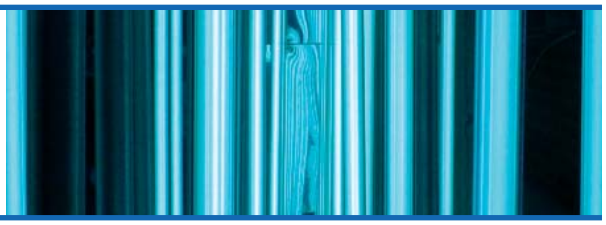
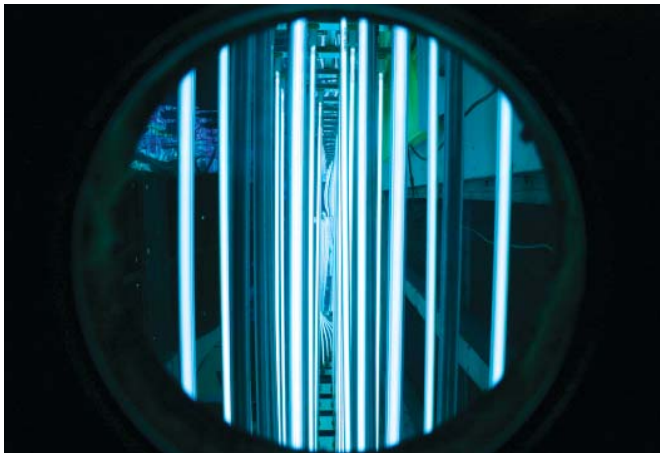
Field Evaluation of Ultraviolet Germicidal Irradiation (UVGI) in an Air Duct System



Building systems can be designed to reduce transmission of airborne diseases such as tuberculosis and influenza and to help defend against bioterrorism agents such as anthrax. This publication summarizes field research about an ultraviolet germicidal irradiation (UVGI) system installed in the ductwork of a retail space in New York City.[1,2] The study reported here was conducted by the Tuberculosis Ultraviolet Shelter Study of St. Vincent's Hospital—Manhattan; the Harvard School of Public Health; and the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute.

Figure 1. UVGI system in operation, as seen through a view portal.



Background

Ultraviolet (UV) radiation exposure damages the DNA of microbial organisms such as bacteria and viruses, and inactivates them (stops them from replicating).[3] UVGI is used in crowded rooms and corridors. It is installed in the open spaces above occupants' heads as well as in the ductwork of ventilation systems.[4] The UV source must be shielded to avoid human exposure.

In 2005, a UVGI system was installed in an existing air-handling plenum serving a commercial space in New York City. The heating, ventilating, and air conditioning (HVAC) system at the site allowed variable mixing of outside air and return air. The system mixed the air and passed it through a plenum equipped with UVGI lamps. The irradiated air then entered a heater/chiller and was delivered to the commercial space.

Project Objectives

- Characterize UV dose from the UVGI system installed at the demonstration site
- Relate UV dose to microorganism inactivation

Equipment

UVGI systems typically use low-pressure mercury discharge lamps. These lamps emit a wavelength (254 nanometers) that causes DNA damage to bacteria and viruses. The lamps also emit some visible short wavelengths that appear to the human eye as blue light (Figure 1).

UVGI lamps are based on conventional fluorescent lamp technology but are constructed of a special quartz glass to transmit UV, and they lack a phosphor coating that would produce white light. Like conventional fluorescent lamps, UVGI lamps are available in linear and compact forms and require ballasts to operate.

The manufacturer of the UVGI system installed 12 four-lamp UV units into the plenum (Figure 2).[5] Lamps were oriented vertically (Figures 2-3), and reflective sheeting was installed in the plenum to increase UV irradiance levels (Figure 3). A circuit breaker deactivated the UVGI system during routine maintenance, and a UV-blocking view portal allowed visual inspection of the UVGI system (Figure 1).

Figure 2. Diagram of air-handling plenum with UVGI equipment (image courtesy Atlantic Ultraviolet).

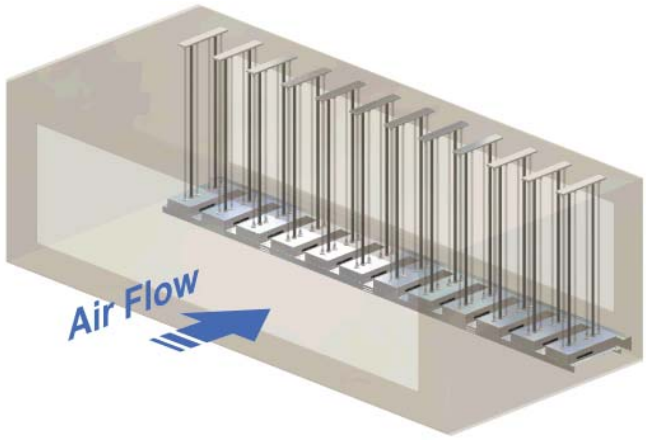
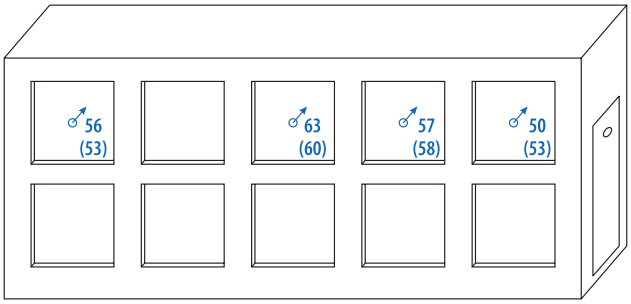


Figure 3. UVGI installation (turned off). Lamps are oriented vertically; reflective sheeting increases UV reflection from plenum walls.

UV Irradiance Measurements

UV irradiance (at 254 nm) is quantified in units of watts per square meter (W/m²). A UV sensor positioned at several locations in the plenum measured *planar irradiance*, the irradiance incident on a flat surface. Initial irradiance measurements were used to create a calculation model. Modeled values were verified in subsequent visits to the field (Figure 4).

Figure 4. Field verification of planar irradiance. (Predicted values shown in parentheses.) Measurements are in units of watts per square meter (W/m²).



Solving Problems in the Field

As with conventional fluorescent lamps, efficient operation of UV lamps requires the mercury inside the lamp to be at a specific vapor pressure. Mercury vapor pressure, and therefore proper lamp operation, varies greatly with temperature and lamp orientation. In this installation, the geometry of the plenum required the lamps to be installed vertically (Figure 3). However, instant-start, high-frequency electronic ballasts operated the lamps so efficiently that there was not enough waste heat at the lamp electrodes to warm the ends of the lamps. This, combined with the vertical lamp orientation, resulted in mercury pooling at the bottom of the lamps—below the cathodes, where the temperature was lowest—which rendered them ineffective at producing UV. The manufacturer redesigned its lamps to move the electrodes closer to the lamp ends, thus ensuring that the bottom end of the lamp was warm enough to vaporize mercury.

Air movement also affects mercury vapor pressure. In this application, UV lamps were directly exposed to circulating air. Moving air lowers the operating temperature of the lamp more than still air does. To stabilize lamp bulb wall temperatures (and thus UV output), quartz glass sleeves were installed for each lamp at the site. As summarized in Table 1, the UV output of lamps without sleeves was greatly reduced when air was moving; however, the output stabilized when sleeves were installed.

Table 1. Impact of moving air and sleeve enclosure on UV output.[6] All conditions used redesigned lamps with shortened cathode supports.

Conditions	UV output, no sleeves W/m² ($T_{ambient}$ = 20°C)	UV output with sleeves W/m² ($T_{ambient}$ = 15°C)	Impact of sleeves
Blower OFF	62.60	61.49	–2%
Blower ON	35.66	60.40	+ 69%
Impact of blower	–43%	–2%	

UV Dose, Fluence, and Fluence Rate

After planar irradiance levels were verified by measurements and calculations, researchers calculated the UV dose delivered to the airborne microorganisms. The effective germicidal radiation level, or *fluence rate*, is measured in units of watts per square meter (W/m^2). The dose, or *fluence*, is calculated by multiplying the fluence rate by the amount of time a microorganism spends in the UVGI field. Fluence describes the UV energy per unit area that an airborne pathogen receives (joules per square meter [J/m^2]). A faster airflow rate shortens the time exposure, thus reducing the dose.

The fluence calculation in the plenum combined measurements of planar irradiance with modeling of the installation and estimates of lamp efficiency (30-40%).[7] The fluence rate for this plenum was calculated as 92 W/m^2, including both direct and interreflected irradiance.[8] Using airflow rates through this plenum, the spatially averaged fluence was calculated as 316 J/m^2.

These values for fluence and fluence rate are "spatially averaged" because they represent an average microorganism's path through the plenum. The maximum-to-minimum ratio of fluence rates for different straight-line particle paths was calculated to be approximately 2:1 in this installation. Actual microorganism paths would likely not be straight lines because of turbulent airflow, thus increasing or decreasing overall dose efficacy.

In order to achieve high inactivation rates for a particular microorganism, all paths must produce a sufficient UV dose. Target fluence amounts vary, depending on the type of microorganism to be inactivated.[9] One strategy is to increase the input power so the path with the minimum fluence meets the target. However, this strategy does not minimize energy use. Another strategy is to make the fluence uniform for all particles passing through the plenum. To maximize uniformity, lamps should be arranged in a regularly spaced array that covers the entire cross section of the plenum. Reflective material added to the sides of the plenum further increases uniformity.

Fluence and fluence rate calculations are important for predicting in advance how well a system will perform with respect to microorganism inactivation rates.

Germicidal Effectiveness

Harvard School of Public Health performed extensive testing to characterize the germicidal effectiveness of this UVGI installation. Because it is impractical to introduce live microorganisms into a field installation, the researchers sampled naturally occurring microorganisms, including fungi, and measured their actual survival rates.

Their results showed that this UVGI installation was effective in reducing the presence of very hardy naturally occurring microorganisms. Through the use of a portable test unit, they also showed that this system would likely be effective against pathogens such as tuberculosis, smallpox, influenza, and anthrax.[10]

Safety, Energy, and Maintenance Implications

UVGI systems require a safety mechanism for deactivating the lamps during routine servicing. Care also needs to be taken to limit exposure of air filters in order to avoid material degradation. UVGI systems, like general fluorescent lighting systems, require regular cleaning, inspection for lamp failure, and re-lamping at the end of useful life. Previous research has recommended UV lamp replacement when UV emission declines to 70% of full output, which translates to over a year of use.[11] Power demand of this UVGI system was measured at 3.22 kW. Based on the operating hours of the demonstration site, usage would be 60 hours per week, or 3,120 hours per year, with an annual energy use of approximately 10,000 kWh (about $1800).

Figure 5. An LRC researcher positions a UV sensor in the plenum opening.

Lessons Learned

- Stabilizing lamp temperature is important to maximize UV output. In this application, quartz glass sleeves successfully stabilized the lamp bulb wall temperature.
- When using a vertical lamp orientation, mercury needs to be prevented from pooling at the bottom of the lamps. In this application, a redesigned lamp with shortened cathode supports prevented mercury pooling.
- If UVGI equipment is adjacent to air filters, UV-resistant filters should be provided.
- The system reduced very hardy, naturally occurring microorganisms, and would therefore be effective against tuberculosis, spore-form microorganisms such as anthrax, smallpox, and, by implication, all other aerosolized viruses, including influenza.

References/Notes

[1] Bierman, A., and J. Brons. 2007. *Ultraviolet Germicidal Irradiation—A Field Evaluation: Measurement Summary Report*... Lighting Research Center, Rensselaer Polytechnic Institute. Report submitted to Saint Vincent Catholic Medical Centers, April 23, 2007.

[2] Rudnick, S., K. Banahan, and M. First. 2006. *Interim Report: Demonstration of Air-Cleansing Effectiveness of In-Duct UVGI*. Harvard School of Public Health. Report submitted to Saint Vincent Catholic Medical Centers, January 9, 2006.

[3] Brickner, P. W., R. L. Vincent, M. W. First, E. Nardell, M. Murray, and W. Kaufman. 2003. *The application of ultraviolet germicidal irradiation to control transmission of airborne disease: bioterrorism countermeasure.* Public Health Rep. 118:99-114.

[4] Lighting Research Center. 2003. *Controlling Tuberculosis Transmission with Ultraviolet Irradiation*. Troy, N.Y.: Rensselaer Polytechnic Institute.

[5] Atlantic Ultraviolet Corporation, Hauppauge, N.Y.

[6] Measurements were taken in 1-minute intervals to determine stabilization. When stabilization was achieved, the resulting measurement was recorded, as shown in Table 1.

[7] General Electric Company. n.d. *GE Germicidal Lamps*. Germicidal lamp technical sheets (LSB), Specialty products – germicidal and UV lamps. Accessed online May 2007 at http://www.gelighting.com/na/business_lighting/education_resources/literature_library/product_brochures/specialty/downloads/germicidal/germicidal_tech_sheets.pdf.

[8] The specular reflective aluminum tiling that was retrofitted to the plenum walls contributed approximately 15% of the total spatially averaged fluence rate.

[9] OSRAM SYLVANIA. 2006. *Engineering Bulletin: Germicidal and Short-Wave Ultraviolet Radiation Lamps, FL-UVC004*. Westfield, IN: OSRAM SYLVANIA.

[10] Analyses of these data are included in a Final Report for NYSERDA Agreement 8280 submitted by TUSS St. Vincent's to NYSERDA. Copies of this final project report may be obtained from Philip W. Brickner, MD (pbrickner@svcmcny.org) or Richard L. Vincent (rvincent@svcmcny.org)

[11] M. First, K. Banahan, and T. Dumyahn. 2007. *Performance of ultraviolet germicidal irradiation lamps and luminaries in long-term service.* LEUKOS 3(3): 181-188.

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