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

Final UVC Brochure / Flyer (Recommendation for Code Actions)

CONSULTANT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Morton H. Blatt Energy Utilization Consultant

Arnold Schwarzenegger, *Governor*

May 2006
CEC-500-03-003
Subtask 4.3d2 Deliverable

CALIFORNIA ENERGY COMMISSION

Prepared By:
Energy Utilization Consultant
Morton Blatt

Submitted By:
Vernon Smith
Program Director
Boulder, Colorado
Commission Contract No. 500-03-003

Prepared For:
Brad Meister
Commission Contract Manager

Ann Peterson
PIER Buildings Program Manager

Nancy Jenkins
Office Manager
ENERGY EFFICIENCY RESEARCH OFFICE

Martha Krebs, Ph.D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

B. B. Blevins
Executive Director

Abstract
This paper provides information on the need for improved indoor quality, energy use and maintenance in schools and other commercial buildings. A primer on the use of ultraviolet radiation for coil cleaning is provided that includes information on the types of UVC systems available, and their sizing, operation, maintenance, safety and cost. Examples of field test experience on the efficacy of the technology are provided. The presence of coil fouling and attendant increase pressure drop and degraded heat transfer and performance are addressed. The possible alternative means of cleaning coils and their attributes are discussed.

Implications of coil fouling and cleaning on relevant building codes are explored with the need for measuring coil degradation and including time-dependent performance in code requirements noted.

Overview

Poor indoor environments in schools influence the health performance and attendance of students. 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 though 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 kinds of UVC systems can be used?

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 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 paper deals primarily with issues related to placement of UVC systems in air handing 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.

What are the possible benefits of UVC?

- **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 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 days[2] and to progressively penetrate between the coil rows and fins with time.

What are the maintenance issues with UVC?

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 can UVC 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 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 humidity[3].

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.

Lamps should be operated continuously to prevent growth of microorganisms.

For coil surface cleaning, lamp placement should 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 catalogs, tables, rules of thumb and analytical methods. 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 ft^2 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.

The International Ultraviolet Association is developing guidelines for UVGI air and surface disinfection systems[4] that includes recommendations on UV lamp sizing to include cooling effects, heating effects, aging, dust accumulation, burn-in, as well as information on safety issues and operation and maintenance of UVC systems. Guidelines for design and installation of surface disinfection systems in new buildings[5] recommends coil selection that avoids corrugated fins and limits fin spacing to 8-12 fins per inch to facilitate penetration of the UV rays into the coil. Combining surface disinfection systems and air disinfection systems is recommended for maximum effectiveness. The latest information from the most current version of these guidelines should be reflected in any codes and standards actions that result from this paper.

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.[6] 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 $\mu W/cm^2$
7 hours/day	0.5 $\mu W/cm^2$
10 minutes	22 $\mu W/cm^2$
2.5 minutes	90 $\mu W/cm^2$

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/cm^2, equivalent to an irradiance of .2 $\mu W/cm^2$ for an eight hour period and .4 $\mu W/cm^2$ for a 4 hour period. Above this level, erythema (skin redness) and photokeratitus (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 be 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 affects that cold occur.

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.

What field data has been published on UVC for coil cleaning?

UVC has been used effectively in many commercial buildings including a number of K-12 schools. 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".[7]

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.[8]

The Stepping Stones Center educational and therapeutic facility in Cincinnati, Ohio, used UVC lights to effectively remove mold from an otherwise unusable building.[9]

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 energy costs.[10]

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.[11]

Central and South West Corporation of Dallas Texas, installed 170 UVC lamps in the air handlers in their nearly 500,000 ft^2 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.[12,13]

Current Study Sponsored by the California Energy Commission
UVC lamp systems were installed in 36 packaged air conditioning units in three school districts across California.[14] Their performance was compared to 18 control units in those school districts over a six week period starting in August 2005. Both packaged rooftop and wall mount type air conditioning units were included in the study. Units that were less than four years old were excluded from the study. The three districts that were included in the study all had year-round schedules. 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.

These study results were somewhat surprising leading us to an investigation of the importance of coil fouling, how this is effected by environmental conditions and the influence of coil cleanliness on system performance. This information follows below along with a description of the pros and cons of alternative coil cleaning techniques.

How Important is Coil Fouling?

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% [15] but can be much greater for marginal or extreme conditions where the units are operating on a steep part of the fan curve or have low refrigerant charge. An analysis of air conditioner coils[16] 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[8, 11, 13, 14] 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- It is 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 – The 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.

Recommendations

Although building performance standards and certification programs are generally based on the as-designed and as-built conditions there is a tendency for building performance to degrade as the building ages. Degradation of the air handler performance, for example, can be affected by the buildup of dirt and microorganisms on the heat exchanger surfaces with the passage of time. This buildup and consequent fouling and performance degradation is exacerbated in the presence of moisture, mold spores, bacteria and other environmental parameters that encourage the growth of microorganisms.

Several issues should be addressed in response to coil performance degradation. Effort should be made to keep the coil in a clean condition to minimize energy use and maintain systems capacity and building comfort. The building operator should regularly inspect and monitor the condition of the air handler/coil surfaces to assess the degree of biological buildup through visual inspection, presence of odor, increased pressure drop and complaints about insufficient cooling. Language in codes and guidelines should refer to ASHRAE guidelines being developed as SPC 180P[17] to provide minimum inspection requirements that preserve a building's ability to achieve acceptable thermal comfort, energy efficiency and indoor air quality in buildings.

Conditions that produce or are likely to produce substantial coil fouling should require the use of coil cleaning procedures. If ultraviolet lights are used to provide this cleaning then adherence to the guidelines outlined in this paper and those being developed by the IUVA[4, 5] with regard to sizing, location, safety, operation, and maintenance should be required.

Substantial additional field testing is needed to quantify the potential improvement in performance accruing from the use of UVC lights in conditions that could otherwise produce substantial coil fouling. Correlations resulting from this testing could then be factored into the calculations employed to evaluate energy performance in codes such as ASHRAE 90 and Title 24. Once this has been done these calculation procedures could be factored into the LEED® rating system to provide for superior energy performance if UVC is used to maintain an otherwise severely fouled coil in a clean condition. Similarly, credits could be provided in the Collaborative for High Performance Schools (CHPS) to reflect performance enhancements due to UVC implementation.

Applicants for building energy code approval by or certification by guidelines should be made aware of the issues regarding building maintenance and operation in order to maintain the performance of the HVAC system over the life of that building.

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) "General Guideline for UVGI Air and Surface Disinfection Systems in New Building Construction," IUVA Draft Guideline IUVA-GO2A-2005, International Ultraviolet Association, 2005.

(5) "Guideline for Design and Installation of UVGI Air Disinfection Systems," IUVA Draft Guideline IUVA-GO1A-2005, International Ultraviolet Association, 2005.

(6) 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

(7) "Breathe Easy: Capistrano Unified Reduces Indoor Air Contaminants by 66%," SchoolFaciliites.com

(8) Freeman, James, "UVC Sheds New Light on SCHOOL MOLD problems," La Porte Independent School District, La Porte, TX, *Heating/Piping/Air Conditioning*, May 2001

(9) "UVC Lights Put an End to Mold Problem," Air *Conditioning/Heating/Refrigeration News*, August 9, 2004

(10) Keikavousi, Firouz, "Florida Hospital Puts HVAC Maintenance Under a New Light," Florida Hospital, *Engineered Systems, March 2004*

(11) 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

(12) "UVC Technology Sheds Light on IAQ Problems," *Air Conditioning /Heating /Refrigeration News*, July 10, 2000

(13) "How do Utilities Save Energy? With UVC for HVAC!," *Contracting Business,* December 2001

(14) "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

(15) 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

(16) 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

(17) "Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems," SPC 180 P