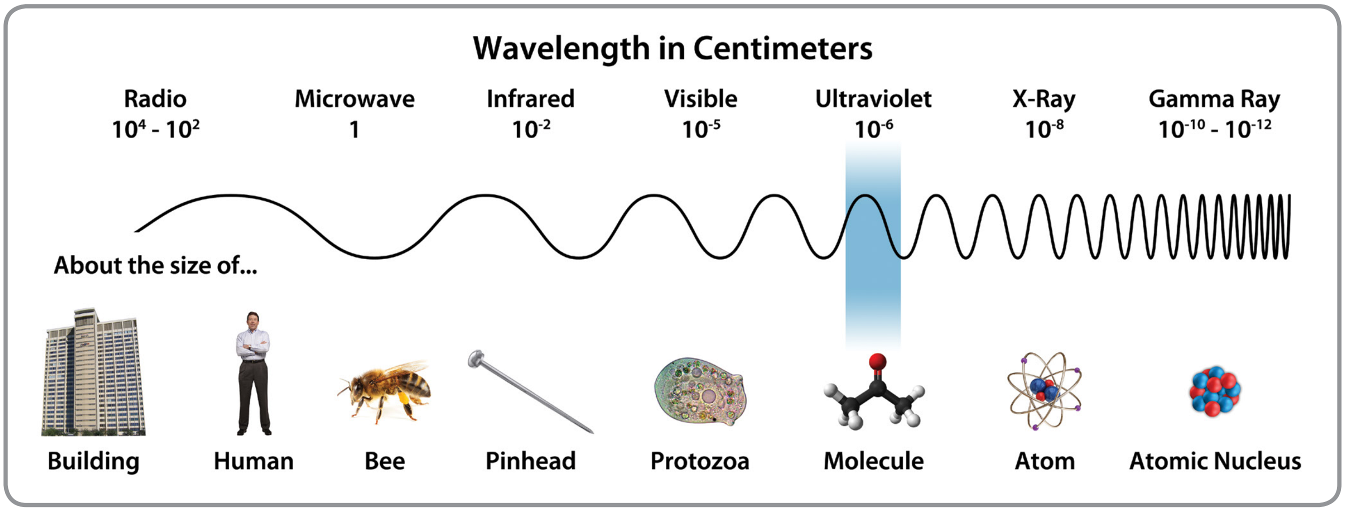
COMMERCIAL SERIES

Fresh-Aire UV® UVGI System Design Guide

Objective

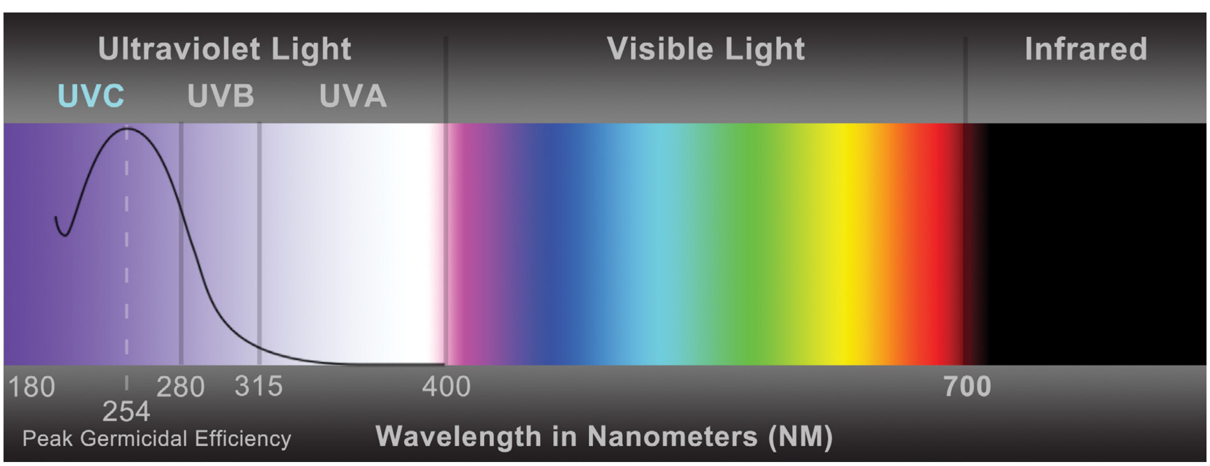
This document is intended to help HVAC engineers, installers and sales representatives responsible for specifying, designing or implementing Ultraviolet Germicidal Irradiation (UVGI) systems for air duct and cooling coil surface disinfection applications. It contains essential information about germicidal UV light, microbial contaminants, volatile organic compounds (VOCs), and the design of UVGI systems to address them. Read this prior to using fresh-Aire UV's proprietary Blue-Calc™ Design and Analysis Service.



Basics of Ultraviolet Light

UV light is high frequency electromagnetic light invisible to the human eye with a frequency range of 100 - 400 nm. It is further broken down into three bands: UVA (320 - 400 nm) such as emitted by black lights and tanning beds; UVB (280 - 320 nm) which can cause sunburn; and UVC (200 - 280 nm). The UVA band is considered non-germicidal while UCB and UVC are germicidal. Radiation wavelengths around 185 nm form ozone, O3, which is toxic and highly reactive.

The most effective UV wavelength for microbe inactivation is UVC – between 200 and 280 nm, with 265 nm being the most common. UV irradiance, or intensity, is expressed in units of W/m2 or µW/cm2. The UV dose, or fluence rate, is expressed in units of J/m2 or µW-s/cm2. A joule (J) is 1 watt x 1 sec.



Basics of Microbes, Pathogens & Allergens

Microbes are microorganisms that cause disease and include bacteria, viruses, and fungi. Bacteria take the form of vegetative (cell) or spore (seed). Fungi may take the form of vegetative, spores, or yeast. A pathogen is a microbe that causes infections in humans and animals. Allergens cause allergic reactions in some individuals and include bacteria, fungi, biological products (e.g. pet dander) and volatile organic compounds (VOC). Viruses are not allergens.

In scientific studies UV light has been proven to kill 90% of microbial contaminants after 10 minutes of exposure and 99% after 1 hour.

Disinfection will occur when the microbe population is reduced after exposure to UV. The UVC band of light alters the DNA of microbes in a manner that causes mutation, cell death, or destroys their ability to reproduce. Thus, they become inactive and harmless. UVC disinfection is not the same thing as sterilization. Disinfection will reduce the microorganism population by up to 99% (UVGI targets), where sterilization means that all microorganisms are killed.

Generally, bacteria are more susceptible to UV than viruses, and fungi are the least susceptible, but there are microbes where that is not the rule.

Vegetative forms of bacteria and fungi are more susceptible to UV than their spore forms, which are dormant and resistant to adverse conditions, including UV exposure. Insects, such as dust mites, are not susceptible to UV.

Microbes are more vulnerable to UV in air than they are on coil surfaces where they have more inherent protection of the coil fins, crevices and shadows.

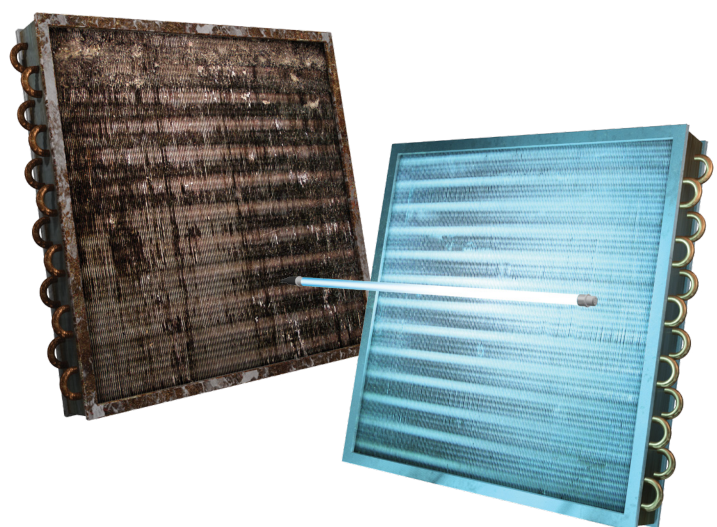
Air purification involves both disinfection (of microorganisms) and the removal of gaseous and particulate contaminants using UVGI together with filtration.

UVGI Benefits

Ultraviolet Germicidal Irradiation (UVGI) is an established disinfection technology for both surface and airborne disinfection in HVAC systems.

Environmental conditions within an air-duct promote the growth of biological contaminants (viz. mold) on damp surfaces such as cooling coils, fans, drain pans, duct walls and other components within the duct. This contamination eventually spreads down the ductwork and into the living spaces.

Coil with mold



Coil after UV light application

Keeping air conditioning coils and AHU interior surfaces free of microbial buildup will improve the efficiency of the unit and increase indoor air quality. Degraded system performance is due to constricted airflow and reduced heat exchange efficiency caused by clogged coil fins and air filters. Studies have shown that a bio-film thickness of only .002” on the coil surfaces can reduce the free area and increase air velocity up to 9%. By rejuvenating the coils and maintaining greater heat transfer, this can result in a 30% increase in cooling capacity when compared to a system with a dirty coil.

Manual coil cleaning methods that use chemicals, washers and scrubbers are costly, difficult to perform, and must be scheduled periodically. In addition, exposure to chemical vapors and microbes during maintenance presents a safety hazard to the workers and occupants.

The payback period for cooling coil disinfection applications is as little as 1 - 2 years due to energy savings and reduced maintenance costs. Continuous UVC exposure maintains coils in an "as-new" condition as long as the UVGI system is operating as designed. Highly contaminated cooling coils can be restored to their original design operating conditions in a few weeks or months.

Design Guidelines

System Configuration

The most effective UVGI system solutions for large commercial buildings will involve both air-stream purification and surface disinfection technologies. The desired exposure time for adequate dosage in ductwork typically is a minimum of one second. When there is limited time of exposure due to the velocity of the moving air-stream, more than one UV light unit may be required to achieve adequate exposure time. While the UV dosage delivered by properly-sized in-duct lamps (perpendicular or axial) may be adequate for inactivating bacteria, airflow rates of 250 - 500 FPM will not result in sufficient UV dwell times to eliminate fungi (mold). However, surface disinfection lamp racks positioned close to the cooling coil will continuously expose the coil surface and ultimately deliver sufficient dosage to inactivate any mold growing there.

It has been well established that UVGI in combination with air filtration is the most effective and economic technology for air purification. UVGI configurations that add traditional gas-phase carbon media are able to remove gaseous contaminants and odors. The carbon changes the contaminants from a gas to a solid phase. UVGI configurations with titanium oxide infused carbon media bring about photocatalytic oxidation (PCO) – a chemical process that not only purifies the air, but also regenerates the gas-phase carbon media, thus eliminating costly periodic media replacement. With PCO solutions, less outdoor air needs to be ventilated, filtered, heated/cooled and sometimes dehumidified, resulting in additional cost savings.

The combination of UVGI and filtration can be designed to target specific contaminants that a facility is interested in. The following table categorizes the optimal technology to deploy for the target contaminant.

Target	Optimal Technology
Bacteria, viruses, fungi	UVC Lamps, In-Duct
Mold & spores	UVC Lamps, Coil Surface
Dust particles, large microbes & allergens	Air Filtration, MERV 8 - 11
VOC & odors	Air Filtration, UV/PCO

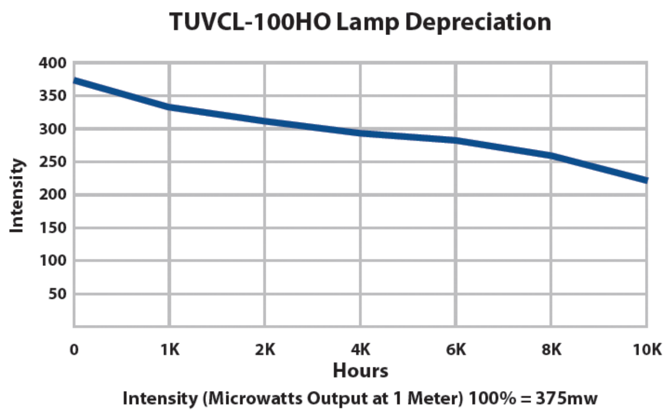
The system designer will need to make economic trade-offs with regard to UV configuration, duct liner, filter technology, and air handling. The primary variables important to the design configuration of a UVGI system include: air duct dimensions (W x H x L); airflow rate; UV lamp specifications (viz. UV power, arc length, lamp radius); lamp quantity and locations; duct reflectivity; and filtration.

Lamp Selection and Sizing

For surface disinfection, direct UVGI exposure can sterilize any surface given enough time. The radiant energy, or dosage, delivered to a coil surface is dependent on UV intensity, the duration of exposure, and the lamp to coil distance. UV lamps should be properly "sized" for the application. Higher intensity lamps can cause damage to internal AHU components and duct materials, and the lamps do not last as long as lower intensity lamps. Driving the UV lamps for more intensity is not necessary. Instead, operating them at optimum UV intensities for maximum lamp life is the preferred method. The average irradiance for a typical coil surface application should range from 100 - 1,000 µW/cm2 due to continuous exposure.

If air-stream disinfection is the approach, then having the most amount of UV production possible is the preferred method. This can be achieved by using high output (HO) UV lamps. The average irradiance for a typical air duct application should range from 1,000 to 10,000 µW/cm2 depending on the microbe to be inactivated and operating conditions such as air temperature, air velocity, and humidity.

The lamp life rating has been established at a point when the lamps intensity drops to 70% of the lamps original output. Typical burn-in times are about 100 hours, and most have a useful operating lifetime of one year or 10,000 hours of continuous operation. UV lamp ratings are determined using photosensor readings taken exactly one meter from the midpoint of the lamp.



Lamp Placement

For air treatment, the location of the UV lamps within the air handling system is of key importance. The lamps should be placed in an area of the air handling system that allows unobstructed irradiation of the UV such that the UV can come into contact effectively with all of the moving air of the air system.

For cooling coil surface treatment, the ideal location is to place the UV lamps in the downstream section of the cooling coil and before the blower. This area is preferred because this section of the air handling system typically is the wettest location, and has more room for the location of the lamps. Also it keeps the irradiation of the UV away from materials that may degrade from the UV light such as the air filter. As an added bonus, the UV lamps can provide the ancillary effect of keeping the drain pan and coiling coils free from any biological growth such as mold, algae or slime which often times can grow in this area. With this in mind, the light source needs to be "detached" from the power source and the UV lamp and power leads must be waterproofed to prevent shorting out or potential shock hazards.

Lamps located crosswise to the airflow typically yield better results than lamps located parallel to the airflow. Cross flow lamps may be oriented vertically, horizontally, or diagonally with similar outcomes.

It is also important is to place the lamps in a configuration that will eliminate or minimize the loss of UV irradiation from effects such as UV shadowing caused by fixture mounts or reflectors. The preferred method of mounting the UV Lamps is to support them with end-mounted brackets, which allow 360° UV light distribution.

Lamps and lamp racks are usually installed symmetrically within the air duct. Where possible, placement of an array of surface lamps should adhere to the following lamp offset design guideline:

- Maximum center to center offset = 30"
- Maximum end to end spacing = 12"
- Maximum distance from a duct or surface edge = 18"
- Distance to cooling coil face = 12"
- Longer lamps may be overlapped or slanted diagonally to fit the dimensions of the duct.

UV Lamp Glass

The "glass" used for germicidal UV lamps comes in two general categories: "soft" quartz and "hard" quartz. Soft quartz is produced with a method and materials similar to those used for flourescent lamps and other types of ordinary glass. Soft quartz is commonly used for germicidal UV lamps, however, this material is not very durable, and care must be taken not to touch the glass surface as this may lead to premature lamp failure. Hard quartz is the material of choice for higher quality germicidal UV lamps. It is produced at much higher temperatures and is more durable and optically pure than the soft varieties

Power Supply

The power supply is a critical component to the optimum operation of a UV Light system. The ballast provides the high initial voltage to create a starting arc, and then limits and controls the amount of current flowing through the UV lamp. Ballasts are either magnetic or electronic.

Magnetic ballasts create an inductive "kick" with sufficient voltage to start the lamp. Aside from being large, heavy, and noisy, magnetic ballasts will drastically reduce the operation and life span of even the best quality UV lamp.

An electronic ballast is a solid-state high frequency switching power supply which increases the efficiency of low pressure lamps by as much as 20%. In addition, they can simultaneously operate multiple lamps in series or parallel, and features can be added into the power supply such as automatic voltage sensing for 120-277 VAC, 50/60 Hz and end of lamp life protection.

These power supplies can be supplied in two different output threshold types: Standard Output - which drives the UV lamp at a standard current level of 425mA; and High Output - which drives the UV lamps at two different current ranges: 850mA and 1200mA. For optimum air treatment, a high output power supply in the upper range of 1200mA is preferred.

Duct Lining

Increasing the UV reflectivity of the surfaces within an air duct will improve UVGI performance by reflecting UVC radiation back into the duct. Lining air duct walls with reflective material in the area of the lamps can increase the UVC dosage by a factor of 2 - 3 times due to the mirror-like reflected images of each lamp. While there may be five or more reflected virtual images within the enclosure, a conservative estimate of the resultant UVC irradiation would be the sum of the direct lamp irradiance and the first inter-reflection. Since new-galvanized steel ducts contribute an additional 57% of reflected energy, the predicted average irradiance would be 1.57 times greater than the calculated direct irradiance. Naturally, dirty duct walls will reduce the contribution of reflected UVC.

The reflected UVC light may be diffuse, as with rough galvanized steel (up to 1.5X); semi-diffused, as with aluminum foil (up to 2X); or specular, as with a mirror-like surface (up to 3X).

Duct Liner Material	UV Reflectance
Aluminum, sputtered on glass	80%
Pressed magnesium oxide	77%
Aluminum, polished	75%
Aluminum, foil	73%
Aluminum paint	65%
New plaster	58%
Galvanized duct, smooth	57%
Galvanized duct, rough	53%
Aluminum, untreated surface	50%
Chrome steel	39%
Stainless steel plate	28%
White paper	25%
White baked enamel	9%
White oil paints	8%

Filtration

Air filtration adds to the removal rates of the larger airborne microbes such as spores, and will protect UV lamps from the accumulation of dust and debris. The ASHRAE Minimum Efficiency Reporting Value, or MERV scale, rates the performance of a filter. That is, how well the filter captures and holds dirt and dust of a specified size range. For UVGI systems, the recommended filtration is MERV 8 - 11.

High-efficiency particulate air (HEPA) filters target allergens and airborne pathogens such as infectious droplet nuclei. HEPA filters are air-cleaning devices that have a demonstrated minimum removal efficiency of 99.97% of particles ≥0.3 microns in diameter.

Medium-efficiency MERV air filters are generally less expensive than HEPA filters and allow quieter HVAC fan operation and higher airflow rates than HEPA filters because they have less airflow resistance.

Maintenance

UVGI Systems greatly simplify the maintenance required with an air-handling unit, especially the cooling coil. However, dust and lamp age combine to reduce the UV irradiance by 20% or more. For that reason, it is important to have both proactive and reactive maintenance procedures.

Periodic visual inspection of the UVGI system should be scheduled. After installation, and periodically, monitor the UV output of the lamps using a calibrated laboratory radiometer.

Strict filter change regimes must be followed or the filters can become clogged causing system damage or allowing contaminates to "cross-over" to the damp components of the air handler where they can flourish.

UVC lamps should be replaced at the end of their useful life – 1 or 2 years depending on model.

It is important to keep the duct in the vicinity of the lamps as clean as possible, as duct wall or liner soiling will reduce UV reflectance and average irradiance in the duct. Clean all fixtures at the time of lamp replacement and clean problematic areas on a scheduled basis – monthly or quarterly.

Safety

Human exposure to UVC light may result in unnoticed eye (cornea) damage and skin (sunburn) damage. While these effects are mostly temporary, they can still be very painful.

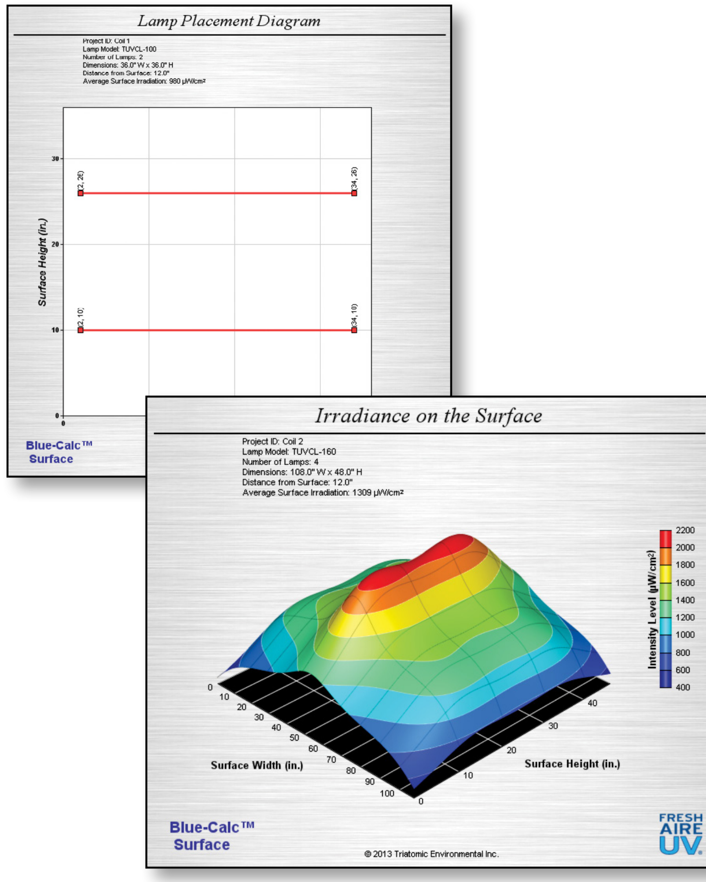
Most materials, including glass and plastic, attenuate UVC radiation. Maintenance personnel should wear protective clothing, eye wear, and gloves when dealing with lamp replacement tasks to protect against broken lamps and accidental UV exposure.

Additional UVC Safety Considerations:

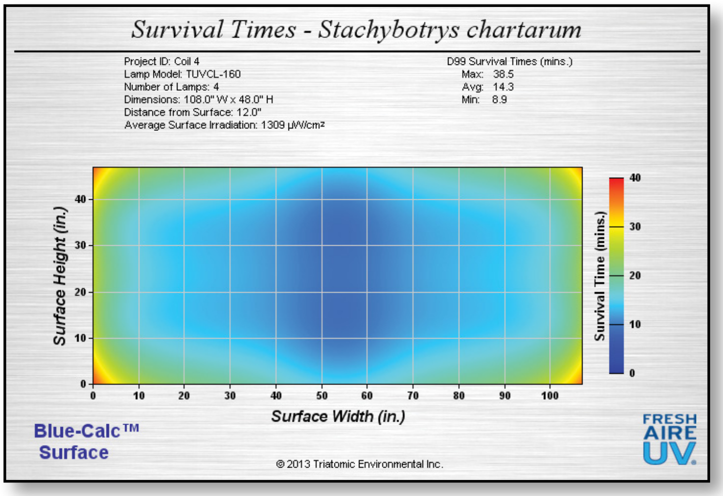
- Dispose of used lamps in accordance with regulations regarding mercury content.
- Air ducts should be fully enclosed to prevent UV leakage.
- All access doors and panels should have multi-language warning labels posted on the outside.
- Interlocks should be installed such that opening any door to a UV lamp chamber will turn off the lamps.
- The UV lamp chamber should have a viewport large enough for the UV state to be viewed from a distance outside the chamber.
- Educate installation and maintenance workers on equipment hazards and safe practices.

Blue-Calc™ Sizing, Design, & Analysis Service

Fresh-Aire UV® offers Blue-Calc, a UVC light design and analysis service using state-of-the-art sizing software for HVAC engineers and contractors. Blue-Calc's unique web service performs calculations of both airborne and cooling coil surface microbe disinfection efficiencies from UVC light exposure and generates detailed color chart and graph image printouts for building owner presentations.



Available at **www.freshaireuv.com**, Blue-Calc's online form prompts engineers and contractors to input the design parameters of any size HVAC system project. The program provides users with sizing, mounting configuration, lamp type and placement specification data that has been factory engineer-reviewed. The design and analysis results provide HVAC engineers a means to optimize and validate their UV system designs early in the design process. Blue-Calc ensures an engineer's UV light configuration will be effective for optimum microbe disinfection and operate to the proper specifications.



Implementation

There are two software tools that Fresh-Aire UV® UVGI engineers use. For air-handling applications, the Blue-Calc Airborne program will analyze air-duct disinfection, and the Blue-Calc Surface program will analyze cooling coil disinfection.

Job parameters are input using an online form, and results are returned in the form of a text summary of the calculation results, charts and graphs.

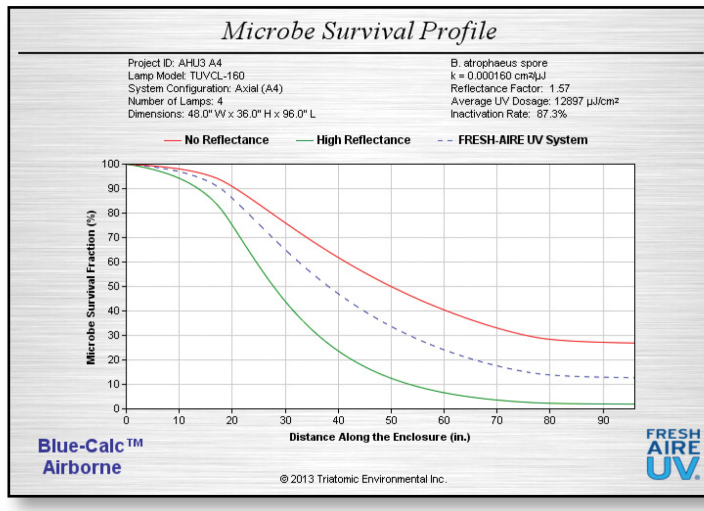
The Blue-Calc Airborne program will automatically position the specified lamp racks within the air duct, and the Blue-Calc Surface program will automatically determine the numbers of lamps needed to cover the coil surface, and their locations. Optionally, the analysis may be run as a "user-placement" job where the engineer specifies the number of lamps and enters their endpoint coordinates.

Software Modeling of Disinfection

The software is based on the mathematical modeling of the UV disinfection process pioneered by industry scientists such as Wladyslaw Kowalski and industry organizations such as the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), and the Air Conditioning and Refrigeration Technology Institute (ARTI).

While actual testing of the UVGI configuration and the microbes of interest is highly desired, it is a very difficult, time consuming, and costly undertaking. Fortunately, UVGI systems can be mathematically modeled with fairly accurate results for the purpose of system sizing. Based on the system configuration and lamp parameters, the software models UV irradiance fields and determines microbe inactivation rates and times.

The irradiance in µW/cm2 at any given point in a duct is mathematically determined using the view factor model of a lamp as a cylinder. The view factor model is accurate and is a widely accepted method of generating irradiance profiles and contour maps. This is the model used by the Blue-Calc software and is described in books and literature by Wladyslaw Kowalski and others (see references).



A microbial population will decay exponentially over time when exposed to UVC. The rates at which the populations decay is species dependent and is characterized mathematically by a UV rate constant, or k-value (i.e. the slope of the decay curve). High values of k mean rapid disinfection rates. Lower values of k mean greater resistance to UVC. Microbes have widely variant susceptibility to UV radiation; k-values vary several orders of magnitude for the different species. Through many years of scientific experimentation (still on-going), the UV rate constants have been measured for a large number of bacteria, viruses, and fungi. This data has been summarized in table form in books and literature published by Wladyslaw Kowalski and others.

The effectiveness of microbe inactivation depends on the UV dosage the organism receives. Dosage is a function of the UV intensity and the duration of exposure. A dose that produces 90% disinfection (10% survival) is described by the mathematical term, D90. Likewise, a dose that produces 99% disinfection (1% survival) is described by the mathematical term, D99.

Some microbe species appear as if there are two separate populations under UVC exposure: a majority population that decays quickly, and a small fraction that shows resistance to decay. This is known as a two-stage decay curve that is mathematically modeled using two different rate constants. For most air duct applications using high output lamps and D99 dosage, and coil surface applications having continuous exposure, the single stage rate constant used by Blue-Calc and other sizing software has been found to be adequate for mathematical modeling of inactivation rates.

Other microbes may exhibit a delayed reaction to the initial or low dose UV exposure. This is known as a shoulder effect. For bacteria and viruses, the shoulder effect is negligible in the modeling of inactivation rates at D90 or higher dosages.

The reflectivity of the duct lining material in air duct applications is a variable taken into account in the model as it will increase the average irradiation in the enclosure by as much a 2 - 3 times.

The effects of relative humidity, air temperature, photoreactivation, airstream patterns, air mixing, and lamp cooling effects are not taken into account in the model. These processes cannot be completely and accurately modeled at present. They are second order variables that can be ignored for most operating conditions. Lamps should be up-sized to account for those effects when relative humidity exceeds 65% within the UVGI system, or other operating conditions are outside design limits.

The effects of repeated exposure in recirculating air systems is cumulative. The Blue-Calc software does not calculate this effect, and consequently the analysis results are conservative for such applications.

Glossary & Acronyms	
AHU	Air handling unit
allergen	A substance, such as pollen, that causes an allergic reaction
bacteria	Tiny, one-celled forms of life that cause many diseases and infections
biofilm	A very thin layer of microscopic organisms that covers the surface of an object
disinfection	A reduction in the microbial population as opposed to sterilization which is a complete elimination of the population
dose UV dose	A value representing the amount of UV exposure an object receives. It is a function of the irradiance multiplied by the exposure time expressed in units of J/m2
D90, D99	A UVC dose that produces 90% (99%) disinfection
Blue-Calc Airborne	Fresh-Aire UV's "sizing" software for the design and analysis of air duct disinfection solutions
Blue-Calc Surface	Fresh-Aire UV's "sizing" software for the design and analysis of surface disinfection solutions
fluence rate	Another term for UV dosage expressed in units of J/m2
gas-phase purification	The airstream is directed through activated carbon, which is a porous material with the capability to absorb volatile organic compounds
HEPA	High Efficiency Particulate Arrestor – A high efficiency particulate filter capable of trapping and retaining at least 99.97% of airborne particles greater than 0.3 microns
IAQ	Indoor Air Quality
IAQP	Indoor Air Quality Procedure – a design procedure meant to reduce odors and irritants from an indoor space that requires calculations of outdoor airflow rates based on analysis of contaminant sources, concentration targets, and perceived air quality targets
MERV	Minimum Efficiency Reporting Value – The ASHRAE filter performance scale in the size range of 0.3 - 10.0 microns
microbe	A microorganism, especially a pathogen, is one that causes disease such as bacteria, virus, and fungus
mold	Any of various fungi that often form a fuzzy growth (called a mycelium) on the surface of organic matter

pathogen	A microbe that causes infections in humans and animals
PCO	Photocatalytic Oxidation – a chemical reaction initiated when UV light shines on a Titanium Oxide coated carbon filter that effectively "oxidizes" (or burns) the trapped microbes and pollutants (VOCs) breaking them down into harmless carbon dioxide and water molecules
photo-reactivation	A natural process that repairs bacteria DNA damaged by ultraviolet light using an enzyme that requires visible light. This process does not occur in viruses or spore forms
purification	The process of improving air quality by reducing the concentrations of microbes and contaminants
spore	A dormant or resting form assumed by some bacteria that enable the bacterium to survive high temperatures, dryness, and lack of nourishment for long periods of time. Similar to a seed, the spore may revert to the actively multiplying form of the bacteria under proper conditions
UVGI	Ultraviolet Germicidal Irradiation – a disinfection method that uses ultraviolet (UV) light at sufficiently short wavelength to kill microorganisms
UV rate constant	aka. k-value The rate at which the microbial population decays under UVC exposure
vegetative microorganism	Bacteria or microorganisms that are actively growing and reproducing where nutrients are available. When nutrients are depleted, spores are released
virus	A minute parasitic microorganism much smaller than a bacterium that may replicate only within a cell of a living plant or animal host
view factor model	Algebraic expressions that compute the amount of diffuse radiation transmitted from one surface to another. In UVGI applications, the expression computes the fraction of UV radiation (in μW/cm2) that leaves the cylindrical lamp body and arrives at a specified area at a specified distance from the lamp
VOC	Volatile Organic Contaminants – organic chemical compounds whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. Examples include acetone, benzene, ethylene glycol, formaldehyde and others. They are commonly used in building materials, industrial chemicals, furnishings, office equipment, and elsewhere
VRP	Ventilation Rate Procedure – a design procedure meant to reduce odors and irritants from an indoor space that prescribes the minimum outdoor air intake based on the typical space contaminant sources and source strengths
yeast	Single cell fungus that differ from the other molds in the way that they propagate. Yeasts multiply by means of budding or sprouting. They are capable of fermenting carbohydrates

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