolling") 8-hours*

Mr. Bleu works the 8:00 am to 8:00 pm shift. His average hourly UVC_{254} dose is shown in the figure below. Because Mr. Bleu worked in various areas during his 12-hour shift, his hourly UVC_{254} dose was not constant.

Did Mr. Bleu exceed the eye TLV for UVC_{254} (noting that if eye criterion of 6 mJ/cm^2 is met, the skin criterion of 10 mJ/cm^2 will also be met)?

Step 1: Make a table with four columns:

- **Time**
- **Hourly UVC_{254} dose** (mJ/cm^2)
- **Cumulative UVC_{254} dose** (mJ/cm^2)
- **Running 8-hour cumulative UVC_{254} dose** (mJ/cm^2)1

Assume no UVC_{254} exposure prior to the beginning of the shift

Time	Hourly UVC_{254} Dose (mJ/cm^2)	Cumulative UVC_{254} Dose (mJ/cm^2)	Running 8-hr Cumulative UVC_{254} Dose (mJ/cm^2)
8:00	0.0	0.0	0
9:00	1.0	1.0	1.0
10:00	0.7	1.7	1.7
11:00	0.6	2.3	2.3
12:00	0.5	2.8	2.8
13:00	1.1	3.9	3.9
14:00	0.9	4.8	4.8
15:00	0.6	5.4	5.4
16:00	0.5	5.9	5.9
17:00	0.7	6.6	5.6
18:00	0.6	7.2	5.5
19:00	1.1	8.3	6.0
20:00	0.7	9.0	6.2

Step 2: Enter "Time" data in the first column and enter the "Hourly UVC_{254} dose" in the second column.

Columns 1 and 2 of table

Step 3: For each hour, starting at 08:00, add the UVC_{254} dose for that hour with the cumulative UVC_{254} dose from the previous hour.

Note: the UVC_{254} dose prior to 08:00 is 0.0 mJ/cm^2.

Column 3 of table

Step 4: For each hour, starting at 08:00:

- Calculate the running 8-hour cumulative UVC_{254} dose by summing the UVC_{254} dose 01:00 to 08:00 and enter this value at 08:00.
- Next, calculate the running 8-hour cumulative UVC_{254} dose by summing the UVC_{254} dose 02:00 to 09:00 and enter this value at 09:00.
- Then calculate the running 8-hour cumulative UVC_{254} dose by summing the UVC_{254} dose 03:00 to 10:00 and enter this value at 10:00.
- Continue through the end of the 12-hour work shift (20:00).

Column 4 of table

EXAMPLE CONTINUES ›

* The ACGIH Physical Hazards Committee has stated that the TLV for the eye is based on an eight-hour running ("rolling") average of exposure.

Example 3: Time-motion assessment using running ("rolling") 8-hours*

Step 5: Look at the "Running 8-hour cumulative UVC_{254} dose" column. At any time, did the UVC_{254} dose exceed the TLV of 6 mJ/cm^2?

Yes, the "Running 8-hour cumulative UVC_{254} dose" exceeded the TLV of 6 mJ/cm^2 at 20:00.

Step 6: What actions do we need to take?

Time	Hourly UVC_{254} Dose (mJ/cm^2)	Cumulative UVC_{254} Dose (mJ/cm^2)	Running 8-hr Cumulative UVC_{254} Dose (mJ/cm^2)
8:00	0.0	0.0	0
9:00	1.0	1.0	1.0
10:00	0.7	1.7	1.7
11:00	0.6	2.3	2.3
12:00	0.5	2.8	2.8
13:00	1.1	3.9	3.9
14:00	0.9	4.8	4.8
15:00	0.6	5.4	5.4
16:00	0.5	5.9	5.9
17:00	0.7	6.6	5.6
18:00	0.6	7.2	5.5
19:00	1.1	8.3	6.0
20:00	0.7	9.0	6.2

B. Note that an increase in UVC_{254} dose in any of the first eight hours would probably result in exceeding the TLV.

C. After 9 hours of his shift, even though the total cumulative dose is >6 mJ/cm^2, the TLV has not yet been exceeded because the running 8-hr cumulative dose has not exceeded the TLV.

A. Because the eye TLV of 6 mJ/cm^2 (over running 8-hrs) was exceeded during the last hour of the 12-hour shift, one should confirm that these measurements are representative of Mr. Bleu's "normal" UVC_{254} exposure. If yes, actions should be taken to reduce his hourly exposure.

APPENDIX C:

Choosing Upper-Room UVC_{254} Fixtures: Example Scenarios

Choosing the most appropriate and cost-efficient UVC fixtures to create an effective upper-room UVC_{254} system is dependent on room shape and dimensions, type of fixtures available, and how occupants will utilize the space.

Three examples demonstrate how these factors can influence final fixture choices for upper-room UVC.

Example Room #1: Low-ceiling room

1 Floor to ceiling height is **too low to safely install upper-room UVC_{254}**

Height 7.5 ft (2.3 m) | Width 10 ft (3 m) | Length 10 ft (3 m)

Example Room #2: Standard office/exam room

1 Floor to ceiling height is **sufficient for upper-room UVC_{254}**

Height 8.5 ft (2.6 m) | Width 10 ft (3 m) | Length 10 ft (3 m)

2 **Calculate room volume:** (V) = (h) x (w) x (l)

V = 850 ft^3 (23.4 m^3)

3 **Calculate required room UVC_{254} output (mW):**

Required UVC_{254} dose* = V (ft^3) x 0.34 mW/ft^3 **or**
= V (m^3) x 12 mW/m^3

*Small rounding difference between calculations in feet vs.meters

Req. UVC_{254} dose = 280-290 mW*

4 **Calculate type and number of UVC_{254} fixtures**

a. Ceiling height is between 8-10 ft (2.4-3 m), use a **louvered/baffled style fixture** (ceiling not high enough to safely use an open design fixture).

b. A manufacturer has louvered/baffled UVC_{254} fixtures with six different levels of UVC output.

c. The goal would be to have enough fixtures (based on UVC_{254} output) to meet the required room UVC_{254} dose for adequate disinfection for the room size. **Here the goal would be a total room UVC dose of 280-290 mW.**

Cost consideration: In general, the cost of a UVC_{254} fixture with an output of 400 mW is not double the cost of a UVC_{254} fixture with an output of 200 mW. The cost of replacement lamps is nearly identical.

In general, select the one UVC_{254} fixture with 400 mW output over two smaller UVC_{254} fixtures based on lifecycle cost (see **Appendix D**), if the room configuration allows.

Manufacturer fixture options for louvered/baffled design (UVC_{254} output)

200 mW . . . . . (0.2 W)
400 mW . . . . . (0.4 W)
600 mW . . . . . (0.6 W)
800 mW . . . . . (0.8 W)
1,000 mW . . . . . (1.0 W)
1,200 mW . . . . . (1.2 W)

One 400 mW UVC_{254} fixture or two 200 mW UVC_{254} fixtures would meet required UVC_{254} dose for disinfection.

If the risk of airborne transmission of TB is low (i.e., an area where one would not expect infectious TB patients), one 200 mW UVC_{254} fixture could suffice.

5 Appropriate air mixing should be installed/verified.

6 Safety exposure for occupants should be considered during design and installation, then verified after installation.

Example Room #3: Large room, high ceiling (with decorative acoustic ceiling panels)

1 Floor to ceiling height is **sufficient for upper-room UVC_{254}**

a. In this example, decorative acoustic architectural panels are hung from the ceiling. The panel bases (lowest points) are 10' (3 m) above the floor.

b. Use the floor to panel height for UVC_{254} considerations and calculations.

Actual Height 20 ft (6.1 m)

Ceiling Panel Height 10 ft (3 m)

Width 40 ft (12.2 m)

Length 50 ft (15.2 m)

2 **Calculate room volume:** (V) = (h) x (w) x (l)

V = 20,000 ft^3 (556 m^3)

3 **Calculate required room UVC_{254} output (mW):**

Required UVC_{254} dose* = V (ft^3) x 0.34 mW/ft^3 **or**
= V (m^3) x 12 mW/m^3

*Small rounding difference between calculations in feet vs.meters

Req. UVC_{254} dose = 6672-6800 mW*

4 **Calculate type and number of UVC_{254} fixtures**

In this case, the functional ceiling is 10 ft (3m) and these values will be used for the dosing calculations as well as for UVC_{254} fixture selection.

a. Because of the decorative ceiling panels, use **louvered/ baffled fixtures** (if no panels were present, the >10 ft (3 m) high ceiling would have allowed open or semi-open UVC_{254} fixtures).

b. A manufacturer has louvered/baffled UVC fixtures with six different levels of UVC_{254} output.

c. Cost-effective choice would be to use as few fixtures as possible. **Six 1.2 W UVC_{254} fixtures would be a practical choice** if they can produce a relatively uniform distribution of UVC_{254} in the room. **Depending on the room geometry, a combination of fixture outputs may be needed.**

If there were no or very few obstructive items in the upper portion of the room, open or semi-open UVC_{254} fixtures could have been considered. Open UVC_{254} fixtures generally start at 3 W and higher in output. For this example, two-to-three open UVC_{254} fixtures would suffice if no panels were present hanging from the ceiling.

Fixtures needed per UVC_{254} fixture output to reach required room UVC_{254} dose of 6,800 mW

#NO.	FIXTURE UVC_{254} OUTPUT
34	200 mW (0.2 W)
17	400 mW (0.4 W)
11	600 mW (0.6 W)
9	800 mW (0.8 W)
7	1,000 mW (1.0 W)
6	1,200 mW (1.2 W)

5 Appropriate air mixing should be installed/verified.

6 Safety exposure for occupants should be considered during design and installation, then verified after installation.

APPENDIX D:

UVC_{254} Cost Considerations

Over the lifetime of an upper-room (UR) UVC_{254} system, the primary costs will be the long-term operation and maintenance costs. The following items are often included in calculation of the lifecycle cost of a UVC_{254} fixture, assuming the "life" of a UVC_{254} fixture is 15 years:

Initial costs	Recurring costs
• UR UVC_{254} fixture(s) • Shipping, customs, taxes • Air mixing system (diffusers, fans, etc.) • Layout design • Installation (fixture, fans, electrical, etc.) • Acceptance testing (UR UVC_{254} performance for inactivation and safety) • UVC meter	• Quarterly maintenance • Annual maintenance • Annual electricity • Annual calibration of UVC_{254} meter

As a general rule-of-thumb, the average annual cost of operating and maintaining UR UVC_{254} can be 10-20% percent of the initial acquisition cost. This represents a new annual budget line for operation and maintenance.

As shown in **Figure 2: Estimated Lifecycle Cost for UVC_{254} system**, the lifecycle cost is critical to understand. An estimate of lifecycle costs for three different quantities of UR UVC_{254} fixtures is shown below:

One UR UVC_{254} fixture	Ten UR UVC_{254} fixtures	Fifty UR UVC_{254} fixtures
UVC_{254} fixture cost .... **$1,000** *(each, not including taxes, shipping, etc.)*	UVC_{254} fixture cost .... **$1,000** *(each, not including taxes, shipping, etc.)*	UVC_{254} fixture cost .... **$1,000** *(each, not including taxes, shipping, etc.)*
	Total lifecycle cost .... **$46,475** *(all UVC_{254} fixtures)*	Total lifecycle cost ...... **$179,500** *(all UVC_{254} fixtures)*
Total lifecycle cost .... **$13,495** *(per UVC fixture)*	Total lifecycle cost .... **$4,648** *(per UVC_{254} fixture)*	Total lifecycle cost .... **$3,590** *(per UVC_{254} fixture)*
Annualized lifecycle cost as a percentage of UR UVC fixture cost.......... **$900 or 90%**	Annualized lifecycle cost as a percentage of UR UVC_{254} fixture cost.......... **$310 or 31%** *(per UVC fixture)*	Annualized lifecycle cost as a percentage of UR UVC_{254} fixture cost.......... **$239 or 24%**

As you see above, the annualized lifecycle costs will decrease as you increase the number of UR UVC_{254} fixtures.

For additional details on lifecycle costs of UR UVC_{254} systems, see the Technical Information Sheet titled: "Disinfecting room air with upper-room (UR) germicidal UV (GUV) systems" https://stoptb.org/wg/ett/assets/documents/ETTI_TechSheet_GUV_final%20version.pdf, developed by the Stop TB Partnership's End TB Transmission Initiative (ETTi).

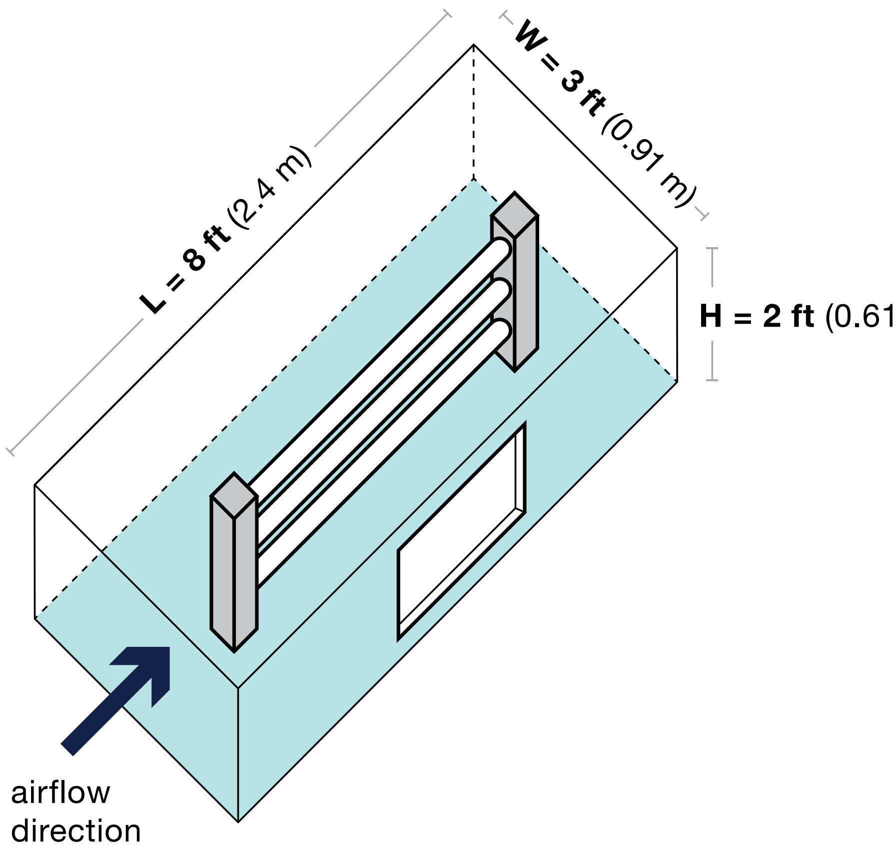
APPENDIX E:

UVC$_{254}$ In-duct Dose Calculation

When designing a new in-duct UVC$_{254}$ system, or installing one into an existing HVAC system, the UVC$_{254}$ dose required will be a function of the average UVC$_{254}$ irradiance in the duct (based on output of the lamp) and the exposure time (based on airflow speed) in the system. Because an in-duct lamp does not require baffles, the UVC$_{254}$ output approaches 100% of the lamp output and can be highly efficient.

Because of the technical requirements — any installation of in-duct UVC$_{254}$ should have a qualified review to verify adequate UVC$_{254}$ dosing is achieved for the purposes of disinfection.

Diagram of in-duct UVC$_{254}$ lamp placement:



Step 1:	Identify specifications of the HVAC system and calculate expected air velocity within duct.	**1. Airflow Rate (Q)** = 3,000 cfm (5,100 m^3/hr) per manufacturer's specifications and Testing & Balancing (T&B) report. **2. Area of duct (A)** = H x W = 2 ft x 3 ft = 6 ft^2 (0.56 m^2) **3.Velocity of Air (V)** = Q / A = 3,000 cfm/6 ft^2 (5,100 m^3/hr/0.56 m^2/3,600 sec/hr) = 500 ft/min (2.5 m/s)
Step 2:	Identify available length of ductwork for UVC placement (check if manufacturer recommends a specific length designated for UVC).	If not designated by the manufacturer, a minimum of 8 ft (2.4 m) for large HVAC systems is often used for installing an in-duct UVC system (vs 2-4 ft for a residential-size system).
Step 3:	Calculate exposure time based on length of in-duct UVC_{254} lamp placement.	Exposure time (t) in the 8 ft length (L) of irradiated duct = L / V = 8 ft/500 ft/min* 60 sec/min (or 2.4 m/2.5 m/s) [convert to meters and seconds] = 0.95 s
Step 4:	Calculate if recommended minimum average irradiance required for in-duct UVC is met.	**Minimum average irradiance for in-duct UVC: 1,000-10,000 μW/cm²** (ASHRAE 2019, chapter 62*) Note: Average UVC_{254} dose received by an airborne pathogen when the average irradiance in the duct is 10,000 μW/cm² is: Dose (μJ/cm²) = 10,000 μW/cm² * 0.95 s = 960 μW*s/cm² = 960 μJ/cm²

* Riley et al. [1976] estimated the UVC_{254} dose necessary to inactivate 90% of M. tuberculosis to be 576 μJ/cm² while Kowalski [2006] estimated the dose to be 1,080 μJ/cm². Given the UVC_{254} dosing in the example above, approximately 90% of the airborne M. tuberculosis passing through the HVAC system should be inactivated in a single pass.

Resources

ASHRAE Epidemic Task Force Filtration and Disinfection Guidance
[1 MB, 38 pages]
https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-filtration_disinfection-c19-guidance.pdf

ASHRAE 2020 Handbook—HVAC Systems and Equipment:
Chapter 17, Ultraviolet Lamp Systems
[252 KB, 10 pages]
https://www.ashrae.org/file%20library/technical%20resources/covid-19/i-p_s20_ch17.pdf

ASHRAE 2019 Handbook – HVAC Applications:
Chapter 62, Ultraviolet Air and Surface Treatment
[4 MB, 18 pages]
https://www.ashrae.org/file%20library/technical%20resources/covid-19/i-p_a19_ch62_uvairandsurfacetreatment.pdf

ASHRAE Position Document on Infectious Aerosols
[659 KB, 24 pages]
www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

CDC Upper-Room Ultraviolet Germicidal Irradiation (UVGI)
https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation/uvgi.html

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