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

## Final Memo on the Alternative Technology and Literature Review

CONSULTANT REPORT

*Prepared For:*
**California Energy Commission**
Public Interest Energy Research Program

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Arnold Schwarzenegger, *Governor*

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# Introduction and Key Issues

This document is the research plan to quantify the impact of UVC Light on coil disinfection and indoor air quality of California K-12 Schools. The two tasks that are reported on in this document are tasks 3.1 and 3.2, the technology assessment and literature review and the study design.

The goal of this project is to determine if ultraviolet light in the "C" band is effective in reducing HVAC-related mold and mildew, thereby improving IEQ and increasing energy savings. When RLW submitted the initial proposal, we stated that we would use data on a UVC product made by Manufacturer A[1]. The UVC lights are designed to mount in the HVAC system supply duct, usually right at the evaporator coil. Manufacturer A claims the UVC lights kill mold and mildew that grows on the evaporator coil and in the drain pan, resulting in increased efficiency of the HVAC unit through better heat exchange and reduced pressure drop.

Prior to submitting the proposal, our team had an established relationship with Distributor A, a main provider of Manufacturer A's UVC products. We had a signed document that guaranteed in-kind contributions of time to help establish a relationship between RLW and school district officials. In reviewing RLW's proposal, the California Energy Commission (CEC) decided it would be worthwhile to expand the study to include similar UVC devices made by other manufacturers. RLW agreed to attempt to recruit other manufacturers to participate in this study since we were already going to be contacting the manufacturers as part of the technology assessment. RLW was successful in locating 3 other manufacturers with some installations in California K-12 schools; however we will not be able to include them in the study due to issues that are discussed later in this document. The first section of this document, Task 3.1 Technology Assessment and Literature Review, summarizes RLW's efforts to recruit other manufacturers and summarizes the available UVC technologies.

In the second section of this document entitled Task 3.2 Study Design, RLW details our plan to conduct the research as described in the proposal. We have expanded on the analysis methodology and the data collection criteria that we provided in the proposal. The key issues that we have addressed in this document are:

- Statistical precision of effect of UVC lights with *n* schools in our sample
- School recruitment criteria
- Critical explanatory variables for the analysis
- Supplementary data collected from schools

This document incorporates the suggestions that were discussed during the Critical Project Review Meeting held on 12/10/03. Any recommended changes to this document will be integrated into a final study design document to be delivered within the next few weeks.

[1] All manufacturers discussed in this report have been assigned names in order to maintain confidentiality and provide an unbiased report to the public.

# Task 3.1 Technology Assessment and Literature Review

The primary objective of this task as stated in the proposal was to ascertain the current practice and existence of available methods and technologies in reducing HVAC-related mold and mildew. However, the primary purpose of this task shifted during the contracting phase of the project once RLW was made aware that the CEC was interested in recruiting other manufacturers for participation in the regression analyses for the study. RLW's primary focus became locating and contacting the major UVC manufacturers across the United States.

Our secondary focus became a summary of the other technologies and methods used to disinfect coils and ducts in HVAC systems. This study is primarily focused on UVC lighting in HVAC systems, but RLW is aware that other mold remedies such as chemical treatments are most often used. In this section we discuss our contact with the other major UVC manufacturers and the different methods and technologies used to control mold in HVAC systems.

We accomplished task 3.1 by performing the following tasks:

- *Conducting web research to identify different UVC technologies and coil cleaning methods and identify UVC manufacturers;*
- *Contacting over 20 potential UVC manufacturers to discuss alternative cleaning practices and to recruit them for the study;*
- *Surveying 22 California air conditioner contractors about their cleaning procedures; and*
- *Conducting a literature review and summarizing existing studies quantifying the impact of UVC.*

This section of the document summarizes our literature review and interview findings.

## *Literature Review*

RLW received a number of recommendations from our project team and associates for sources of information on UVC manufacturers. We started with a thorough Internet search, which resulted in approximately 15 manufacturers and/or distributors. Our first observation was that it was very difficult to distinguish between a manufacturer and a distributor from marketing material. We knew that we would have to call all of the companies on our list to eliminate the distributors. Our second step was to search the ASHRAE website for publications relating to UVC in HVAC systems. We found numerous articles that are discussed in the technology assessment section and are documented in the bibliography. In those publications we found a few references to other manufacturers/distributors and a wealth of information on HVAC systems and evaporator coil fouling. We also searched the Thomas Register to locate a few more manufacturers. We finally searched through numerous trade magazines that are targeted at HVAC contractors such as:

- Engineered Systems,
- Building Design & Construction,
- Mechanical Engineering,
- ASHRAE Journal,
- EC&M,
- HPAC, and

- Power Engineering.

Our literature search resulted in the names of 36 manufacturers/distributors, 22 of which were manufacturers and 16 of which were distributors. Of the 22 manufacturers, 9 did not make UVC products for HVAC applications, rather they manufactured UV devices for curing or water sterilization applications. RLW spoke with 12 manufacturers of UVC lights for HVAC systems. The information from the manufacturers we interviewed is summarized in the following sections.

## *Manufacturer Interviews*

RLW spoke with 12 manufacturers of UVC lights to discuss their potential participation in this study. We interviewed each of the manufacturers using the interview guide found at the back of this document. We interviewed the manufacturers to help us better understand current UVC products and technologies, market barriers, product availability, customer demand, markets served, and available research. Every manufacturer that we contacted was very willing to assist us with the study. The remainder of this section summarizes the qualitative responses we received from the 12 manufacturers.

We first asked the manufacturers how their product differs from their competitors. We received a range of very technical responses, such as intensity, size of lamps, output, UL rating, safety features, and reflectors. We summarize the responses we received during the interviews on manufacturing devices in the technology assessment section of this report.

When manufacturers were asked the main reason why customers purchased their products, the resounding answer was to improve indoor air quality. A few manufacturers mentioned energy efficiency, but most steered away from this claim and preferred to focus on air quality, acknowledging that there are energy implications, but not wanting to claim this as a benefit.

The primary decision maker with regard to installing the UVC devices depends primarily upon the size of the company. If the company is small, then the manufacturers typically work with the presidents or a high-level executive to install the lights. If the company is very large, there are typically mechanical engineers or building maintenance operators who work with the manufacturers to install the lights.

All the manufacturers agree that very few buildings in the country have UVC lights installed in their HVAC systems. Most thought the percentage of buildings was below 5%, with more installations occurring on the South and East coasts since the cooling season is longer there. They said that the percentage of new construction that had UVC lights specified in the T24 plans was even lower than retrofit buildings. Most installations are occurring in retrofit applications since most people are reacting to existing mold and moisture problems, instead of preventing problems.

We asked the manufacturers what they thought were the main barriers to the adoption of UVC for HVAC. Many manufacturers said that the main problem is that people are just not aware of the benefits of the technology. Many people have misconceptions that the technology will produce ozone or will damage eyesight. They feel that more information needs to be disseminated that states the benefits of the technology in simple terms that are easy for people to understand.

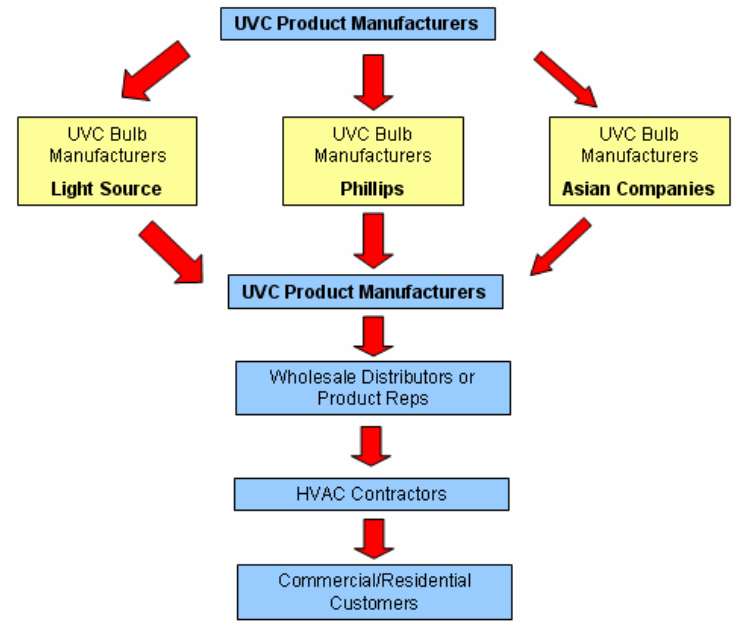
Once interest is piqued, the manufacturers said that consumers need to be shown the cost payback of the technology in terms of chemical cleaning costs vs. UVC lights and energy savings from the lights. The manufacturers were in agreement that once those obstacles were overcome, the sale is relatively easy.

All the manufacturers have noticed an increased interest in UVC for HVAC in the last few years. Many attribute this simply to the fact that information is being spread around and more people are becoming aware of the technology. Some thought that it was due to the advances in the technology.

Most of the manufacturers said they had sold some lights to CA businesses, but mostly in-room systems to hospitals. Only 3 of the manufacturers we spoke to had sold to CA K-12 schools. One manufacturer with probably the most school installations is participating in the study (Manufacturer A). A second manufacturer explained that they do not know how many schools have their lights since they sell directly to a wholesale distributor who sells to HVAC contractors (Manufacturer B). The third manufacturer also said that they do not know how many schools have their lights since they sell to a wholesale distributor who sells to HVAC contractors (Manufacturer C). The fourth manufacturer declined to participate, concerned that their customers would not want to be identified as having IAQ issues (Manufacturer D). The HVAC contractors actually work with the consumers, so most of the time they do not know who the bulbs go to, unless it is a custom installation where they need to get involved. The marketing manager tried, but found it impossible to track down that information for us.

Most of the manufacturers we talked to had a similar distribution system. Figure 1 shows how the product flow was explained to us. The UVC manufacturers are at the top of the chart. They design the product, including the ballasts and the bulb specifications. All the manufacturers then pass that information on to other manufacturers who produce the UVC bulbs. There are 2 main bulb manufacturers in the US, Light Source and Phillips. There are a few smaller companies in Asia and Europe that supply some of the manufacturers that we spoke with. The bulbs are then sent back to the UVC product manufacturers who package the lamps in ballasts and other self-contained units, create marketing material, and conduct their own testing. Most of the manufacturers then sell their product to wholesale distributors or product representatives across the country. The wholesale distributors sell directly to HVAC contractors who work with the customers to install the UVC device. Interestingly, most manufacturers do not track where the bulbs are finally installed since they do not have direct contact with the contractors.

**Figure 1: Product Flow Diagram**



The manufacturers were finally asked what share they had of the UVC for HVAC market. This was very difficult to gauge for most manufacturers since there is such a small market for these products. However the manufacturers were able to tell RLW who the biggest market players and their biggest competitors were, by counting the number of competitive bids they had submitted and won. There are only a handful of companies that have been producing this technology for more than a few years, and those companies were mentioned by most of the manufacturers: American Ultraviolet, Luminaire, Sanuvox, Steril-Aire, and UVDI to name a few. All of the manufacturers named were then contacted by RLW.

### International Ultraviolet Association

A few manufacturers referred RLW to an organization named IUVA, the International Ultraviolet Association (www.iuva.org). This organization is the only professional group that primarily serves the UV market. The primary goal of IUVA as stated on their website is:

> *...to advance the science, engineering and applications of ultraviolet technologies to enhance the quality of human life and protect the environment.*

IUVA serves all professional fields with interests in UV technology, including UV disinfection for drinking water and HVAC systems. The organization has seen increased interest in UV from all over the world in the last few years. One factor that has surely increased attention for the technology is the decision by the United States Environmental Protection Agency (USEPA) to include UV disinfection of surface water in the upcoming US drinking water regulations. IUVA was incorporated as a non-profit in April 1999 and has over 600 members in 35 countries. They sponsored their first conference on UV air treatment in November 2003. Most of the major players in the UV industry attended this conference.

RLW was told that IUVA was working to establish standards for the UVC industry. RLW contacted the executive director of IUVA to verify this fact. The executive director did confirm that the association was beginning to organize focus groups to discuss the topic of UV air treatment standards. He said that they are at the beginning phase of the process and he expects the entire process to take at least 2 years to complete. The US Environmental Protection Agency or the Department of Health are the likely organizations that would oversee the standards process, with input from IUVA. Regulation of this industry is critical to the further acceptance of the technology since some of the manufacturers feel very strongly that the UVC products on the market differ greatly. While unregulated, consumers may be purchasing products that do not produce the output necessary to reduce mold, thereby giving the entire industry a bad reputation. This situation needs to be rectified by passing regulations for the industry that mandate certain output levels and safety features on the lights that are proven to be successful through standardized testing procedures.

## *ACCA California survey*

The Air Conditioning Contractors of America (ACCA) is the largest national trade association for heating, ventilation, air conditioning and refrigeration contracting businesses (www.accacalifornia.org). Their California chapter is headquartered in Orange, CA and has a membership of approximately 450 members throughout California. RLW contacted the *Chapter Executive* of ACCA California with the intention of asking if they were aware of any reports that had quantified the extent to which mold affects HVAC systems in California.

Instead, RLW was told that CAL-ACCA would be willing to administer a short survey to their members via email, while only billing RLW for a few hours spent setting up the survey. RLW saw this as an excellent opportunity to collect primary data from the market players that were most familiar with the building component that we were studying. Additionally, the Chapter

Executive offered to include a short summary of the study in the newsletter that they send to all CAL-ACCA members. RLW sees this as an important future means of information dissemination that we can utilize in the market connections portion of the project.

RLW developed a short survey instrument that attempted to understand how extensive the mold problem was, the market penetration of each method, and why certain methods are selected over UVC lights. Although this study will ultimately report on CA K-12 schools, we wanted to ensure that we obtained as high a response rate as possible, therefore we asked contractors to restrict their responses to CA commercial buildings.

RLW primarily wanted to understand how often contractors encountered commercial HVAC systems that had coils or ductwork with visible mold growth. RLW understands that in order for mold to be visible, there must be a significant quantity of spores present. Therefore, we didn't feel it appropriate to simply ask about visible mold since many buildings may unknowingly have mold problems that materialize through IEQ complaints. Thus we included questions about how often their customers contacted them to inspect, repair, or clean their HVAC systems in response to IAQ issues, and how often they thought these IAQ issues were a result of mold or bacterial growth problems on the evaporator coil or in the ductwork.

RLW also wanted to understand what percentage of businesses have regularly scheduled maintenance contracts for their HVAC systems and with what regularity those contracts were scheduled. The contractors were then asked what services they provided in their standard maintenance contract. If they cleaned evaporator and condenser coils, they were asked what percentage of the time they ordinarily applied some basic treatments/technologies such as UVC in order to quantify the market penetration of each treatments/technologies. RLW also wanted to summarize the costs and benefits of each technology or method used to clean coils, therefore the contractors were finally asked why they used methods other than UVC lights to clean coils.

The Chapter Managers have developed a system by which they can type survey questions into a program that creates a link to an online survey that is sent via email. The CAL-ACCA Chapter Executive sent the survey to over 350 active members of CAL-ACCA. The CAL-ACCA members were sent 3 emails asking them to respond to the survey in a period of 5 days. A total of 22 contractors responded to the survey. The remainder of this section summarizes the survey responses.

Table 1 presents the rather surprising results of the question about how often the contractors encountered commercial HVAC systems that have coils or ductwork with visible mold growth. While a small percentage of contractors (5%) stated that they never encountered mold, the majority (55%) stated that they very seldom encountered mold. Another 32% said that they sometimes encountered mold, and only 9% said that they very often encountered mold. Nobody said that they always encountered mold. The key to this question is the word **visible** mold. Some of the manufacturers' websites acknowledge that the mold that may be causing IAQ problems may not be visible. Therefore, a potential barrier to the adoption of the UVC technology is if contractors do not acknowledge coil buildup as mold, but assume it to be dust or dirt fouling instead. What the survey results **do** tell us is that 95% of the surveyed contractors have encountered visible mold growth on coils. If a statistical study were completed, it would likely find that most contractors have encountered visible mold growth, therefore signaling that commercial buildings in California are good candidates for this preventative technology.

**Table 1: Visible Mold Growth**

| Commercial coils or ductwork with visible mold growth | Percent |
|---|---|
| Never | 5% |
| Very Seldom | 55% |
| Sometimes | 32% |
| Very Often | 9% |

Table 2 presents the responses given when contractors were asked often their customers contact them to inspect, repair, or clean their HVAC systems in response to an indoor air quality issue. The great majority (73%) of contractors said that they were contacted in response to an IAQ issue 'just a few times in the past'. Fourteen percent stated that they were contacted 'more than just a few times, but not on a regular basis'. The remaining 14% said they were contacted 'fairly regularly' in response to an IAQ issue. None of the contractors said that they 'never' or 'all the time' received calls regarding IAQ issues. Overall, all the contractors had dealt with IAQ complaints in the past and considering the increased interest in Sick Building Syndrome, we can only expect the number of IAQ calls to increase over time.

**Table 2: Indoor Air Quality Contacts**

| Customers contact them in response to an indoor air quality issue | Percent |
|---|---|
| Just a few times in the past | 73% |
| More than just a few times, but not on a regular basis | 14% |
| Fairly regularly | 14% |

The contractors were then asked if they thought that IAQ issues they were contacted about were a result of mold on the coils or ductwork. Table 3 presents the results by how often contractors thought this occurred. The majority (45%) thought that this 'very seldom' was the case, with 41% believing that this occurred 'sometimes'. Ten percent of contractors thought that mold was the cause of the IAQ complaints 'very often' or 'always', while only 5% of contractors thought that this was 'never' the case.

**Table 3: IAQ Contact a Result of Mold**

| How often the indoor air quality issues are a result of mold on the coil or in the ductwork | Percent |
|---|---|
| Never | 5% |
| Very Seldom | 45% |
| Sometimes | 41% |
| Very Often | 5% |
| Always | 5% |

RLW would like to present some information in the final report on the costs of a regular maintenance contract vs. installation of UVC lights. To begin the data collection needed for this comparison, we asked the contractors what fraction of California's commercial businesses have regularly scheduled maintenance contracts for their HVAC systems. Table 4 presents the results by percentage of business bins. Only 5% of the contractors said that 0-10% of CA businesses have regularly scheduled maintenance contracts. The majority of contractors (45%) said 11-25%, while 18% of contractors said 26-50%, and 32% of the

contractors said that 51-75% of CA businesses have regularly scheduled maintenance contracts.

**Table 4: Regular HVAC Maintenance Contracts**

| Businesses with regular HVAC maintenance contracts | Percent |
|---|---|
| 0-10% | 5% |
| 11-25% | 45% |
| 26-50% | 18% |
| 51-75% | 32% |

Table 5 shows the percentage of the contractors' customers with regular maintenance contracts that would fall within each maintenance time period. On average, 41% of their customers had quarterly or more often maintenance procedures scheduled. Fourteen percent of their customers had semi-annual contracts, and 6% had annual contracts. Approximately 38% of their customers had no regular contact and called them when they experienced a problem with their HVAC systems.

**Table 5: Regularity of HVAC Maintenance Contracts**

| Customers with Standard Maintenance Contracts | Percent |
|---|---|
| Quarterly or more often | 41% |
| Semi-annual | 14% |
| Annual | 6% |
| No regular contract | 38% |

Table 6 presents the percentage of contractors who stated that their standard maintenance contract with their company included the procedures listed. All the contractors replaced the filters. The most common procedures in descending order are presented in the table below.

**Table 6: Standard Maintenance Contract Procedures**

| Included in a standard maintenance contract | Percent |
|---|---|
| Filter replacement | 100% |
| Drive belt replacement | 68% |
| Refrigerant charge testing | 82% |
| Visual inspection | 95% |
| Oil and lube | 86% |
| Economizer functional testing | 77% |
| Condenser coil cleaning/fin realignment | 77% |
| Evaporator coil cleaning | 59% |
| Air flow testing | 23% |
| Air balancing | 14% |
| Other, Please Specify | 32% |

The contractors that stated 'Other' above were asked what the other procedure was that they performed. Here are those responses:

*Heating Check*

*Check motor amperage, inspect wiring for damage*

*Test and clean heater section*

*Electrical inspection, adjustments, calibrations, noise*

*Tighten electrical, functional test, noise and vibrations*

The contractors who cleaned the condenser and evaporator coils as part of their standard maintenance procedures were then asked what percentage of the time they ordinarily applied the following treatments, technologies, and methods as part of their coil cleaning. Table 7 shows that chemical treatments were used by 91% of the contractors. Water rinses, high pressure water, brushes, vacuuming, and removing the contaminated equipment were also common procedures. Fewer than 10% of the contractors said they used UVC to clean coils.

**Table 7: Coil Cleaning Treatments**

| Apply treatment as part of coil cleaning | Percent of Respondents | Percent of Time |
|---|---|---|
| Chemical treatment | 91% | 57% |
| Water rinse | 77% | 67% |
| High pressure water | 55% | 40% |
| Brush | 41% | 59% |
| Vacuum coils | 36% | 49% |
| Removal of contaminated equipment | 27% | 29% |
| Ultraviolet light (UV-C) | 9% | 10% |
| Steam cleaning | 5% | 10% |
| Compressed Air | 5% | 10% |
| Other | 5% | 8% |

The contractors that did not use UVC were then asked why they chose their method over UVC lights. Seven of the respondents stated that the technology was too expensive and customers did not want to spend the money on unproven technologies. A few respondents said that their method was faster and better than UVC lights, killing the spores in the process. Some of the other verbatim responses we received are below:

*(We prefer other methods because they are)…not installed on equipment.*

*UVC is usually an aftermarket installation, not a maintenance procedure.*

*We chemical clean our coils and have not seen a lot of mold.*

*We don't have any portable UV light setups.*

*We highly recommend UVC in situations involving high density of people, medical/labs/ or 24/7 buildings (police departments/ fire). The source of mold must be corrected, such as standing water, air borne food particles, etc.…*

## *Technology Assessment*

This summarizes the differences in the currently available UVC technologies and summarizes the key research studies that have quantified the effect of UVC. RLW asked all of the manufacturers for references to studies that quantified the effect of UVC on IAQ or energy. We received numerous references to studies and also located additional studies during our literature search. The bibliography contains a listing of the studies that we found to be the most relevant to this research project (more studies to be added later).

## UV wavelengths

Ultraviolet radiation is invisible light with a frequency just below the visible spectrum. The region of the ultraviolet spectrum is classified into three wavelength ranges and is distinguished by how energetic the ultraviolet radiation is:

- UV-A, from 315 nanometers (nm) to 400 nm
- UV-B, from 280 nm to 315 nm
- UV-C, from 100 nm to 280 nm

Ultraviolet radiation in the "A" band, or UV-A is the weakest form. It causes skin aging, wrinkles and can also damage outdoor plastics and paint. It is sometimes used to treat skin disorders. UV-B is stronger than UV-A and is the most harmful to us, having been linked to skin cancer and cataracts. Both UV-B and UV-A cause suntans and sunburns. UV-C has the shortest wavelength and can not penetrate the atmosphere to reach us. At the present time, the effect of UV-C to the human body is not clear. The World Health Organization claims that all three bands are classified as a probable human carcinogen, yet many manufacturers said that the lamps have low penetrating ability and the UVC light is nearly completely absorbed by the outer, dead layer of skin. They did say that the light does reach the most superficial layer of the eye where overexposure can cause reddening and painful but temporary irritation, but it cannot penetrate to the lens of the eye and cannot cause cataracts. We will have to follow up on this subject, however it is not exactly relevant to the application we are studying since the lamps in the HVAC systems will always be enclosed in the system.

Ultraviolet germicidal irradiation (UVGI) is another name for UV-C and has been used for more than 70 years to kill harmful microorganisms of all types in a great many applications such as food processing, water sanitation, and hospital disinfection. The germicidal wavelength of 253.7 nm within the UV-C segment is most effective at inactivating microorganisms, mold spores, and contaminants and is the wavelength claimed to be produced in the UV-C lamps by the manufacturers.

UVGI "penetrates the organism's nucleus, disrupting the molecular bonds of its DNA. This disruption or breakage renders the microbe unable to reproduce. Without the ability to reproduce, the organism dies moments later leaving no offspring. Some airborne pathogens are more resilient to the effects of UV energy than others. For instance, viruses are easier to destroy than bacteria, with mold spores requiring the largest UV dose for effective reduction.[2]"

## UVC Applications

In the past 10 years, manufacturers have started to produce UVC for HVAC systems. The manufacturers have had to adjust their main line of UVC products to work in HVAC systems because they otherwise would suffer drastic output losses and loss in "killing power" when exposed to cold and/or moving air. According to some manufacturers, not all of the products on the market have these adjustments and the lamps are not working correctly once installed in the HVAC systems since the lamps are tested at room temperature.

There are two applications within the HVAC system for UVC:

1. Placement near the evaporator coil and drain pan (discharge side), or

[2] www.ultravation.com

2. System air ducts (in return air or downstream of coil).

The first option for the lamps is referred to as “surface” microbial growth control systems since the lamps are placed directly in front of the coils to kill the mold that is growing on the surface of the coils. The second lamp types are used in ducts for “airborne” microbial control. These lamps are high intensity since the kill must occur within seconds of passing by the UV-C lamp.

## UVC Products

The product offerings and technical specifications vary widely from manufacturer to manufacturer. RLW searched for an unbiased comparison of the available products and came up with no such comparisons. As statistical researchers, we are not equipped to provide technical product comparisons, so the scope of this technology assessment is to provide an overview of some of the types of systems available on the market. We have summarized the key characteristics of systems provided by a few manufacturers without turning the section into a product comparison, but rather a summary of product offerings. We discuss a representative sampling of the available products and accessories offered by manufacturers of UVC devices for HVAC systems.

### *Manufacturer A*

Started in 1996, Manufacturer A specifically manufactures UVC systems only for HVAC applications. They manufacture 6 different series of products named ‘UVC Emitters’ that are designed for all types of applications in residential, health care, food processing, commercial, educational, and industrial facilities. Their product offerings are diverse and are available for all different types of installations such as limited access installations and roof top installations.

Their standard installation series (DE Series) lamps are designed for air and surface disinfection in medium to large systems and offers the following key features:

- Mounted singularly, end-to-end and/or in parallel on duct walls or in rack arrays to satisfy almost any HVAC cavity configuration.
- Installed anywhere in a system: coils, drain pans, return and supply ducts, mixing plenums, exhaust systems, etc
- Four sizes (18", 24", 30" and 36" lengths) and various voltage options
- Equipped with 1/2" electrical conduit openings on each end to facilitate coupling and wiring fixture to fixture and to power.
- Power source is a Class P2, electronic rapid start type with a power factor of >0.95 and a power conversion of >75%.
- Reflector is constructed of heavy gauge, specular finished aluminum alloy with a minimum 86% reflectance at 254 nm.
- Emitter tube is a very high output, hot cathode, T5 diameter, medium bi-pin type that produces broadband UVC of 250-260 nm. Each tube produces the specified output at any airflow velocity and air temperature of 35-170° F.
- Produces no ozone or other secondary contamination.

**Figure 2: Examples of Standard Installation Products and Installations by Manufacturer A**

Manufacturer A also offers products that are installed from the exterior and through the wall of HVAC equipment, making them ideal for germicidal sites that are not easily accessed internally. These products have many features that are similar to the standard mount series.

*Accessories*

- Cleaning Kits – These include disposable gloves and clean-wipes containing isopropyl alcohol eliminate any contaminants that may have been introduced during installation that may degrade the glass.
- Transformers - Allows for the installation of 208/230Vac type X-Mount Plus, NEMA 4x, UVC Emitters™ and fixtures in 480Vac equipped rooftop units.
- Radiometer - device provides visual and analog outputs to monitor a UVC system, and a NO/NC relay to actuate an alarm or provide system shutdown.

**Manufacturer B**

Established in 1995, Manufacturer B's mission was to design a line of Residential and Commercial UV Air Purifiers that would address IAQ and Sick Buildings. This company offers a wide array of products, from ceiling tile mounts to tubular systems to filter and UVC combinations. They also offer wall-mounted systems, "L" shaped coil cleaners designed for installation in front of Commercial HVAC Coils, and "walls" of UVC lights for duct installations.

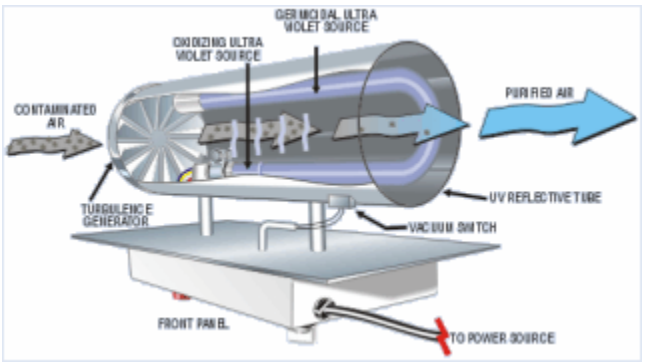
An interesting system that they offer is the tubular air purification system, which is designed to mount horizontally within the return plenum of light commercial or commercial HVAC systems and offers the following key features:

- An aluminum reflecting tube surrounding the lamp that increases the lamp's strength 3 fold. The reflective tube confines the air so that it is forced past the lamp. As well, the reflective tube protects the surrounding area from UV and allows remote

installations as well as installations exterior to the air handler and flex duct installations.

- The 'Turbulator' is a fan-like turbulence generator that slows, twists and mixes the air around the lamp, increasing the time the contaminants are suspended in front of the lamp, thereby increasing the kill rate.
- The Mercury Vapor "J" lamp within the tube has two parts, the first being the UV-V section that is used for oxidization and destroys odors in the air. The much larger portion of the lamp is UV-C that eradicates the bacteria and other microorganisms that pass through the chamber.
- Vacuum sensing switch for automatic operation, or direct hardwire to Air Handler
- Available in multiple voltages and lengths and customizable
- Produces no ozone or other secondary contamination.

**Figure 3: Example of a Product from Manufacturer B**




## Manufacturer C

Manufacturer C began in 1982 as a manufacturing company specializing in air filtration equipment designed to benefit allergy patients who needed a clean indoor environment. They more recently expanded their product line to include some UVC systems for both surface and air disinfection in commercial and residential applications.

They offer four standard UVC product lines, with the option to mount the lamps internally, or use as insert-type UVC fixture where the ballast is mounted outside the HVAC system and the lamp inside the system. Three of the product lines consist of the "stick" type fixture, with one or two bulb configurations. They also offer an extra long system for large applications that can accommodate bulbs up to 5 feet in length. Some features of their products include:

- High-intensity H-tube lamp design
- Installation brackets for easy install
- Multi-voltage electronic ballast
- Lampholders simplify lamp replacement
- Air handler viewport
- Multiple lamp lengths
- NEMA 4X weatherproof enclosure

- Tilt-Lamp capability
- Optional remote safety interlock
- Limited lifetime warranty
- Dual safety devices that have earned an ETL safety listing.
- Single or dual bulb configurations
- Produces no ozone or other secondary contamination.
- Remote mounted lamp capability that allows placement of one, or two of the lamps anywhere within 6 feet of the chassis.

**Figure 4: Examples of Standard Products from Manufacturer C**

## *Summary of UVC Literature*

### *GSA adoption of UVC*

The U.S. General Services Administration follows certain standards for all Public Buildings Service, including HVAC, electrical, safety, landscape, etc. The following recommendation is taken from the 2000 GSA Facilities Standards document, #5 Mechanical, section 5.4, Drains and Drain Pans[3]:

> *"Ultraviolet light (C band) emitters shall be incorporated downstream of all cooling coils and above all drain pans to control airborne and surface microbial growth and transfer."*

### *Air-Conditioning and Refrigeration Technology Institute (ARTI) Study*

ARTI published a report in November 2002 that investigated the ability of UVGI lamps to inactivate **airborne** environmental microbial aerosols in ventilation devices. The researchers found that a single lamp inactivated more than 50% of the vegetative organisms that were protected bvy organic material or increases in humidity. They found that bacterial or fungal spores were much more difficult to kill and required the use of 6 times as many lamps.

Key factors for designing UVGI systems is lamp irradiance **at operating conditions**, microbial resistance data, having a tested bioaerosol dose model, and duct wall reflectance. Of the physical factors that might influence UVGI lamp performance (output), air temperature and flow rate, lamp design, and ballast design were found to be the most significant[4].

[3] The complete GSA document can be found at: http://hydra.gsa.gov/pbs/pc/facilitiesstandards/, pg 125

[4] VanOsdell et al. 2002, pg ii

The study compares different lamp parameters that are critical to the performance in the air ducts[5].

**Air temperature and Velocity –** The UVGI output is optimized at certain design temperature depending on the material in the lamp wall. Some manufacturers use quartz lining and other products to insulate the lamps. The lamp output is reduced when the temperature increases or decreases from the design temperature. Low temperatures can also reduce the operating life of lamps. Increased air flow increases heat transfer and can cool the lamps below their optimum temperature.

**Humidity –** Water molecules absorb UV, so increased absolute humidity should reduce the effectiveness of UVGI.

**Lamp and Ballast Design –** No standard rating tests are performed on lamps/ballasts making decisions difficult for consumers. High-output lamps are driven by electronic ballasts, low-output lamps are driven by magnetic ballasts. High-output lamps are designed to operate at lower temperatures, and are thought to be low-pressure lamps operated at higher power loads than the low-output lamps. Low-output lamp irradiance degrades greatly as the temperature drops below 58 degrees.

**Reflectance –** Effective irradiance delivered to the microorganisms is increased thorough reflected UV energy.

**Location–** Microorganisms located in shaded or protected regions will not be irradiated.

**Ozone –** Ozone production was not detectable in this study.

The research also supports our findings that the industry does not use a standard test to measure UVGI lamp output that is presented in most sales literature. Therefore, the lamps are difficult to characterize, except through direct measurement[6]. The research arose out of a desire of the ventilation industry to independently evaluate manufacturers' claims and design guidance of UV lights. It was sponsored by: the U.S. DOE, ARI, Copper Devlopment Association, NYSERDA, Refrigeration Service Engineers Society, and Heating, Refrigeration and Air Conditioning Institute of Canada.

### *The Lancet Medical Journal*

In a study recently published in *The Lancet* medical journal, scientists assessed whether ultraviolet germicidal irradiation (UVGI) of drip pans and cooling coils within ventilation systems of office buildings would reduce microbial contamination, and thus occupants' work-related symptoms[7]. The study found that the lamps resulted in substantial reduction of viable microorganisms on exposed surfaces, and a large fall in workrelated symptoms in 771participating office workers. The research was sponsored by the Medical Research Council, The National Institute for Occupational Safety and Health (NIOSH), and Sanuvox, Montreal, which manufactured and installed the UV lamps.

The study was conducted in 3 office buildings in Montreal, Canada over a period of 48 weeks. The UVGI systems were alternately turned off for 12 weeks then turned on for 4 weeks, for a total of 3 controlled interventions by the team. The scientists found that the lights reduced overall sickness by approximately 20% and respiratory problems by 40%.

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[5] VanOsdell et al. 2002, pgs 21-30

[6] VanOsdell et al. 2002, pg 6

[7] Menzies et al. 2003, pg 1785

The researchers estimate that since the office or office-like indoor environment is now the workplace for more than 70% of the work force in North America and Western Europe, the installation of UGVI in most North American offices could resolve work-related symptoms in about 4 million employees, and economic benefits of $5–75 billion per year in the USA alone.

The use of UVGI led to a 99% reduction of microbial contamination on exposed surfaces, but airborne microbial levels did not fall by much (25-30%). The researched proposed the following potential reasons for this finding[8]:

- Amounts of airborne fungi and endotoxins were too low to detect a significant difference,
- The remaining airborne bacteria might have been from local sources, including the workers themselves;
- UVGI reduced growth of fungi and bacteria associated with common ailments (sinusitis, asthma, or influenza)
- UVGI reduced the aerosolisation of microbial antigenic proteins.

The article went on to estimate the cost of installing UVGI in the ventilation system of a generic 11,148 square meter office building with 1000 occupants would cost US$52 000, and $14 000 per year for energy, maintenance, and bulb replacement (estimates from manufacturer)[9].

### *Norwegian Defense State Agency Study*[10]

The authors of this study investigated the effect of UVC on IAQ in a ventilatioin plant in a typical office building. They ran a controlled experiment by applying UVC lamps to one AHU and leaving the second AHU serving a different part of the same building without lamps. The researchers sampled and tested the amounts of airborne mold spores, MVOC (microbial volatile organic compounds), and microorganisms on surfaces throughout the ventilation plant and corresponding rooms. Contrary to Mensies' conclusions, they found no significant differences between spore counts taken before and after the application of the UVC to the air handler units. They conclude that UVC-irradiation has no detectable effect on IAQ, in any case not to affect IAQ with respect to microbes in buildings where the concentration of microbes is initially low. They go on to say that general recommendations to install UVC-systems in HVAC-plants are not justified, but they may be useful in buildings having problems with moldy filters, hence reducing mold growth and odoriferous volatiles.

### *The Effects of UVC in a Commercial Office Building*

Three professors at the University of Tulsa, Oklahoma undertook another study similar to the two previously mentioned studies[11]. Again this study included the installation of UVC lamps in the AHU of an office building during the summer in a hot and humid climate. Air, bulk, and water samples were taken prior to and after UVC installation. The researchers found a positive correlation between operation of the UVC lamps in the AHUs and the reduction of microbial growth in duct lining samples and drain pan water samples. They concluded that the effect was a direct line-of-sight mechanism of reduction.

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[8] Menzies et al. 2003, pg 1790

[9] Menzies et al. 2003, pg 1791

[10] Pettersen et al. 2003

[11] Shaughnessy et al. 1998

### *Current Trends in UVGI Disinfection*

This study reports on the general UV-C technology and a potential guideline for a rating value for UVGI[12]. Dr. Wally Kowalski, a lead researcher in the UVGI field at Penn State University, is working on guidelines to facilitate the sizing and selection of systems tailored for specific applications. An aspect of these proposed guidelines involves the specification of a UVGI Rating Value (URV) for air disinfection systems that parallels the ASHRAE 52.2-1999 method for testing and rating filters known as MERV (minimum efficiency reporting value). The proposed rating system would be based upon average intensity, dosage, and the corresponding kill rate. The researchers believe the URV would result in standardization of system sizes and eliminate confusion about system performance.

The study goes on to discuss how UVC is used as a means of protecting indoor environments against bioterrorism threats by providing an additional level of air disinfection.

### *Dimensional Analysis of UVGI Air Disinfection Systems*[13]

This study used dimensional analysis to evaluate the factors that contribute to effective UVGI systems. The authors concluded that the eight most significant parameters that determine performance of diffusively reflective UVGI systems are shown to the dose, the reflectivity, the duct geometry, the lamp aspect ratio, lamp location, and various combined functions of these parameters.

Principal among the parameters is the proximity effect, or the phenomenon that locating lamps close to diffusive reflective surfaces can increase the average intensity of the enclosed UV field which can lead to a 25% or greater improvement in system efficiency.

Another observation that is made is that at some unspecified level of performance, the gains in kill rate due to increasing power diminish in comparison to the gains to be had from increasing reflectivity. This can result in energy savings that can be realized by enhancing the effectiveness of the UVC by specifying highly reflective panels in a UVC system.

### *Mold Remediation*

RLW searched a variety of websites (accheckup.com, electrofin.com, etc.) on coil mold remediation and found that many mold remediation procedures did not call for UVC. A typical coil cleaning consists of a vacuum, water spray, cleaning solution, and a water rinse, with the chemical makeup of the cleansing solutions varying with each contractor. Some of the characteristics of the coil cleaners on the market are: hypoallergenic, biodegradable, not harmful to coil or wiring, non-flammable, removes chlorides, bleach, and acid. The price varies depending on the scope of the job, but is generally inexpensive at approximately $100 to $300 per cleaning.

RLW did encounter the National Indoor Air Quality Institute (www.niaqi.com/hc-diy-hvac.html) website that offers training to contractors on how to properly handle mold remediation in HVAC systems. They first recommend fixing the source of the moisture problem by fixing pipes, roofs or walls, or reducing humidity levels. They offer a “Mold Remediation Kit” that contains a chemical remover, a biocide to prevent future mold growth, and UVC Lights.

[12] Kowalski et al. 2002

[13] Kowalski et al. 2003

# Deliverables

## *Manufacturer Call List*

Confidential

Manufacturer Interview Guide

Hello, my name is _____, I am calling on behalf of the California Energy Commission's Public Interest Energy Research Program (PIER). As part of the current PIER study, we are researching the energy saving and IAQ benefits of using UVC lights in HVAC systems. We are calling on UVC manufacturers to better understand current UVC products and technologies, market barriers, product availability, customer demand, markets served, and available research. Would you have time to discuss your UVC product line with us?

*Name:* _____ *Phone 1:* _____

*Title:* _____ *Phone 2:* _____

*Company:* _____

## UVC Product Specifications

Q1. Can you tell me a little bit about your particular UVC product line? How does it differ from your competitors? (Coil or Duct placement?)

_____
_____
____

Q2. What are the reasons why customers purchase your products? (Reduce HVAC consumption, IAQ, reduce maintenance, odors) Are there any special features that convince people to buy?

_____
_____
____

Q3. Who are the primary decision makers?

_____
__

Q4. What are the market barriers that are impeding this technology from becoming more widely adopted and used? *(Try to prioritize responses)*

_____
_____
____

Q5. What are some alternative technologies that are used to mitigate mold in HVAC systems (coils, ducts)? How do those compare with UVC lights? Which are most commonly used (try to get market share)? Are any standard practice?

_____
_____
____

Q6. Can you estimate the percentage of existing buildings in CA that have HVAC-related mold and mildew? How do you think that affects performance? How many of those buildings use UVC lights to mitigate the mold? Does that differ across the country?

_____
_____
____

Q7. What percentage of the new commercial buildings that are currently being constructed in CA have UVC lights installed on their HVAC systems? Does that differ across the country?

_____
_____
____

Q8. Do you manufacture UVC lighting products for residential use? How about for commercial use? (If feasible, ask for percentage breakdown)

_____Residential
_____Commercial ***(if NO commercial, THANK AND TERMINATE CALL)***

## Marketing

Q9. This study consists of a market connections component. How could we present UVC information that will help you sell your product? (i.e. performance uncertainties)

_____
_____

Q10. What obstacles need to be overcome in making the sale? Do you have marketing materials that help you overcome these obstacles? Could you share these with us?

_____
_____

Q11. What sort of trends have you seen in the UVC lighting industry over the past few years? For example has demand for UVC lighting changed, is customer awareness noticeably different, has the technology changed, etc.) What market influences do you think have driven these recent industry trends?

_____
_____

Q12. We are looking for reports that can help us better understand this technology, such as information on market barriers, energy savings, and IAQ benefits. Do you have anything like this that you might be willing to share with us?

_____
_____

## Markets Served

Q13. Do you currently have commercial customers in <u>California</u> that are buying UVC lighting products?

01 Yes
02 No (***Skip to Q15 – only ask about sales outside of CA*** )
03 DK: Who would?_____
04 Refused ***(Skip to 0 if you think that they may be willing to share data, If not Skip to Q16)***

Q14. Regarding your commercial sales **in California**, what types of commercial customers are purchasing UVC lighting systems from your company? Do you know approximately what proportion of your sales go to these markets?

Q15. Do you have any information on what market share your company has on UVC lighting product sales **in California**? Outside of California?

_____
_____

**(ONLY IF THEY SELL TO CALIF. SCHOOLS)** We are looking to expand our study to include other manufacturers. Would your company be willing to share its UVC sales data with the researchers of this study?

05 Yes/Maybe ***(Great. I'll have our project manager contact you this week to discuss the specifics of the study)***
06 No
07 Don't Know: Name _____ Phone: _____

## Operation and Maintenance

Q16. Do you have installation instructions regarding placement of the lamps? How about operation and maintenance instructions for the lamps?

_____
_____

Q17. Are these instructions different from those of your competitors? If yes, how do they differ?

_____
_____

Q18. Who are your biggest competitors?

_____
_____

Thank you very much for your time. This information will be very useful in advancing UVC technology in the market.

## *ACCA California Survey*

RLW Analytics, Inc. is conducting a study on behalf of the California Energy Commission's Public Interest Energy Research Program (PIER). The goal of this project is to determine if ultraviolet light in the "C" band (UVC) is effective in reducing HVAC-related mold and mildew, thereby improving indoor environmental quality (IEQ) and reducing energy consumption through improved heat transfer. One component of the study is to compare the different methods and technologies used to control mold in HVAC systems. As a CAL-ACCA member, RLW is soliciting your input on any mold mitigation techniques used in your current practice on **California commercial** buildings. Your input is greatly appreciated.

1. How often do you encounter commercial HVAC systems that have coils or ductwork with visible mold growth?
    1) Never
    2) Very Seldom
    3) Sometimes
    4) Very Often
    5) Always
    6) Not sure

2. How often do your customers contact you to inspect, repair, or clean their HVAC systems in response to an indoor air quality issue?
    1) Never
    2) Just a few times in the past
    3) More than just a few times, but not on a regular basis
    4) Fairly regularly
    5) All the time, one of my most common complaints

3. How often do you believe these indoor air quality issues are a result of mold or bacterial growth problems on the evaporator coil or in the ductwork?
    1) Never
    2) Very Seldom
    3) Sometimes
    4) Very Often
    5) Always
    6) Not sure
    7) Not applicable (no reported IAQ problems by my customers)

4. Based upon your experience in the industry, what fraction of California's commercial businesses have regularly scheduled maintenance contracts for their HVAC systems?
    1) 0-10%
    2) 11-25%
    3) 26-50%
    4) 51-75%
    5) 76% or more
    6) I have no idea

5. For each of the following categories, please report the approximate percentage of your customers that would fall within each:

1) _____% of my customers have **quarterly** maintenance contracts set up with my company.
2) _____% of my customers have **semi-annual** maintenance contracts set up with my company.
3) _____% of my customers have **annual** maintenance contracts set up with my company.
4) _____% of my customers **do not have regularly scheduled** maintenance contracts, instead they usually call when something is not working properly, or when they are experiencing comfort problems.

6. A standard maintenance contract with my company will typically include the following activities…

| | "X" if Included |
|---|---|
| 1) Filter replacement | |
| 2) Drive belt replacement | |
| 3) Refrigerant charge testing | |
| 4) Visual Inspection | |
| 5) Oil and lube | |
| 6) Economizer functional testing | |
| 7) Condenser coil cleaning/fin realignment | |
| 8) Evaporator coil cleaning | |
| 9) Air flow testing | |
| 10) Air balancing | |

7. When cleaning evaporator and condenser coils, what percentage of the time do you ordinarily apply the following treatments, technologies, and methods as part of your cleaning?

| | Percent |
|---|---|
| a. High pressure water | |
| b. Chemical treatment | |
| c. Water rinse | |
| d. Vacuum coils | |
| e. Ultraviolet light (UV-C) | |
| f. Removal of contaminated equipment | |
| g. Brush | |
| h. Steam cleaning | |
| i. Other | |

8. (If UVC not used) Why do you use that method over UVC lights?

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# CONFIDENTIAL - Names of Manufacturers

| Manufacturer Code | Name |
|---|---|
| Manufacturer A | |
| Manufacturer B | |
| Manufacturer C | |
| Manufacturer D | |