Ultraviolet Germicidal Irradiation in Building Air-Handling Systems: State-of-the-Art

Shelly L. Miller, University of Colorado Boulder
Julia Luongo, University of Colorado Boulder

Buildings consume a large percentage of the U.S. energy budget. Of the estimated 102 quadrillion BTUs consumed in 2009, 40 percent was used in buildings, with 18 percent and 22 percent used in commercial and residential buildings, respectively (Figure 1; DOE, 2009). Building energy consumption directly translates into CO_2 emissions: 39 percent of the total U.S. emissions were attributable to buildings in 2009, which represents 8 percent of the total global emissions (DOE, 2009).

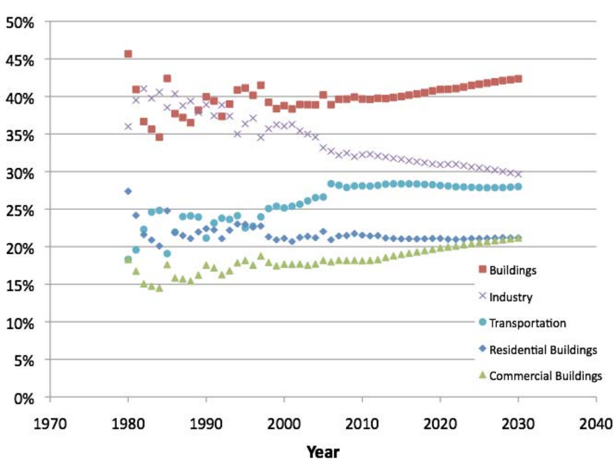

Figure 1. US building energy consumption (%). http://buildingsdatabook.eren.doe.gov/, Table 1.1.3.

More than half of the energy consumed in commercial buildings is for space heating (36 percent), ventilating (7 percent) and cooling (8 percent) the indoor environment (EIA, 2003). Degraded heating, ventilating, air-conditioning, and refrigeration (HVAC&R) system performance can translate into increased energy use in buildings. One reason for degraded performance is particle deposition and biofilm growth on cooling and heating coils (Figure 2). Heat exchanger surfaces are an ideal site for biofilms due to the presence of adequate nutrients (debris inherent on coil surfaces) and moisture (Morey, 1988). In many natural and engineered systems biofilms are an undesirable artifact of bacterial attachment to surfaces. Biofilms are a complex mixture of microorganisms, void spaces, excreted byproducts, organic matter, precipitates, sorbed ions and particles (Sutherland, 2001).

Figure 2. Coil fouling blocks airflow. Photo from epb.lbl.gov/coilfouling.

Microbial taxa identified by culturing methods in both office buildings and homes include *Aspergillus versicolor, Cladosporium cladosporioides, Alternaria alternate, Penicillium* spp. and *Methylobacterium* spp. (e.g. Menzies et al., 2003, Levetin et al., 2001, Hugenholtz et al., 1995). This contamination often contributes to building-related diseases, including hypersensitivity diseases, such as allergic rhinitis, asthma and hypersensitivity pneumonitis. Building-related lower respiratory symptoms and mucous symptoms were shown to be elevated in buildings with lack of cleaning of drip pans and cooling coils (Mendell et al., 2006). Kadoma and McGee (1986) reported that residents living in centrally air-conditioned homes had more complaints of eye irritation, sneezing, nasal congestion, and cough. Also, air-conditioned homes were enriched with total bacteria, *Aspergillus* spp. and Gram-positive cocci compared to outdoor air (a pattern that did not hold for naturally ventilated homes). In addition to potential negative health effects, the air–conditioning performance was significantly degraded by 54 percent in contaminated air-handling units (Ali and Ismail, 2008). One study shows degraded air-conditioning performance translated into a 10-30 percent increase in energy use in homes (Palani et al., 1992). Modeling studies by Siegel et al. (2002) estimated that residential air conditioning systems foul enough to double evaporator pressure drop in about 7 years (much sooner than the expected 15-30 year lifetime) and such degradation causes a 5 percent drop in efficiency and capacity.

It has been reported that many A/C systems, at least in the Sun Belt, grow mold and Gram negative bacteria, known contributors to poor indoor air quality. Fouled coils cause a significant increase in resistance to airflow (air horsepower) and a decrease in heat exchange efficiency via a reduction in fin space open area, which result in increased interstitial velocity and insulating properties. In more sophisticated systems, compensation results from an increase in Hertz (RPM) for variable drives (fans and pumps), increases in chilled water volume and a decrease in chilled water temperatures, and outdoor air volume. In less sophisticated systems, motors are re-shaved to provide additional pressure and other aspects of system operation are manually modified, as methods of compensation, for lost capacity and all requiring additional energy use. In thermostat-only operated DX systems, system run-time is extended and outdoor air volumes are reduced as much as possible, but these often lead only to higher space temperatures and humidity, and poor occupant space responses.

Coil cleaning is commonly recommended by most equipment manufacturers to be performed regularly (Fencl, 2012). With coil fin counts at 14, or more, fins per inch today, coil performance is a major concern – any loss in coil performance over time is reasonable, reported and anticipated. In addition to resulting in poor indoor psychometrics, compensation for any such loss in performance includes increased energy use. Many systems are maintained only annually using wet cleaning and chemical disinfection practices. Chemicals used to abate microorganism growth and to clean coils can be dangerous to both service personnel and occupants alike, and in addition, detrimental to system lifetime.

Technologies to decrease coil biofouling would help to keep the system running at capacity, keep the pressure drop across the heat exchanger low and reduce maintenance costs. One technology that is currently being used in buildings to decrease biofouling is ultraviolet germicidal irradiation (UVGI, or UVC). UVC mercury vapor lamps (peak radiation at 254 nm) are most commonly installed just downstream of the cooling coils on the supply side, irradiating the surfaces of the coil and drain pan to prohibit microbial growth (bacteria and mold) from fouling the coil and drain pan (Levetin et al., 2001; ES 2006; Menzies et al., 2003, Bahnfleth, 2011). The GSA requires new building construction, under the GSA contracts, to apply UVC in this manner (GSA, 2005). 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."

This application is reported to reduce maintenance costs, reduce pressure drop across the evaporator coils, and improved heat transfer of evaporator coils, therefore resulting in overall energy savings. The energy savings are also a result of improved airflow and reduction in required air handler (fan) energy. Because **LEED certification** points are based on strategies that will have greater positive impacts on energy efficiency and CO_2 reductions, it is conceivable that deploying UVC coil cleaning technology could count for LEED credits, for example, specifically in the "Innovation by Design" area (USGBC, 2011).

Surprisingly, only minimal research has been conducted regarding the impact of germicidal irradiation on biofilms that are fouling cooling coils, despite the installation and current operation of many of these systems (Bahnfleth 2011). Kowalski (2009) estimates that cleaning of coils with UVC proceeds rapidly and fouled coils are restored to good condition, saving energy and maintenance costs so effectively that the retrofit of a UVC coil cleaning system pays for itself in about 2-4 years. The author also notes there are few published studies available on this topic. Anecdotal evidence that this technology works and can save operational and maintenance costs is promising.

- American Electric Power in Dallas, Texas, observed a significant drop in pressure across the coil, saving $139,000 over a 2-year period, which was 15 percent of the total energy costs (AEP, 2001).
- A Tacoma, Wash., jail saved 34,100 therms of natural gas/year resulting in a savings of more than $70,000/year in natural gas costs (Checket-Hanks, 2006).
- A Florida hospital documented within weeks of installation, static pressure over the coil decreasing from 1.8 inches of water to 0.7 inches of water, doubling air velocity within the 27-year-old, 6000 cfm air-handling unit and saving $5,000 (Keikavousi, 2004).

- A Texas hospital estimated utility cost savings ranging from 18-42 percent after installation of UVC lamps in the air-handling units (ACHR News, 2007).

However, to the best of our knowledge, there have been no studies that clearly demonstrate whether the application of UVC actually results in energy savings as measured by power consumption metering.

In other studies regarding the fouling of air-conditioning coils, energy savings results were inconclusive (Siegel, 2002). Some of these studies used laboratory fouling and may not have properly simulated the biological fouling found as compared to organic matter accumulated on cooling coils in actual installations. In one study performed using room air conditioners in a laboratory setting, the coils were loaded with real coil fouling material collected from field units. Significant loss in the unit's coefficient of performance was recorded (Ali and Ismail, 2008). In a field study by the California Energy Commission, two different manufacturers of UVC systems installed systems in School HVAC equipment (Okura, 2006). This study indicated a trend to a savings, however the study was too short and not enough data was collected to obtain the statistical accuracy and time needed. In addition, the cooling season at these particular selected schools was very short as no summer session was held.

Energy savings is not the only added benefit from using UVGI in air-handling units. A recent study showed that UVC coil cleaning technology had a significant impact on the indoor air quality and improved health of patients in a hospital. UVC coil cleaning was implemented in a neonatal intensive care unit's air-handling unit. Results showed significantly decreased HVAC surface, environment (including air samples) and tracheal microbial colonization, as well as ventilator-associated pneumonia and use of antibiotics (Ryan et al., 2011). In addition, a study by Menzies et al. (2003) in office buildings found that use of UVC coil-cleaning technology installed on the upstream side of the coil "was associated with significantly fewer work-related symptoms overall." The study concluded that applying this technology in most North American offices could reduce work-related symptoms in roughly 4 million employees caused by microbial contamination of HVAC systems, and it would be cost-effective compared with the yearly losses from absence because of building-related illness. Energy saving studies performed by others (typically UVC equipment users, UVC equipment manufacturers, and electric utility companies) have often shown significant energy savings (Witham, 2007; Duggan, 2002). However these studies have not been prepared with independent third-party participation or the savings have been calculated from system operating parameters. hese results are therefore subject to question as they have not been performed with actual calibrated power meters and comparison of UVC vs. non-UVC-equipped HVAC systems. More research is needed that will objectively investigate and document the effectiveness of UVC coil cleaning by measuring the actual energy used in qualified similar HVAC&R systems both with and without UVC installed. Currently most of the information on energy savings is not available in the peer-review literature and only a few studies have been published on environmental impacts. If anticipated energy savings are proven with well-designed experimental measurements in real buildings, this energy saving, maintenance saving and indoor environmental quality improving technology may be accepted for wide spread use. It should prove to be an excellent tool for reaching energy saving goals for many buildings containing HVAC&R systems.

REFERENCES

ACHR News. (2007) UVC lights keep hospital cool, efficient. Air Conditioning, Heating, Refrigeration News, Sept 10, 2007, http://www.steril-aire.com/images/riogrande.pdf, accessed Dec 2009.

Ali, A.H.H. and Ibrahim M. Ismail, I.M. (2008). Evaporator Air-Side Fouling: Effect on Performance of Room Air Conditioners and Impact on Indoor Air Quality, HVAC&R Research, 14:209-219.

Bahnfleth, W.P. (2011). UVGI in air handlers, ASHRAE Journal, April, pp. 70-72.

Checket-Hanks, B. (2006). UVC helps cut heating costs in jails. Air Conditioning, Heating, Refrigeration News, Jan 16, 2006, http://www.steril-aire.com/images/tacoma-jail.pdf, accessed Dec 2009.

DOE. (2009). 2009 Buildings Energy Data Book. Department of Energy, http://buildingsdatabook.eren.doe.gov/, accessed Dec 2009.

Duggan, W (2002). UVC Lighting in HVAC System, Operational Savings Benefits. The Facility Managers Institute Newsletter, Spring, 1-4.

EIA. (2003). 2003 Commercial Building Energy Consumption Survey. Energy Information Administration, http://www.eia.doe.gov/emeu/cbecs/, accessed Oct 2012.

ES. (2006) Ultraviolet light for coil cleaning in schools. Engineered Systems, http://www.esmagazine.com/articles/ultraviolet-light-for-coil-cleaning-in-school, accessed Aug 3, 2012.

Fencl, F. (2012). Personal Communication.

GSA (2005). Facilties Standards for the Public Buildings Service. PBS-P100. US General Services Administration, Office of the Chief Architect, Washington, DC. http://www.gsa.gov/P100.

Hugenholtz, P., Cunningham, M.A., Hendrikz, J.K., and Fuerst, J.A. (1995). Desiccation Resistance of Bacteria Isolated from an Air-Handling System Biofilm Determined using a Simple Quantitative Membrane Filter Method, Letters in Applied Microbiology, 21:41-46.

Keikavousi, F. (2004). Florida hospital puts HVAC maintenance under a new light. Engineered Systems, March 2004, http://www.steril-aire.com/images/floridahospital.pdf, accessed Dec 2009.

Kodama, A.M., and McGee, R.I. (1986). Airborne Microbial Contaminants in Indoor Environments. Naturally Ventilated and Air-Conditioned Homes, Archives of Environmental Health, 41:306-311.

Kowalski, W. (2009). UVGI for cooling coil disinfection, air treatment, and hospital infection control. Final report, American Air & Water, Inc.

Levetin, E., Shaughnessy, R., Rogers, C.A., and Scheir, R. (2001). Effectiveness of Germicidal UVC Radiation for Reducing Fungal Contamination within Air-Handling Units, Applied and Environmental Microbiology, 67:3712-3715.

Mendell, M.J., Cozen, M., Lei-Gomez, Q., Brightman, H.S., Erdmann, C.A., Girman, J.R., and Womble, S.E. (2006). Indicators of Moisture and Ventilation System Contamination in U.S. Office Buildings as Risk Factors for Respiratory and Mucous Membrane Symptoms: Analyses of the EPA BASE Data, Journal of Occupational and Environmental Hygiene, 3:225-233.

Menzies D., Popa J., Hanley J., Rand T., and Milton D. K. (2003). Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double-blind multiple crossover trial. Lancet, 362:1785-91.

Morey, P.R. (1988). Microorganisms in Buildings and HVAC Systems: A Summary of 21 Environmental Studies. ASHRAE IAQ '88, pp. 10-24.

Okura, S. (2006). Improving Indoor Environmental Quality and Energy Performance of California K-12 Schools, Project 3, Effectiveness of UVC Light for Improving School Performance. Consultant Report from RLW Analytics, Inc., California Energy Commission CEC-500-03-003. http://www.archenergy.com/ieq-k12/Public/Proj3_Deliverables/D3.0e_UVCFinalReport_2006-0629.pdf, accessed July 17, 2012.

Palani, M., O'Neal, D. and Haberi, J. (1992). The Effect of Reduced Evaporator Air Flow on the Performance of a Residential Central Air Conditioner, Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, TX, 20-26.

Ryan, R.M., Wilding, G.E., Wynn, R.J., Welliver, R.C., Holm, B.A., and Leach, C.L. (2011). Effect of enhanced ultraviolet germicidal irradiation in the heating ventilation and air conditioning system on ventilator-associated pneumonia in a neonatal intensive care unit. J. Perinatol. 9:607-614.

Siegel, J., Walker, I., Sherman, M. (2002). Dirty air conditioners: energy implications of coil fouling. Lawrence Berkeley National Laboratory. http://escholarship.org/uc/item/0t8438wg, accessed Dec 2009.

Sutherland, I.W., (2001). Biofilm exopolysaccharides: a strong and sticky framework. Microbiology 147:3–9.

Witham, D. (2007). ASHRAE IAQ 2007: Healthy & Sustainable Buildings. Presented in Baltimore, MD.

USGBC, 2011. http://www.usgbc.org/DisplayPage.aspx?CategoryID=19, Accessed Sept. 9, 2011.