Ultraviolet Germicidal Irradiation (UVGI):
What you need to know

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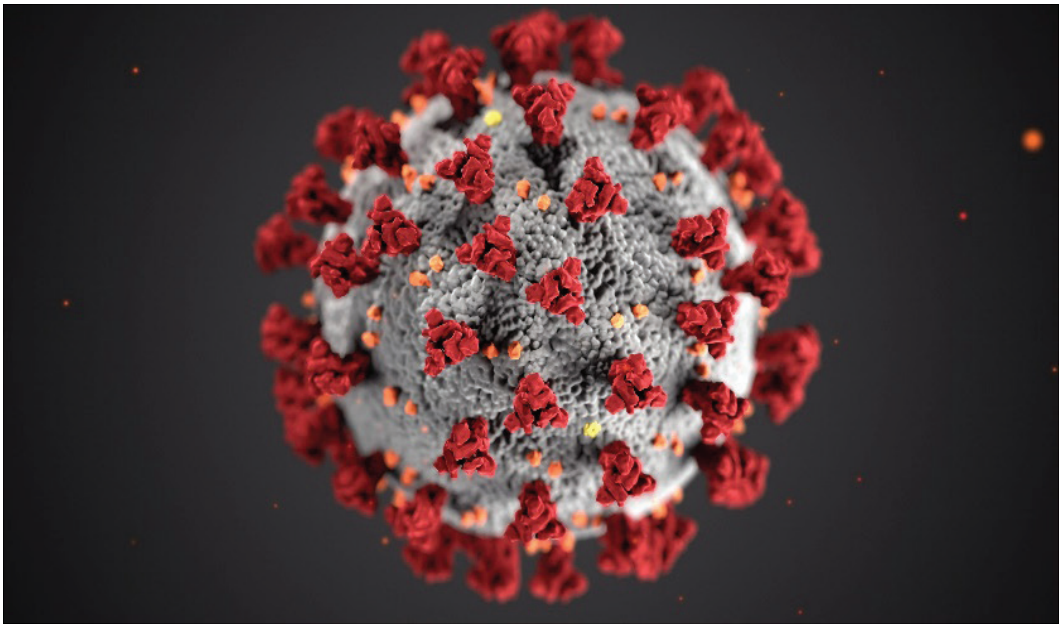


Even though Coronavirus (or more specifically COVID-19) caught every one of us by surprise and probably changed the way of life that we were used to, completely; it is only an example of hundreds (and more) pathogens that are around us. Pathogens are biological agents (more commonly known as microbes) that cause disease or illness to their host. The most famous pathogens are viruses, bacteria, and fungi. Some pathogens (such as bacteria or fungi) are 'alive' and some are (such as viruses) are not. There are actually opposing views on the term 'alive' for viruses. They are basically proteins and genetic materials that survive and replicate within another life form. Therefore, I the absence of a host, viruses are unable to replicate, and many are unable to survive for a long time.

Disinfection (what is it) vs. cleaning vs. sanitizing vs. sterilization

Regardless of the environment, people are always at risk of the harmful effect of different types of pathogens. Many of the harmful pathogens are easy to spread and can survive for some time on surfaces and/or are airborne (so they can stay in air for a longer time). Therefore, it is important for everyone (specifically owners of buildings and commercial users) in understanding different levels of cleanness and their related procedures and standards (Rutala, 2008).

- Cleaning: Cleaning removes dust, germs, and debris from surfaces. Cleaning usually is done with scrubbing, washing, and rinsing, and will result in lowering the number of pathogens on a surface (not necessarily killing them). Cleaning is commonly being done in households and commercial buildings.

- Sanitizing: Sanitizing reduces the number of pathogens to a lower level than cleaning (using sanitization material). Practically, sanitization can reduce the number of pathogens to a safe level (depending on the application). Sanitization is mostly being done in food (and related) industries.

- Disinfection: Disinfection is killing or inactivating pathogens. Killing is usually being used for the 'alive' pathogens while inactivation is being used for viruses. When the protein layer of a virus is destroyed (for example resolved in a disinfection chemical), the virus will become inactivated and cannot survive within its host anymore. Disinfection is not cleaning the surfaces or removing pathogens; but it will lower the risk of infection. Disinfection is currently being widely used to inactivate Coronavirus (for example by use of chemicals in the buildings or ultraviolet irradiation)

- Sterilization: Disinfection usually is being done to a certain level (for example until 90% or 99% of the selected pathogens are killed or inactivated); but sterilization completely kills (or inactivates) all pathogens and prevents their growth and reproduction. Sterilization are commonly used in medical facilities (infamous application is sterilization of surgery rooms).

Common disinfection methods

There are 3 common methods for disinfection in residential and commercial buildings, each having their own pros and cons (Rutala, 2008).

1- Chemical disinfectants: This method is the most widely used approach to disinfecting surfaces. Various chemicals can be used to inactivate viruses on different type of surfaces. Some common type of disinfectants are alcohol, chlorine and its compounds, formaldehyde, and hydrogen peroxide.

- Advantages: Relatively inexpensive; easy to use; well-known and familiar

Source: BC Centre for Disease Control

◆ Disadvantages: Manual disinfection process (prone to errors and not all surfaces will be covered); not common or effective for air disinfection; harmful to skin and respiratory system and harmful residue; corrosive effects on materials

2- Ozone disinfection: Ozone (O3) is a versatile and powerful disinfectant which is mostly being used for air disinfection. Ozone disinfection have been well-documented in water treatment applications; but their application in buildings air disinfection is so far limited.

◆ Advantages: As a gas, it can penetrate every corner of the room; no harmful residue (as it will convert to oxygen);

◆ Disadvantages: Expensive (as Ozone needs to be produced on-site); highly corrosive (not appropriate for surface disinfection); harmful for respiratory system

3- Ultraviolet radiation: Ultraviolet (UV) radiation can inactivate viruses by destruction of their DNA. It also can kill bacteria and fungi, while being irradiated with certain dosage. It has been widely used for water treatment as well as healthcare environments (operating rooms, biological safety cabinets, etc.) to disinfect surfaces and air.

◆ Advantages: Limited corrosiveness on certain materials; automated disinfection; flexible applications

◆ Disadvantages: Relatively expensive, not safe if skin or eye is exposed

Ultraviolet Germicidal Irradiation (UVGI)

Although UVGI is not a "new" technology; but it has been seeing a rapid growth in commercial and health applications as it has shown proven disinfection capabilities for surfaces, air, and water. There is quite a significant history to UV irradiation studies, going back to 1814 when Fraunhofer mapped different spectral bands of sunlight (including UV). The earliest scientific observation of germicidal effect of UV was done by Dawn and Blunt in 1877. Since then, many advancements has been done

Source: InterestingEngineering.com

to increase the effectivity of the germicidal effect of UV and to demonstrate that as a reasonable solution for disinfection; until 1994 at which the Center of Disease Control (CDC) acknowledged UV effectiveness for control of Tuberculosis for the first time. It took CDC about 10 years after that, until at 2003 it formally sanctioned UVGI to be used in hospitals as an effective disinfection tool (Kowalski, 2009).

To get a little more into technical details, let's start by defining what is an ultraviolet irradiation and how it can inactivate pathogens. As you might know, sunlight is a source of a large spectrum of light radiation. This means that it does not only include the visible light spectrum but other spectrums which are not visible to eye but have their characteristics, features, and applications.

Referring to figure the figure below, light includes a continuous spectrum of wavelengths (different energy levels) measured in Nanometers (nm). Visible light only includes wavelengths of 380-780nm. Wavelength larger than 780nm (up to 1mm) are considered infrared, which has the most popular applications as night vision and heat vision. Wavelengths smaller than 380nm (down to 100nm) are called UV. The UV region is divided into three bands: UVA (315-380 nm) UVB (280-315 nm) UVC (100-280 nm).

UVA (also known as "black light") is the least harmful of all and usually is being used to create an artistic colored glowing effect on objects (Stanford Solar, 2015). It also is the main type of light used in tanning beds. UVB can cause sunburn (and eventually melanoma). In moderate (controlled) levels, UVB exposure can hep the skin to produce a type of vitamin D, eventually playing a role in bone and health muscles (Ultraviolet (UV) Radiation, 2020).

UVC, which is mostly being filtered out by the ozone layer, is known to have germicidal effects by destroying the ability of microorganisms to reproduce by causing photochemical changes in nucleic acids (Kowalski, 2009). The germicidal effectiveness of UVC is at its peak at the wavelength of about 260-265nm. This means that these wavelengths have the maximum amount of radiation energy being absorbed by the DNA.

Before getting into details of how UVGI can be used in different applications, first let's get introduced to a few common terms.

UVGI Terms and Definitions

Understanding multiple terms being used in UV systems, can help to select the best combination of UV technologies (National Institute for Occupational Safety and Health, 2009).

Irradiance (intensity): The irradiance is the density of irradiation on a flat surface. This term is usually used to determine how powerful a UV source is. Irradiance is described in units of or . As this value indicates the amount of radiation reaching to a surface, it will decrease by increasing the distance from the UV light source. The value of irradiance at different distances from the source is usually being reported in the UV lamp data sheets.

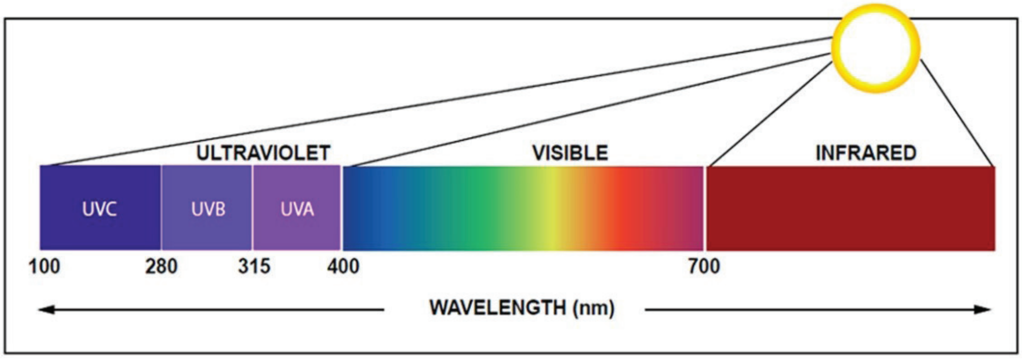
UV Dose (fluence rate): UV dose is the mount of UV energy being absorbed by a unit volume. The dose is usually being calculated by the amount of Irradiance multiplied by the time of exposure; therefore, its unit is or .

Survival: The percentage of the specific pathogens subject to UV exposure to survive from it. For example, the survival of 10% (or 0.1) indicates that 90% of the specific pathogens have been inactivated.

UV rate constant (decay rate constant,): The slope of a survival curve for a pathogen exposed to UVGI, which is directly related to the sensitivity of the pathogen to UVGI and is unique to each species. This unit is being reported for each type of pathogens. There have been multiple studies on the UV rate constant for many different types of pathogens and the results are publicly available.

UV bulbs and lamp fixtures: UV radiation is being generated within a bulb. The bulbs are placed within a fixture which also includes the required electronics to start the light and keep its power constant (as much as possible). Also, the fixture might include specific designs to guide the UV light, depending on the application. There are 3 main types of lamps when it comes to UV radiation generation (Low vs. Medium pressure UV lamps, 2011):

- Low pressure lamps: These lamps are usually having higher efficiency (up to ~35%) as they require lower input power to generate UV radiation power. They have good lifetime and are usually being used when there is not a need for a high-power UV radiation (more time can be spent on the disinfection process). They operate on a lower temperature so overall they seem to be safer comparing to medium pressure ones.



* Medium pressure lamps: As the name clearly shows, these lamps are being operated at higher internal pressures (and temperatures). They are less efficient (~8-10%). However, they do generate higher UV power which makes the operation time faster.

* Light emitting diodes (LED): As a newer technology, UV LEDs are more environmentally friendly as they do not contain harmful mercury (as opposed to other lamp types), do not produce ozone, and consume less energy. LED technology is relatively new and comparing to the traditional ones, it is generally more efficient and more controllable. The only drawback is that although there are many UV LEDs commercially available, the technology is yet to be scaled up after demonstrating its clear advantage over the traditional lamps.

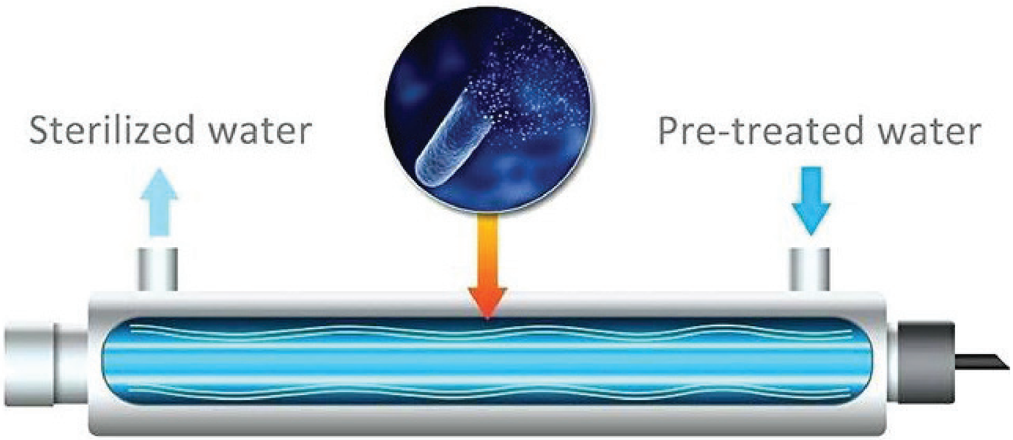
Different use of UVGI

There are 3 main usage for UVGI systems, namely air, surface, and water disinfection. Depending on the application, different technologies can be selected and combined to shape a final solution (Kowalski, 2009).

UV water disinfection: UV water disinfection has been conventionally used for water treatment and to purify water from harmful bacteria. The technology is bringing chemical-free process with minimal energy and maintenance required. These systems are being widely used in commercial applications but are not typically used for residential water treatment.

UV surface disinfection: Similar to water disinfection, UV surface disinfection has a long track record of successful implementation in different capacities. Today, we can see UV surface disinfection technologies being used in healthcare facilities (hospital operation rooms for example) or for disinfection of specific equipment or material surfaces (such as dental and medical equipment). In the wake of the Covid-19 pandemic, there has been a tremendous growth in manufacturing and applications of UV surface disinfection for small appliances, clothes, masks and Personal Protection Equipment (PPE), etc. However, before using a UV lamp fixture (or a gadget) to disinfect a surface, there are multiple considerations to be made. An important note to consider is that pathogens are typically less vulnerable to UV radiation when they are on a surface, as they have an inherent protection.

Also, most of the readily available gadgets to do surface disinfection for small items and appliances, if not evaluated and certified, might not have enough irra-



Source: World Water Reserve

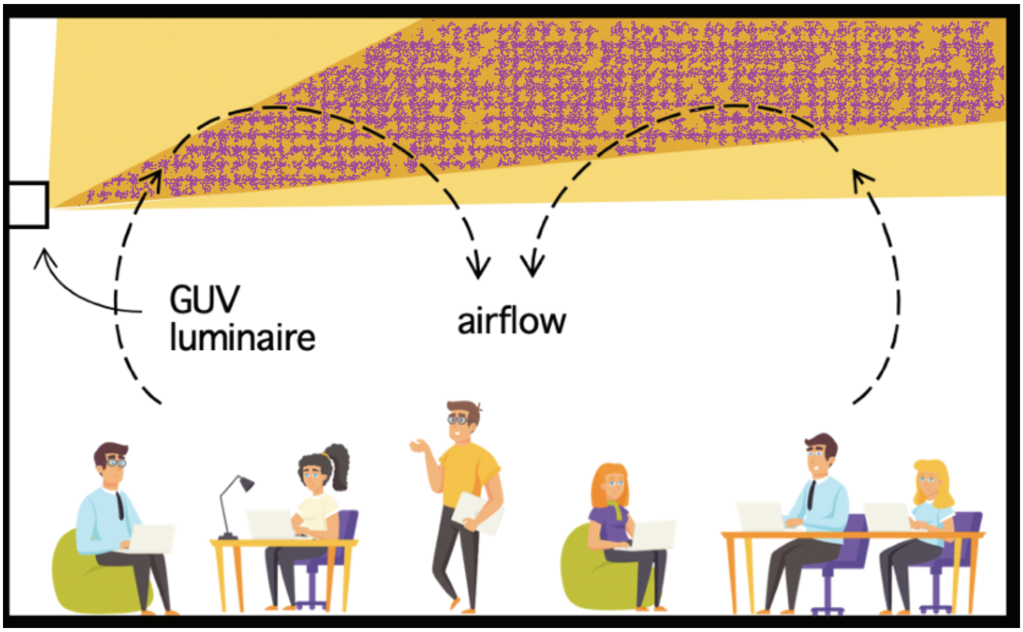
diation based on the type of UV source and the wavelength. Even if a UV light is being generated with an acceptable irradiation, there should be clear instructions regarding the exposure time, so that the UV dose required to inactivate the pathogens is being applied. As there are limited items commercially available on online marketing platforms which adhere by these criteria and have passed required regulatory approvals, purchasing and using the surface disinfectants should be done diligently.

It is worth noting that surface disinfection and air disinfection systems are somehow inter-related. Most air disinfection systems will simultaneously perform some surface disinfection and similarly most surface disinfection systems will also disinfect the air around them. This is a beneficial factor as airborne pathogens are often surface-borne and vice-versa.

UV Air Disinfection: Although, typically airborne pathogens are presenting a higher risk of infection and disease transmission (and higher overall cost for the healthcare system) comparing to water and surface pathogens; there are far fewer air disinfection technologies in place. Even in the context of using UVGI, their use in air disinfection has been subject to misinterpretations, misconceptions, and arguments. However, in recent years, and after extensive studies, the field has been shown great promises in terms of disinfecting air from airborne pathogens and reducing air-transmitted diseases, significantly.

Air disinfection using UVGI has is being performed through multiple approaches, commercially. The most well-known approaches are in-duct and upper room disinfection systems. The in-duct systems are being used when an HVAC system is present in a building and the air is being exchanged multiple times in an hour going through the air-conditioning system. As the "dirty" air is being circulated out of the room and being filtered and cleaned before coming back to the room, there is the potential to use UV disinfection in the way (in-duct) to assure that air borne pathogens are being inactivated. This approach has the benefit of disinfecting the air to a very low survival while the UV lamps are inside the ducts and therefore can always be used with no dangers for humans. The drawback for this approach is that it can only be used when there is an existing HVAC system in place and even in these cases it needs modifying the HVAC system (changing its design and also the system itself to install UV lamps inside the ducts). Therefore, although this approach has shown promising results and is being used as a commercial solution, but its usage in older or residential buildings is very limited (if not impossible).

The second approach to use UV for air disinfection is upper room disinfection. In these systems, UV controlled radiation creates a germicidal zone of UV rays that are confined to the upper portion of a room (Kowalski, 2009). Air that enters into this zone is disinfected assuming that it receives enough UV dose (i.e. adequate UV irradiance and a long-enough exposure). In these systems, the UV radiation should be designed and controlled so the UV irradiance in the lower room (where people are present) is not going over a very conservative threshold. As the UV lamps can work in upper room area continuously (assuming that the UV radiation is not penetrating the lower room more than the safety standards); this approach is a safe UV air disinfection application. This approach is considered the most effective application for room air disinfection (IES Photobiology, 2020).



It is worth noting that both approaches for UV air disinfection require detailed engineering design. There are UV lamp fixtures commercially available for both approaches (with some technical information or application guidelines); however, each building (or indoor environment) has its own characteristics based on size, occupancy, usage, floor plan, air conditioning, etc.; and all these factors should be considered before a useful practical solution can be designed.

UV and safety

The use of UVGI systems presents a health hazard for humans especially by causing eye damage and skin burn. As the hazards are not being visual or cannot be felt in real time, one should carefully design a UVGI system to ensure it adheres with the available safety protocols. The hazards can be minimized (if not fully eliminated) by proper engineering design and control and monitoring procedures. As a simple rule of thumb, UV surface disinfection systems should be designed such that they only work when no one is present in a room; while the upper room air disinfection systems should be designed such that the UV radiation entering the lower room zone is not exceeding a certain criteria.

UV effect on eye: The effect of a long exposure to higher density UV radiation on eye can be painful but are usually temporary. The severity depends on the UV dose and the wavelength of the light. If there is an excess in the amount of UV radiation being absorbed by one's eye, lasting damages might occur in forms of Cataracts, Conjunctivitis, or Photokeratitis.

UV effect on skin: As the effect of UV (and especially UVC) on skin is well-documented, there are well known agencies which have set exposure limits and protocols for the use of UVGI systems such that the results are safe for human. The main ones are American Conference of Governmental Industrial Hygienists (ACGIH), NIOSH, and the International Commission on Illumination (CIE). These agencies not only provide criteria for exposure limits for eye and skin; but also provide guidelines on how to measure the UV irradiation to ensure compliance, and how to design different UVGI systems to ensure safety (design requirements for each application). Therefore, once again, the need for an engineering design of any practical solution to use UVGI is underlined.

Another item to consider while designing a UVGI solution is its potential effect on the materials. UV radiation can cause secondary effects on materials as there is a chance for photochemical reactions and heat being generated (Kowalski, 2009). Specifically, photodegradation of materials can potentially be hazardous and lead to fire hazard and/or maintenance costs. Therefore, a secondary study on the materials being used in each application (cooling coil, duct, upper room, room equipment, etc.) is required when designing a solution so that minimum adverse effects can happen.

UV applications

Even though UV germicidal effect has been well-researched in the last few decades, its applications are still limited due to the need for technical design and considerations and the lack of need for building disinfections. A widely used applicated has been its usage in medical and healthcare facilities, where there has always been a need for a sophisticated disinfection approach.

Considering the current pandemic situation and the possibility of a similar event happening in near future, UVGI application in commercial and residential buildings is gradually becoming an area of interest.

In commercial buildings such as restaurants, office buildings, industrial facilities, educational facilities, malls and airports, etc., there is a significant need for a comprehensive solution which can work effectively and continuously (as the current cleaning and disinfection protocols are only useful for the short-term issues). An important fact to consider is that not only the building characteristics and its floor plans and ventilation systems are affecting the UVGI system design; but also the health hazard levels and pathogens associated with every building and application type is different (therefore, a different UVGI system is required). Based on this and before designing any UVGI system, a full study of the physical and environmental characteristics of the building and its application is required. Moreover, there has been certain studies for different commercial building types to investigate the type of pathogens which are more common, which can help in designing the optimum UVGI solution.

For residential applications, the same considerations are required to be investigated. For instance, living accommodations vary from single unit houses to large apartments (and hotels) where thousands of people might live or reside. Different types of ventilation systems, geographical areas (temperature, humidity, common diseases), and even the furniture being used in the residential buildings can affect the effectivity and efficiency of a UVGI system.

References

IES Photobiology, C. (2020). ***IES Committee Report: Germicidal Ultraviolet (GUV) – Frequently Asked Questions***. Illuminating Engineering Society.

Kowalski, W. (2009). ***Ultraviolet Germicidal Irradiation Handbook*. Berlin: Springer-Verlag.**

Low vs. Medium pressure UV lamps. (2011, 11 25). Retrieved from UVO3: https://www.uvo3.co.uk/low-vs-medium-pressure-uv-lamps/

National Institute for Occupational Safety and Health, (. (2009). ***Environmental Control for Tuberculosis: Basic Upper-Room Ultraviolet Germicidal Irradiation Guidelines for Healthcare Settings***. Centers for Disease Control and Prevention.

Rutala, W. A. (2008). ***Guideline for Disinfection and Sterilization in Healthcare Facilities*** . Centers for Disease Control (CDC).

Stanford Solar, C. (2015). ***UV Light***. Stanford.

Ultraviolet (UV) Radiation. (2020, 8 19). Retrieved from U.S. Food and Drug Administration (FDA): https://www.fda.gov/radiation-emitting-products/tanning/ultraviolet-uv-radiation