

ADVANCED HVAC SYSTEMS FOR IMPROVING INDOOR ENVIRONMENTAL QUALITY AND ENERGY PERFORMANCE OF CALIFORNIA K-12 SCHOOLS

Fact Sheet for UVC

CONSULTANT REPORT

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Ultra Violet Lights for Coil Cleaning for K-12 Classrooms

Prepared for the Coalition for Adequate School Housing Annual Meeting participants

Poor indoor environments in schools influence the health performance and attendance of students. Many existing school space conditioning systems have dirty cooling coils, drain pans and plenums that have been fouled by the growth of microorganisms including viruses, bacteria and yeasts and molds. Air passing through and over the dirty coils, drain pans and plenums is likely to be contaminated and could therefore fail to provide the indoor air quality and comfort that can produce optimal student and teacher performance. Microorganism growth can also increase air-flow resistance, and reduce heat transfer, lowering the capacity and energy efficiency of the cooling system. Manually cleaning the coils is a laborious process that only temporarily removes the contaminants.

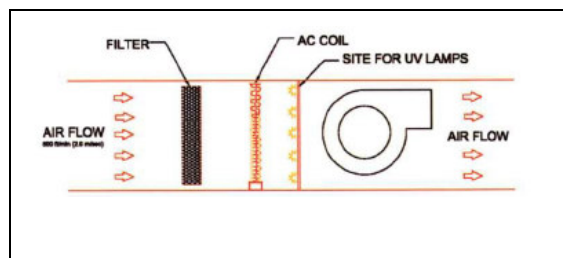
Using ultraviolet germicidal irradiation, produced by lamps designed specifically for this purpose, can provide continuous, cost-effective coil cleaning. These lamps are designed to emit radiation in the wavelength of 253.7 nanometers that provides the greatest disinfection ability. (The range spectrum of 200 to 280 nm is the "C" range of ultraviolet radiation, hence the term UVC.) The radiation is absorbed by the DNA molecule of the microorganism, producing mutation and deactivation. Thinner walled viruses are most readily deactivated, followed by bacteria and then fungi.

What are the benefits?

- **Indoor air quality** – may be improved since the coils that are continuously cleaned by UVC are thus no longer an incubation site for microorganisms. Air flowing through the coils is not contaminated, resulting in cleaner air being delivered to the classroom.
- **Maintenance Benefits**- may accrue from use of UVC lights to keep coils continuously clean, avoiding the laborious coil cleaning actions that will otherwise be required to return coils to a clean condition.
- **Energy Benefits** – may be provided by ultraviolet lighting that cleans cooling coils, reducing pressure drop, improving heat transfer and increasing system capacity, resulting in overall cooling energy savings.

How important is indoor air quality?

Evidence strongly suggests that poor environments in schools, primarily due to the effects of indoor pollutants, adversely influence the health, performance and attendance of students and teachers. This evidence links high concentrations of several air pollutants to reduced school attendance. There is also persuasive evidence that microbiological pollutants are associated with increases in asthma effects and respiratory infections, both of which are related to reduced school performance and attendance.¹ UVC lights offer an effective means of



Typical UVC lamp installation in air handling unit

(With permission of UVDI)

both reducing energy use and delivering fresh air to improve classroom air quality.

The lamps are designed to clean both the coil and drain pan surfaces in a few hours or a few days² and to progressively penetrate between the coil rows and fins with time.

The sidebar discusses some of the issues related to coil fouling and the pros and cons of traditional methods and UVC for cleaning fouled coils

What are the maintenance issues?

An effective traditional coil cleaning program cleans the coils three to four times per year. Use of UVC lamps can eliminate the need for these costly, laborious cleaning treatments that create system downtime and use chemicals, biocides or pressure washing. Mechanical or chemical washing may also damage coils.

UVC lamps should be inspected to see if they are dirty and cleaned on a regular basis, as needed. Some installations have a view port to permit visual observation of the lamps, without entering the air handling unit. The frequency of cleaning of the UVC lamps depends on the level of filtration and whether the lamps are upstream or downstream of the filter. Some practitioners suggest that if lamps are installed downstream of an effective filter, the lamps will not need to be cleaned at all before they need to be replaced. To clean the lamps, they can be wiped with a soft lint-free cloth (when the lamps are "off") moistened with isopropyl alcohol or glass cleaner, to assure that the lamps are operating at optimal efficiency. Lamps lose their efficacy with age and are generally replaced annually or whenever the output falls below 70% of the initial output.

Some practitioners of UVC systems recommend manual cleaning of the coils prior to installation and operation of the UVC lamps. This allows the UVC lamps to keep the coil in a continuously clean condition without fear of dispersing deactivated mold

and other microorganisms that might otherwise be present if the UVC lamps were used to deactivate microorganisms on a dirty coil and drain pan. Another option that may work for school buildings is to initially operate the UVC system when the building will be unoccupied for a sufficient period such as the summer vacation break to deactivate the organisms and “flush” them from the building prior to occupancy.

How does it save energy?

Cooling system energy can be saved by removing microorganisms from the coil, drain pan and plenum area, reducing air-side pressure drop, increasing air-side heat transfer and increasing system capacity.

Lamps are generally operated continuously to achieve the most effective cooling system cleaning and indoor air quality improvement. The resulting lamp energy use must be less than the cooling system energy savings for overall savings to accrue. In a typical installation the installed lamp power could be as low as less than 1% of HVAC system power for large systems and as high as 5% or greater for smaller systems. The savings produced by the lamps need to exceed these levels to achieve net energy savings for the installation.

How will this technology fit in with sustainable building and high performance school practice?

While UVC is not specifically addressed under the LEED-rating system it can be directly responsible for additional points for superior energy performance in the Innovation by Design area. Cooling energy savings potential can result in additional points for exceeding energy code requirements.

While UVC is not specifically addressed in The Collaborative for High Performance Schools (CHPS) credits, Superior Energy Performance receives additional CHS points starting at 2 points for a 15% reduction in total net energy use Compared to a Title 24-2005 baseline and increasing in increments of 2 points for each additional savings 5% of savings, up to a maximum of 35% and 10 points.

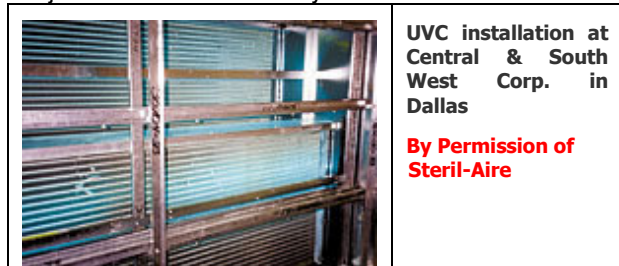
What kinds of UVC systems can I use?

There are three main types of UVC systems that are generally used in buildings: in-duct, upper-room, and air handler systems. In-duct systems provide a high level of ultraviolet radiation sufficient to kill microorganisms in the air flowing past the lamps. Upper room units are installed in occupied rooms above the heads of the occupants, shielded from their view, relying upon personnel movement and heat sources to create currents that cause air flow through the units. They are most often used in rooms with low air turnover. Air handler systems are placed near the cooling coil and drain pan in the delivery plenum and are designed to provide ultraviolet radiation that deactivates microorganisms that would otherwise foul the surfaces of the air handling unit. This application; irradiation of stationary surfaces, has long UVC exposure times and therefore lower intensity requirements than the

other types of UVC systems that are trying to disinfect a moving air stream.

Low-pressure UVC systems use lamps that are designed to provide radiation at the 253.7nm wavelength that is most effective in deactivating microorganisms. The lamps use low pressure mercury vapor, operating on the same principles as a fluorescent lamp but differing in not containing phosphors that convert UV to visible light. Another difference is that UVC lamps are made of quartz or soda barium glass which transmits UVC, rather than common glass which does not.

This article deals primarily with issues related to placement of UVC systems in air handling units in the proximity of the cooling coil and drain pan. In all cases it is recommended that filtration be used in conjunction with the UVC system.



Can UVC be used in most HVAC systems?

Manufacturers of UVC systems have designed equipment configurations suitable for all major types of air conditioning systems used in schools, ranging from unit ventilators to unitary single package and split systems and built-up systems used in site-built classrooms to the wall mounted single package systems used in relocatable classrooms.

Equipment configurations suitable for retrofit are also available for these types of air conditioning systems used in existing schools. Care must be taken to assure that the lamps are placed in the best position to maximize the view factor between the lamp and the coil/fin and drain pan surfaces.

How should the lamps be sized, located and operated?

Lamps operate most effectively in still air at 25°C. Temperatures both above and below 25°C result in reduced lamp performance. Lamps are most effective when they are new and clean and lose their efficacy with age and lack of cleanliness. The effect of humidity has little effect on lamp output but germicidal efficacy appears to decrease with increasing relative humidity³.

Since lamps lose their efficacy with age and operating conditions often differ from optimal, lamps need to be oversized so they can provide effective performance for a reasonable duration in a real world environment of dust, humidity and cooling air flow. Manufacturers will take this into account in providing and locating lamps and reflectors to provide the

appropriate lamp intensity for the installation of interest.

For coil surface cleaning, lamps should be placed to provide good coverage of the coil face. The travel path of the UV rays should be directly through the gaps between the coil fins. The placement and sizing of the lamps depends on the types of microorganism in the system, the dimensions of the installation and the desired level of disinfection. Many design approaches are available for sizing UVC systems including using catalogs, tables, analytical methods and rules of thumb. In general the manufacturer will take the responsibility of sizing the product to meet the conditions required by the application. One manufacturer suggests that 24 inches of high intensity UVC tube length be used for every 4 ft² of coil face area and that the ideal distance between the fixture and the coil is half the distance between rows or half the height of a one row coil if it is less than 24 inches.

Lamps should be operated continuously to prevent growth of microorganisms.

What are the safety issues?

Excessive exposure to UVC causes temporary redness and inflammation of the conjunctiva of the eye. Both should resolve within 24 to 48 hours. The cornea is very sensitive to UVC but UVC does not penetrate the cornea, therefore adverse lens or retinal effects are not experienced except for people who have had cataract surgery to remove their lens or cornea.⁴ View ports designed to see if the UVC lamps are operating properly or need to be cleaned should be constructed of glass or Lexan since UV does not penetrate either of these materials.

The Illuminating Engineering Society of North America (IESNA) cited the following exposure limits set by the American Medical Association:

UVC Human Exposure Limits	
Exposure Duration	Exposure Limit
Continuous	0.1 $\mu\text{W}/\text{cm}^2$
7 hours/day	0.5 $\mu\text{W}/\text{cm}^2$
10 minutes	22 $\mu\text{W}/\text{cm}^2$
2.5 minutes	90 $\mu\text{W}/\text{cm}^2$

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends threshold limit values (TLV) for UVC exposure in an 8 hour period of 6.0 mJ/cm², equivalent to an irradiance of .2 $\mu\text{W}/\text{cm}^2$ for an eight hour period and .4 $\mu\text{W}/\text{cm}^2$ for a 4 hour period. Above this level, erythema (skin redness) and photokeratitis (external eye inflammation) occurs. UV exposure and leakage needs to be minimized. (A tell-tale blue glow provides a clue to UV leakage.)

UVC lamps should be designed to avoid emitting radiation below at the 200nm wavelength that produces ozone.

Plastic-coated wiring can become brittle when exposed to UV and can create a fire hazard. Glues that hold filter pleats together or to hold the filter to the frame can be degraded by UV. The exposure of UV to these materials must be avoided.

While these hazards are real and care should be taken to avoid unsafe practices, experienced manufacturers and installers are well aware of the safety issues accompanying the use of UVC in occupied buildings and have designed fixtures, safety interlocks, and installation, servicing and operating procedures to avoid any potentially adverse effects that could occur.

Has it been done before?

Yes. UVC has been used effectively in many commercial buildings including a number of K-12 schools. Some examples of the benefits of UVC installation in schools are provided below:

An article on UVC classroom installation in the Capistrano Unified School District in California, claimed reduction in indoor air contaminants (skin cell fragments of 66% and pollen of 50%) and "every 15 to 20 minutes the air in that classroom will be purified resulting in a major improvement over previous conditions".⁵

The LaPorte Independent School District in Texas installed UVC lamps in a building that had been infected with fungal growth that had been treated with costly cleaning, inspections, and chemical sprays. The UVC installation eliminated the need for these costly, time consuming treatments and provided the ancillary benefit of almost a 10% reduction in energy use compared to a similar facility that had less hours of operation.⁶

The Stepping Stones Center educational and therapeutic facility in Cincinnati, Ohio, used UVC lights to effectively remove mold from an otherwise unusable building.⁷

UVC lamp systems were installed in 36 packaged air conditioning units in three school districts across California. Their performance was compared to 18 control units in those school districts over a six week period starting in August 2005. Microbial samples were taken from the surfaces of the cooling coils for each of the units prior to the installation and operation of the UVC lamp systems and also at the end of the test period. Each sample was subjected to fungal and bacterial testing. Results showed that the UVC lamps notably reduced the levels of microbial counts in the evaporator coils in the air conditioning units. (Total fungal and gram positive bacteria reductions from 65 to 100% of colony forming units were found.) Airflow and efficiency measurements were also made on the units and showed a positive trend (1 to 2% improvement in air flow) in reducing

pressure drop, and improving air flow but this trend was not statistically significant for the sample size and conditions evaluated. The study is continuing with analysis of student attendance records to determine if the UVC lamp systems had an effect on absentee rates. Recommendations for further study with larger sample sizes and conditions more conducive to coil performance degradation are being provided.⁸

Examples of use of UVC in other types of commercial buildings include the following:

Florida hospital in Orlando, Florida installed UVC lamps in a 27 year old air handling unit and within weeks of the installation, air velocity over the coil more than doubled and pressure drop was reduced by over 60%, saving at least 15% of HVAC system energy costs.⁹

Application of UVC in the coil/drain pan area of the HVAC system in an office building in Montreal found a 99% reduction in AHU surface microorganisms, a 25 to 30% reduction in airborne bacteria, a 20% drop in worker absenteeism and a 40% drop in respiratory problems.¹⁰

Central and South West Corporation of Dallas Texas, installed 170 UVC lamps in the air handlers in their nearly 500,000 ft² building in 1998, providing an approximately 28% reduction in air-conditioning system energy use and coils that are free of mold and organic buildup without any use of chemical cleaning or biocidal treatment.^{11,12}

In GSA-2003, Facilities Standards for Public Buildings¹³, the U.S. General Services Administration requires that UVC be used in buildings in their jurisdiction. "Ultraviolet light (C band) emitters/lamps shall be incorporated downstream of all cooling coils and above all drain pans to control airborne and surface microbial growth and transfer. Applied fixtures/lamps must be specifically manufactured for this purpose. Safety interlocks/features shall be provided to limit hazard to operating staff."

Sounds good. But what does it cost?

The initial cost of the lamps and related control equipment and the annual/periodic replacement costs of the lamps are additional costs accrued with the UVC systems. This should be compared to the maintenance costs that will otherwise result from regular chemical, biocidal or pressure cleaning.

Incremental energy use of the lamps must also be considered. Practitioners of these systems have asserted that the additional cost of UVC systems is more that offset by the elimination of costly air handler system cleaning, and incremental coil energy use reduction and that short paybacks are generally achieved.

Furthermore the quantification of the value of reduced absenteeism, and greater learning performance can greatly multiply these benefits. In the end, it may often be the promise provided by using UVC to improve indoor environments and to consequently enhance student and teacher health and productivity that turns the decision in favor of this technology.

Fair or Foul? Coil fouling is defined as an increase in pressure drop above 100% compared to a new coil. Reduced air flows from coil fouling can cause typical efficiency degradation of less than 5%¹⁴ but can be much greater for marginal or extreme conditions. An analysis of air conditioner coils¹⁵ showed that they were relatively insensitive to low and moderate amounts of air flow reduction due to fouling. When air flow was reduced by 35%, the coil had just a 6% drop in EER with the majority (4.6% of the 6%) occurring in last two years of the coil's twenty year life projection.

Both of these studies indicate that substantial fouling is needed to produce modest (~5%) degradation in efficiency. The level of fouling needed to provide the opportunity to save significant amounts of energy as cited in the Texas and Florida studies just described (see References 7, 9 and 10), is likely to be indicative of humid, warm conditions that have produced considerable microbial growth that may have gone untreated for some time.

Pros and Cons of Coil Cleaning Technologies – The following compares the perceived advantages and disadvantages of traditional coil cleaning methods that use chemicals, biocides or pressure washing to the attributes if UVC lights for coil cleaning. Both types of technologies lacking well-documented quantitative studies of coil degradation and the subsequent benefit of cleaning methods and systems.

UVC Technology

Pros- Surface cleaning is quick and effective. Continuous cleanliness is maintained, sustaining cleanliness benefits. Maintenance (lamp cleaning and replacement) is quick and simple.

Cons- Unclear how UVC light penetrates well below the surface envelope of the coil to disinfect and clean deep within the coil. UVC only addresses biofouling and does not affect other contaminants. Cleaning could take weeks or months to reach maximum effectiveness. The initial cleaning period may need to be coordinated with breaks/school shutdown periods to avoid transmittal of dead/deactivated organisms into the occupied space.

Traditional Coil Cleaning Technologies

Pros – Coil is cleaned to the full extent that is manually possible immediately after treatment. HVAC technicians are familiar with these technologies, infrastructure exists for their deployment.

Cons- Pressure washing could drive contaminants deeper into the coils. Chemicals and biocides need to be carefully removed to avoid subsequent air contamination. Cleaning can require facility shutdown, disassembly of equipment. The coil cleanliness degrades steadily immediately after initial treatment.

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References:

- (1) Mendell, Mark and Heath, Garvin, "A Summary of Scientific Findings on Adverse Effects of Indoor Environment on Student's Health, Academic Performance and Attendance," LBNL for the U.S. Department of Education, Doc # 2004-06, April 2004
- (2) Kowalski, Wladyslaw, "UV Cooling Coil Disinfection", The Pennsylvania State Indoor Environment Center for American Air and Water, Inc., September 1, 2005
- (3) Peccia, Jordan; Werth, Holly; Miller, Shelly; and Hernandez, Mark, "Effects of Relative Humidity on the Ultraviolet Induced Inactivation of Airborne Bacteria", *Aerosol Science and Technology* 35: pp 728- 740, University of Colorado, (2001)
- (4) Brickner, Philip; Vincent, Richard; First, Melvin; Nardell, Edward; Murray, Megan; and Kaufman, Will; "The Application of Ultraviolet Germicidal Irradiation to Control Transmission of Airborne Disease: Bioterrorism Countermeasure," *Public Health Reports*, pp 99-114, Volume 118, March-April 2003
- (5) "Breathe Easy: Capistrano Unified Reduces Indoor Air Contaminants by 66%," SchoolFacilities.com
- (6) Freeman, James, "UVC Sheds New Light on SCHOOL MOLD problems," La Porte Independent School District, La Porte, TX, *Heating/Piping/Air Conditioning*, May 2001
- (7) "UVC Lights Put an End to Mold Problem," *Air Conditioning/Heating/Refrigeration News*, August 9, 2004
- (8) "Improving Indoor Environmental Quality and Energy Performance of California K-12 Schools, Project 3, Effectiveness of UVC Light for Improving School Performance," RLW Analytics for the California Energy Commission under Contract 59903-300, Draft Report, January 6, 2006
- (9) Keikavousi, Firouz, "Florida Hospital Puts HVAC Maintenance Under a New Light," *Florida Hospital, Engineered Systems*, March 2004
- (10) Menzies, Dick; Popa, Julia; Hanley, James A.; Rand, Thomas; and Milton, Donald K.; "Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double blind multiple crossover trial," Montreal Chest Institute, McGill University, *The Lancet*, Volume 362, November 29, 2003, www.thelancet.com
- (11) "UVC Technology Sheds Light on IAQ Problems," *Air Conditioning/Heating/Refrigeration News*, July 10, 2000
- (12) "How do Utilities Save Energy?, With UVC for HVAC!," *Contracting Business*, December 2001
- (13) GSA-2003, *Facilities Standards for Public Buildings*, U.S.GSA, Office of the Chief Architect, Section 5.9 HVAC Systems and Components
- (14) Siegel, Jeffrey; Walker, Iain; and Sherman; "Dirty Air Conditioners: Energy Implications of Coil Fouling," 2002 *ACEEE Summer Study on Energy Efficiency in Buildings*, 1.287-1.299
- (15) Peterson, George; deKieffer, Rob; Proctor, John; and Downey, Tom; "Persistence #3A, An Assessment of Technical Degradation Factors: Commercial Air Conditioners and Energy Management Systems," Proctor Engineering Group for the CADMAC Persistence Committee, February 25, 1999

