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FACT VS. FICTION: Clarifying Myths About UV and Indoor Air Quality

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Introduction

As the world emerges from the COVID-19 pandemic, the increased focus on Ultraviolet (UV) disinfection in HVAC systems is expected to remain as one of many lasting elements of the so-called “new normal”. Various government and industry organizations, such as CDC, GSA, ASHRAE and IUVA, include UV-C as a recommended mitigation step to reduce airborne transmission and to improve the indoor air quality in commercial buildings.

Yet, despite its widespread implementation as an effective disinfection step, UV technology remains a challenging topic and a potential source of confusion for specifying engineers, contractors and end-users. This is, in part, due to the vast proliferation and marketing of UV devices with different designs, capabilities, and price points. This has contributed to incorrect application as well as false or misleading claims regarding product efficacy, safety and implementation for existing and new HVAC systems. This whitepaper will help clarify the Top 10 common misconceptions regarding UV technology and its application in HVAC systems.

Overview | Ten Common Misperceptions About UV Technology

1. All UV wavelengths are inherently germicidal in nature
2. UV light is equally effective in killing all bacteria, viruses and fungi
3. All UV lamps have the same germicidal output, power and efficiency
4. Cumulative Intensity of a fixture is equal to the sum of individual lamp Intensity
5. UV lamp Intensity is the same as UV lamp Dose
6. Coil Cleaning application is straightforward and easy-to-design
7. Airstream Disinfection application depends only on the number of lamps used
8. Coil Cleaning design can be applied for Airstream Disinfection
9. Air Handling Unit (AHU) and in-duct design requirements are equivalent
10. UV-C lamps all have the same lamp life, regardless of use

Myth 1 | All UV wavelengths are inherently germicidal in nature

All UV wavelengths do not have the same germicidal efficacy. In fact, most microorganisms exhibit peak UV absorption around 265 nm wavelength, which results in maximum damage via inactivation of cell DNA.

The ultraviolet spectrum is a band of electromagnetic radiation at higher energies than visible light, split into four major bands: UV-A (315 - 400 nm), UV-B (280 - 315 nm), UV-C (200 - 280 nm), and vacuum UV (VUV, 100 - 200 nm). UV-C light in the 200 - 280 nm range has been proven to be the most germicidal in nature and has been used for water, air, and surface disinfection for decades. UV-A and UV-B have shown significantly lower effectiveness (1000 times less) compared to UV-C wavelengths and are also more harmful to human skin and eyes. Blue light (405-420 nm) has shown some effect on bacteria only, but not for viruses and requires much higher doses than UV-C light to achieve any significant level of inactivation.

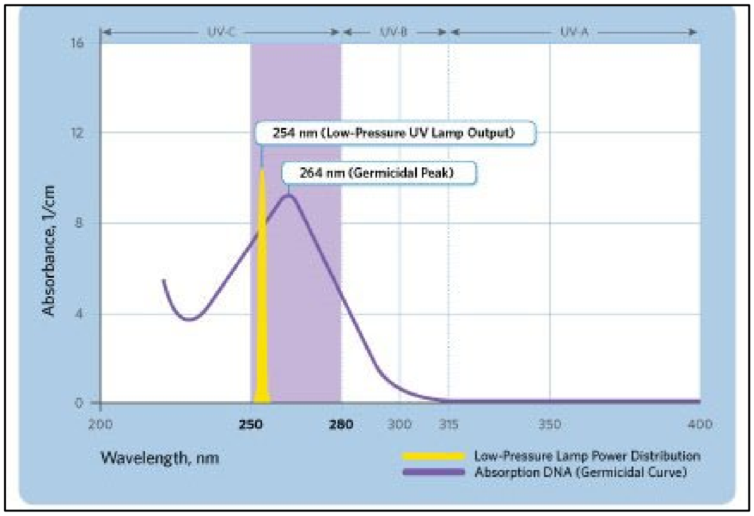

Figure 1. UV Wavelength and DNA Absorption Curve

In addition to having higher energy compared to other UV wavelengths, the main advantage of UV-C light is that the DNA and RNA of most microorganisms have a preferential absorption within these wavelengths, exhibiting peak susceptibility around 265 nm. Low pressure mercury lamps emit almost all their spectral output at 254 nm, which is close to this absorption peak and therefore enjoy the most widespread use in all UV disinfection applications worldwide. At this wavelength, pyrimidine dimerization, the primary mechanism for microorganism inactivation by UV-C light, occurs. The formation of pyrimidine dimers leads to changes to the double helix structure, cell mutation and ultimately to the death of the cell.

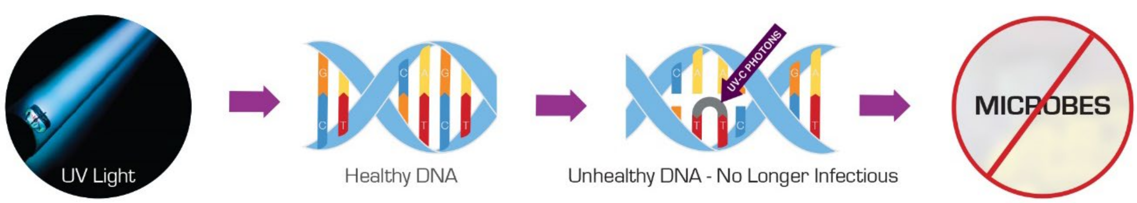

Figure 2. UV-C Inactivation Mechanism of DNA

Myth 2 | UV light is equally effective in killing all bacteria, viruses and fungi

While the DNA structure of most microorganisms is damaged by UV-C light, their susceptibility is affected by their unique shape, cell structure and cell chemistry. In general, viruses are the easiest to inactivate compared to vegetative bacteria, spores and fungi – all of which require much higher UV energy.

The susceptibility of a specific microorganism to UV is generally expressed in terms of the "k-value", the UV-C inactivation rate constant for the specific microorganism. The k-value is then used to determine the D90 dose, i.e., the dose required to inactive 90% of the microorganism in a single pass, and calculated from the formula:

$$D90 = 2.303/k \qquad (1)$$

Although the k-values or D90 values for different microorganisms are available in published literature,[1] reported values for some microorganisms may differ widely. Variations in published *k*-values may relate to differences in conditions under which the UV irradiance of the microbial population was conducted (in air, in water, or on surfaces), the methods used to measure the irradiance level, and errors related to the microbiological culture-based measurements of microbial survival.[2] Because no standard methods are currently available for the determination of inactivation rate constants, care is necessary when applying values reported in the literature to applications under different environmental conditions.

Bacteria	
Bacillus anthracis	8,700
Bacillus anthracis spores	46,200
Escherichia coli	6,600
Legionella pneumophila	12,300
Mycobacterium tuberculosis	10,000
Salmonella typhi - Typhoid Fever	7,000
Staphylococus aureus	6,458
Vibrio comma – Cholerae	6,500
Clostridium difficile – C-diff	38,500
Vancomycin-Resistant Enterococci - VRE	12,600

Virus	
Infectious Hepatitis	8,000
Influenza A	4,558

Mold	
Aspergillus flavus	99,000
Aspergillus niger	330,000

Figure 3. UV-C Dose Required For 99% Inactivation

Myth 3 | All UV lamps have the same germicidal output, power and efficiency

This is not true as there are various factors that govern the germicidal effectiveness of a UV lamp. The proliferation of UV devices has exponentially expanded the number and type of UV light sources being used today with varying wavelengths, wall plug efficiencies and power outputs. There is also confusion about terminology used for UV output and we see specifications using different metrics for UV output requirements such as:

- Spectral output wavelength e.g., 253.7 nm, 265 nm, 222 nm, 365 nm
- Lamp wattage (input power)
  - Lamps are available with different wattages (outputs) for the same length

Lamp Output	UV Watts	UV Intensity* @ 1 meter (mw/cm^2)
Standard Output – 21”	8.5	84
High Output - 21”	17.5	172
Standard Output – 33”	15	145
High Output – 33”	27	240
Standard Output – 61”	25	280
High Output – 61”	45	380

Figure 4: Different Lamp Outputs (* representative values only)

- UV output power (wall plug UV efficiency)

Lamp Type	Wavelength	Efficiency*
Low Pressure Hg	254 nm	30-35%
Medium Pressure	200 - 350 nm	10-20%
Pulsed Xenon	200 - 300 nm+	< 10%
Far UV	220 nm	5-20%
LEDs	265 - 280 nm	< 10%

Figure 5: Different Lamp Outputs (*representative values only)

- UV intensity
  - The UV-C intensity received by a surface decreases exponentially the further the surface is from the lamp.
  - Intensity is inversely proportional to the square of the distance (Inverse Square Law).

- This information is relevant when deciding lamp placement for a coil disinfection application.

- UV Dose
  - This is the cumulative UV intensity achieved over a period of time
  - UV Dose = Intensity x Exposure Time

Myth 4 | Cumulative Intensity of a fixture is equal to the sum of individual lamp intensity

This is not necessarily true. The fact is that that the total intensity depends on the configuration of the lamps in the UV fixture. Fixtures can come in different shapes and sizes, and it is extremely rare that the total intensity output would simply be the sum total of the individual intensities. In addition, quite often we come across a specification which may prescribe a certain lamp intensity but is not clear whether it is for one lamp or for complete fixture. It is therefore important to distinguish and clarify whether a specification for intensity has been written for a single lamp or a fixture.

Myth 5 | UV lamp Intensity is the same as UV lamp Dose

Dose is not the same as Intensity. The UV-C dose delivered at a target surface or object is the product of UV-C irradiance (intensity) at that target and exposure time, meaning that a higher UV-C dose can be delivered by increasing the intensity of UV-C light and the exposure time. This formula is extremely important when sizing a UV-C system for coil or airstream disinfection. A large dose can be delivered to a coil surface with a low UV-C irradiance because of the essentially infinite exposure time, making it relatively easy to disinfect the coil cost-effectively. On the other hand, for airstream disinfection, where the air velocity is typically 500 feet per minute inside the AHU (or even higher in the supply ducts), the UV-C exposure time for a microbe is a fraction of a second and would therefore require a much higher UV-C irradiance to achieve a high level of disinfection.

Dose = *Intensity x Time*

Intensity	**50 µw/cm^2**
	x 60 sec
Exposure Time	**x 60 min**
	x 24 hours

Dosage = 4,320,000 µw-sec/cm^2

Figure 6. UV Dose Calculation Example

Myth 6 | Coil Cleaning application is straightforward and easy-to-design

Cooling coil disinfection using UV-C depends on a number of variables which govern correct sizing and application. These variables include:

- Microorganism type
- Lamp type/wavelength
- Lamp power (Wattage)
- Lamps configuration (proximity to coil) in space
- Wind chill factor
- Air flow rate
- Temperature and relative humidity
- Duct reflectivity

Current practice for effective coil disinfection is to mount the UV-C lamps in close proximity to the coil (12-24” distance), spacing the lamp rows to provide an even distribution of UV-C energy across the coil face. ASHRAE has recommended minimum irradiation levels of 50-100 microwatts/cm² to be applied to the coil surface[3]. Sizing for coil disinfection is therefore based only on the intensity on the coil surface and not dosage.

Some manufacturers recommend applying of irradiance values higher than ASHRAE minimum recommendations and mounting lamps on both sides of the coil. While oversizing may be conservative, this may lead to unnecessary increased equipment costs and energy consumption. Parameter modeling that accounts for the above variables helps generate intensity distribution profiles on desired area to help determine optimal system design and lamp configurations. The manufacturer should be able to provide model outputs from independently validated software. In addition, the manufacturer should be able to provide validation of their system performance.

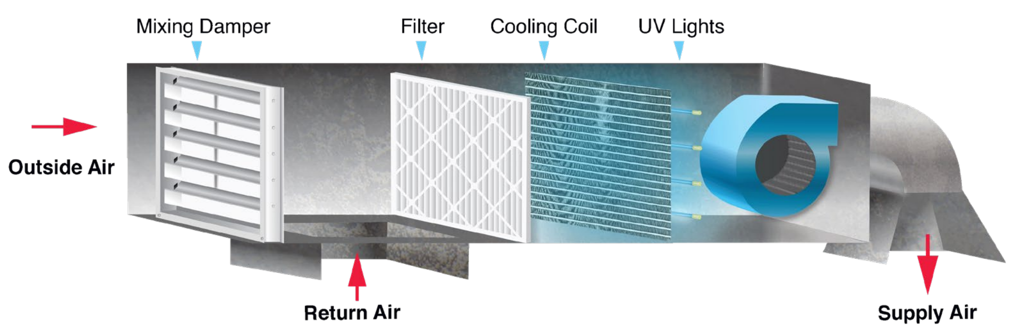

Figure 7. Typical UV Installation in an Air Handling Unit

Myth 7 | Airstream Disinfection application depends only on the number of lamps used

While people recognize that airstream disinfection is different from coil disinfection, a common myth is that all you need is a few more lamps. This is not true as the effect of variables such as airflow velocity and duct dimensions have a pronounced effect on the efficacy of the UV system. Air flow speeds up to

500 fpm are common inside the central AHU, providing a short exposure time of approximately 0.25 seconds. Compared to coil disinfection, which is sized by intensity, air disinfection systems are designed to deliver the right amount of dose for the target microorganism. Therefore, the short exposure time would require a much higher number of lamps and higher output from the UV system.

Typical intensity required for coil disinfection	**50-100 µw/cm^2**
Typical intensity required for air disinfection *to achieve ASHRAE recommended minimum dose of 1500 µw-sec/cm^2*	**6250 µw/cm^2**

Figure 8. Coil Disinfection Intensity vs. Airstream Disinfection Intensity

Myth 8 | Coil Cleaning design can be applied for Airstream Disinfection

The COVID-19 pandemic has spawned a broad proliferation of unproven, unvalidated UV systems which are often either undersized or oversized for the application without due consideration of the design factors discussed here. Some of the common misapplications which have been reported are systems which claim air disinfection, but have been sized for coil applications (i.e., sizing is based on intensity rather than dose), or can be simply upgraded by adding just a few more lamps. This is not true as installation specifications vary widely, based on the required dose and multiple parameters relative to the site characteristics. The following example illustrates this in practice:

According to ASHRAE guidelines[3] required for airstream disinfection in a HVAC system, a minimum dose of 1500 microwatts /cm^2-sec is recommended for a minimum irradiance zone of 2 feet. At the ASHRAE recommended intensity of the coil of 100 microwatts/cm^2, this results in an applied dose of only 24 microwatts/cm^2-s compared to a minimum dose required of 1500 mw/cm^2-s. Even if we increase the intensity over ten-fold to, say 1250 microwatts/cm^2 , that is still not sufficient to achieve the required dose for airstream disinfection because of the short exposure time. The effect is accentuated even further at higher air flow speeds.

Applied Intensity (mW/cm2)	Applied Dose (mW-s/cm2)		Required Dose (mW-s/cm2)
	500 fpm	**1000 fpm**	
100	**24**	**12**	**> 1500**
1250	**300**	**150**	**> 1500**

Figure 9. Intensity Versus Dose Example

While there is infinite time for coil disinfection, which requires relatively low UV intensity levels, there is only a fraction of second available to disinfect the virus particles moving in an air stream and therefore require much higher lamp intensities**.**

Myth 9 | Air Handling Unit (AHU) and in-duct design requirements are equivalent

A related misperception is that a system which is properly designed for a central AHU is also applicable for the supply ducts. The fact is that installation specifications vary widely, based on the required dose and multiple parameters relative to the site characteristics. Duct geometries are much smaller compared to the central AHU resulting a much higher air flow velocity. Figure 9 above shows the higher intensities required for higher airflow velocity. As recommended earlier, parameter modeling that accounts for duct dimensions, air flow velocity, temperature, relative humidity and duct reflectivity etc. should be used to determine the most optimal system design for number of lamps, intensities and lamp arrangement.

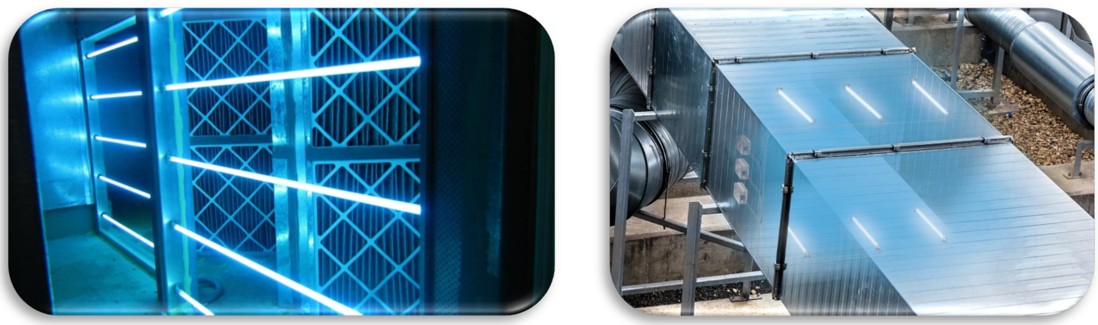

Figure 10. Typical Air Handling Unit (AHU) and In-Duct Installations

Myth 10 | UV-C lamps all have the same lamp life, regardless of use

Another common myth is that all lamps have the same lamp life, irrespective of use conditions. Low pressure mercury UV lamps are built similar to fluorescent lamps and are subject to filament wear over use. They typically exhibit a drop of 10-15% in intensity over 9,000 hours of continuous use. Frequent on/off cycling will impose greater stress on the lamp filaments resulting in a greater rate of reduction and a shorter lamp life. Therefore, the useful lamp life will be below the manufacturer's maximum rating. A properly designed system should factor in this drop in lamp intensity at end of life when sizing a system.

Summary

- UV devices are not all the same and, as such, do not have the same performance, efficacy and safety.
- Key considerations for product selection should distinguish between lamp wavelengths, individual lamp versus fixture output, intensity versus dosage.
- Correct sizing of UV systems should account for the multiple variables affecting the applied UV intensity and dose.
- Coil disinfection design is based on Intensity on coil surface whereas air disinfection design is based on applied Dosage.
- Design and performance of a Manufacturers' UV system should be verified prior to use.

References

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3. ASHRAE Epidemic Task Force Available Resources (Online 2021) Filtration/Disinfection. Retrieved from https://www.ashrae.org/ technical-resources/filtration-disinfection.