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EvolAIR™ Application Methodology for Determining Projected Levels of Pathogen Inactivation

The EvolAIR™ product is unique among the Acuity Brands Lighting (ABL) portfolio of UV disinfection* technology products in that no ultraviolet energy is introduced to the space when properly installed and operated. Rather, air is circulated through an enclosed chamber where it may be treated without concern for occupant safety. In this regard, EvolAIR is like portable room air cleaners that have been in use for decades. Fine particle filtration is combined with UV irradiation to purify the air and inactivate pathogens** as air is being passed through the device. Unlike portable air cleaners, however, which often rest on the floor, EvolAIR resides at the ceiling and may provide lighting in addition to air treatment.

When projecting levels of pathogen inactivation that may be achieved by devices that provide UV irradiation directly into space, such as PulseX™ or products that incorporate Care222® modules, we use Visual® lighting software to perform certain calculations. This software is a suitable tool because the calculations needed are similar to the methodologies used for visible illuminance calculations and it is designed to handle volumetrics-based complexities. When projecting levels of pathogen inactivation that may be achieved by enclosed devices like EvolAIR, however, it is possible to use a simplified calculation methodology because these devices draw air through a compartment and process air at a constant rate. Therefore, to project levels of pathogen inactivation, we simply need to know the amount of air being processed (room volume, ft^3), the rate at which it is being processed per device (cfm), the number of devices employed, and something referred to as the Clean Air Delivery Rate (CADR). CADR is defined in ANSI/AHAM AC-1-2015, Method for Measuring Performance of Portable Household Electric Room Air Cleaners.[1] CADR is the volumetric airflow rate of clean air exiting the room air cleaner. Historically, it has been a measure of the air cleaner's ability to reduce smoke, dust, and pollen particles in the 0.10 to 11 micrometer (µm) size range from the air based on air flow and filter efficiency. The rate is specific to a pollutant. As used by ABL, CADR expresses the rate of pathogen reduction for a single pass through the device due to both filtration and ultraviolet irradiation, with the irradiation results determined by wavelength and spectral power distribution. The CADR will vary by spectrum and pathogen. Although pathogens are aerosol particles that are smaller than smoke, dust and pollen, and UV does not physically remove aerosols, CADR is still a useful measure that allows us to project pathogen inactivation rates for EvolAir devices. These devices operate in a manner similar to portable air cleaners, using a combination of air filtration and UV irradiation. Particle removal efficiency for specific particle sizes can easily be tested, and we expect the use of a CADR rating that is specific to photobiological UV pathogen treatment to align with CADR standards being developed by applicable standards organizations. CADR for these devices that use a combination of filtration and UV for pathogen reduction is easily calculated using methods presented here. Equivalent air changes per hour (eACH) incorporates CADR, is also easily calculated, and is a metric that enables performance comparison across various methodologies.

Application Analysis

The rate at which air is being processed through the EvolAIR device was measured by UV Partners and determined to be 50 cfm.[2] Given the dimensions of the chamber, the velocity of the air flow across the UV lamp was computed to be 185 fpm and the dwell time was calculated to be 0.65s. The latter is the amount of time the air is exposed to UV germicidal irradiation. For optimum results, the International Ultraviolet Association (IUVA) recommends that this value exceed 0.25s. Likewise, it is important that the velocity of air passing over the lamp not exceed the normal range (400-600 fpm) recommended by UV lamp manufacturers as that could induce cooling that diminishes the UVGI output of the lamp. Computer analysis performed by UV Partners[2] predicts an average irradiance within the chamber of 468W/m^2 which corresponds to an average dose of 302 J/m^2 as determined in accordance with Equation 1 below. The dose received by the air in a single pass is the product of the dwell time and average irradiance as follows.

$$D = t \times E \qquad \text{Eq. 1}$$

Where,

D = dose, J/m^2
t = dwell time, s
E = Irradiance, W/m^2

According to the *Ultraviolet Germicidal Irradiation Handbook*, the equation that relates survival rate to dose for the first stage of decay is as follows:

$$S = e^{-kD} \qquad \text{Eq. 2}$$

Where,

D = dose, J/m^2
S = survival, fractional
k = UV rate constant, m^2/J

Note that the handbook states "This is a first order decay rate model and is generally adequate for most UVGI design purposes, provided the UV dose is within first order parameters. This is because disinfection rates of 90–99% can generally be achieved in the first stage of decay, and this is adequate for most design purposes. "[3] Regardless, if one applies the first order decay model rather than one of the other decay models, the first order model would merely overestimate the dose required for inactivation of greater than 99%.[4] The Acuity Brands Pathogen Inactivation Dose Reference List contains $D_{99.9}$ values for a variety of pathogens and three UV lamp technologies. The k value can be established from this data as follows:

$$D_{90} = D_{99.9}/3 \qquad \text{Eq. 3a}$$
$$D_{99.9} = 3 \times D_{90} \qquad \text{Eq. 3b}$$

Where,

D_{90} = dose for one log or 90% inactivation
$D_{99.9}$ = dose for three log or 99.9% inactivation

Solving Eq 2 for k yields:

$$k = -\ln(S)/D \quad \text{Eq. 4}$$
$$k = -\ln(S_{10})/D_{90} \quad \text{Eq. 4a}$$
$$k = -\ln(S_{1})/D_{99} \quad \text{Eq. 4b}$$
$$k = -\ln(S_{0.1})/D_{99.9} \quad \text{Eq. 4c}$$

D_{90} is the dose for one log, or 90% inactivation which corresponds to a survival fraction (S_{10}) of 10% or 0.1. Thus, substituting these values into equation 4 yields the k-value, which is both lamp (wavelength) and pathogen specific. k-values for many pathogens and lamp types may also be obtained from published tables. k-values utilized were derived from the Acuity Brands Pathogen Inactivation Dose Reference List.

Having solved for a specific k-value, we can return to equation 2 and solve for the single pass survival fraction using the single pass dose reported by UV Partners. The fraction of inactivation will simply be 1 minus the resulting survival fraction, S. This fraction is the contribution that UV makes to reduction of pathogen load in the air, but we should also account for filtration as some particles will be physically removed from the air as well.

Filters do not remove particles uniformly. Rather, the removal efficiency varies with particle size and the speed of air passing through the filter. Larger and slower particles tend to be more easily trapped. The size of most pathogens can be found in published tables[3]. The EvolAIR filter was tested by Blue Heaven Technologies in Louisville, Kentucky in accordance with ANSI/ASHRAE 52.2-2017.[5,6] The testing confirmed that the filter achieved a MERV 7 rating and the removal efficiencies by particle size were reported as follows:

Data - Particle Removal Efficiency

Particle Size Range (um)	Geometric Mean Diam (um)	Particle Removal Efficiency
0.30 - 0.40	0.35	0.0
0.40 - 0.55	0.47	0.0
0.55 - 0.70	0.62	0.0
0.70 - 1.00	0.84	1.4
1.00 - 1.30	1.14	7.4
1.30 - 1.60	1.44	13.4
1.60 - 2.20	1.88	25.1
2.20 - 3.00	2.57	42.0
3.00 - 4.00	3.46	55.1
4.00 - 5.50	4.69	62.6
5.50 - 7.00	6.20	64.5
7.00 - 10.00	8.37	60.7
		(%)

Values in the far-right column correspond to the particle removal efficiency (%) for each particle size range in the left column, with no dust loading. Since maintenance protocols call for periodic filter cleaning and replacement, these are the values conventionally employed. Also, as filters generally become more efficient at removing particles as they load with dust, these are the lowest particle removal efficiencies one would expect. Note that the survival fraction is equal to 1 minus the filter efficiency in decimal form (%/100). Filtration and UV irradiation combine to provide an overall net impact described by the following relation[2]:

$$S_2 = (1 - IR)(1 - RR)S_0 \qquad \text{Eq. 5}$$

Where,

S_2 = combined survival population (from UV irradiation and filtration)
IR = inactivation rate due to UV irradiation
RR = decimal removal rate due to filter
S_0 = initial population

Having previously established the inactivation and removal rates due to UV irradiation and filtration respectively, only the initial population remains unknown. If that is taken to be 100% or 1.0, S_2 then represents the survival fraction for the combined system. The combined removal efficiency is naturally equal to 1 minus that survival fraction. The $CADR_{combined}$[3] is equal to this value multiplied by the airflow rate[2] of the device as follows:

$$CADR_{combined} = (1 - S_2) \times Q \qquad \text{Eq. 6}$$

Where,

$CADR_{combined}$ = Combined Clean Air Delivery Rate (cfm)
S_2 = combined survival fraction
Q = Airflow rate (cfm)

Once again, the $CADR_{combined}$ describes the rate of clean air delivery for a single pass through the device. It can be expressed in terms of equivalent air changes per hour (eACH), meaning that the rate of pathogen inactivation/removal achieved is the same as if the HVAC system were providing this number of actual air changes per hour of clean or outside air. The value of the eACH calculation is that it allows comparison among different methodologies. The eACH is shown as:

$$eACH = n * 60 * CADR_{combined} / V \quad \text{Eq. 7}$$

Where,

eACH = Equivalent air changes per hour
$CADR_{combined}$ = Combined clean air delivery rate (cfm) of one EvolAIR unit
n = number of EvolAIR units
60 = 60 min/hr conversion
V = volume of room air (ft^3)

From the *Ultraviolet Germicidal Irradiation Handbook*[3] equation 8.12 provides the following relation:

$$S_t = S_0 e^{-ACHt} \quad \text{Eq. 8}$$

Where,

S_t = airborne survival fraction at time t
S_0 = initial airborne concentration
ACH = air changes per hour
t = time (s)

Equivalent air changes per hour (eACH) may be substituted for ACH in this equation to determine the final survival population for any combination of disinfection methodologies. Additionally, if the initial population is taken to be 100% the result will be simplified to the fraction of pathogens that survive. The equation reduces to the following:

$$S_t = e^{-eACHt} \quad \text{Eq. 9}$$

Where,

S_t = airborne survival fraction at time t
eACH = equivalent air changes per hour
t = time (s)

The total inactivation/removal rate is equal to 1 minus the airborne survival fraction at time t. Thus, we can solve for the pathogen inactivation/removal resulting from UV irradiation and filtration at any given point in time.

Alternatively, it is useful to solve for the time required to achieve a given rate of pathogen inactivation/removal. For example, a three-log reduction is commonly sought. Rearranging equation 9 to solve for t yields the following:

$$t = \ln(S_t) / eACH$$

Where,

S_t = airborne survival fraction desired
eACH = equivalent air changes per hour
t = time (s)

Note that S_t is the desired survival population. Thus, for three-log inactivation/removal, the value would be 0.001 (1 - 0.999). The performance of EvolAIR™ can therefore be projected solving for either the rate of pathogen inactivation/removal given time, or time given the desired rate of pathogen inactivation/removal. However, it is important to note that two key assumptions are inherent to the described approach:

1) Air is perfectly mixed within the space
2) No new bioaerosols are being introduced

Although the *Ultraviolet Germicidal Irradiation Handbook*[3] does provide methods to account for the introduction of bioaerosols and ABL is interested in providing this capability in future software, for now no standards exist to guide us in the choice of an appropriate amount of bioaerosol introduction by application. Assumptions about the level of occupancy in a space and the likelihood that the space will be occupied would be required to determine the expected amount of bioaerosol introduction, and without scientific guidance, we will not make assumptions about these factors. Thus, until standards can be established, we are assuming that no bioaerosols are being introduced.

**All references to "disinfection" are referring generally to bioburden reduction and are not intended to refer to any specific definition of the term as may be used for other purposes by the U.S. Food and Drug Administration or the U.S. Environmental Protection Agency. Bioburden reduction is a function of fixture run time and the distance to the UV light source, airflow, room size, shadow areas and/or other factors, and the level of reduction will vary within a specific space. This fixture is [these fixtures are] not intended for use in the cure, mitigation or prevention of disease and is [are] not certified or approved for use as [a] medical device[s] by the FDA. It is the obligation of the end-user to consult with appropriately qualified Professional Engineer(s), a Certified Infection Control professional and a Certified Industrial Hygienist, as applicable, to determine whether this fixture meets [these fixtures meet] the applicable requirements for system performance, code compliance, safety (including safety and hazard alerting signs), suitability and effectiveness for use in a particular application design. In no event will Acuity Brands Lighting be responsible for any loss resulting from any use of this fixture in an application design.*

***Refer to EvolAIR DN and EvolAIR NDN product specification sheets at acuitybrands.com/UV-Products for efficacy claims and claim substantiation regarding specific pathogens.*

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[1] ANSI/AHAM AC-1-2015, Method for Measuring Performance of Portable Household Electric Room Air Cleaners

[2] Performance Analysis of the UV Angel Air System, UV Partners, Grand Haven, MI, January 29, 2020

[3] Ultraviolet Germicidal Radiation Handbook, Wladyslaw Kowalski, Springer Verlag 2009

[4] Activation credit of UV radiation for viruses, bacteria and protozoan (oo) cysts in water: A review, W.A.M. Hinen, E.F. Beerendonk, G.J. Medema. Water Research, January 2006. https://doi.org/10.1016/j.watres.2005.10.030

[5] ANSI/ASHRAE standard 52.2-2017

[6] Blue Heaven Technologies test report no. 22-024-1, 1-Feb 2022, Rigid Pad Air Filter