

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

Attachment IV Applications Guidelines for Displacement Ventilation and UVC Applications

CONSULTANT REPORT

Prepared For:

California Energy Commission
Public Interest Energy Research Program

Prepared By:

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

Applications Guide for Off-the-Shelf
Equipment for Displacement Ventilation Use

CONSULTANT REPORT

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Objectives

These guidelines provide a primer on displacement ventilation to introduce the concept to school facility decision makers, equipment specifiers and manufacturers. An introductory overview leads to a discussion of benefits and application considerations that shows each of these market participants when to consider displacement ventilation. A discussion of equipment information, product offerings and recommendations is designed to assist school officials and specifiers in making a preliminary assessment of the equipment that could meet their needs. This information is also provided for manufacturers to help them see how their product offerings might be expanded to meet the expected increasing demand for this emerging technology.

Summary

These guidelines begin with an overview of indoor air quality, acoustics, comfort, and energy use problems in K-12 schools, and how displacement ventilation can help solve these problems. Case studies are presented that illustrate that DV has worked in schools and other buildings around the country. The conditions favoring displacement ventilation are then outlined illustrating that K-12 classrooms in California are an attractive application for displacement ventilation. Design considerations for DV in schools are noted and equipment considerations, selection information, and product options are presented for mechanical equipment (packaged systems and chillers), controls and diffuser selection. Recommendations are provided as to the steps to be taken in effectively implementing displacement ventilation systems in K-12 schools in California

The problem and the displacement ventilation solution

Poor environments in schools influence the health, performance and attendance of students. Many existing school space conditioning systems using conventional mixed ventilation systems fail to provide the indoor air quality, acoustics, and comfort that can produce optimal student and teacher performance.

Displacement ventilation (DV) is a cost effective means of providing an optimal indoor environment by delivering cool supply air directly to the occupants in a space. The air is cooled so that it enters the room at about 65 °F, considerably warmer than with a conventional air conditioning system. The fresh air, supplied near the floor at a very low velocity, falls towards the floor due to gravity and spreads across the room until it comes into contact with heat sources. The cool supply air rises as it picks up heat from occupants and equipment. The warm, stale air ascends to the ceiling where it is exhausted from the space. This vertical airflow pattern near each occupant often referred to as a *thermal plume*, makes it less likely that germs will spread horizontally across the room. This air distribution system provides for effective ventilation, since the fresh supply air is delivered directly to each occupant. All these advantages can be provided at a first cost that is comparable to that of less effective conventional mixed ventilation systems that rely on creating fully mixed air in the room.

What are the benefits of using displacement ventilation systems in schools?

The learning environment will be improved in a way that delivers more fresh air to the students and teacher, while controlling noise, providing comfort and reducing energy use. These healthy surroundings should result in improved health, (lowered absentee rates) and better productivity (higher test scores)

Indoor air quality should be improved

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 attendance levels. There is also persuasive evidence that microbiological pollutants are associated with increases in asthma effects and respiratory infections, which are both related to reduced school performance and attendance.¹ Displacement ventilation systems offer an effective, energy-efficient means of delivering fresh air and removing airborne pollutants to improve classroom air quality.

Indoor air quality is improved since the rising thermal plumes carry away contaminants towards the ceiling exhaust. This air pattern also inhibits transfer of pollutants from one student to another and between the students and the teacher. Improved ventilation effectiveness with displacement ventilation provides better pollutant removal and enhanced indoor air quality than achieved with a mixed ventilation system.

Background noise can be reduced

Displacement ventilation can improve acoustics because of the low background noise caused by low supply air velocities and the remotely located cooling and delivery equipment. Both these features aid in designing to ANSI recommendations. This is of particular advantage when compared to unit ventilators or wall-mounted equipment. The low velocity air leaving the diffuser is very quiet compared to the noisy, inrush of air often experienced with mixed ventilation system diffusers. As a result, building acoustic standards are more easily achieved with displacement ventilation systems. It will no longer be necessary to turn off the air conditioner in the classroom to be able to hear the students and teachers

How does it save energy?

There are several reasons behind the cooling energy savings with DV. First and foremost, the higher supply air temperature (SAT) of 65°F greatly increases the potential for free cooling. In some California climates, there are 2,000 hours annually when the outside temperature is between 55 °F and 65°F. This benefit is especially evident in coastal California climates.

Secondly, the higher supply air temperature also increases the efficiency of mechanical cooling equipment. There is less “lift” – less work required for the compressor to raise the refrigerant pressure and temperature before it reaches the condenser.

Finally, since warmer air is exhausted from the ceiling return, DV systems reduce cooling coil loads. There are two zones in the classroom, a stratified occupied zone and a mixed upper room zone. Much of the heat from the upper part of the room never enters the occupied zone and thus does not have to be removed by the cooling system.

Each of these savings contributes to a large cooling energy savings.

What does it cost?

The additional costs of the displacement ventilation systems are for the low-velocity displacement diffusers and for the enhanced compressor capacity control needed to maintain the flow rate and temperature. The displacement diffusers carry a slight cost premium of about \$1 to \$2/ft² over a conventional set of four ceiling diffusers per classroom.² However, some of this is offset by the simplification of ductwork. In some cases, using displacement ventilation provides an opportunity to downsize cooling equipment, which will also offset some of the added diffuser and capacity control cost. Practitioners of these systems have found that construction costs of schools using displacement ventilation are quite comparable to first costs of an average school construction project using mixed ventilation.

What field experience do we have to show that displacement ventilation works?

Displacement ventilation has been used in schools in the Northeast and Midwest since the 1990s, and has recently been installed in demonstration schools in California. Several school examples have been documented where DV systems have made a significant difference in changing the culture, providing fresher air, relief from asthma and other disorders, creating a fresher environment with fewer absences. A teacher in Boscawen, NH suffering from asthma and other complaints with the previous systems had perfect attendance after the displacement ventilation systems were installed.³ Student absentee rates also fell. In a school in Overland Park, KS, the culture has changed as result of installation of displacement ventilation systems. Where teachers had been complaining of poor indoor air quality, they now cannot believe the difference that the new systems have made.⁴ In Elk River, Minnesota visitors to a school with displacement ventilation often note that the air seems noticeably fresher than in traditional buildings.⁵ In Howell Township in New Jersey 60% lower absentee rates were obtained as a result of use of displacement ventilation systems.⁶ Several school districts that have used displacement ventilation systems now specify them as a requirement for new schools and major remodels.

Under a research program sponsored by the California Energy Commission, a displacement ventilation and a standard mixed ventilation system were installed, instrumented and operated in adjacent classrooms at the Kinoshita Elementary School in the Capistrano Unified School District in Orange County, California. The DV system used a packaged rooftop unit with a variable capacity scroll compressor capable of delivering a continuous flow of 62°F to 65°F supply air. The mixed ventilation system used a standard packaged unit delivering 55°F air to the classroom. The DV conditioned classroom had consistently lower CO₂ levels at the return than in the occupied zone,

illustrating that a stratified room air distribution was created that effectively swept pollutants out of the occupied zone. The acoustics were consistently better for the DV classroom (40-44dBA) compared to the control classroom (48-50dBA). After a calibration period that corrected faulty economizer and room air temperature settings, the DV system cooling savings were 39% for the month of November 2005. Savings were principally due to the extended economizer range of the DV system and the reduction in cooling load in the occupied zone. Teacher feedback has been positive with the teacher in the displacement ventilation system saying; “It’s like walking in fresh air, like being outside all the time. During open house all the other teachers wanted to know when they’re getting one in their classrooms.”

What applications could benefit most from use of displacement ventilation?

The best applications of displacement ventilation are those that meet the following requirements.

Facility Requirements

- Minimum ceiling height of 9 feet (in order to develop the thermal stratification and pollutant concentration gradients needed to make the concept effective)
- High performance windows, preferably double-pane, low- ϵ (emissivity), to minimize radiant heat loss and cold downdrafts
- Floor space allocation for at least two low-velocity diffusers per classroom (each can be on the same wall near the corners of the room), with each diffuser taking up about 1.5 ft² of floor space and 5 ft² of wall space. For very large spaces with a linear floor dimension greater than 35 feet, four diffusers are recommended with an additional two diffusers on the opposite wall.
- Avoid stationing occupants within 2 to 4 feet of the diffuser to prevent drafts and disturbance of the airflow pattern
- Exhaust should be located at or near the ceiling (to permit the hot air in the unoccupied zone to be readily exhausted to the exterior of the room)
- Thermostats should be at least 6 to 8 feet from the nearest supply diffuser to assure representative room temperature readings
- Tight envelope requirements with insulation exceeding Title 24 requirements if the low velocity displacement diffusers are to be used for heating

Acoustics Requirements

- The low velocity (40 to 70 ft/min) diffusers used with displacement ventilation can help meet the ANSI S12.60 Acoustics Standards and the Collaborative for High Performance Schools criteria that background noise is at a level of 35dBA or less for core learning spaces. These ratings will permit effective student-teacher interactions while the HVAC is running.
- Specify diffusers that will provide a Noise Criteria rating of NC 27 or better

Climate-Related Issues and Approaches

- Provide a perimeter heating system in climates such as Truckee where the winter design dry bulb temperature is lower than 15°F. For all other climates in California, if the building meets Title 24 requirements, the heating needs can be

met by supplying air at 80 to 90°F and 1100 ft³/min through the low-velocity displacement ventilation diffusers.

- Humidity control issues may be of importance for Southern California coastal climates or in areas where heavy irrigation requirements or other moisture sources could create high humidity. Indoor moisture sources can be very important in this regard, as well. In these cases, consider augmenting the displacement ventilation system with ancillary humidity control equipment or techniques when the absolute humidity would otherwise be greater than the indoor design limit recommended by ASHRAE 55-2004 (of .012 lbs of moisture per lb of dry air) for more than 10% of the time. Humidity control options to be considered should include return air bypass, mixed air bypass, runaround coils and condenser or exhaust air heat recovery.
- The displacement ventilation systems should be able to handle the cooling loads of all classrooms built to Title 24 requirements without need for an auxiliary cooling system. Displacement ventilation systems should be able to handle cooling loads of up to 25 BTU/hr-ft².
- Many hours between 55°F and 65°F to take advantage of increased economizer use and consequent energy savings (Southern California coastal regions, with a long mild cooling season, will see the greatest economizer benefits.)

Indoor Air Quality and Other Issues

- Contaminants are lighter than the surrounding air (this enables the thermal plume to entrain contaminants such as volatile organics and microorganisms)
- Indoor air quality is an issue (the improved ventilation effectiveness and consequent feeling of “freshness” is a major plus for DV)
- Densely occupied spaces , with steady occupancy, low levels of disturbance
- Internal cooling loads dominate to take advantage of the thermal plume effect

The climate conditions that favor displacement ventilation, reasonable cooling loads, low heating loads and low humidity all are present in much of California. The importance of fresh air and good indoor air quality are clearly important issues in California with a track record of no-smoking ordinances and concern for air quality. Good learning environments are important for everyone with an interest in our schools, children and teachers.

Ceiling heights of 9 feet or greater, dense and steady occupancy with low levels of disturbances are all present in most California classrooms, particularly at the elementary levels.

Designing displacement ventilation systems for K-12 schools

The Displacement Ventilation Design Guide: K-12 Schools⁷ provides details on the design of displacement ventilation systems for schools. In addition to the items mentioned in the previous section, the following elements should be considered in this design.

HVAC System Requirements

- Control supply air temperature to within 3°F of the set point (~65°F), this will typically require a level of control that cannot be achieved with single stage packaged units. This will typically require a system with multiple cooling stages or a variable speed compressor. Systems with only two cooling stages may meet this requirement if hot-gas bypass is used at low load conditions. Typically this will often require a programmable controller or controls capable of discharge air temperature control.
- Control of the space temperature should be maintained by varying the supply air volume, supply air temperature, or both. A constant air volume system is possible but a variable air volume (VAV) system is recommended as the preferred control strategy. Designs that permit capacity control in order to vary supply to match cooling demand will facilitate maintaining stratification with a steady flow of air
- When using the low-velocity diffusers for heating, a supply air temperature of 80-90°F is recommended. This requires a low heating stage (35 MBH) when using gas heating.
- For systems that do not provide 100% outside air, an integrated, fully-modulating economizer (not two-position) with either differential dry-bulb or differential enthalpy control (preferably factory-installed, but could be an original equipment add-on)
- A low-ambient setting is recommended for the economizer, so that the outside air is blended with return air to maintain the minimum required supply air temperature when the outside air temperature falls below the minimum allowable supply air temperature, typically 62°F for classrooms.

Diffuser Requirements

- Use low face velocity (40 to 70 ft/min) supply air delivery
- Use two diffusers per classroom with a combined noise criteria of NC27 or lower for classroom spaces
- Locate diffusers along an interior wall, common wall or exterior wall to deliver air low in the space
- Locate returns at or near the ceiling

Optional HVAC Systems Features

- Variable-speed drive capable to reducing fan speed and fan power during part-load conditions. VAV control is preferred for several reasons: it saves energy, it promotes stratification in the space, which is one source of the energy benefits of DV, and it reduces indoor noise levels and the potential for drafts during reduced air flow. VAV is the preferred method of control but is not a fixed requirement.
- With VAV control, the economizer should incorporate an adjustable minimum damper position, so that the outside air volume can be maintained as the fan speed is reduced.
- Demand-controlled ventilation can save energy when the displacement ventilation system provides good ventilation effectiveness by reducing the amount of outside air intake required to provide good air quality in the breathing zone. The CO₂ sensor should be located in the occupied zone of the space.

- The supply air temperature set point can be reset higher during low load conditions, thus extending the range of economizer cooling.
- The HVAC system may need to be augmented with additional heating dehumidification and cooling capability to meet the diverse needs of the extreme heat, cold and humidity that could be present in some locations in California.

There are three main components that need to be addressed in the design and specification of the displacement ventilation system; the mechanical system, the controls and the delivery system (the diffusers). The issues surrounding each are itemized in the sections above.

Mechanical system options

The main attributes to be provided by the HVAC system are the ability to deliver 65°F supply air, a steady flow of 1000 to 1200 cfm for typical classrooms, the ability to provide heating with a morning warm-up sequence to heat the room to the set point prior to occupancy, the capability for providing humidity control without reheat, and the means to take advantage of the increased economizer hours between 55°F and 65°F. There are several mechanical system options that could be used to achieve these objectives as discussed in the following sections:

Central Plant

One way of providing these attributes is with a central plant providing chilled water using a centrifugal or positive displacement chiller. This type of system would use a chiller, central boiler and either rooftop air handling units or if the space and acoustic design permits, fan coil units. Supply air temperature to each classroom can be controlled to nearly any set point with the hot and chilled water valves on each air handling unit. Chilled and hot water temperature reset strategies allow energy efficient, comfortable operation at part load. The advantages of this type of approach are good overall energy efficiency, individual temperature control for each classroom, reheat requirements are small or nonexistent, application to DV is controls-based and straight forward to implement. Disadvantages are high capital cost, high level of maintenance training required to support this system, and reliance on one mechanical system for many classrooms; creating a potential significant comfort problem should the unit not be operable.

The equipment should have at least three cooling stages, and permit a design chilled water set point of 51°F with a 10°F differential at the cooling coil. DDC controls should be provided with capability for chilled and hot water temperature reset. The air handling unit should incorporate an integrated economizer with differential dry-bulb or differential enthalpy control.

The sequence of operation and control of the central plant is suggested to have a nominal supply air temperature set point for cooling of 65°F with reset from 62°F to 68°F as the return temperature varies from 80°F to 74°F. The nominal supply air temperature for heating is suggested to be 85°F with reset from 80°F to 90°F as the return temperature

varies from 70°F to 60°F. During morning warm up the heating supply air temperature set point can be set to 110°F.

The integrated economizer should use a differential dry bulb control and high temperature (75°F) and low temperature (50°F) lockouts. The cooling valve should control the supply of any additional cooling capacity that cannot be met solely by the outdoor air. During economizer operation the dampers should be modulated to maintain the cooling supply air temperature set point.

The central plant can be used with fan coil units that contain heating and cooling coils. The fan coils typically provide a constant air volume. Another option is to have a large air handling unit that serves multiple classrooms or school spaces. The units can include a variable speed drive with variable air volume control for fan energy savings during periods of reduced loads. This option provides greater control flexibility afforded by the fan coil units. For example, the large air handling units come with DDC controls, programmable control strategies such as supply air reset, variable air volume control and economizer control.

The Air-conditioning and Refrigeration Institute (ARI) maintains a Directory of Certified Product Performance on their web site; <http://www.aridirectory.org/index.html> The Directory provides listings for five manufacturers of air-cooled rotary screw positive displacement chiller with a total of 32 products cited. The water-cooled chiller listings contain information on 79 centrifugal compressor units produced by four manufacturers (Carrier, McQuay, Trane and York), 3 positive displacement reciprocating compressor units manufactured by Carrier, and 64 positive displacement screw compressor chillers produced by five manufacturers (Carrier, Dunham-Bush, McQuay, Trane and York).

Packaged Direct Expansion (DX) Variable Air Volume (VAV) Systems

These systems typically employ multiple stage or variable capacity compressors with multi-speed fans and are at least 15 tons (180,000 BTU/hr) in capacity. As such these systems would handle the space conditioning requirements of several classrooms. For example a 25 ton unit could serve a wing of 8 classrooms. The systems should have a minimum of three cooling stages without the use of hot gas bypass, and with turndown capability to 33% of full capacity. These systems should use thermal expansion valves, modulating natural gas heating, VAV control with a variable frequency drive and static pressure reset and a modulating powered fan. The units should also have an integrated air side 100% economizer, flexible programmable controls, and a discharge air temperature sensor. Optional features include differential enthalpy controls, return air bypass or dampers for humidity control, and supply air temperature reset control.

Control set points are similar to that described for the central plant. Supply air temperature can be controlled by compressor staging. The economizer should be integrated with the first cooling stage. Classroom temperature control is achieved by varying the terminal damper position to vary air volume to the space. The boxes should allow a minimum airflow that is 30% or less of the design airflow, to minimize potential

for overcooling. In heating classroom temperature control is also achieved by varying the box damper position.

The economizer should be configured as an integrated economizer with differential enthalpy control. The DX cooling supplies any additional cooling that is required that cannot be met by outdoor air alone. During economizer operation, the dampers should be modulated to maintain the supply air temperature set point for cooling. Although not a standard part of the controls package, a low limit may be required to limit economizer operation during low outdoor temperatures. The logic for the modified supply air temperature settings as well as resets would need to be included in the packaged unit controller's logic. Supply static pressure is maintained by modulating the fan speed to maintain a fixed static pressure. A minimum fan speed is set to ensure proper system operation under low load conditions.

The Air-conditioning and Refrigeration Institute (ARI) maintains a Directory of Certified Product Performance on their web site; <http://www.aridirectory.org/index.html> The Directory provides listings for 26 manufacturers of Unitary Large Equipment with 63 different brands and 817 products.

Packaged Single Zone Direct Expansion (DX) Units

These units typically 3 to 5 tons in cooling capacity, with each unit conditioning a single class room, are the preferred systems for many California classrooms. These units are relatively simple (with a single speed compressor and fan) compared to the other options discussed and therefore require the least sophisticated operator training. They are also relatively inexpensive and easy to install. Failure of one of these units will not impact the space conditioning of the other spaces in the school. On the other hand, since the loads are often significantly less than design levels, the systems will cycle on and off to meet the sensible loads. This reduces the equipment efficiency and can also compromise student comfort.

For displacement ventilation, it is desirable that the HVAC system have some means of capacity control and maintaining the supply air temperature above the minimum set point (63-65°F). Most existing packaged single zone units do not have capacity control or the ability to deliver air at these temperatures and as such cannot be recommended for displacement ventilation systems.

There are several packaged unit options that are on the market, or are soon to be on the market, that should be considered.

At least one manufacturer⁹ provides a means of using a constant volume DX unit to deliver variable air volume to the space, utilizing a bypass air damper. While this unit is typically used in multi-zone situations, it could be used to supply variable air flow to a single zone. Coupled with hot gas bypass this could permit a single speed unit to achieve some of the supply air temperature and flow modulation requirements useful to successful deployment of displacement ventilation. Unfortunately neither the bypass damper nor the hot gas bypass is an energy efficient approach to the situation. What is

needed is a unit that will achieve capacity and flow control in an energy efficient manner. The specifications of that unit are as follows:

- Provide 3-5 ton total cooling capacity at design outdoor temperature (105°F DB for Sacramento, i.e.). Provide cooling supply air at 63-65 °F without reheat. Provide options for 3, 3.5, 4, 4.5 and 5 tons using a single curb size.
- Provide a cooling supply air temperature of 65°F with control to within 2-3 °F for varying ambient temperatures, inlet air temperatures, and load conditions.
 - To measure supply air temperature, a sensor and associated wiring and controls would need to be included.
 - The control should maintain a minimum supply air temperature set point of 65°F to within 3°F for part-load conditions down to 25% and outside air conditions down to 75°F.
 - Optional capability to reset supply air temperature set point upwards in cooling based upon return air temperature or space temperature
- Provide capability for cooling at design supply airflow of 400-600 cfm/ton, with optional capability for varying the air volume at part load.
- Provide a means for varying the capacity of the system to maintain the supply air temperature set point in cooling. For capacity modulation, the system may require one or more of the following:
 - Multiple stages using multiple compressors or a variable speed compressor
 - Variable-capacity compressor
 - Variable speed supply fan for multiple stage or variable capacity units.
 - Multiple-staging of compressors through porting holes should be avoided, as stepped control can lead to control and comfort issues.
- Maintain the minimum outside air volume required by Title 24 standards (15 cfm/person).
- Provide an economizer with both high temperature and low temperature dry-bulb lockouts. High temperature lockout can be a fixed dry-bulb or differential (comparison with return) temperature.
- The unit should have a low-temperature trip to prevent freezing of the evaporator coil during part-load conditions. Provide refrigerant circuit protection as needed.

The variable-capacity compressor system has been successfully tested in the Kinoshita Elementary School demonstration project as noted earlier in the section on field experience. Plans are being made to bring this prototype single package unit into production and into the market in 2007. The unit that was tested was nominally 4 tons in capacity, utilizing an air side economizer with differential dry bulb control, a thermal expansion valve for refrigerant control, a 4 ton digital scroll compressor and controller, and an inverter for the indoor fan.

The system has a flexible control sequence for variable air volume and temperature control with a single compressor. The space temperature is primarily controlled by varying the supply air flow to the space. The supply air temperature set point is nominally set at 65°F for displacement ventilation. The supply air temperature is controlled to the supply air temperature set point by varying the capacity command to the compressor. The capacity command can vary from 10% to 100% of full output. The compressor controller controls the scroll operation to achieve the specified output. When the capacity command is below 10%, the compressor will shut off.

If the supply fan is at the maximum speed and the supply air temperature is still unable to meet the load, the software includes a configurable amount of reset. The supply air temperature will reset downwards to meet the space load. If the supply fan is at the minimum speed and the cooling output exceeds space demand, the supply air temperature is reset upwards.

The system uses an integrated economizer with differential dry-bulb control. The economizer is used whenever the outside air temperature is less than the return air temperature. The economizer control includes an adjustable minimum outside air damper position to ensure proper ventilation air as the fan speed varies.

The system provides heating through a single-stage of gas heating. The airflow is set to the maximum during heating to moderate supply air temperature. (In heating the goal is a well-mixed airspace).

The unit is controlled with programmable time clocks, and unoccupied setback temperatures. Additionally, a morning warm-up sequence can provide heating prior to occupancy.

Control strategies

Control of the economizer and other systems functions has been discussed in the description of each mechanical system option. This section deals principally with the critical control requirements of the displacement ventilation system, controlling the space temperature by varying the supply air temperature, the supply air volume, or both.

Variable air volume systems will allow for fan energy savings at part-load conditions. Control strategies that allow for variation of both the supply air volume and supply air temperature have the greatest potential for energy savings. A 65°F supply air temperature is often only needed at design cooling conditions. Supply air temperature reset will maximize the potential for free cooling.

Because of room air temperature stratification, the thermostat location is an important design consideration. It should be located at a height approximately equal to head level of seated occupants (42 in.). The thermostat should be located outside of the adjacent zone of the diffuser, to avoid cool drafts at foot level. A location at least 6 ft from the nearest diffuser will work well for space temperature control.

There are fundamental displacement ventilation control requirements that must be met by any HVAC system. The supply air temperature should be controlled to within 3°F–4°F of

the supply air temperature set point to maintain comfort by varying supply air flow, supply air temperature, or both air volume and flow. Specify Supply air temperature reset should be specified to maximize the potential for free cooling. Implement a low ambient temperature lockout should be used with the economizer. A morning warm-up sequence is recommended to minimize heating needs during occupied hours.

A good control option for displacement ventilation systems is variable air volume (VAV) control. With this control strategy, the supply air volume is the primary means of space temperature control. The supply air volume is adjusted up or down to maintain the space at the cooling set point. For a typical classroom, the supply air volume is varied from the minimum required for ventilation (450 cfm) to the design air flow rate required for cooling (1200 cfm). Over this region the supply air temperature is held constant at the supply air temperature set point (typically, 65°F).

When the space drops well below the cooling set point, outside of the control band, the minimum supply air flow rate of 65°F air is overcooling the space. At this point the supply air temperature is reset higher. The supply air temperature is reset upwards from the original set point of 65°F towards a maximum set point, around 70°F. The supply air temperature reset enables more energy efficient operation by reducing the operating hours of the cooling equipment. At a point when the cooling demand called for by the control is lower than the lowest cooling output of the HVAC system, the cooling system shuts off. The supply air flow rate is held constant at the minimum setting until the space drops below the heating set point. At this point, the supply air volume is reset to the minimum value required by the heating equipment. (This may or may not be higher than the minimum airflow required for ventilation.) If the mechanical system is capable of modulating heating output, the supply air temperature can be varied over a range with changes in space temperature.

A constant air volume control strategy can also be effective for displacement ventilation systems. However, this strategy does not take advantage of the large potential for fan energy savings of VAV systems. With this strategy, the supply air volume flow is held constant at the maximum airflow required for cooling (typically, 1200 cfm). The supply air temperature is adjusted as the primary means of space temperature control. The supply air temperature is adjusted from a minimum setting (62°F) to a maximum setting of a few degrees below the space cooling set point (70-72°F). If the space is still overcooled when the supply air temperature is at its maximum, cooling is disabled. The heating control strategy is designed to maintain the supply air temperature at the heating set point.

Compared to the VAV strategy above, the constant air volume strategy uses more air, but at a higher temperature. Through increased economizer use, this strategy could result in a lower cooling energy, but will always use more fan energy than the VAV control strategy.

A combination of the VAV and constant air volume strategies is to vary both the supply air volume and temperature concurrently. This sequence is similar to the VAV control

sequence. However, the supply air temperature is allowed to vary with changes in the space temperature. If the space temperature is below the cooling set point and remains below the cooling set point, the supply air temperature is increased. This happens independently of the supply air volume. Typically, the supply air volume loop responds more quickly to changes in room temperature than the supply air temperature (reset) loop. This sequence requires careful tuning, and is more suitable for chilled water systems or larger systems that have sophisticated DDC controls.

Manufacturers of mechanical systems will often include complete control packages in their product offerings. The specifier should take care in choosing one that permits the flexibility and functionality described in this section and the section on mechanical systems.

Displacement ventilation system control strategies for economizer operation, heating, humidity control, using 100% outside air, heat recovery, natural ventilation integration and demand control ventilation are all described in detail in the Design Guide for the project and will not be discussed here.

Diffuser options

Low-velocity diffusers used with displacement ventilation have different design criteria than ceiling diffusers used for mixing ventilation. The air from a ceiling register is discharged at a high velocity in order to induce the adjacent room air into the air stream, creating mixing. The performance of these types of diffusers is characterized by throw (the axial distance that air stream travels before it reaches a specified terminal velocity) and the air diffusion performance index, or ADPI. These metrics don't apply to displacement diffusers.

The main concern with diffuser operation is providing a uniform flow of low velocity air to create a stratified room air distribution pattern without creating drafts in the occupied zone. The intent of the low-velocity, displacement diffusers is to supply conditioned air at a very low velocity, so that it flows along the floor until it meets a heat source.

Performance of diffusers for displacement ventilation is characterized by an *adjacent zone*. The adjacent zone is the region near the diffuser where the local air velocity exceeds a specified comfort threshold (typically 40 feet/minute). Placing occupants in contact with the cool air temperatures and higher velocities in the adjacent zone can lead to drafts and discomfort. The adjacent zone for displacement diffusers is specified by manufacturers, for a given supply air temperature and flow rate. For classrooms and other school spaces, the diffuser should be selected so that the occupants are situated outside of the adjacent zones.

Another key design criterion for displacement diffusers is the Noise Criteria (NC) rating. This is a measure of the sound level attributed to air movement through the diffusers, compared against reference performance curves. Best practices for classroom acoustic design includes a background noise level of 35 dBA or lower. A noise criteria rating of

27-28 NC is approximately equal to an indoor noise level of 35 dBA (decibels on an A-weighted scale). Thus, the diffusers should be specified for a combined noise criteria of NC-27. For two diffusers, this means noise criteria of NC-24 per diffuser.

While diffusers for DV do take up considerable wall space, there are several diffuser options that can be seamlessly integrated into the space. Installers and occupants often comment on how they appear to be part of the building design.

Some common diffuser options include the corner diffuser located in the corner of the space. Air is typically supplied to the top of the unit from a concealed duct. This is a common option for classrooms. The half-round 180° diffuser is typically located along an interior wall, providing for uniform cooling as the supply air flows out towards the exterior wall. Freestanding 360° circular diffusers are located in the interior of large, open spaces allowing for large airflows without the presence of drafts. Air can be supplied from the top or from an underfloor plenum. Recessed rectangular diffusers can be recessed into the wall to minimize impact on floor space. Plenum diffusers are rectangular diffusers that may be integrated underneath casework, or used underneath stairways in theaters and auditoriums.

The general rule with a diffuser is to limit the air velocity across the diffuser opening to about 50 to 60 feet/minute, resulting in a diffuser outlet area of about 10 ft² each. There are at least five major displacement diffuser manufacturers; Halton, Price, Trox, Flakt Woods and Air Diffusion. Halton, Price and Trox have substantial operations in the United States. Literature on each of these companies' displacement diffuser product lines is available via the internet. Manufacturers can assist with the sizing for a particular application.

Recommendations

Displacement ventilation systems are very well suited to classroom applications in California and as such should be a prime candidate for new construction and major renovation projects, particularly in the elementary school grades. This guideline provides the necessary material for school officials to make the initial screening of displacement versus mixed ventilation systems. Specifiers can use these applications guidelines in conjunction with the Displacement Ventilation Design Guide: K-12 Schools⁷ to select appropriate mechanical systems, controls and diffusers for the project. Manufacturers should be aware of the attractiveness of displacement ventilation systems as an emerging technology for schools in California and should quickly plan to provide small packaged unitary equipment with variable cooling capacity, variable supply air flow rate and 65°F supply air temperature capability to meet this fast growing market.

References

- 1 - Mendell, Mark and Heath, Garvin, LBNL for the U.S. Department of Education, Doc # 2004-06, *A Summary of Scientific Findings on Adverse Effects of Indoor Environment on Student's Health, Academic Performance and Attendance*, April 2004.
- 2 - *Displacement Ventilation Design Brief*, Energy Design Resources, 2005.
<http://www.energydesignresources.com/resource/199/>
- 3 - Schaffner, Christopher, *Displacement Ventilation in Classrooms, Report of Visit to Boscawen Elementary School, Boscawen, N.H.*, 1999.
<http://www.greenengineer.com/ideas/boscawen.htm>
- 4 - Personal communication with Monte Soukup, Head of Planning, Blue Valley School, Overland Park, Kansas, September 20, 2005.
- 5 - *Rebuild America Energy Smart Schools- Success Story, Elk River School District*, U.S.D.O.E., October 2004.
- 6 - Telephone interview with Michael Sherber, Avon CT, February 2004.
- 7- "Displacement Ventilation Design Guide: K-12 Schools," Architectural Energy Corporation for the California Energy Commission, June 2006.
- 8- "Improving Indoor Environmental Quality and Energy Performance of California K-12 Schools, Draft Equipment List and Performance Specification," Architectural Energy Corporation for the California Energy Commission, March 11, 2005.
- 9- "VariTrac™ Changeover Bypass VAV (Tracker System CB)", VAV-PRC003-EN, Trane, June 2004.

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

Applications Guide for Off-the-Shelf
Equipment for UVC Use

CONSULTANT REPORT

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Applications Guidelines for Off-the-Shelf UVC Equipment for Coil Cleaning

Objectives

These guidelines provide a primer on ultraviolet lighting systems for coil cleaning for school facility decision makers, equipment specifiers and manufacturers. An introductory overview leads to a discussion of benefits and application considerations that shows when to consider installation of ultraviolet lighting systems. A discussion of equipment information, product offerings and recommendations is designed to assist school officials and specifiers in making a preliminary assessment of the equipment that could meet their needs. Information is also provided that might help manufacturers see how their product offerings might be viewed by other market participants.

Summary

These guidelines begin with an overview of indoor air quality, maintenance, and energy issues in K-12 schools, and how ultraviolet lighting systems can help address these issues. Case studies are presented that illustrate how ultraviolet lighting has worked in schools and other buildings around the country. System sizing, location and operation are discussed. The conditions favoring use of ultraviolet radiation for coil cleaning are then outlined. Equipment selection considerations, including manufacturer selection information, and product options are presented for ultraviolet lighting systems and for lamps, and ballasts.

Introduction

Information on ultraviolet lighting for coil cleaning can be found on the California Energy Commission website¹ and in a recently published article in *Engineered Systems* magazine.² Briefly, ultraviolet radiation in the “C” wavelength range (UVC) has been used to irradiate dirty air handling system components to deactivate microorganisms on the coils and drain pans of these systems. The UVC is designed to rapidly clean the surfaces and to subsequently penetrate between the coil fins to clean within the coils. The objective in removing the microbiological contamination in cleaning the coils is to reduce the pressure drop and enhance the air-side heat transfer, improving the system energy efficiency. Another benefit that has been claimed is improved indoor air quality, resulting from reduced entrainment of microbes into air passing over the coil before it enters the room.

The benefits of ultraviolet lighting for coil cleaning are (in a retrofit situation) achieved by returning coil performance to the as-built condition or (in a new building situation) by maintaining the coil in a continuously clean condition. As addressed in the article in *Engineered Systems* magazine,² it is not clear from available data whether coils get dirty enough in the California environment to make cleaning a cost-effective proposition. There is however anecdotal data that indicates that using ultraviolet light in the “C” spectrum (UVC) to clean coils that have been heavily fouled in environments that promote heavy microbial growth can be beneficial. There is also well-designed research that has provided evidence in office buildings that this surface cleaning carries over into the workspace with reduced airborne microorganisms and improvements in health and attendance.

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.

UVC systems use low-pressure lamps that are designed to provide radiation at the 253.7nm wavelength that is most effective in deactivating microorganisms. The lamps use 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.

These guidelines deal primarily with issues related to placement of UVC systems in air handling units in the proximity of the cooling coil.

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 lower school performance and attendance.³ UVC lights offer a potentially effective means of both reducing energy use and delivering fresh air to improve classroom air quality.

UVC lamps are designed to clean both the coil and drain pan surfaces in a few hours or a few days⁴ and to progressively penetrate between the coil rows and fins with time. 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 therefore not contaminated, resulting in cleaner air being delivered to the classroom.

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, tedious cleaning treatments that create system downtime and use chemicals, biocides or pressure washing. Mechanical or chemical washing may also damage coils. Maintenance benefits may accrue from use of UVC lights to keep coils continuously clean, avoiding these laborious coil cleaning actions that will otherwise be required to return coils to a clean condition. UVC lamps should be inspected to see if they are dirty and then cleaned on a regular basis, as needed. Some installations have a view port to permit visual observation of the

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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?

Energy benefits may be provided by ultraviolet lighting that cleans cooling coils, by reducing pressure drop, improving heat transfer and increasing system capacity, resulting in overall cooling energy savings. 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.

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.⁵ 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:

Table 1: UVC Human Exposure Limits	
Exposure Duration	Exposure Limit
Continuous	0.1 $\mu\text{W}/\text{cm}^2$
7 hours/day	0.5 $\mu\text{W}/\text{cm}^2$
10 minutes	22 $\mu\text{W}/\text{cm}^2$
2.5 minutes	90 $\mu\text{W}/\text{cm}^2$

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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 $0.2 \text{ } \mu\text{W/cm}^2$ for an eight hour period and $0.4 \text{ } \mu\text{W/cm}^2$ for a 4 hour period. Above this level, erythema (skin redness) and photokeratitis (external eye inflammation) occurs. UV exposure and leakage needs to be minimized. (A tell-tale blue glow provides a clue to UV leakage.)

UVC lamps should be designed to avoid emitting radiation below the 200nm wavelength that produces ozone. Lamps contain mercury and should therefore be treated with care if the lamps are broken and must be disposed of properly at a hazardous waste facility.

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

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

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 than offset by the elimination of costly air handler system cleaning, and incremental coil energy use reduction and that short paybacks are generally achieved.

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 as well as 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.”⁶

The LaPorte Independent School District in Texas installed UVC lamps in a building that had been infected with fungal growth, which in the past had been treated with costly

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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.⁷

The Stepping Stones Center educational and therapeutic facility in Cincinnati, Ohio, used UVC lights to effectively remove mold from an otherwise unusable building.⁸

Examples of UVC use 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.⁹

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

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

Current California Energy Commission Study of Indoor Air Quality in Schools

In a study sponsored by the California Energy Commission,¹³ UVC lamp systems were installed in 36 packaged air conditioning units in three school districts across California. Their performance was compared to 18 control units in those school districts over a six week period starting in August 2005. 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 to an investigation of the importance of coil fouling, how this is affected 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%¹⁴ 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 coils¹⁵ showed that they were relatively insensitive to low and moderate amounts of air flow reduction due to fouling. When air flow was reduced by 35%, the coil had just a 6% drop in EER with the majority (4.6% of the 6%) occurring in the 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^{7, 9, 11, 12} 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 of UVC lights for coil cleaning. Both types of technologies lack well-documented quantitative studies of coil degradation and the 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. Coordinating the initial cleaning period with breaks/school shutdown periods could 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.

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.¹⁶

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

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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 systems¹⁷ including catalogs, tables, rules of thumb and analytical methods. The analytical methods include point source models; line source models; integrated point source models; view factor models; and dimensionless models. Some of these models can take into account secular and diffuse reflectivity, and light baffles. In general the manufacturer will take the responsibility of sizing the product to meet the conditions required by the application.

One manufacturer suggests that 24 inches of high intensity UVC tube length be used for every 4 ft² of coil face area and that the ideal distance between the fixture and the coil is half the distance between rows or half the height of a one row coil if it is less than 24 inches.

The International Ultraviolet Association is developing guidelines for UVGI air and surface disinfection systems¹⁸ 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 buildings¹⁹ recommend 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 used in sizing UVC systems and selecting components for coil cleaning.

What situations would most benefit from UVC lamps for coil cleaning?

The following paragraphs provide a few pointers on climate, environmental and facility/HVAC system issues that could make UVC lamps for coil cleaning a desirable option for a K-12 school facility in California:

Climate Issues

- Consider coil-cleaning technologies if high humidity, high temperature and the presence of microbial sources could cause coil biofouling and resultant reduced air flow, lower heat transfer and consequent reduction in cooling capacity could create comfort and energy use issues.
- Most California climates have relatively benign dry climates with regard to microbial growth.
- Coastal Southern California areas have high relative humidity compared to the rest of the state.

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- Agricultural areas such as Imperial Valley and the San Joaquin Valley with normally high summer temperatures but low humidity may have elevated humidity levels due to extensive irrigation in these areas that could be of some concern.
- Composting vegetation and disturbed soil from farming or construction can be significant sources of microbes.

Environmental Issues

- Microbial loads have been excessive in sampling in existing District schools.
- Coil fouling has been experienced in existing schools in the District and problem that must be addressed in those schools and in new schools in the District.
- Indoor air quality problems that may contribute to high absenteeism, low test scores and other indoor air quality complaints (musty, “dirty socks” odor) have heightened the Districts awareness of the need to look at UVC as a solution to these problems.
- In schools or classrooms where the students may have immune systems that have been compromised and every effort should be employed to provide a healthy, productive teaching environment.

Facility/HVAC System Issues

- UVC can keep coils continuously clean, and may be a viable substitute coil cleaning methods that use chemicals, biocides or pressure washing that often require facility shutdown and only provide intermittent cleaning.
- UVC requires minimal lamp maintenance particularly when the lamps are placed downstream of the filter, thus making them good candidates for areas that are difficult to service because they are in high traffic areas or they are difficult to access because of their remoteness or configuration. In any case, the units will need some servicing to assure lamp cleanliness and to replace the lamps as recommended by the manufacturer.
- If humidifiers are used that produce saturated conditions in the proximity of the coil and drain pan this will enhance the growth of mold and bacteria. These situations should be candidates for UVC lamps to clean the coils.
- Returning coils to near their as-built condition or keeping coils clean from the start of their installation and operation can offset the need for adding additional HVAC system capacity, saving facility improvement capital as well as reducing operating costs.
- Lamps need to be placed where there is ample space in the air-handling unit, a good line of sight to the coil, and the opportunity to avoid exposing materials that are sensitive to degradation from UVC light.
- Placing lamps downstream of the cooling coil usually provides a direct line of sight to the drain pan affording an opportunity to disinfect that source of moisture and microbial growth.
- For coil cleaning the travel path of the UV rays should be directed through the gap between the coil fins.
- Filtration should be used in conjunction with any UVC system.

Equipment Selection

There are several approaches to achieving coil cleaning with UVC lights. One approach, the one that seems to be most widely used, is to place the lamps on the downstream side of the coil where there is a good line of sight to this wettest side of the coil, and to both the coil and the drain pan. This places the lamp on the occupant side of the coil so some manufacturers of this configuration take extra care in providing shielding of UVC energy from users (and vulnerable plastic wiring, shellacked motor windings and other components) with shields and reflectors. The reflectors concentrate the UVC energy on the coil and drain pan surfaces. Lamps placed on the downstream side of the filter require minimal inspection for dirt buildup and resulting cleaning, perhaps quarterly or less. By contrast, others may use high output lamps and may not shield them, providing some disinfection of the air stream over and by the UVC lamps.

Others put their lamps on the upstream side of the coil but this creates line of sight problems to the drain pan. If the objective is improved coil performance this may not be an issue. Proximity of the filter to upstream side of the coil may make the installation of a UVC fixture difficult, but with sufficient space this type of installation could provide effective coil cleaning. The adhesives used in some filters may be damaged by UVC so this is a consideration as well. Since air filters are frequently changed this provides the potential for mishandling and breakage of the lamps. Lamps installed upstream of the filters need to be inspected, and may need to be cleaned, every month.

As mentioned above, it is important that enough space is available to provide proximity of the lamp and good line of sight to the surfaces to be cleaned to assure high enough UVC irradiance to provide the desired germicidal disinfection. UVC lamps and fixtures are made to be installed in all types of HVAC system configurations. For some units this may be difficult due to lack of space and access. Unit ventilators and wall mounted units are particularly compact and therefore may present particular problems in this regard.

Another difference between products is the branding of the components. Most UVC system manufacturers use components such as lamps and ballasts with models available to the user from recognized commercial manufacturers of these components. This permits the user to shop for replacement components and to obtain a competitive price and attractive delivery terms. Purchasing from a manufacturer that puts its own brand on the component may provide some assurance of quality and adherence to the terms of the guarantee/warranty. On the other hand branding could limit the replacement choices available to the user resulting in a higher price and less attractive delivery schedule than would occur if products were used that had commercially available alternatives.

UVC Manufacturers

Once having decided that UVC should be considered for an installation, it is recommended that the decision maker talk to several manufacturers of UVC lights to:

- Listen to claims about their product and decide whether those claims seem reasonable in the context of the information presented in these guidelines and the decision makers expectations for the product
- Ask for product layout and design assistance
- Ask for quotes, delivery and installation schedules

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- Ask for performance guarantees, and warranties (lamps are generally warranted for 1 year, ballasts for 5 years and fixtures for as high as 3 years)
- Request a performance verification plan to assure that the units operate as claimed
- Ask for installation, operation and maintenance guidelines
- Ask for references in K-12 schools with similar climate and configuration

A compilation of major manufacturers and their websites is given below in Table 2. The web sites can be used to scan product offerings and related information and to locate a manufacturer's representative in the geographical area of the project being planned.

Table 2: Manufacturers of UVC Air and Surface Treatment Systems	
Company	Web Site
Allanson Environmental Systems	www.swordfishuv.com
American Air and Water	www.americanairandwater.com
American Ultraviolet	www.americanultraviolet.com
Atlantic Ultraviolet (Aerologic)	www.ultraviolet.com
Catalyx Technologies	www.catalyx.com
Dust Free	www.dustfree.com
Environmental Dynamics and Design	www.eddipure.com/air_quality.htm
Hanovia Ltd	www.hanovia.com
Living Ultra Healthy	www.premiumairproducts.com
Lumalier	www.lumalier.com
Natural Lighting	www.naturallighting.com
NQ Environmental	www.nqinc.com
Peterson Air Purifiers	www.breatheCLEAN.com
Sanuvox Technologies	www.sanuvox.com
Sentry Ultraviolet	www.sentryuv.com
SterilAire	www.sterilaire.com
Triatomic Environmental	www.freshaireuv.com
Ultravation	www.ultravation.com
UVDI	www.altruv.com
UV Resources	www.UVResources.com
Ultraviolet Systems	www.ultravioletsystems.com
Vigilair Systems (formerly FP Technologies)	www.vigilairsystems.com

If the decision maker decides to purchase the system from a manufacturer and their representative, the transaction is likely to be turnkey, with the manufacturer and their representative sizing the components; providing the lamps/tubes, fixtures/housings, reflectors, ballasts, sleeves, wiring, and view ports; delivering them to the site; installing them and trouble-shooting their startup; and checking back, to assure that the units are performing as promised. If a decision maker decides to put together their own units they will have to perform all of these functions. This will likely entail designing and building fixtures, wiring and safety switches/interlocks and view ports for each UVC system installed. If all the HVAC systems are similar then one design may suffice for all units.

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The major purchased components will be the UVC lamps or tubes and the ballasts/power supplies that drive the lamps.

UVC Lamps

The low pressure mercury lamps that are usually used in UVC systems for coil cleaning produce a spectrum that peaks near 253.7 nm. High output lamps have three to four times the UVC output for a given lamp length than conventional lamps. Lamps come in several configurations in order to suit particular situations. The most common type of UV lamp is the cylindrical lamp, having connectors at both ends. Biaxial lamps use two cylindrical lamps in parallel with the connector at one end. U-tube lamps are similar to biaxial lamps and use a single connector at the base end, except they have a continuously curved bend at the outer end.

Some of the major manufacturers of UVC lamps are listed in Table 3 along with their web sites. They typically offer a range of lamps sizes and configurations. For example First Light offers a variety of shapes in 5 sizes of lamps in ranging from 12 watts to 48 watts in input power and 2.8 watts to 13.5 watts in output UVC power. All are rated for 9000 hours.

General Electric offers 5 sizes of biaxial lamps ranging from 5 watts to 55 watts in input power and 1 watt to 17 watts in output UVC power. All are rated for 8000 hours. They also offer 4 cylindrical lamps ranging from 4 watts to 55 watts in input power and .8 watt to 18 watts in output UVC power with ratings of 6000 hours for the smaller lamps and 8000 hours for the 39 watt and 55 watt lamps.

Heraeus offers cylindrical, biaxial and u-shaped lamps in sizes ranging from 5 watts to 300 watts in input power.

Philips has a large array of product offerings in different configurations and sizes ranging from 5 watts to 115 watts with ratings of 5000 hours for some of the specialty lamps, 8000 hours for the PL-L and PL-S lines and 9000 hours for other lamps.

Table 3: Manufacturers of UVC Lamps	
Company	Web Site
First Light	www.firstlightusa.com/germicid.htm
General Electric	www.geconsumerproducts.com/pressroom/press_releases/lighting/specialty_lighting/uvgermicidal.htm
Heraeus Noblelight	www.heraeusnoblelight.com
Osram Sylvania	www.sylvania.com
Philips	www.uvdisinfection.philips.com
Ushio	www.ushio.com/categ_uvgermicidal.htm

Ballasts

The lamp ballast performs both a starting function (in ionizing the gas in the UVC lamp) and a current limiting function. A high initial voltage provides the starting arc and the ballast then limits the current to maintain lamp longevity. Both magnetic ballast and electronic ballast are employed but electronic ballasts are recommended for their energy

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efficiency and reliability. The specifier should assure that the ballasts meet safety and operational features/specifications such as follows:

- Total harmonic distortion of less than 10% when operated at normal line voltage
- Power factor greater than 96% for large installations
- Output frequency above 42kHz to minimize interference with infrared control systems and to eliminate visible flicker
- Meet ANSI C82.11, Lamp Ballasts- High Frequency Fluorescent Lamp Ballasts
- Meet UL listing requirements and be rated for use in air handling spaces
- Five year warranty
- Meet applicable energy efficiency standards and FCC Title 24 requirements
- Ballasts should be labeled for use with a particular UVC lamp.

Since the ballast is likely to be provided as part of a package delivered by the UVC system manufacturer, these specifications should serve as a check list for the specifier and school facility personnel for assuring that the delivered components meet these requirements. Some of the major manufacturers of ballasts for UVC lamps are listed in Table 4 along with their web sites.

Table 4: Manufacturers of Ballasts for UVC Lamps	
Company	Web Site
Advance Transformer (PureVOLT)	www.advancetransformer.com
Amtek	www.amtekballast.com
Magnetek	www.magnetek.com
Philips	www.uvdisinfection.philips.com
Robertson Transformer	www.robertsonww.com
Sunpark	www.sunpkco.com
Universal	www.universalballast.com
UV Electric	www.uvelectric.com

Recommendations

Ultraviolet lighting systems to clean coils should be considered for situations where biofouling and consequent reduction in indoor air quality are likely to be linked as important issues. The conditions that promote coil fouling, moisture/humidity, and microbial sources may only be present in selected areas and situations in California but for those conditions, UVC systems could be valuable tools. Keeping the coils clean can reduce pressure drop and enhance heat transfer in coils that might otherwise be contaminated by growth of microorganisms and could therefore eliminate a source of contamination of the air flowing through the coil into the classroom. These guidelines provide information that can be used by school facility decision makers and their architects and engineers to decide whether UVC systems might help their situation and to provide pointers on how to select the right manufacturer, systems and components.

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References

- (1) California Energy Commission's PIER IEQ Program website
www.archenergy.com/ieq-k12.
- (2) Blatt, Morton, et. al., "Ultraviolet Light for Coil Cleaning in Schools," *Engineered Systems*, pp50-60, 95 March 2006.
- (3) 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.
- (4) Kowalski, Wladyslaw, "UV Cooling Coil Disinfection", The Pennsylvania State Indoor Environment Center for American Air and Water, Inc., September 1, 2005.
- (5) 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.
- (6) "Breathe Easy: Capistrano Unified Reduces Indoor Air Contaminants by 66%,"
www.schoolfacilities.com
- (7) Freeman, James, "UVC Sheds New Light on SCHOOL MOLD problems," La Porte Independent School District, La Porte, TX, *Heating/Piping/Air Conditioning*, May 2001.
- (8) "UVC Lights Put an End to Mold Problem," *Air Conditioning/Heating/Refrigeration News*, August 9, 2004.
- (9) Keikavousi, Firouz, "Florida Hospital Puts HVAC Maintenance Under a New Light," Florida Hospital, *Engineered Systems*, March 2004.
- (10) Menzies, Dick; Popa, Julia; Hanley, James A.; Rand, Thomas; and Milton, Donald K.; "Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double blind multiple crossover trial," Montreal Chest Institute, McGill University, *The Lancet*, Volume 362, November 29, 2003, www.thelancet.com.
- (11) "UVC Technology Sheds Light on IAQ Problems," *Air Conditioning /Heating /Refrigeration News*, July 10, 2000.
- (12) "How do Utilities Save Energy? With UVC for HVAC!," *Contracting Business*, December 2001.
- (13) "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.

Applications Guidelines for Off-the-Shelf UVC Equipment for Coil Cleaning

- (14) Siegel, Jeffrey; Walker, Iain; and Sherman; “Dirty Air Conditioners: Energy Implications of Coil Fouling,” 2002 *ACEEE Summer Study on Energy Efficiency in Buildings*, 1.287-1.299.
- (15) Peterson, George; dekieffer, Rob; Proctor, John; and Downey, Tom; “Persistence #3A, An Assessment of Technical Degradation Factors: Commercial Air Conditioners and Energy Management Systems,” Proctor Engineering Group for the CADMAC Persistence Committee, February 25, 1999.
- (16) 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).
- (17) “Draft Guideline for Design and Installation of UVGI Air Treatment Systems,” IUVA Draft Guideline IUVA- 2004-A1, International Ultraviolet Association, 2004.
- (18) “General Guideline for UVGI Air and Surface Disinfection Systems in New Building Construction,” IUVA Draft Guideline IUVA-GO2A-2005, International Ultraviolet Association, 2005.
- (19) “Guideline for Design and Installation of UVGI Air Disinfection Systems,” IUVA Draft Guideline IUVA-GO1A-2005, International Ultraviolet Association, 2005.