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Research Studies

UV Articles/Whitepapers

UV Effectiveness Against Coronavirus

Table of Contents

1.0 Executive Summary

This white paper examines the effectiveness of ultraviolet (UV) light treatment in eliminating different strains of coronavirus. Initially, UV light and its properties that contribute to sanitation, as well as lighting conditions that promote thorough disinfection are presented to provide a background on the mechanisms of UV light treatment. UV bands responsible for killing harmful microbes are dangerous to humans. Taking this precaution into consideration, best practices surrounding UV light safety are also showcased in the paper. UV disinfection has been around for decades and is commonly found in food processing, wastewater plants, hospitals and laboratories. These use cases reinforce the feasibility of utilizing UV light to eliminate coronavirus.

Larson Electronics is a manufacturer of industrial lighting systems, explosion proof devices and power distribution products. The company has more than 40 years of experience in the industrial sector, serving a wide range of organizations. Leveraging the establishment's expertise in lighting equipment, UV light devices used for UV disinfection are showcased in the paper to provide sanitation solutions for businesses and operators affected by the coronavirus.

2.0 Introduction

UV light contains several unique properties and characteristics, which can be used to disinfect viruses, bacteria, mold, spores and other harmful microbes. This sanitation method relies on UV-C wavelengths, i.e. UV bands within a range of 200 nm to 280 nm, to deactivate the cellular ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), as well as the reproductive capabilities of microorganisms. According to data from the International Ultraviolet Association (IUVA)[1], UV treatment has been around for more than 40 years. As a tried-and-tested solution, UV disinfection is prevalent in hospitals, medical or healthcare centers, laboratories, food processing, wastewater facilities, HVAC system management and more.

At the beginning of 2020, the spread of coronavirus 2019 (COVID-19 or SARS-CoV-2) caused a surge in using UV light to sanitize buildings, work sites, equipment, respirator masks and patient rooms. UV treatment is confirmed to eliminate COVID-19 by Juan Leon, an environmental health scientist at Emory University[2]. Through published studies and documentation, researchers have verified UV-C sanitation to deactivate previous strains of the coronavirus, such as Severe Acute Respiratory Syndrome (SARS-CoV) with the first human case appearing as far back as 2002 and Middle East Respiratory Syndrome (MERS-CoV) with the first human case appearing as far back as 2012. During the spread of SARS-CoV and MERS-CoV (respectively), UV light disinfection played a vital role in preventing the spread of disease.

In addition to coronavirus, UV light is used to deactivate other types of harmful disease-causing microbes. According to experts from University of British Columbia, University of Alberta, University of Colorado-Boulder and Trojan Technologies[3], UV-C light is capable of killing tuberculosis, *e.coli*, *methicillin-resistant S. aureus* (MRSA) and more. This form of sanitation also targets mold, spores, fungi and yeast.

There is a myriad of factors that must be taken into consideration when administering UV-C light to eliminate viruses or bacteria in the area. These factors include: light intensity, duration of treatment, distance between the UV light source and object or surface, obstructions and environment (temperature and humidity). To ensure effective UV disinfection, different types of UV-C devices can be utilized. A portable sanitation cart that emits a full, 360-degree UV-C beam is ideal for sanitizing large rooms or facilities; while a handheld UV-C lamp is designed for cleaning objects or hard-to-reach surfaces and equipment. A compact UV sanitation box could be used to disinfect personal devices and tools on the field or at facilities. UV light is also capable of disinfecting air in occupied spaces.

UV-C light is harmful to humans as it can cause burns on the skin and damage the cornea. To ensure safety, individuals should proactively avoid UV exposure through the use of safety glasses, gloves, suits and other protective gear.

3.0 UV Light Sanitation

UV light contains special properties that deactivate the RNA and DNA of harmful microbes. Successful UV-C sanitation requires taking the following into consideration: UV wavelength or band range, light intensity, exposure and duration of treatment. As short-wave UV-C light is dangerous to humans, safety must be prioritized during UV disinfection by wearing protective gear, including gloves, suits, glasses, visors and masks.

3.1 How Does UV-C Disinfection Work?

UV light consists of three primary wavelength ranges: long-wave UV-A (315nm to 400nm), medium-wave UV-B (280nm to 315nm) and short-wave UV-C (200nm to 100nm), as defined in

ISO-21348 Standard[4]. In outdoor environments, UV-C is completely absorbed by the ozone layer of the Earth's atmosphere. This UV range is known as the germicidal range due to its ability to deactivate viruses and bacteria (UV-A and UV-B do not have the capabilities – because of this, the focus of the paper is the UV-C range). UV-C light can be generated by artificial light sources, such as mercury vapor and fluorescent lamps. This technological advancement ushered the mainstream application of UV radiation for disinfection, allowing UV-C light to be used in buildings.

During sanitation, UV-C light in large, concentrated doses causes RNA and DNA mutations in microbes during absorption. The ideal wavelength for peak absorptivity occurs at a wavelength of 254nm to 262nm. According to a 2012 study published in *US National Library of Medicine National Institutes of Health*[5], UV-C treatment has the following devastating effects on microbes:

"The light-induced damage to the DNA and RNA of a microorganism often results from the dimerization of pyrimidine molecules. In particular, thymine (which is only found only in DNA) produces cyclobutane dimers. When thymine molecules are dimerized, it becomes very difficult for the nucleic acids to replicate and if replication does occur it often produces a defect that prevents the microorganism from being viable."

It should be emphasized that when enough thymine dimers are made in the cell, DNA replicated in cell mitosis ceases. This deactivation mechanism is also applicable to viruses that only have RNA, i.e. "photochemical dimerization reaction takes place between two uracil bases". UV sanitation of an area is considered successful when the virus or bacteria is deactivated and reproductive capabilities are significantly reduced or stopped. Such objectives prevent the microbe from spreading and decreases the rate of infection (for harmful viruses or bacteria).

3.2 Intensity, Exposure and Duration

For thorough and consistent disinfection, UV light must be applied radiantly with an exposure rate of 400 mJ/cm^2 (exposure rate requirements may vary). The rate of exposure is critical to the application of UV. When an object is removed from the UV field, irradiation ceases immediately (carryover treatment does not occur). The response of UV treatment is often described as sigmoidal. Immediately after exposure, microorganisms sustain maximum injury. After the initial phase, only a minimal dose of UV is needed to finish off the remaining survivors. The process ends in a tailing phase, which diminishes UV-resistant microorganisms. An estimated 5-60 minutes of exposure is required when conducting UV treatment. This range is wide; as light intensity must also be factored in during the process. Intense UV light exposure is more effective and makes the sanitation process quicker, compared to UV light administered at low intensity levels and far distances. Furthermore, surfaces must come in contact with the light beam to ensure effective sanitation. The presence of shadows may hinder UV-C light rays from reaching the target area.

3.3 UV Light Safety

UV-C light is a powerful solution against disease-causing microorganisms. For humans, exposure to this range of UV light is harmful. Direct exposure can lead to skin burns and damage the cornea. Unlike standard (non-UV) illumination, looking at UV lamps does not cause a natural squinting reaction. In some cases, the negative effects of UV exposure are delayed by more than six hours. As a safety precaution when sanitizing rooms, humans should not be present in the area during the process. Operators may setup temporary signs around the space to ensure people are aware of ongoing sanitation and avoid exposure.

3.4 Methods of UV Treatment

There are numerous ways to facilitate UV treatment and administer UV-C light for sanitation in rooms and on surfaces or objects. For large spaces or facilities, a portable UV cart with four to eight UV-C fluorescent lamps is ideal to ensure wide and full coverage of the area. This solution is also applicable to sanitizing public transit fleets (buses and trains) and commercial planes. A UV handlamp can be utilized to disinfect hard-to-reach surfaces, odd-sized equipment and objects. This type of UV light may come equipped with a light guard to reduce light spillage or unwanted UV exposure in the surrounding area. A permanent UV sanitation solution for offices or buildings could come in the form a dual lighting fixture with a combination of standard (non-UV) and UV-C lamps. The air of occupied spaces can be sanitized using UV-C light. This type of disinfection device consists of a UV-C lamp protected by a heavy-duty enclosure (to prevent exposure) and is equipped with vents to promote air flow. The compact unit cleans the air passively and discreetly (no noise).

4.0 UV-C and Coronavirus

The coronavirus comes in many forms. During the spread of these strains (respectively), UV light was used as a reliable method of sanitation. The effectiveness of UV-C light in deactivating SARS-COV-2 extends to rooms and protective equipment, such as N95 masks. Maximizing UV light treatment requires using different types of UV devices to promote the reach and intensity of UV-C light beams.

4.1 Types of Coronavirus

According to the National Institute of Allergy and Infectious Diseases[6], there are many forms of coronavirus. Three strains that are potentially fatal to humans (if left untreated) include: SARS-

CoV, MERS-CoV and SARS-CoV-2. These strains target the breathing or respiratory systems of humans, making clean air an essential aspect of recovery. Under a microscope, the coronavirus contains club-like spikes around its body and has a large RNA genome[7]. SARS-CoV-2 is highly infectious and can be spread through contact and the air. Moreover, men and senior citizens are more susceptible to getting sick from this coronavirus strain, compared to women and children. To date, there are no pharmaceutical drugs or vaccines available on the market today that eliminates SARS-CoV-2. Medical treatment for coronavirus involves addressing the primary and underlying symptoms associated with the disease, such as inflammation, difficulty breathing, fever, pulmonary fibrosis and more.

4.2 UV Effectiveness on Previous Coronavirus Strains

4.2a SARS-CoV

UV-C light is effective in eliminating different types of coronavirus. In a 2004 study[8], scientists examined the effects of UV-C light in the 254nm spectrum on survivability of SARS-CoV cultures. The tests were performed in a biosafety level 3 (BSL3) lab. Researchers were able to inactivate SARS-CoV to non-infectious levels through UV-C exposure, heat treatment of 65°C+ and “alkaline (pH > 12) or acidic (pH < 3) conditions”, as well as formalin and glutaraldehyde treatments. Following this study, scientists attempted to eliminate SARS-CoV from non-cellular products in a 2006 experiment[9] using the following disinfection methods: heat treatment, UV-C light and chemical treatment. The results indicated that heat treatment at 60°C deactivated SARS-CoV in 15-30 minutes. UV-C light was able to achieve sanitation in 40 minutes. Comparing the two disinfection methods, multiple cycles of heat treatment can damage the surface or equipment not designed for use or exposure at high temperatures. At germicidal doses, UV-C light does not have the same effect on surfaces (an extremely high dose of UV-C light is required to cause damage to non-sensitive surfaces).

The results from the two studies above can be confirmed in another research. In a 2003 study[10], scientists successfully disinfected the SARS coronavirus to undetectable levels by exposing the microbes to UV irradiation for 60 minutes. The researchers were able to conclude that UV exposure caused the virus to become ineffective and reduced viral activity to a non-infectious state. More recently, a study published in 2020[11] showed that UV-C treatment against SARS-CoV was still effective since it emergence more than 15 years ago. In this study, researchers applied shortwave UV-C light to inactivate SARS-CoV from platelet concentrates and plasma. During treatment, a half to 75% dose of the full UV-C dose (0.2 J/cm^2) was administered to SARS-CoV. This treatment reduced the virus to ineffective levels and to the limit of detection (LOD) in platelet concentrates. Researchers were able to eradicate SARS-CoV in plasma at 25% of the full UV-C light dose (30 J/cm^2). Uniform treatment of the samples were ensured through vigorous agitation during application of UV-C light.

All studies conducted over a period of more than 15 years that attempted to prove the effectiveness of UV-C light treatment against SARS-CoV were successful and displayed very similar results, when applying the same UV germicidal light and dosage range. Furthermore, recent studies showed that less than the full UV-C dose is capable of deactivating the virus to non-infectious levels.

4.2b MERS-CoV

In addition to SARS-CoV, UV-C treatment was tested and used extensively during the MERS-CoV outbreak in 2012. This coronavirus strain reached a 45% mortality rate and spread to nine countries during its peak. A 2016 study published in *Infection Control and Hospital Epidemiology (ICHE) journal*[12] revealed UV-C light to effectively deactivate MERS-CoV. During the study, researchers applied UV-C light which reduced MERS-CoV to undetectable levels at a reduction rate of >99.999%. This rate was achieved after five minutes of UV-C exposure and remained undetectable after continued treatment of 30 minutes. A 2018 study[13] confirmed the above findings, which also showed UV-C light to be effective in reducing MERS-CoV to safe levels. The tests utilized UV-C light in the 254 nm range with a total dose of 0.2 J/cm^2 to platelet concentrates and plasma. During a test that applied 0.15 J/cm^2 (75% of the full UV-C dose) of UV-C light, MERS-CoV was eliminated to infectivity levels below the detection limit.

4.3 UV Impact on SARS-CoV-2

To date, SARS-CoV-2 is the most recent strain of the coronavirus. Compared to SARS-CoV and MERS-CoV, this strain has a high secondary infection rate and is capable of spreading more rapidly. The Food and Drug Administration (FDA) released a 2020 memo[14] recommending the use of UV disinfecting devices that leverage the UV-C spectrum to eliminate SARS-CoV-2.

A 2020 study[15], recommends using germicidal UV radiation to prevent “viral replication” of SARS-COV-2 and improve lung capabilities for patients. Researchers from the study concluded that such devices, which include systems used to administer UV-C light or radiation, can improve survival rate of individuals. At the front lines, UV-C light is proven to be effective in sanitizing N95 filtering facepiece respirators (N95 FFRs). Medical staff must deal with the shortage in N95 respirators and other protective devices by disinfecting the equipment and reusing them. This practice was tested by researchers from the University of Nebraska Medical Center[16], through administering a 300 mJ/cm^2 dose of UV germicidal irradiation on N95 FFRs. The scientists highlighted that single-stranded RNA SARS-COV-2 can be inactivated with UVGI exposure of 2-5 mJ/cm^2, which was exceeded by the researchers in the study.

During the decontamination process, scientists utilized two UV-C light towers with eight UV lamps in the 254nm spectrum. N95 masks were fastened on wires, which held several respirators on the line (total of three lines). The UV units each produced an intensity of 400 µW/cm^2. To improve exposure rate, the room hosting sanitation was covered with a UVreflective coating. A UV sensor monitored light intensity and proper dosage inside the room. Cycles were designed to run until dosage reached above 300 mJ/cm^2. Cycles were stopped using a remote immediately after reaching the minimum UV dose. Medical specialists that participated in the study intend to re-use N95 FFRs until the respirator fit is compromised (due to the shortage in masks). Moreover, researchers advised UV-C disinfection to be feasible in sanitizing other types of medical equipment. The practice of sanitizing N95 respirators is supported by N95DECON[17], an organization consisting of scientists and clinicians across the US, including Harvard University, Massachusetts Institute of Technology, University of Michigan, University of California and more.

The findings above can be confirmed through another study published in 2020[18]. In this study, scientists observed an applied UV-C dose of 1,000 mJ/cm^2 on each side of N95 FFRs to eliminate SARS-CoV-2. An initial conservative UV-C dose of 2,000 mJ/cm^2 is recommended by the authors to ensure thorough sanitation, account for potential errors in dose estimation and complete coverage of surfaces on the masks. Although heat treatment at 60°C for 90 minutes was also tested as an alternative disinfection method for N95 FFRs, scientists cited uncertainty in applying heat treatment to protective gear as it could compromise the effectiveness of the devices after multiple sanitation cycles. UV-C light, at recommended doses (180 mJ/cm^2 to 6,900 mJ/cm$^{2)}$, does not have these effects on N95 FFRs. The authors took six UVGI studies performed on N95 FFRs into account in their recommendation. A 2020 study published in *Journal of the American Academy of Dermatology*[19] provided similar recommendations. Four models of N95 FFRs were tested in the study, which were exposed to UVGI doses of 120-950 J/cm^2. The results showed minimal degradation on the masks.

5.0 Conclusion

Published scientific research and studies conducted by medical organizations have proven the effectiveness of using UV-C light to deactivate or sanitize various strains of the coronavirus, including the latest SARS-COV-2 strain. The mainstream, prevalent use of UV light in well-established industries, such as food processing, wastewater treatment and healthcare (hospitals), reinforces the viability of the sanitation method, making it a tried-and-tested solution. Reliability and peace of mind are the secondary benefits that come with UV sanitation, as this disinfection method has been around for decades.

To ensure proper disinfection, UV-C light intensity, duration, exposure and deployment should be carefully maximized. Using a variety of UV lights and devices, from portable UV disinfection carts and UV air sanitizers to compact UV handlamps and UV sanitation boxes, is recommended for a complete approach to sanitation on the field or in facilities. During the disinfection process, individuals should avoid exposure to UV light, as it can damage the skin and cornea.

Proper safety equipment, including gloves, suits, masks, glasses and visors, must be used to prevent UV exposure.

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Far-UV 222nm Effectiveness Against Coronavirus

LARSON ELECTRONICS LLC • 9419 E US HWY 175 • KEMP, TX 75143
p: 1-800-369-6671 • intl: 903-498-3363 • f: 903-498-3364 • sales@larsonelectronics.com

Table of Contents

1.0 Executive Summary

This white paper examines the effectiveness of far ultraviolet (UV) light treatment in eliminating different coronavirus strains. Information surrounding far-UV rays with 222 nm properties that contribute to sanitation provide a background on the mechanisms of this form of UV light treatment. Currently, excimer lamps are the primary artificial light source of choice for far-UV disinfection. The advantages of using far-UV lamps for sanitation are also covered in the white paper, along with its effectiveness against different strains of the coronavirus.

According to data from the International Ultraviolet Association (IUVA)[1], UV treatment has been around for more than 40 years. As a tried-and-tested solution, UV disinfection is prevalent in hospitals, medical or healthcare centers, laboratories, food processing, wastewater facilities, HVAC system management and more.

Larson Electronics is a manufacturer of industrial lighting systems, explosion proof devices and power distribution products. The company has more than 40 years of experience in the industrial sector, serving a wide range of organizations and businesses. Leveraging the establishment's expertise in lighting equipment, this paper supports the use and effectiveness of far-UV 222nm lights for germicidal applications.

2.0 Introduction

UV light contains several unique properties and characteristics, which can be used to disinfect up to 99.9% of viruses, bacteria, mold, spores and other harmful microbes. According to experts from University of British Columbia, University of Alberta, University of Colorado-Boulder and Trojan Technologies[2], UV-C light is capable of killing tuberculosis, *e.coli*, *methicillin-resistant S. aureus* (MRSA) and more. Initially, this sanitation method relied on the UV-C spectrum, i.e. UV-C rays within the range of 200 nm to 280 nm (optimized at 254 nm), to deactivate the cellular ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), as well as the reproductive capabilities of microorganisms. Although highly effective in eliminating microbes on surfaces and in the air, the 200 nm to 280 nm UV-C range is dangerous to humans. Extended exposure to this UV-C range, typically using fluorescent UV lamps, can cause mild to severe sunburns and temporary to permanent vision loss without proper safety gear.

Advancements in UV light technology addresses the drawbacks and limitations of traditional UV-C sanitation using 200 nm to 280 nm bands by introducing far-UV sanitation lights to the market. This type of germicidal lamp utilizes 222 nm UV rays to eliminate bacteria, viruses, mold, spores, fungi and other deadly microbes. Moreover, far-UV light is considered to be eye and skin safe for humans, as 222 nm UV rays cannot penetrate the skin to levels that cause burns or severe damage. A 2018 study published in the US National Library of Medicine National Institutes of Health[3] has proven that chronic irradiation with 222 nm far-UV lamps does not cause epidermal lesions often associated with exposure to traditional 254 nm UV-C rays. This finding, among others, revolutionizes the application of UV-C disinfection, allowing the lights to be deployed safely in busy locations, occupied areas, manufacturing floors, restaurants, public buildings, mass transit areas and more. Mercury-free excimer lamps with quartz glass are the artificial light source of choice when implementing far-UV disinfection on surfaces.

There is a myriad of factors that must be taken into consideration when administering UV-C light – both optimized 254 nm and far-UV 222 nm – to eliminate viruses or bacteria in buildings. These factors include: light intensity, duration of treatment, distance between the UV light source and object or surface, obstructions and environment (temperature and humidity). To ensure effective UV disinfection, different types of far-UV devices can be utilized. A portable sanitation cart that emits a full, 360-degree 222 nm UV beam is ideal for sanitizing large rooms or facilities; while a handheld UV-C lamp is designed for cleaning objects or hard-to-reach surfaces and equipment. A compact far-UV sanitation box may could be used to disinfect personal devices and tools on the field or at facilities. This ozone-free UV light is also capable of disinfecting air in occupied spaces.

At the beginning of 2020, the spread of coronavirus 2019 (SARS-CoV-2) caused a surge in using UV light to sanitize buildings, work sites, equipment, respirator masks and patient rooms. Through published studies and documentation, researchers have verified UV-C sanitation to deactivate previous strains of the coronavirus, such as Severe Acute Respiratory Syndrome (SARS-CoV) with the first human case appearing as far back as 2002 and Middle East Respiratory Syndrome (MERS-CoV) with the first human case appearing as far back as 2012. During the spread of SARS-CoV and MERS-CoV (respectively), traditional UV light disinfection using the 200 nm to 280 nm range played a vital role in preventing the spread of disease.

3.0 UV Light Sanitation

UV light contains special properties that deactivate the RNA and DNA of harmful microbes.

3.1 How Does UV-C Light Sanitation Work?

UV light consists of three primary wavelength ranges: long-wave UV-A (315nm to 400nm), medium-wave UV-B (280nm to 315nm) and short-wave UV-C (200nm to 100nm), as defined in ISO-21348 Standard[4]. In outdoor environments, UV-C is completely absorbed by the ozone layer of the Earth's atmosphere. This UV range is known as the germicidal range due to its ability to deactivate viruses and bacteria (UV-A and UV-B do not have the capabilities – because of this, the focus of the paper is the UV-C range). UV-C light can be generated by artificial light sources, such as excimer, mercury vapor and fluorescent lamps. This technological advancement ushered the mainstream application of UV radiation for disinfection, allowing UV-C light to be used in buildings.

During sanitation, UV-C light in large, concentrated doses causes RNA and DNA mutations in microbes during absorption. The ideal wavelength for peak absorptivity occurs at wavelengths of 254nm to 262nm (for traditional UV sanitation) and 222 nm. According to a 2012 study published in US National Library of Medicine National Institutes of Health[5], UV-C treatment has the following devastating effects on microbes:

"The light-induced damage to the DNA and RNA of a microorganism often results from the dimerization of pyrimidine molecules. In particular, thymine (which is only found only in DNA) produces cyclobutane dimers. When thymine molecules are dimerized, it becomes very difficult for the nucleic acids to replicate and if replication does occur it often produces a defect that prevents the microorganism from being viable."

It should be emphasized that when enough thymine dimers are made in the cell, DNA replicated in cell mitosis ceases. This deactivation mechanism is also applicable to viruses that only have RNA, i.e. "photochemical dimerization reaction takes place between two uracil bases". UV sanitation of an area is considered successful when the virus or bacteria is deactivated and reproductive capabilities are significantly reduced or stopped. Such objectives prevent the microbe from spreading and decreases the rate of infection (for harmful viruses or bacteria). Higher UV doses must be applied to bacteria that is capable of actively repairing thymine dimers (not applicable to coronavirus).

3.2 Far-UV 222 nm Properties and Safety

Far-UV 222 nm light contains effective germicidal properties that are significantly safer to humans, compared to other penetrative UV wavelengths, as the bands are not cytotoxic or mutagenic to mammalian cells. A 2017 study[6] highlights the level of safety 222 nm light imposes on mammalian skin, which directly resembles human skin, during exposure. Authors of the study cited that far-UV light cannot penetrate the stratum corneum of the skin, thus protecting foundational basal cells from damage. By comparison, UV rays in the 254 nm spectrum can penetrate the stratum corneum of the skin, capable of reaching as far as the stratum spinosum, and damage basal cells. Far-UV 222 nm is considered to be safe on human eyes, as suggested by the researchers of the study. This specific UV band cannot penetrate the thick barrier protecting the cornea. The germicidal effectiveness and capabilities of far-UV 222 nm are very similar to conventional UV-C 254 nm, as both UV bands fall within the UV-C range of 200 nm to 280 nm.

Researchers in the 2017 study tested the safe characteristics of far-UV 222 nm by exposing skin samples to 222 nm UV rays. In the tests, a 222 nm UV-C excimer light was positioned at a distance of 9 cm with a power density of 0.036 mJ/cm^2. Researchers also tested chronic exposure of far-UV 222 nm light by administering a far-UV dose of 157 mJ/cm^2 in a 7-hour period to mice. In both tests (skin samples and chronic exposure), traditional UV sanitation lights in the 254 nm range were tested using the same types of samples for comparison.

After exposure to 222 nm light, the skin samples in the first test did not produce lesions or display signs of irritation, as well as did not generate damaging levels of cyclobutane pyrimidine dimers (CPD) and pyrimidine-pyrimidone 6-4 photoproducts (6-4PP). In the second set of tests involving mice, researchers analyzed the effects of the UV-C lights on the epidermis (skin). Observations were taken 48 hours after exposure. The results showed that the skin of mice exposed to far-UV 222 nm lights did not significantly increase in epidermal thickness at 20.1 um. While mice exposed to traditional 254 nm UV-C lamps displayed 60.9um or a 3-fold increase in epidermal thickness. This reaction is closely associated with severe tissue hyperplasia, i.e. an increase in cellular proliferation that can lead to (but not always) tumors and cancer.

Based on the results from both tests, the researchers concluded that far-UV 222 nm light can be recommended as an effective sanitation method. According to the researchers, this form of UV germicidal treatment can be administered safely without extensive protective clothing and imposing significant risks related to skin cancer and cataracts.

In order for far-UV 222 nm lamps to effective in occupied areas, the units should not impose risks to humans when deployed over long periods of time. Continuous, 24/7 sanitation is a common requirement in UV air sanitation, permanent UV disinfection fixtures and HVAC

LARSON ELECTRONICS LLC • 9419 E US HWY 175 • KEMP, TX 75143
p: 1-800-369-6671 • intl: 903-498-3363 • f: 903-498-3364 • sales@larsonelectronics.com

disinfection. In meeting such operating requirements, a 2020 study[7] uncovers the long-term effects of far-UVC 222 nm light on the skin. Using mice as samples, the scientists applied a 222 nm dose of up to 1.0 kJ/m^2 twice per week over a period of 10 weeks. The results showed no inflammation and no skin tumors. By comparison, samples exposed to UV-B light developed skin tumors after 10 weeks.

3.3 UV-C 222 nm Germicidal Excimer Lights

Spectral-selective excimer lamps are the artificial light source of choice when generating far-UV 222 nm light for sanitation. The term “excimer” is short for excited dimer, which refers to the presence of dimeric molecules with nanosecond-lifespans in an excited state. The specific working excimer molecule is closely associated with the UV wavelength that the lamp emits, as well as the light’s use and application. In the case of 222 nm excimer lights, the working exciplex molecule is KrCl. The compound consists of one atom of krypton (Kr) and one atom of chlorine (Cl). This granular approach to leveraging a single UV wavelength, e.g. 222 nm, 172 nm, 308 nm, etc., suggests that excimer lamps release (and can be classified as) quasi-monochromatic light. A bandpass filter can be applied to remove lower, higher and stray UV bands to ensure safe and effective sanitation.

Excimer germicidal lamps typically take the form of conventional, compact linear lights. These lights are non-toxic, mercury free and do not contain fluid. The units require support from a driver that protects the device from abnormal power conditions and ensures power stability. During use, excimer lights offer instant start, are cool to operate (low operating temperatures) and consume low energy. Reflectors around the lamp can be added to improve light beam distribution and intensity. Unlike traditional UV sanitation lights within the 200 nm to 280 nm range and as established in the previous section, excimer lights do not require extensive safety gear. Furthermore, the lamps can be secured close to the target surface without generating intense heat in the surrounding area.

4.0 UV-C 222 nm and Coronavirus

The coronavirus comes in many forms. During the spread of these strains (respectively), UV-C light was used as a reliable method of sanitation.

4.1 Types of Coronavirus

According to the National Institute of Allergy and Infectious Diseases[8], there are many forms of coronavirus. Three strains that are potentially fatal to humans (if left untreated) include: SARS-CoV, MERS-CoV and SARS-CoV-2. These strains target the breathing or respiratory systems of humans, making clean air an essential aspect of recovery. Under a microscope, the coronavirus contains club-like spikes around its body and has a large RNA genome[9]. SARS-CoV-2 is highly infectious and can be spread through contact and the air. Moreover, men and senior citizens are more susceptible to getting sick from this coronavirus strain, compared to women and children. To date, there are no pharmaceutical drugs or vaccines available on the market today that eliminates SARS-CoV-2. Medical treatment for coronavirus involves addressing the primary and underlying symptoms associated with the disease, such as inflammation, difficulty breathing, fever, pulmonary fibrosis and more.

4.2 UV Effectiveness on Previous Coronavirus Strains

4.2a SARS-CoV

UV-C light is effective in eliminating different types of coronavirus. In a 2003 study[10], scientists successfully disinfected the SARS coronavirus (CoV-P9) to undetectable levels by exposing the microbes to UV irradiation for 60 minutes. The researchers were able to conclude that UV exposure caused the virus to become ineffective and reduced viral activity to a non-infectious state. More recently, a study published in 2020[11] showed that UV-C treatment against SARS-CoV was still effective since it emergence more than 15 years ago. In this study, researchers applied shortwave UV-C light to inactivate SARS-CoV from platelet concentrates and plasma. During treatment, a half to 75% dose of the full UV-C dose (0.2 J/cm^2) was administered to SARS-CoV. This treatment reduced the virus to ineffective levels and to the limit of detection (LOD) in platelet concentrates. Researchers were able to eradicate SARS-CoV in plasma at 25% of the full UV-C light dose (30 J/cm2). Uniform treatment of the samples were ensured through vigorous agitation during application of UV-C light.

In both studies, researchers did not specify the 222 nm UV wavelength. As it has been established that the 222 nm band falls in within the UV-C range of 200 nm to 280 nm, the UV-C scope showcased in the studies above includes 222 nm.

4.2b MERS-CoV

In addition to SARS-CoV, UV-C treatment was tested and used extensively during the MERS-CoV outbreak in 2012. This coronavirus strain reached a 45% mortality rate and spread to nine countries during its peak. A 2016 study[12] tested the effectiveness of using UV-C emitters to deactivate MERS-CoV on surfaces. Although the study did not specify the 222 nm wavelength, it is widely known that the 222 nm band falls within the UV-C range of 200 nm to 280 nm and carries similar germicidal capabilities. In the study, researchers applied a MERS-CoV sample inside a UV-C permeable container. The UV-C lamps were setup 4 feet from the samples. In the tests, the UV-C lights were able to reduce the virus to undetectable levels within 5 minutes of treatment. Levels stayed undetectable for 30 minutes after exposure, resulting in 5.9 log_{10} reduction (99.999% successful reduction rate).

4.3 Far-UV 222 nm Light Impact on SARS-CoV-2

To date, SARS-CoV-2 is the most recent strain of the coronavirus. Compared to SARS-CoV and MERS-CoV, this strain has a high secondary infection rate and is capable of spreading more rapidly. The Food and Drug Administration (FDA) released a 2020 memo[13] recommended the use of UV disinfecting devices that leverage the UV-C spectrum to eliminate SARS-CoV-2.

A 2020 study[14] aimed to determine the effectiveness of far-UV 222 nm light on human coronaviruses from subgroups alpha (HCoV-229E) and beta (HCoV-OC43). During the tests, researchers applied a far-UV dose of 1.2 and 1.7 mJ/cm^2 to aerosolized alpha coronavirus 229E and beta coronavirus OC43 samples. The 222 nm UV light source inactivated 99.9% of both viruses. Researchers concluded that based on the results of the tests, adhering to the far-UV exposure limit of 3 mJ/cm^2/hour would inactivate 99.9% of coronaviruses in public locations within 25 minutes. Increasing the intensity of the light, e.g. by a factor of 2, would reduce the required exposure time without exceeding exposure limits. It is important to highlight that although the tests were not conducted specifically on SARS-CoV-2 strain, the scientists issued recommendations on using far-UV 222 nm light to eliminate the latest SARS-CoV-2 coronavirus because all human coronaviruses share similar genome sizes. The genome size of viruses is an essential determinant of UV radiation sensitivity. Furthermore, the 222 nm UV band falls within the germicidal UV-C range of 200 nm 280 nm.

A recent study (also published in 2020)[15] confirms the methods and results achieved in the above research. In this study, Japanese scientists tested the eradication of SARS-CoV-2 samples using far-UV 222 nm light. A krypton-chloride excimer lamp with a band filter was applied 24 cm above the samples. During the tests, a dose of 0.1 mW/cm^2 was utilized with the following range: 10-300 seconds. The results showed that 10-30 seconds of exposure eliminated 88.5 to 99.7% of viable SARS-CoV-2 (a 2.51 log reduction at 30 seconds minimum). Exposure times of

60 seconds and 300 seconds did not increase the effectiveness or log reduction of the UV process and resulted in a 2.51 log reduction rate.

5.0 Conclusion

UV-C light, within the range of 200 nm to 280 nm, has powerful germicidal capabilities that has been proven to be effective in deactivating various strains of the coronavirus. Conventional UV-C treatment using 254 nm UV-C light is known to be harmful to humans, which can cause skin burns and cornea damage. Advancements in UV light research has isolated specific UV-C bands, namely far-UV 222 nm, to serve as a possible alternative to 254 nm. Far-UV 222 nm is eye and skin safe for humans, allowing artificial light sources that leverage far-UV bands to be potentially used in occupied areas and public locations.

The effectiveness of the 200 nm to 280 nm UV-C range against coronavirus strains, i.e. SARS-CoV, MERS-CoV and SARS-CoV-2, has been established by several studies in the past decades. The 222 nm band falls within this range, thus carrying very similar germicidal capabilities and behavior. Based on compiled research (see section 4.3), sanitation using far-UV 222 nm excimer lamps require a smaller dose than conventional 254 nm fluorescent units, i.e. 2 mJ/cm^2 (duration of UV treatment may vary depending on the intensity of the lamp and distance of the far-UV light source from the target area). This UV dose, which is the same recommended UV dose for inactivating H1N1 influenza virus with 222 nm lamps, does not exceed standard limits imposed by various regulations. Because of this, far-UV 222 nm has the potential to be used for sanitation in public locations, high traffic areas and occupied areas.

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p: 1-800-369-6671 • intl: 903-498-3363 • f: 903-498-3364 • sales@larsonelectronics.com

Understanding Ultraviolet (UV) Radiation and its Effects

Ultraviolet (UV) radiation is a form of light that can be found on the light spectrum and comes in various strengths (wavelengths), some of which can be harmful to human skin and eyes. All radiation is a form of energy, which is usually invisible to the human eye. UV radiation is just one form of radiation and is measured on the electromagnetic (EM) spectrum, a scientific scale[1]. The sun is the biggest producer of UV radiation. Solar emissions from the sun include visible light, heat and ultraviolet (UV) radiation[2].

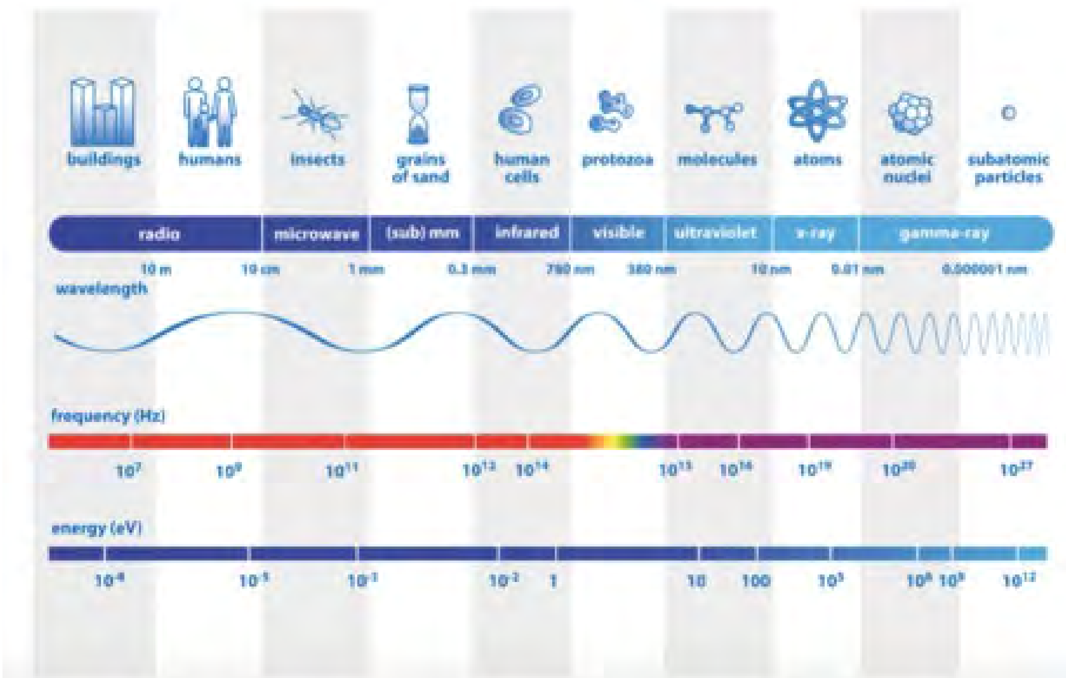
The UV spectrum is divided into three sections that include UV-A, UV-B and UV-C, with all of UV-C and only most of UV-B being absorbed by ozone, water vapor, oxygen and carbon dioxide, and none of UV-A being absorbed or filtered through the atmosphere[3]. This means the no UV-C makes it through Earth's atmosphere, some UV-B rays do and all of UV-A rays do. The aim of this white paper is to break down the different types of UV radiation and explain their effects.

Understanding UV Light Wavelength Ranges and Their Uses

In its natural form, UV light is generated by the sun and falls in the center of the light spectrum. At the beginning of the light spectrum are radio waves with infrared light next, then visible light and then ultraviolet light. Following UV are x-rays, gamma rays and then cosmic rays. Most sources of light generate some level UV light. The light spectrum chart below shows the different types of light, the type of wavelength (short or long), and where each one falls in relation to the rest.

[1] "Ultraviolet (UV) Radiation", https://www.fda.gov/radiation-emitting-products/tanning/ultraviolet-uv-radiation#1
[2] "UV Radiation", https://www.who.int/uv/faq/whatisuv/en/
[3] Ibid.

UV Light



Stanford Solar Center, http://solar-center.stanford.edu/about/uvlight.html

The intensity and source of UV radiation or light is determined by the wavelength range it falls in. There are four ranges, including UV-A, UV-B, UV-C and UV-V. For the purpose of this paper we will ignore UV-V, or vacuum UV. "The term vacuum UV (below ≈ 200 nm) refers to the wavelength range where a vacuum apparatus is often used, because the light is strongly absorbed in air…the vacuum UV includes the far and extreme UV[4]." The first type is UV-A (blacklight UV) and this is found within the wavelength range of 400nm to 315nm; UV-B (dangerous UV) is found within the wavelength range of 315nm to 280nm; UV-C (germicidal UV) is found within the wavelength range of 280nm to 200nm with 253.7nm (254nm) being the ideal wavelength to kill viruses and bacteria; and UV-V (vacuum UV) is found within the wavelength range of 200nm to 100nm. In the subsequent sections, each of these UV ranges will be broken down in more detail.

[4] "Ultraviolet Light", https://www.rp-photonics.com/ultraviolet_light.html

Wavelength	Description
400nm-315nm	UVA – Blacklight UV
315nm-280nm	UVB – Dangerous UV
280nm-200nm	UVC – Germicidal UV at 254nm
200nm-100nm	UVV – Vacuum UV

UV-A (Blacklight UV): 315nm – 400nm

UV-A radiation is part of a UV pair, which includes UV-B, that is associated with skin and eye damage, including skin cancer. UV-A has a longer wavelength and is associated with the aging of the skin[5]. UV-A radiation falls between 315nm and 400nm on the electromagnetic spectrum. This type of UV radiation (UV-A) is produced by the sun and is one of two types of UV that makes its way through Earth's atmosphere. None of the UV-A rays coming down from the sun are absorbed into the atmosphere, which makes this type of UV dangerous for human skin and eyes[6]. There are also 500 times more UV-A rays than UV-B rays in sunlight because none of the rays are filtered through the atmosphere[7]. Because of this, it's important to wear protective clothing and/or sunscreen as well as sunglasses to protect the skin and eyes.

Human eyes can't see these UV-A rays, but the skin can feel it. When skin is unprotected, UV-A rays damage the DNA in skin cells, which produces genetic defects (or mutations) that can lead to skin cancer and premature skin aging[8]. This long-wavelength UV radiation "accounts for approximately 95 per cent of the UV radiation reaching the Earth's surface… [and] can penetrate into the deeper layers of the skin," – the dermis. This type of UV radiation causes skin damage such as premature wrinkling, and recent studies have shown that UV-A "may also help enhance the development of skin cancers[9]." The eyes can also be damaged by too much exposure to UV-A rays, which can cause cataracts and eyelid cancers[10].

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[6] "UV Radiation", https://www.who.int/uv/faq/whatisuv/en/
[7] "What is the difference between UVA and UVB rays?", https://uihc.org/health-topics/what-difference-between-uva-and-uvb-rays
[8] "UV Radiation and Your Skin", https://www.skincancer.org/risk-factors/uv-radiation/
[9] "UV Radiation", https://www.who.int/uv/faq/whatisuv/en/
[10] "UV Radiation and Your Skin", https://www.skincancer.org/risk-factors/uv-radiation/

This type of UV radiation is powerful and can penetrate cloud cover and windows, unlike UV-B, which cannot penetrate glass windows[11].

UV-B (Dangerous UV): 280nm – 315nm

UV-B radiation / light rays have a shorter wavelength (compared to UV-A) and can reach the outer layer of the skin – the epidermis – but doesn't penetrate as deeply as UV-A rays[12]. This type of UV radiation falls between 280nm and 315nm on the electromagnetic spectrum. Exposure to this type of UV radiation causes tanning, sunburn and in extreme cases, blistering[13]. UV-B is also the skin-cancer-causing UV, playing the largest role in causing malignant melanoma and other types of skin cancer[14]. UV-B rays can cause the same kind of eye damage as UV-A rays, which is why it is important to wear sunglasses when out in direct sunlight. In some cases, UV-B rays can be filtered out with material such as glass since UV-B cannot penetrate glass[15].

Benefits of UV-B

There are some benefits to UV-B radiation, including helping the skin to produce vitamin D3, which when used with calcium plays an important role in bone and muscle health[16]. However, this type of exposure is only beneficial depending on the amount of vitamin D in a person's diet, skin color, use of sunscreen, clothing, where the person lives (longitude and latitude), time of day and time of year[17]. Phototherapy using UV radiation "in the form of lasers, lamps, or a combination of these devices and topical medications that increase UV sensitivity, are sometimes used to treat patients with certain diseases who have not responded to other methods of therapy[18]."

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[11] Ibid.
[12] "Ultraviolet (UV) Radiation", https://www.fda.gov/radiation-emitting-products/tanning/ultraviolet-uv-radiation#1
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[17] "Ultraviolet (UV) Radiation", https://www.fda.gov/radiation-emitting-products/tanning/ultraviolet-uv-radiation#1
[18] Ibid.

UV-C (Germicidal UV): 200nm – 280nm

UV-C is the most damaging to human skin and eyes, but none of the rays produced by the sun make it through Earth's atmosphere[19]. Instead, we produce UV-C for various uses, including disinfecting and sanitation. UV-C is also known as germicidal UV and that's because it is the only type of UV that is effective at disinfecting air, surfaces and water. UV-C falls between 280nm and 200nm with the ideal for killing germs, viruses, bacteria, mold spores and other contaminants being 253.7nm, or 254nm generalized. A study published in 2018 by *Nature* in their *Scientific Reports* section claims that even far-UV-C light (207nm to 222nm) efficiently and effectively inactivates bacteria and viruses, such as tuberculosis and influenza, without harming exposed skin of mammals, including humans. It should be understood that far-UV-C is not as strong as germicidal UV-C, which can inactivate both multi-drug-resistant and drug-sensitive bacteria as well as various strains of viruses[20].

This type of UV can be found in special UV lamps that are used in UV disinfecting products such as UV sanitation carts, UV shoe cleaners, UV elevator cleaners and others. This type of UV is also used inside HVAC systems such as air conditioners. This type of light can be used to kill bacteria on the air conditioner condenser coils to stop the spread of germs before they become an issue, and UV light can be used to purify the air as it circulates through the system.

Conclusion

In conclusion, the use of UV-C light has been found to be a very effective method in killing viruses, bacteria and other pathogens in many industries and even at home. Both UV-A and UV-B can be harmful to human skin and eyes, and can even lead to certain types of skin cancer and cataracts. However, there are some useful benefits to UV-B, such as light therapy and increasing one's vitamin D3 levels. What's important to remember is that the human eye cannot see UV radiation, but it can see UV light. However, the UV rays coming from the sun

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[19] "UV Radiation", https://www.who.int/uv/faq/whatisuv/en/

[20] "Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases", https://www.nature.com/articles/s41598-018-21058-w

cannot be seen, but can be felt on the skin. Skin and eyes must be protected when in direct sunlight for prolonged periods of time, especially in the summer months. UV-C is the strongest and most dangerous to human skin and eyes, and even though it does not make its way through Earth's atmosphere, it can still be produced artificially for use in the health care, industrial and commercial sectors as well as at home for disinfecting and sanitizing. Caution should always be taken when using UV lights for cleaning and when out in the hot sun.

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Understanding How UV Light Breaks Down and Kills Viruses

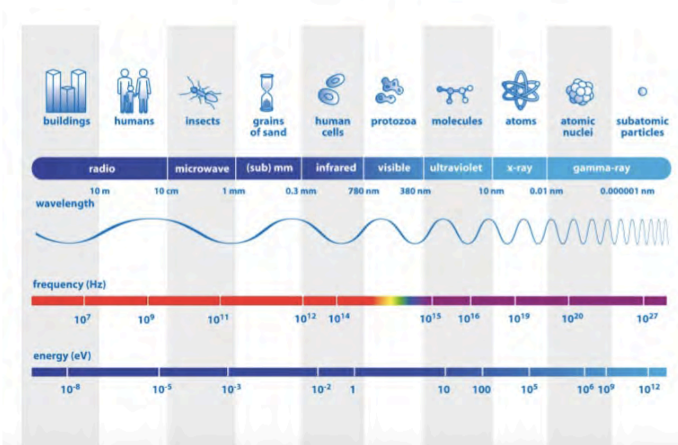
Ultraviolet (UV) light has long been known to be a viable disinfectant for water, air and surfaces. If the UV light is used properly it can help mitigate the risk of contracting an infection from a virus if one comes into contact with a contaminated surface. However, there are many different types of viruses and UV light making it difficult to understand the nuances of how UV light actually kills a virus.

The aim of this paper is to give the reader a clear understanding of what UV light is, the different degrees and uses of various ranges of UV light, what a virus is, its makeup and how it can be degraded and killed using UV light.

What are the Different Types of UV Light?

Ultraviolet light in its natural form comes from the sun and falls in the center of the light spectrum. The light spectrum starts with radio waves and moves to infrared, visible light and then ultraviolet light, which is followed by x-rays, gamma rays and cosmic rays. Most sources of light generate some level UV.

UV Light



Stanford Solar Center, http://solar-center.stanford.edu/about/uvlight.html

Ultraviolet light comes in four wavelength ranges, which determine the light's intensity, strength and source. UV-A (blacklight UV) is found within the wavelength range of 400nm to 315nm; UV-B (dangerous UV) is found within the wavelength range of 315nm to 280nm; UV-C (germicidal UV) is found within the wavelength range of 280nm to 200nm with 253.7nm (254nm) being the ideal wavelength to kill viruses and bacteria; and UV-V (vacuum UV) is found within the wavelength range of 200nm to 100nm.

Wavelength	Description
400nm-315nm	UVA – Blacklight UV
315nm-280nm	UVB – Dangerous UV
280nm-200nm	UVC – Germicidal UV at 254nm
200nm-100nm	UVV – Vacuum UV

The only wavelength of UV on the entire UV spectrum that is effective in disinfecting air, surfaces and water is germicidal UV-C (253.7nm or 254nm generalized). The shorter and longer wavelengths outside of germicidal range are not produced by germicidal UV lamps. UV-B comes from sunlight with most solar UV-B absorbed by the ozone layer. However, long-term exposure to UV-B can cause sunburn and other health issues. UV-A is a longwave UV that can cause tanning of the skin and early skin aging.

A study published in 2018 by *Nature* in their *Scientific Reports* section claims that even far-UV-C light (207nm to 222nm) efficiently and effectively inactivates bacteria and viruses, such as tuberculosis and influenza, without harming exposed skin of mammals, including humans. It should be understood that far-UV-C is not as strong as germicidal UV-C, which can inactivate both multi-drug-resistant and drug-sensitive bacteria as well as various strains of viruses[1].

What is a Virus?

Simply put, a virus is a microscopic organism that can be found almost anywhere on earth and can infect everything from plants to animals to humans and even fungi and bacteria. Viruses are complex in that there are many types and can affect different organisms in different ways. For example, a virus can have one specific type of effect on one type of organism, but a completely different effect on another type of organism. This explains why a virus that kills humans has no effect on dogs or cats.

[1] "Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases", https://www.nature.com/articles/s41598-018-21058-w

Viruses can also vary in their complexity with some having simple makeups while others have more elaborate compositions[2].

Viruses are considered to be the most abundant biological entity on the planet with no cure, no matter what type of virus it is. The only way to prevent the spread of a virus is by using vaccines or disinfection methods. Viruses are parasitic, meaning they cannot replicate and spread without a host such as a human or animal. Viruses are dependent on a host because they do not contain ribosome, which means they can't make their own proteins, a necessity for reproduction and spreading[3].

The genetic makeup of a virus consists of either RNA (ribonucleic acid) or DNA (deoxyribonucleic acid) that is surrounded by a coating of protein, fat (lipid), or glycoprotein. The purpose of the RNA and DNA is to encode the genetic information that is unique for each virus. "The true infectious part of any virus is its nucleic acid, either DNA or RNA but never both,"[4].

Once inside the body of the infected organism, the virus inserts genetic material into the host and takes over the host's functions. After the cell is infected, the virus continues to replicate itself, but "produces more viral protein and genetic material instead of the usual cellular products… earning viruses the classification of parasite,"[5].

Within the virus community there are viruses that have different types of nucleic acid, including single-stranded RNA (ssRNA), single-stranded DNA (ssDNA), double-stranded RNA (dsRNA), and double-stranded DNA (dsDNA). The effectiveness and dose level of any method to kill any given virus depends on the type of nucleic acid it contains[6]. The more strands of nucleic acid a virus has, the more complex and harder to kill it is.

Since the actual infectious part of a virus is the nucleic acid, either its RNA or DNA then this is the part of the virus that needs to be negatively affected in order to degrade and kill it. UV-C and far-UV-C attack the nucleic acid of a virus and renders it useless and eventually killing it off.

How Does UV Light Kill Viruses and Bacteria?

The effect of UV light on human skin becomes obvious during the warmer months of summer when people experience sun burn when exposed to direct sunlight for too long. UV light from the sun can also cause skin cancer, which damages cells in the body. Considering these effects of UV light from

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the sun on humans it makes sense that UV light on a shorter and stronger wavelength can be just as effective, if not more effective, in immobilizing and killing viruses and bacteria.

In order to inactivate and kill a virus, it has to be directly exposed to shortwave UV – UV-C at 254nm. When this happens in a constant and consistent manner, the UV irradiation bombards the virus with UV light and breaks down its cell walls[7]. This is crucial because as mentioned earlier a virus cannot produce its own protective shell of protein or other material, so once it is severely damaged by UV-C the virus cell itself cannot repair the damage.

More specifically, microorganisms such as viruses suffer damage to their nucleic acids when bombarded with high-energy, short wavelength UV light – UV-C at 254nm. The UV light is absorbed by the RNA or DNA creating new bonds between the UV energy and the virus' nucleotides. This bonding creates double bonds, or dimers, that typically affect the thymine molecules. This damage to the thymine molecule is the most common type of photochemical damage that occurs in this process. When the formulation of multiple thymine dimers occurs in the DNA or RNA of a virus, the virus cannot replicate and is unable to continue infecting the host.

If a virus cannot replicate it loses its ability to infect the host and eventually dies off. This is especially important when trying to contain a virus that can spread rapidly by physical contact with humans or surfaces or through the air.

In conclusion, the use of UV light has been found to be a very effective method in killing viruses and bacteria if used properly and within the germicidal wavelength of 254nm. As discussed, it is possible to utilize far-UV light, which occurs on a less damaging wavelength higher up on the scale. However, this type of UV would have to be used in higher doses. So long as the UV light is strong enough and used properly (directed at an infected surface or environment for a sustained time), the UV light will bombard the virus cells with high levels of energy and break down the RNA and DNA of the virus rendering it unable to replicate itself and further infect the host.

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How Does UV Light Disinfect the Corona Virus

Ultraviolet (UV) light is a useful tool for thorough disinfection and sanitation. Specifically, the UV-C range (wavelengths ranging between 200 nm and 280 nm) is capable of eliminating viruses, bacteria, mold and spores – including the COVID-19 corona virus, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), e. coli, yeast and more. This solution is being used in large-scale wastewater treatment, medical facilities, laboratories, manufacturing, food processing and hospitals.

How Does it Work?

During the disinfection process, UV-C light targets the DNA of the microbe. Exposure to the light causes thymine dimers to form in the DNA. As more thymine dimers are formed, damage starts to accumulate inside the DNA. Bumps also appear in the DNA as a result of the dimers. These cellular mutations negatively affect growth and the risk of non-repair increases. Eventually, the damage becomes too extensive and the cell dies. DNA replication is stopped, which reduces infection or spread rate of the virus.

UV-C Light and Viruses

UV light has been tested as an effective solution against a myriad of viruses. According to an article published in *Journal of Virological Methods*, SARS caused by the corona virus (SARS-CoV) is eliminated through exposure to UV light in the 254 nm range. UV treatment has also been found to kill MERS or MERS-CoV, a type of corona virus that emerged in 2012. In a study published in the *US National Institutes of Health's National Library of Medicine* (NIH/NLM), UV-C light deactivated MERS-CoV within 5-10 minutes of exposure.

When it comes to the latest outbreak of COVID-19, UV light has been confirmed to be effective in eliminating the virus by Juan Leon, an environmental health scientist at Emory University, and Dr. Lena Ciric, an associate professor at University College London. UV-C treatment is already proven to work on previous strains of the corona virus, i.e. SARS-CoV and MERS-CoV, as mentioned above. Therefore, it makes sense for the light to be used against COVID-19.

Best Practices

Unlike liquid cleaning agents, no contact with the surface or device is required when sanitizing with UV-C light. It does not leave a residue or cause discoloration after the process. There is no downtime after sterilization – the area or equipment can be used immediately after disinfection. It is important to consider that the longer the surface, area or device is treated by the UV light, the higher the disinfection rate. This is because more thymine dimers are generated in the DNA of the virus. Furthermore, the UV light should be intense to ensure thorough sanitation. The effectiveness of the light decreases as the distance from the light increases.

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UV Sanitation Light Use Cases, Applications and Effectiveness

UV disinfection lights are revolutionizing the way people and businesses impose or maintain sanitation standards. Using the UV-C range, or wavelengths between 200 nm and 280 nm, the units are capable of eliminating up to 99% percent of dangerous viruses, bacteria, mold, spores and other harmful microbes, including the COVID-19 corona virus. It can achieve this rate without needing to come in direct contact with the surface or object.

Unlike other technologies, UV-C germicidal lights are tried and tested in the field and in various operating environments. Even before the spread of COVID-19, UV lamps were already being used to disinfect products on manufacturing lines, treat water in wastewater plants and passively clean hard-to-reach sections of HVAC systems (coils, pans and vents). The wide and successful application of UV sanitation lights in these industries reinforces their use cases during the COVID-19 pandemic.

Effectiveness of UV Sanitation Lights

UV sanitation is effective in eliminating harmful microbes, as recommended by the Centers for Disease Control and Prevention (CDC) in a study published in Infection Control and Hospital Epidemiology (Anderson DH, et al., 2013). The disinfection method has been extensively documented to be successful in removing several disease-causing microorganisms such as: staphylococcus aureus, e. coli, tuberculosis (TB), influenza and more.

During the process, the rate of sanitation depends on a handful of factors, i.e. intensity of the UV light, the distance between the light and surface or object, type of microbe, barriers between the light and target area (ideally, there should not be any) and the microorganism's level of resistance. Generally, an estimated 15-30 minutes of UV exposure is recommended for rooms or sanitation using low-to-moderate UV lamps. UV sanitation boxes and hand lamps can disinfect surfaces or objects at a faster rate, due to their ability to get close to the target and administer an intense UV light beam.

Use Cases and Applications

- **Commercial Fleets, Public Transit Hubs and Aviation:** Portable UV-C sanitation carts are being deployed to quickly disinfect the inside of buses, trains, airplanes and other types

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of busy commercial fleets. The process is noticeably faster and more efficient, compared to wiping down individual seats and large surfaces. Furthermore, less manpower is required to conduct sanitation of large fleets. A small group can carry out disinfection effectively without compromising thoroughness.

- **Hospitals, Healthcare Centers and Clinics:** The healthcare sector is one of the first industries to adopt UV sanitation lights. The units are used to clean patient rooms, hallways, lobbies or waiting areas, emergency facilities and more. This use case is closely associated with COVID-19, as the light targets viruses and aggressive microbes in hospitals. Some healthcare organizations have fully incorporated UV disinfection carts with daily operations.

  UV sanitation cabinets have also been found inside hospitals and medical labs. This type of UV disinfection device is designed to sterilize equipment or devices before use.

- **Emergency Services/First Responders and Temporary Shelters:** Paramedics use UV-C sanitation lamps to remove dangerous viruses and bacteria from ambulances after carrying out emergency services. During sanitation, individuals hang a UV-C light inside the vehicle and exit the area. After approximately 20 minutes, the light is turned off.

  Local fire departments are using UV-C sanitation boxes to sterilize equipment, including N95 masks. As a solution to the current global shortage, firefighters clean the masks by putting them inside UV-C disinfection boxes for a short period of time. N95 masks are typically for single use only. But due to a sudden increase in demand and cases of COVID-19, first responders needed to extend the use of the masks (up to 10 times before degradation sets in).

- **Businesses in the Industrial Sector:** UV-C disinfection lights promote workplace safety by keeping operating floors, storage rooms and delivery bays free from disease-causing microorganisms. These units could be used after business hours, when facilities are empty.

- **Stadiums/Auditoriums and Schools:** Businesses that cater to or serve large groups of people on a daily basis, such as public stadiums and schools, can benefit from UV-C disinfection carts. The system can be deployed to sanitize seats, rooms, lockers, hallways, stairways and areas with high foot traffic.

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- **Senior Assistance Facilities:** Senior citizens are one of the most affected demographics in the recent COVID-19 outbreak. Because of this, locations that frequently host the elderly must be kept clean at all times. UV-C disinfection lights present a fast way to sanitize senior assistance facilities.

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Far-UV 222 nm vs 254 nm: Safety and Germicidal Effectiveness

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Table of Contents

1.0 Executive Summary

This white paper compares the safety and germicidal effectiveness of 222 nm and 254 nm ultraviolet (UV) wavelengths when applied to sanitation. An overview UV-C sanitation is provided to establish the mechanisms of disinfection with UV light. Next, the properties of both UV-C bands are showcased in order to highlight their unique characteristics and various associated safety precautions. Artificial light sources capable of emitting these types of UV-C light are carefully assessed to determine the practicality of deployment based on technological limitations and environmental factors (temperature, humidity, etc.). The white paper concludes with recommendations on how to best leverage far-UV 222 nm and 254 nm for sanitation purposes in industrial and commercial sites.

Larson Electronics is a manufacturer of industrial lighting systems, explosion proof devices and power distribution products. The company has more than 40 years of experience in the industrial sector, serving a wide range of organizations and businesses. This paper supports the use and effectiveness of 222 nm and 254 nm UV lights for germicidal applications.

2.0 Introduction

According to data from the International Ultraviolet Association (IUVA)[1], UV treatment has been around for more than 40 years. As a tried-and-tested solution, UV disinfection is prevalent in hospitals, medical or healthcare centers, laboratories, food processing, wastewater facilities, HVAC system management and more. At 2018, the UV disinfection equipment market was valued at $1.1 billion by Allied Market Research. This industry is forecasted to reach $3.4 billion by 2026 (or at a compound annual rate of 15 percent from 2019 to 2026).

UV light contains several unique properties and characteristics, which can be used to disinfect up to 99.9% of viruses, bacteria, mold, spores and other harmful microbes. According to experts from University of British Columbia, University of Alberta, University of Colorado-Boulder and Trojan Technologies[2], UV-C light is capable of killing tuberculosis, *e.coli*, *methicillin-resistant S. aureus* (MRSA) and more. Initially, this sanitation method relied on the UV-C spectrum, i.e. UV-C rays within the range of 200 nm to 280 nm (traditionally optimized at 254 nm), to deactivate the cellular ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), as well as the reproductive capabilities of microorganisms. Although highly effective in eliminating microbes on surfaces and in the air, the 254 nm UV-C band is dangerous to humans. Extended exposure to this UV-C wavelength, typically using fluorescent UV lamps, can cause mild to severe sunburns and temporary to permanent vision loss without proper safety gear.

Advancements in UV light technology addresses the drawbacks and limitations of traditional UV-C sanitation using 254 nm bands by introducing far-UV sanitation lights to the market. This type of germicidal lamp utilizes 222 nm UV rays to eliminate bacteria, viruses, mold, spores, fungi and other deadly microbes. Moreover, far-UV light is considered to be eye and skin safe for humans, as 222 nm UV rays cannot penetrate the skin to levels that cause burns or severe damage. A 2018 study published in the US National Library of Medicine National Institutes of Health[3] has proven that chronic irradiation with 222 nm far-UV lamps does not cause epidermal lesions often associated with exposure to traditional 254 nm UV-C rays. This finding, among others, revolutionizes the application of UV-C disinfection, allowing the lights to be deployed safely in busy locations, occupied areas, manufacturing floors, restaurants, public buildings, mass transit areas and more. Mercury-free excimer lamps with quartz glass are the artificial light source of choice when implementing far-UV disinfection on surfaces.

Both far-UV 222 nm and conventional 254 nm have similar germicidal capabilities, but their properties and behavior under varying conditions differ slightly. Notably, far-UV bands are not readily absorbed by water vapor. UV 254 nm does not possess these qualities; however, artificial light sources that emit 254 nm typically decline in effectiveness when exposed to temperatures above 40°C for extended periods of time. Far-UV 222 nm artificial light sources are compact, energy efficient and mercury-free.

As both UV bands utilize the same mechanism when deactivating bacteria and viruses, other factors must be considered when choosing between far-UV 222 nm and conventional 254 nm lamps. Such factors include the area of deployment (occupied or empty), distance of target surface or area, access to UV lamp technology (to date, 222 nm excimer lamps are not readily available in mainstream markets) and preferred method of disposal (traditional, mercury-based 254 nm UV lights are toxic and require sustainable disposal at the end of their lifecycle).

3.0 UV Light Sanitation

UV light contains special properties that deactivate the RNA and DNA of harmful microbes. The UV-C range of 200 nm to 280 nm is responsible for this germicidal mechanism. Both far-UV 222 nm and traditional 254 nm bands are included in this germicidal range.

3.1 How Does UV-C Light Disinfection Work?

UV light consists of three primary wavelength ranges: long-wave UV-A (315nm to 400nm), medium-wave UV-B (280nm to 315nm) and short-wave UV-C (200nm to 100nm), as defined in ISO-21348 Standard[4]. In outdoor environments, UV-C is completely absorbed by the ozone layer of the Earth's atmosphere. This UV range is known as the germicidal range due to its ability to deactivate viruses and bacteria (UV-A and UV-B do not have the capabilities – because of this, the focus of the paper is the UV-C range). UV-C light can be generated by artificial light sources, such as excimer, mercury vapor and fluorescent lamps. This technological advancement ushered the widespread application of UV disinfection, allowing UV-C light to be used in buildings.

During sanitation, UV-C light in large, concentrated doses causes RNA and DNA mutations in microbes during absorption. The ideal wavelength for peak absorptivity occurs at wavelengths of 254nm to 262nm (for traditional UV sanitation) and 222 nm. According to a 2012 study published in US National Library of Medicine National Institutes of Health, UV-C treatment has the following devastating effects on microbes:

"The light-induced damage to the DNA and RNA of a microorganism often results from the dimerization of pyrimidine molecules. In particular, thymine (which is only found only in DNA) produces cyclobutane dimers. When thymine molecules are dimerized, it becomes very difficult for the nucleic acids to replicate and if replication does occur it often produces a defect that prevents the microorganism from being viable."

It should be emphasized that when enough thymine dimers are made in the cell, DNA replicated in cell mitosis ceases. This deactivation mechanism is also applicable to viruses that only have RNA, i.e. "photochemical dimerization reaction takes place between two uracil bases". UV sanitation of an area is considered successful when the virus or bacteria is deactivated and reproductive capabilities are significantly reduced or stopped. Such objectives prevent the microbe from spreading and decreases the rate of infection (for harmful viruses or bacteria). Higher UV doses must be applied to bacteria that is capable of actively repairing thymine dimers.

Far-UV 222 nm and conventional 254 nm UV light utilizes the same mechanism (as described above) to eliminate microorganisms on surfaces and in the air. Both types of UV bands are capable of achieving above 99 percent inactivation rates. Choosing between the two artificial light sources depend on other factors, such as cost, area of deployment, etc.

4.0 Far UV-C 222 nm

Far-UV 222 nm bands have intense germicidal properties with decreased risks of photo-reactivation, which are considered to be eye and skin safe for humans. Excimer lamps that offer 222 nm are energy efficient, non-toxic and easily disposable at the end of their expected lifecycle.

4.1 UV 222 nm Wavelength Properties

Far-UV 222 nm light is at the low range of the UV-C spectrum. Leveraging its germicidal abilities, this UV band is capable of inactivating harmful microbes. The 222 nm wavelength is particularly effective in disrupting chemical bonds in dangerous or toxic gases and bio-toxins. Applying this observation in comparing the properties of 222 nm and 254 nm, the far-UV band could achieve higher UV absorption than conventional 254 nm. The possibility of photo-reactivation is also decreased due to the high energy of 222 nm.

Spectral-selective excimer lamps are the artificial light source of choice when generating far-UV 222 nm light for sanitation. The term “excimer” is short for excited dimer, which refers to the presence of dimeric molecules with nanosecond-lifespans in an excited state. The specific working excimer molecule is closely associated with the UV wavelength that the lamp emits, as well as the light’s use and application. In the case of 222 nm excimer lights, the working exciplex molecule is KrCl. The compound consists of one atom of krypton (Kr) and one atom of chlorine (Cl). This granular approach to leveraging a single UV wavelength, e.g. 222 nm, 172 nm, 308, nm, etc., suggests that excimer lamps release (and can be classified as) quasi-monochromatic light. A bandpass filter can be applied to remove lower, higher and stray UV bands to ensure safe and effective sanitation.

Excimer germicidal lamps typically take the form of conventional, compact linear lights. These lights are non-toxic, mercury free and do not contain fluid. Excimer lights feature instant on and off capabilities, reaching 100 percent output in less than a second. This artificial light source can be toggled and deployed in locations within a temperature range of 0°C to 100°C. Compared to conventional UV 254 nm light sources, excimer lamps offer high power density. Reflectors around the lamp can be added to improve light beam distribution and intensity. With a compact footprint, smaller disinfection lights can be used to eliminate microbes. The units require support from a driver that protects the device from abnormal power conditions and ensures power stability. Unlike traditional 254 nm UV sanitation lights, excimer lights do not require extensive safety gear during use. Furthermore, the lamps can be secured close to the target surface without generating intense heat in the surrounding area.

4.2 Safety Considerations

Far-UV 222 nm light contains effective germicidal properties that are significantly safer to humans, compared to other penetrative UV wavelengths, as the bands are not cytotoxic or mutagenic to mammalian cells. A 2017 study[5] highlights the level of safety 222 nm light imposes on mammalian skin, which directly resembles human skin, during exposure. Authors of the study cited that far-UV light cannot penetrate the stratum corneum of the skin, thus protecting foundational basal cells from damage. By comparison, UV rays in the 254 nm spectrum can penetrate the stratum corneum of the skin, capable of reaching as far as the stratum spinosum, and damage basal cells. Far-UV 222 nm is considered to be safe on human eyes, as suggested by the researchers of the study. This specific UV band cannot penetrate the thick barrier protecting the cornea.

Researchers in the 2017 study tested the safe characteristics of far-UV 222 nm by exposing skin samples to 222 nm UV rays. In the tests, a 222 nm UV-C excimer light was positioned at a distance of 9 cm with a power density of 0.036 mJ/cm^2. Researchers also tested chronic exposure of far-UV 222 nm light by administering a far-UV dose of 157 mJ/cm^2 in a 7-hour period to mice. In both tests (skin samples and chronic exposure), traditional UV sanitation lights in the 254 nm range were tested using the same types of samples for comparison.

After exposure to 222 nm light, the skin samples in the first test did not produce lesions or display signs of irritation, as well as did not generate damaging levels of cyclobutane pyrimidine dimers (CPD) and pyrimidine-pyrimidone 6-4 photoproducts (6-4PP). In the second set of tests involving mice, researchers analyzed the effects of the UV-C lights on the epidermis (skin). Observations were taken 48 hours after exposure. The results showed that the skin of mice exposed to far-UV 222 nm lights did not significantly increase in epidermal thickness at 20.1 um. While mice exposed to traditional 254 nm UV-C lamps displayed 60.9um or a 3-fold increase in epidermal thickness. This reaction is closely associated with severe tissue hyperplasia, i.e. an increase in cellular proliferation that can lead to (but not always) tumors and cancer. Based on the results from the tests, the researchers concluded that far-UV 222 nm light can be recommended as an effective sanitation method. According to the researchers, this form of UV germicidal treatment can be administered safely without extensive protective clothing and imposing significant risks related to skin cancer.

In a 2019 study[6], scientists compared the effects of far-UV 222 nm and 254 nm light on the cornea. The cornea is the outer layer of the eye that acts as a protective barrier against irritants, such as debris and bacteria, and plays a primary role in light absorption. Damage to the cornea often results in vision impairment or loss. During the study, researchers exposed rats to 222 nm and 254 nm lights at 30, 150, and 600 mJ/cm^2 intensities. The animals exposed to far-UV 222 nm did not display corneal damage. Moreover, cyclobutane pyrimidine dimer-positive cells were not present in the samples exposed to 222 nm, which reduces cellular proliferation risks responsible for cancer. By comparison, UV 254 nm imposed a wide range of damage at various UV intensities on the samples. At 600 mJ/cm^2, corneal erosion was evident. Superficial punctate keratis (eye disorder from cellular death on the cornea) was observed on samples exposed to UV 254 nm at doses higher than 150 mJ/cm^2.

4.3 Germicidal Effectiveness

In the 2017 study from section 4.2, scientists tested the effectiveness of 222 nm on MRSA (USA300, multilocus sequence type 8, clonal complex 8, staphylococcal cassette chromosome mec type IV). The samples were separated and exposed to 222 nm excimer lamps (filtered) and 254 nm lights for comparison. The results of the tests showed 222 nm bands to be “almost as efficient” in eliminating MRSA as conventional 254 nm.

At 222 nm, UV light is capable of inactivating airborne aerosolized viruses at low doses. A 2018 study[7] presents the effectiveness of this type of artificial light source in eradicating aerosolized H1N1 influenza virus. In the study, researchers used excimer lamps as a primary disinfection device. A far-UV dose of 2 mJ/cm^2 was administered on the sample. The lights were positioned 11 cm from a UV transparent plastic film, with a 65 percent transmission rate. A certified class II type A2 biosafety cabinet housed the chamber with the samples. The results showed that the 222 nm light eliminated more than 95 percent of the aerosolized H1N1 influenza virus.

A 2020 study (pre-print; under review)[8] aimed to determine the effectiveness of far-UV 222 nm light on human coronaviruses from subgroups alpha (HCoV-229E) and beta (HCoV-OC43). During the tests, researchers applied a far-UV dose of 1.2 and 1.7 mJ/cm^2 to aerosolized alpha coronavirus 229E and beta coronavirus OC43 samples. The 222 nm UV light source inactivated 99.9% of both viruses. Researchers concluded that based on the results of the tests, adhering to the far-UV exposure limit of 3 mJ/cm^2/hour would inactivate 99.9% of coronaviruses in public locations within 25 minutes. Increasing the intensity of the light, e.g. by a factor of 2, would reduce the required exposure time without exceeding exposure limits. It is important to highlight that although the tests were not conducted specifically on SARS-CoV-2 strain, the scientists issued recommendations on using far-UV 222 nm light to eliminate the latest SARS-CoV-2 coronavirus because all human coronaviruses share similar genome sizes. The genome size of viruses is an essential determinant of UV radiation sensitivity.

Far-UV 222 nm light has the potential to revolutionize food processing and sanitation standards. A 2020 study[9] showed that far-UV 222 nm lamps can inactivate *Alicyclobacillus acidoterrestris* spores, which are known to have high thermal resistance. In food processing facilities handling juices, the microorganisms also thrive in extreme conditions and can germinate at low pH levels. Scientists were able to achieve complete inactivation by 5 logs at a concentrated dose of 2,011 mJ/cm^2. Compared to mercury-based UV 254 nm lights, non-toxic 222 nm excimer lamps come with lower contamination risks when used in large-scale food processing.

5.0 UV-C 254 nm

Conventional UV 254 nm contains powerful disinfection properties and is rapidly absorbed by microorganisms. When using UV 254 nm lights, typically in the form of UV-C fluorescent lamps, operators must wear protective gear to prevent skin burns and corneal damage.

5.1 UV 254 nm Wavelength Properties

UV 254 nm is within the germicidal range of the UV-C spectrum. Compared to UV-B and UV-A, this range has up to 2 times more electron volt energy (eV). UV-C 254 nm light is absorbed rapidly by microbes, contributing to its ability to destroy bacteria and viruses. This UV band is powerful and can force doubly-bonded molecules to rearrange their structures. Damage imposed on microorganisms are typically long term or fatal.

Fluorescent fixtures, medium-pressure mercury discharge lights and induction lamps are the most common types of UV 254 nm artificial light sources used for sanitation. In order to generate the UV 254 nm band, phosphor is removed from the tube. Furthermore, the tube is manufactured using doped fused quartz (can produce 185 nm ozone) or soda-lime glass (cannot produce 185 nm ozone) so that UV 254 nm bands from the mercury arc can pass through the material. Quartz-based UV-C lights increase electrical efficiency and require a short warm-up time of 30 seconds to reach full output. This type of 254 nm fluorescent light source typically overheats in environments above 40°C. At this temperature, UV-C output decreases. T5 or T6 high-output quartz UV lamps can be used for areas requiring intense disinfection. This alternative provides up to 2 times more output compared to legacy quartz UV-C lights. UV fluorescent units rely on mercury to produce illumination, via two electrodes. Induction lights that offer UV 254 nm do not contain electrodes, resulting in a longer lifespan and increased reliability. The units are well sealed and energy efficient.

5.2 Safety Considerations

UV-C 254 nm light is a powerful solution against disease-causing microorganisms. For humans, exposure to this range of UV light is harmful. Direct exposure can lead to skin burns and damage the cornea. Human cells attempt to repair DNA damage when exposed to UV-C 254 nm. Failure to repair the damage can result in tumor growth. Unlike standard (non-UV) illumination, looking at UV lamps does not cause a natural squinting reaction. In some cases, the negative effects of UV exposure are delayed by more than six hours. As a safety precaution when sanitizing rooms, humans should not be present in the area during the process. Operators may setup temporary signs around the space to ensure people are aware of ongoing sanitation and avoid exposure. Exposure to chemicals, such as mercury, xenon and argon, is a possibility should the lamp or bulb shatter during use. Moreover, due to the presence of toxic chemicals, the lamp must be properly disposed at the end of its lifecycle.

5.3 Germicidal Effectiveness

A 2020 study[10] provides a comprehensive overview of the germicidal effectiveness of 254 nm UV light. The researchers from the study applied a mercury vapor lamp with a UV 254 nm band to the following types of microbes (on nitrocellulose filter papers):

- Escherichia coli ATCC25922 (*E. coli)*
- Extended Spectrum Beta-Lactamase-producing *E. coli* (ESBL)
- MRSA
- *Mycobacterium tuberculosis* (MTB)
- Influenza A Viruses H1N1 and H3N2

The results showed successful elimination at a rate of 3-$\log_{10}$ inactivation for bacteria, 4-$\log_{10}$ inactivation for viruses and 5-$\log_{10}$ inactivation for MTB. It took between 10 to 30 minutes of exposure to achieve such levels of inactivation during the tests.

In another 2020 study[11], recommendations to use germicidal UV light to prevent "viral replication" of SARS-COV-2 and improve lung capabilities for patients were issued. Researchers from the study concluded that such devices, which include systems used to administer UV-C light or radiation, can improve survival rate of individuals. At the front lines, UV-C light is proven to be effective in sanitizing N95 filtering facepiece respirators (N95 FFRs). Medical staff must deal with the shortage in N95 respirators and other protective devices by disinfecting the equipment and reusing them. This practice was tested by researchers from the University of Nebraska Medical Center, through administering a 300 mJ/cm^2 dose of UV germicidal irradiation on N95 FFRs. The scientists highlighted that single-stranded RNA SARS-COV-2 can be inactivated with UVGI exposure of 2-5 mJ/cm^2, which was exceeded by the researchers in the study.

UV 254 nm light is capable of eradicating common dust mites (*Dermatophagoides pteronyssinus [D. pteronyssinus]* and *Dermatophagoides farinae [D. farinae]*). A 2012 study[12] demonstrated such capabilities through direct UV exposure. Researchers tested exposure times ranging between 5-60 minutes and distances between 10-55 cm. An immediate mortality success rate of 100 percent was achieved when the UV lamp was positioned at 10 cm distance for 60 minutes. Egg-hatching capabilities were reduced by a whopping 50 percent for both types of mites. Increasing the duration of exposure also increased the mortality rate of UV treatment, while increasing the distance between the UV lamp and the samples decreased such rates. Interestingly, UV treatment had a more devastating effect on the eggs compared to the adult mites. Based on the results of the study, the scientists cited UV 254 nm light to be effective in disrupting the lifecycle of mites at the embryonic stage to reduce the proliferation of allergens.

6.0 Conclusion

Both far-UV 222 nm and conventional 254 nm wavelengths are effective in eliminating viruses, bacteria, spores and other disease-causing microbes. As these bands fall within the UV-C germicidal range of 200 nm to 280 nm, the UV rays utilize the same mechanism to disrupt and inactivate microorganisms. A closer look at the properties of 222 nm UV bands suggests that it is not easily absorbed by water vapor. Therefore, for long irradiation distances in the air, the far-UV band could be less effective (but still capable of inactivating viruses and bacteria and achieving above 99% inactivation success rates) in environments saturated with water vapor. The safety benefits of 222 nm UV light dictate its applications in buildings and busy locations. The wavelength is considered to be eye and skin safe for humans, as it does not cause the formation of potentially cancerous CPDs. Additionally, 222 nm excimer lamps are mercury-free, energy efficient and environmentally friendly. The units can be deployed in occupied areas, public locations and busy facilities without imposing devastating health risks.

Traditional 254 nm UV light is a very powerful sanitation solution that leverages fluorescent or induction units. From a health perspective, the UV band can cause skin burns and corneal damage. This type of artificial light source is most effective when deployed in empty rooms, cabinets, UV boxes or ovens and via handheld devices. UV 254 nm lamps should not be administered in occupied or busy areas without protective equipment. Safety gear in the form of bio-hazard suits, coats, safety glasses, visors, gloves, barriers and curtains must be used at all times when using traditional 254 nm lamps to prevent exposure.

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UV Sanitation Light Use Cases, Applications and Effectiveness

UV disinfection lights are revolutionizing the way people and businesses impose or maintain sanitation standards. Using the UV-C range, or wavelengths between 200 nm and 280 nm, the units are capable of eliminating up to 99% percent of dangerous viruses, bacteria, mold, spores and other harmful microbes, including the COVID-19 corona virus. It can achieve this rate without needing to come in direct contact with the surface or object.

Unlike other technologies, UV-C germicidal lights are tried and tested in the field and in various operating environments. Even before the spread of COVID-19, UV lamps were already being used to disinfect products on manufacturing lines, treat water in wastewater plants and passively clean hard-to-reach sections of HVAC systems (coils, pans and vents). The wide and successful application of UV sanitation lights in these industries reinforces their use cases during the COVID-19 pandemic.

Effectiveness of UV Sanitation Lights

UV sanitation is effective in eliminating harmful microbes, as recommended by the Centers for Disease Control and Prevention (CDC) in a study published in Infection Control and Hospital Epidemiology (Anderson DH, et al., 2013). The disinfection method has been extensively documented to be successful in removing several disease-causing microorganisms such as: staphylococcus aureus, e. coli, tuberculosis (TB), influenza and more.

During the process, the rate of sanitation depends on a handful of factors, i.e. intensity of the UV light, the distance between the light and surface or object, type of microbe, barriers between the light and target area (ideally, there should not be any) and the microorganism’s level of resistance. Generally, an estimated 15-30 minutes of UV exposure is recommended for rooms or sanitation using low-to-moderate UV lamps. UV sanitation boxes and hand lamps can disinfect surfaces or objects at a faster rate, due to their ability to get close to the target and administer an intense UV light beam.

Use Cases and Applications

- **Commercial Fleets, Public Transit Hubs and Aviation:** Portable UV-C sanitation carts are being deployed to quickly disinfect the inside of buses, trains, airplanes and other types of busy commercial fleets. The process is noticeably faster and more efficient, compared to wiping down individual seats and large surfaces. Furthermore, less manpower is required to conduct sanitation of large fleets. A small group can carry out disinfection effectively without compromising thoroughness.

- **Hospitals, Healthcare Centers and Clinics:** The healthcare sector is one of the first industries to adopt UV sanitation lights. The units are used to clean patient rooms, hallways, lobbies or waiting areas, emergency facilities and more. This use case is closely associated with COVID-19, as the light targets viruses and aggressive microbes in hospitals. Some healthcare organizations have fully incorporated UV disinfection carts with daily operations.

  UV sanitation cabinets have also been found inside hospitals and medical labs. This type of UV disinfection device is designed to sterilize equipment or devices before use.

- **Emergency Services/First Responders and Temporary Shelters:** Paramedics use UV-C sanitation lamps to remove dangerous viruses and bacteria from ambulances after carrying out emergency services. During sanitation, individuals hang a UV-C light inside the vehicle and exit the area. After approximately 20 minutes, the light is turned off.

  Local fire departments are using UV-C sanitation boxes to sterilize equipment, including N95 masks. As a solution to the current global shortage, firefighters clean the masks by putting them inside UV-C disinfection boxes for a short period of time. N95 masks are typically for single use only. But due to a sudden increase in demand and cases of COVID-19, first responders needed to extend the use of the masks (up to 10 times before degradation sets in).

- **Businesses in the Industrial Sector:** UV-C disinfection lights promote workplace safety by keeping operating floors, storage rooms and delivery bays free from disease-causing microorganisms. These units could be used after business hours, when facilities are empty.

- **Stadiums/Auditoriums and Schools:** Businesses that cater to or serve large groups of people on a daily basis, such as public stadiums and schools, can benefit from UV-C disinfection carts. The system can be deployed to sanitize seats, rooms, lockers, hallways, stairways and areas with high foot traffic.

- **Senior Assistance Facilities:** Senior citizens are one of the most affected demographics in the recent COVID-19 outbreak. Because of this, locations that frequently host the elderly must be kept clean at all times. UV-C disinfection lights present a fast way to sanitize senior assistance facilities.

Tips for UV Light Safety in Industrial Sites

When using ultraviolet (UV) light for disinfection, there are several safety precautions to consider. These units are equipped with lamps that emit the UV-C range (wavelengths ranging between 200 nm and 280 nm). Long-term intense exposure to this range is harmful to human eyes (corneal injuries) and skin (erythema/skin cancer). Eye-related burns caused by UV light may feel like getting sand in the eye. Because of this, individuals should proactively ensure safety standards are properly observed at all times during operation of the light.

Minimizing Exposure

As a general guideline, individuals should minimize exposure to UV-C light beams from artificial light sources when possible. Looking directly at the lamp at close distances is not recommended. At times when exposure to the light is unavoidable (for example, when using UV handlamps to disinfect a surface or object), use protective eyewear such as glasses, covered visors or full face masks. Cover as much of the hands, arms, legs and neck as possible. Avoid touching a disinfection lamp that is on.

During large-scale sanitation with UV disinfection carts, people should not be present inside the room. Block off access to the general area by setting up signs, markers or cones around entrances and connecting hallways. For designated sanitation areas, a permanent warning sign can be used. Close and cover all windows to contain stray UV-C light beams in the room and prevent exposure to external locations.

When deploying UV lights, direct the lamp toward the target surface, area or object before activation. Do not stand in front of the lamps when turning on the UV disinfection cart. After sanitation, power down the UV light before entering the room or handling the cart.

Light Maintenance and Care

Periodically check the UV lamp before and after use for damage (especially when experiencing light flicker). If the lamp becomes too hot to touch, allow it to cool down before inspection. Do not handle broken or cracked UV bulbs with bare hands.

Protection from infectious viruses and bacteria should be top priority during UV sanitation. Wearing respiratory masks while performing UV disinfection is an effective way to avoid breathing in harmful microbes and chemicals (such as concentrated cleaning solutions). It also reduces direct contact with skin, when touching the face and mouth.

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UV Light Degradation and its Effects on Materials

Ultraviolet (UV) light imposes degrading effects on different types of materials and surfaces. This process is known as UV degradation, which originally and naturally stems from the sun. However, with the rise of artificial UV lights that emit UV-A, UV-B or UV-C bands (depending on the lamp), UV degradation now extends to indoor locations. Specifically, buildings that use UV lights for sanitation, paint curing, quality inspection, materials testing and machining are prone to this form of damage.

As the deteriorating effect varies from material to material, choosing products made from UV-stable polymers or reinforced with UV-resistant coatings is an effective way to deter UV degradation in work facilities and on machines. Below takes a closer look at the impact of UV light on common industrial materials and UV-resistant solutions that prevent degradation.

Rubber

Rubber is a resilient manufacturing material that is prone to UV damage in extreme conditions, which can cause the component to lose its elastic features, display cracking or become soft. A 2007 study[1] presents the effects of 300 nm to 700 nm UV light on samples of rubber. All samples represent the same type of rubber found in bridge bearings that connect overhead roadways. Accelerated UV exposure tests were conducted on samples of natural rubber (NR), chloroprene rubber (CR), ethylene-propylene-diene rubber (EPDM) and high damping rubber (HDR) at staggered durations. The results showed all samples displayed cracking on the surface after 720 hours; though the amount of damage varied depending on the specific type of rubber sample. Scientists concluded in the study that UV light makes rubber stiff and decreases its “elongation at break and tensile strength.” This UV degradation mechanism causes rubber to become hard and brittle.

Plastic

UV degradation of plastic is common and is frequently found on a wide range of outdoor equipment exposed to the sun for long periods of time. This form of UV degradation appears chalky (a fine powder residue) and can fade colors, making coatings look dull. During the degradation process, the photons that make up plastic generate free radicals when exposed to UV light. Catalyst residues and impurities, which may act as receptors, causes the material to become unstable resulting in damage. Cross linking, or hardening of the surface, may also occur and is associated with brittle.

Not all plastics have the same tolerance to UV light. Unmodified plastics, such as polyoxymethylene (POM) and acrylonitrile butadiene styrene (ABS), are more prone to UV degradation compared to polyethylene terephthalate (PET), polyamide 12 (PA12) and polyphenylene oxide (PPO). High-grade plastics that offer resistance to UV light and are less prone to UV damage include polytetrafluoroethylene (PTFE), fluorinated ethylene-propylene (FEP) and polyimide. Damage from UV light on high-strength plastics is usually limited to the surface, roughly 0.5mm in depth.

Glass

Glass, such as fused silica, displays degradation when exposed to UV light (though the material can withstand high working and melting temperatures). The components responsible for this form of damage are impurities, including iron and other metals. When exposed to UV light, these impurities interfere and interact with the structure of the glass. As a result, UV transparency of the material is reduced. Silica is also known to contain particles (non-bonded silicon and oxygen atoms) that absorb and interact with specific UV bands, i.e. vacuum-UV and UV-C. This interaction can cause defects to occur.

Compared to unstable polymers, glass offers robust resistance against UV rays. Because of this, glass is a material that can be utilized to reinforce parts of devices and tools for outdoor use. For instance, pulley systems infused with glass fibers (acting as a UV stabilizer, e.g. glass-reinforced nylon pulleys on industrial rigs) are applicable to outdoor applications requiring UV resistance. This type of glass-reinforced material deters UV degradation of the pulley, which may come in the form of disintegration or cracking.

Ceramic

Ceramic is moderately resilient against UV degradation (however, paint or coatings on the surface may not offer the same level of durability). UV exposure can degrade impurities in ceramic, causing it to turn brownish yellow. A 1993 study[2] showcases the effects of UV light on advanced ceramics. The researchers utilized a xenon arc UV lamp with a band range of 230 nm to 1,000 nm, which was applied to alumina ceramic samples. The scientists found the 480 nm UV band to cause the samples to turn brownish yellow. It is important to highlight that although ceramic can withstand mild UV exposure, the material is prone to degradation at extreme temperatures.

UV-Resistant Solutions

There are many ways to reduce, slow down or block UV degradation on materials. Such UV-resistant solutions involve the addition of an organic coating that acts as a barrier between the material and UV light. Furthermore, UV absorbers is a form of protection which converts UV rays and dissipates the energy as heat, as well as prevents oxidation-related damage. UV absorbers can be found in acrylics, polycarbonate and unsaturated polyesters.

Lastly, choosing materials with less impurities that are sensitive to or become unstable under the presence of UV light is an effective way to deter degradation. This is because, in most cases, it is the impurities (or additives) that cause unwanted reactions and lead to UV damage (see glass and ceramic above). High-grade or purity materials with less impurities should be utilized in equipment that will be exposed to UV rays, such as outdoor sites with limited shade. It would also be possible to choose specific grades of materials based on the UV band range applicable to the device or machine. For example, selecting materials with UV-stable additives or less impurities that are reactive to 200 nm to 280 nm UV-C wavelengths is ideal for UV sanitation equipment, as UV-C is the germicidal range responsible for disinfection. This practice could help promote long-term use of UV cleaning devices and prevent degradation.

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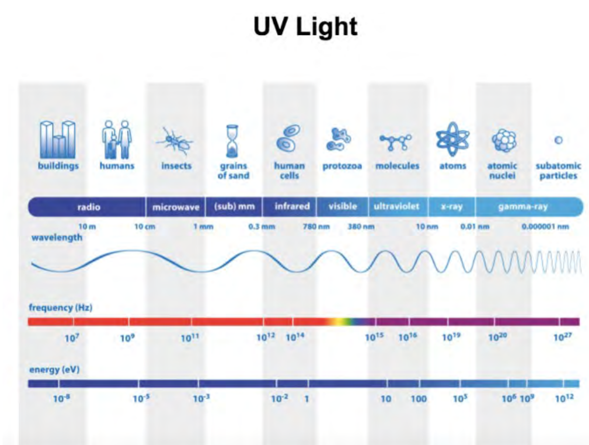
The Effectiveness of Using UVGI in HVAC Systems for Air Sanitation

Ultraviolet (UV) light has an incredible ability to disinfect air, water and surfaces when used within the proper wavelength range. There are many applications a UV light can be used in, including installed into HVAC systems to disinfect the air before it reaches the intended environment. How exactly does a UV light kill bacteria and viruses when installed in an HVAC system and what type of UV light is best for this application? The aim of this paper is to answer these questions for the reader.

The first sections of this paper will give a clear understanding of the different types of UV light that exist, how UV light in specific wavelength ranges break down and kill viruses, bacteria and other pathogens, and finally, how UV light can work when installed inside HVAC systems.

What are the Different Types of UV Light?

Ultraviolet light in its natural form comes from the sun and falls in the center of the light spectrum. The light spectrum starts with radio waves and moves to infrared, visible light and then ultraviolet light, which is followed by x-rays, gamma rays and cosmic rays. Most sources of light generate some level UV.



Stanford Solar Center, http://solar-center.stanford.edu/about/uvlight.html

Ultraviolet light comes in four wavelength ranges, which determine the light's intensity, strength and source. UV-A (blacklight UV) is found within the wavelength range of 400nm to 315nm; UV-B (dangerous UV) is found within the wavelength range of 315nm to 280nm; UV-C (germicidal UV) is found within the wavelength range of 280nm to 200nm with 253.7nm (254nm) being the ideal wavelength to kill viruses and bacteria; and UV-V (vacuum UV) is found within the wavelength range of 200nm to 100nm.

Wavelength	Description
400nm-315nm	UVA – Blacklight UV
315nm-280nm	UVB – Dangerous UV
280nm-200nm	UVC – Germicidal UV at 254nm
200nm-100nm	UVV – Vacuum UV

The only wavelength of UV on the entire UV spectrum that is effective in disinfecting air, surfaces and water is germicidal UV-C (253.7nm or 254nm generalized). The shorter and longer wavelengths outside of germicidal range are not produced by germicidal UV lamps. UV-B comes from sunlight with most solar UV-B absorbed by the ozone layer. However, long-term exposure to UV-B can cause sunburn and other health issues. UV-A is a longwave UV that can cause tanning of the skin and early skin aging.

A study published in 2018 by *Nature* in their *Scientific Reports* section claims that even far-UV-C light (207nm to 222nm) efficiently and effectively inactivates bacteria and viruses, such as tuberculosis and influenza, without harming exposed skin of mammals, including humans. It should be understood that far-UV-C is not as strong as germicidal UV-C, which can inactivate both multi-drug-resistant and drug-sensitive bacteria as well as various strains of viruses[1].

What is a Virus?

Simply put, a virus is a microscopic organism that can be found almost anywhere on earth and can infect everything from plants to animals to humans and even fungi and bacteria. Viruses are complex in that there are many types and can affect different organisms in different ways. For example, a virus can have one specific type of effect on one type of organism, but a completely different effect on another type of organism. This explains why a virus that kills humans has no effect on dogs or cats. Viruses can also vary in their complexity with some having simple makeups while others have more elaborate compositions[2].

Viruses are considered to be the most abundant biological entity on the planet with no cure, no matter what type of virus it is. The only way to prevent the spread of a virus is by using vaccines or disinfection methods. Viruses are parasitic, meaning they cannot replicate and spread without a host

[1] "Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases", https://www.nature.com/articles/s41598-018-21058-w

[2] "What to know about viruses", https://www.medicalnewstoday.com/articles/158179

such as a human or animal. Viruses are dependent on a host because they do not contain ribosome, which means they can't make their own proteins, a necessity for reproduction and spreading[3].

The genetic makeup of a virus consists of either RNA (ribonucleic acid) or DNA (deoxyribonucleic acid) that is surrounded by a coating of protein, fat (lipid), or glycoprotein. The purpose of the RNA and DNA is to encode the genetic information that is unique for each virus. "The true infectious part of any virus is its nucleic acid, either DNA or RNA but never both,"[4].

Once inside the body of the infected organism, the virus inserts genetic material into the host and takes over the host's functions. After the cell is infected, the virus continues to replicate itself, but "produces more viral protein and genetic material instead of the usual cellular products… earning viruses the classification of parasite,"[5].

Within the virus community there are viruses that have different types of nucleic acid, including single-stranded RNA (ssRNA), single-stranded DNA (ssDNA), double-stranded RNA (dsRNA), and double-stranded DNA (dsDNA). The effectiveness and dose level of any method to kill any given virus depends on the type of nucleic acid it contains[6]. The more strands of nucleic acid a virus has, the more complex and harder to kill it is.

Since the actual infectious part of a virus is the nucleic acid, either its RNA or DNA then this is the part of the virus that needs to be negatively affected in order to degrade and kill it. UV-C and far-UV-C attack the nucleic acid of a virus and renders it useless and eventually killing it off.

What are Bacteria?

Bacteria are single-celled microorganisms that can be found all over the earth, including in living hosts such as plants, animals and humans, and in water, soil and on surfaces. There are both beneficial and harmful bacteria that can positively or negatively affect plants, animals and humans if contact with bacteria is made. Bacteria are considered to be living organisms and harmful infections caused by bacteria are often easily resolved with the use of antibiotics. The DNA and RNA of bacteria float freely in cytoplasm and features a cell wall and cell membrane. Bacteria reproduces via fission, a form of asexual reproduction[7].

When comparing viruses to bacteria there are many differences, which makes it clear that there are several different ways to kill each – the strain or type of bacteria or virus also can determine the measures taken to eliminate them in humans, in the air and on surfaces. Below is a brief comparison between the two most common entities that cause infections in humans.

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Differences Between Viruses and Bacteria

	BACTERIA	VIRUS
Brief overview	Constitute large domain of prokaryotic microorganisms; a few micrometers in length; have different shapes (rods, spirals, spheres, etc.)	A small infectious agent that replicates only inside the living cells of other organisms.
Ribosomes	Present	Absent
Cell wall	Peptidoglycan/Lipopolysaccharide	No cell wall. Protein coat instead.
Living attributes	Living organism	Differing opinions on whether viruses are life forms or organic structures that just interact with living organisms.
Nucleus	No	No
Number of cells	Unicellular – one cell	No cells; not living (?)
Structure	DNA & RNA float freely in cytoplasm. Has cell wall and cell membrane.	DNA or RNA enclosed in a coat of protein.
Reproduction	Fission – a form of asexual reproduction.	Invades host cell and takes over cell enabling it to make copies of its DNA/RNA and destroys host cell in releasing new viruses.
Treatment	Antibiotics	Vaccines prevent spread; antiviral meds slow reproduction, but cannot stop it completely; UVGI kills viruses on surfaces and in the air before infecting a host.
Enzymes	Yes	Yes
Infection	Localized	Systemic
Benefits	Some bacteria are beneficial (i.e. gut bacteria in humans).	None
Size	Larger (1000nm)	Smaller (20-40nm)

Adapted from Diffen.com, Bacteria vs. Virus, https://www.diffen.com/difference/Bacteria_vs_Virus

How Does UV Light Kill Viruses and Bacteria?

The effect of UV light on human skin becomes obvious during the warmer months of summer when people experience sun burn when exposed to direct sunlight for too long. UV light from the sun can also cause skin cancer, which damages cells in the body. Considering these effects of UV light from the sun on humans it makes sense that UV light on a shorter and stronger wavelength can be just as effective, if not more effective, in immobilizing and killing viruses and bacteria.

In order to inactivate and kill a virus, it has to be directly exposed to shortwave UV – UV-C at 254nm. When this happens in a constant and consistent manner, the UV irradiation bombards the virus with UV light and breaks down its cell walls[8]. This is crucial because as mentioned earlier a virus cannot produce its own protective shell of protein or other material, so once it is severely damaged by UV-C the virus cell itself cannot repair the damage.

More specifically, microorganisms such as viruses and bacteria suffer damage to their nucleic acids when bombarded with high-energy, short wavelength UV light – UV-C at 254nm. The UV light is absorbed by the RNA or DNA creating new bonds between the UV energy and the virus' or bacteria's nucleotides. This bonding creates double bonds, or dimers, that typically affect the thymine molecules. This damage to the thymine molecule is the most common type of photochemical damage that occurs in this process. When the formulation of multiple thymine dimers occurs in the DNA or RNA of a virus, the virus cannot replicate and is unable to continue infecting the host.

If a virus cannot replicate it loses its ability to infect the host and eventually dies off. This is especially important when trying to contain a virus that can spread rapidly by physical contact with humans or surfaces or through the air. With bacteria, which is a single-celled microorganism that has both DNA and RNA, once the DNA or RNA is attacked by the UV light the bacteria is damaged and cannot replicate itself.

How Does UV Light Inside HVAC Systems Help Mitigate the Spread of Viruses and Bacteria?

Killing viruses and bacteria at the source or before they spread to where they can be inhaled or come into physical contact with humans is the best way to mitigate their spread and stop infections. HVAC systems (heating, ventilation and air conditioning systems) provide acceptable air quality and thermal comfort. HVAC can be found in single-family homes, apartment buildings and condominiums, hotels, senior living facilities, hospitals, industrial facilities, schools and universities, office buildings and more. Given the broad use of HVAC systems and how many people around the world rely on them for clear and breathable air it makes sense that UV light would be used inside the system to kill bacteria and viruses to make the air as clean as possible.

The type of UV light used inside HVAC systems is called UVGI, which means ultraviolet germicidal irradiation. There are two ways HVAC UV lights are used inside systems: coil sterilization and air sterilization. Coil sterilization is the most common type of HVAC UV light method because it can run 24 hours a day, seven days a week to ensure maximum sterilization. With this type of application, "a

[8] "How Can Light Kill Viruses?", https://science.howstuffworks.com/life/cellular-microscopic/light-virus1.htm

'stick-type' light is installed inside the return air duct and it sterilizes the air handler coil,"[9]. On an HVAC system the coil and drain pan are typically the places where contaminants such as viruses and bacteria can originate. By adding a UV light to the coil, the origin of the contamination is treated before any bacteria, virus or mold spores are able to become airborne and contaminate the air[10].

The air sterilization method, on the other hand, is where a UV light "is installed in the return air duct and cycles on with the air handler blower… [and] a complete UV light unit sterilizes moving air itself as it is pushed through the HVAC system,"[11]. With this method, the air is already assumed to be or is contaminated and is itself treated, as opposed to treating the coil before the contamination makes it into the air as with the previous coil sterilization method. With this method, the UV light only turns on when the heating or cooling system is running, unlike the previous method[12].

However, it should not be assumed that sticking a UVGI light inside of an HVAC system will be sufficient in cleaning the air. There are a few factors that need to be considered before installing a UVGI into an HVAC system, including the wavelength and intensity of the UV lamp (as discussed above – UV-A, UV-B, UV-C), the number of lamps installed, the position of the lamps inside the system, and the reflectivity of the air duct[13]. Once UVGI lights are installed inside the HVAC system, the UV-C light kills bacteria, viruses and mold spores as described above the sections explaining how UV light kills these contaminants.

In conclusion, the use of UVGI light inside HVAC systems can be extremely effective in purifying and sterilizing the air inside homes, commercial buildings and industrial facilities to help mitigate the spread of airborne pathogens. As we've seen, UV light has been found to be a very effective method in killing viruses and bacteria if used properly and within the germicidal wavelength of 254nm. As long as the HVAC system type and size, as well as the sterilization method being used, number of lamps needed, placement of lamps and strength of UV lamps are taken into consideration, UVGI is an ideal solution to air sterilization and airborne pathogen mitigation.

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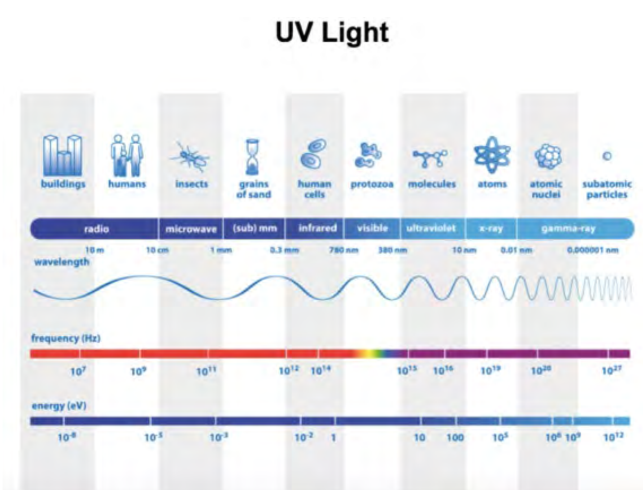
UV Disinfection Process to Prevent Buildup of Contaminants on Air Conditioner Coils

Ultraviolet (UV) light has the ability to thoroughly disinfect the air, surfaces and water and has been used in a wide variety of settings for various applications, including in HVAC systems. In this paper we will be focusing specifically on air conditioning (AC) systems and their evaporator cooling coils, which are known to have the potential to harbor mold spores, bacteria and other contaminants. The evaporator coils inside of an AC unit is a prime place where bacteria and mold can grow, so it is important to understand the options available to disinfect them and how that process actually works. The aim of this paper is to address how UV light can be used to prevent the buildup of bacteria, mold and other harmful substances on the coils inside AC systems.

The first few sections of this paper will give the reader a clear understanding of the different types of UV light that are available, how UV light in specific wavelength ranges breaks down and kills viruses, bacteria, mold spores and other pathogens, and finally, how UV light works on coils inside of AC units.

What are the Different Types of UV Light?

Ultraviolet light in its natural form comes from the sun and falls in the center of the light spectrum. The light spectrum starts with radio waves and moves to infrared, visible light and then ultraviolet light, which is followed by x-rays, gamma rays and cosmic rays. Most sources of light generate some level UV.



Stanford Solar Center, http://solar-center.stanford.edu/about/uvlight.html

Ultraviolet light comes in four wavelength ranges, which determine the light's intensity, strength and source. UV-A (blacklight UV) is found within the wavelength range of 400nm to 315nm; UV-B (dangerous UV) is found within the wavelength range of 315nm to 280nm; UV-C (germicidal UV) is found within the wavelength range of 280nm to 200nm with 253.7nm (254nm) being the ideal wavelength to kill viruses and bacteria; and UV-V (vacuum UV) is found within the wavelength range of 200nm to 100nm.

Wavelength	Description
400nm-315nm	UVA – Blacklight UV
315nm-280nm	UVB – Dangerous UV
280nm-200nm	UVC – Germicidal UV at 254nm
200nm-100nm	UVV – Vacuum UV

The only wavelength of UV on the entire UV spectrum that is effective in disinfecting air, surfaces and water is germicidal UV-C (253.7nm or 254nm generalized). The shorter and longer wavelengths outside of germicidal range are not produced by germicidal UV lamps. UV-B comes from sunlight with most solar UV-B absorbed by the ozone layer. However, long-term exposure to UV-B can cause sunburn and other health issues. UV-A is a longwave UV that can cause tanning of the skin and early skin aging.

A study published in 2018 by *Nature* in their *Scientific Reports* section claims that even far-UV-C light (207nm to 222nm) efficiently and effectively inactivates bacteria and viruses, such as tuberculosis and influenza, without harming exposed skin of mammals, including humans. It should be understood that far-UV-C is not as strong as germicidal UV-C, which can inactivate both multi-drug-resistant and drug-sensitive bacteria as well as various strains of viruses[1]. Before we get into how UV light can be used on evaporator cooling coils inside air conditioning units, let's first explore viruses, bacteria, what they are and how they differ from each other. This foundation is necessary in order to better understand how UV light works to kill them, especially on a wet evaporator coil inside a cooling unit.

What is a Virus?

A virus is a microscopic organism that can be found almost anywhere on earth and can infect everything from plants to animals to humans and even fungi and bacteria. Viruses are complex in that there are many types and can affect different organisms in different ways. For example, a virus can have

[1] "Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases", https://www.nature.com/articles/s41598-018-21058-w

one specific type of effect on one type of organism, but a completely different effect on another type of organism. This explains why a virus that kills humans has no effect on dogs or cats. Viruses can also vary in their complexity with some having simple makeups while others have more elaborate compositions[2].

Viruses are considered to be the most abundant biological entity on the planet with no cure, no matter what type of virus it is. The only way to prevent the spread of a virus is by using vaccines or disinfection methods. Viruses are parasitic, meaning they cannot replicate and spread without a host such as a human or animal. Viruses are dependent on a host because they do not contain ribosome, which means they can't make their own proteins, a necessity for reproduction and spreading[3].

The genetic makeup of a virus consists of either RNA (ribonucleic acid) or DNA (deoxyribonucleic acid) that is surrounded by a coating of protein, fat (lipid), or glycoprotein. The purpose of the RNA and DNA is to encode the genetic information that is unique for each virus. "The true infectious part of any virus is its nucleic acid, either DNA or RNA but never both,"[4].

Once inside the body of the infected organism, the virus inserts genetic material into the host and takes over the host's functions. After the cell is infected, the virus continues to replicate itself, but "produces more viral protein and genetic material instead of the usual cellular products… earning viruses the classification of parasite,"[5].

Within the virus community there are viruses that have different types of nucleic acid, including single-stranded RNA (ssRNA), single-stranded DNA (ssDNA), double-stranded RNA (dsRNA), and double-stranded DNA (dsDNA). The effectiveness and dose level of any method to kill any given virus depends on the type of nucleic acid it contains[6]. The more strands of nucleic acid a virus has, the more complex and harder to kill it is.

Since the actual infectious part of a virus is the nucleic acid, either its RNA or DNA then this is the part of the virus that needs to be negatively affected in order to degrade and kill it. UV-C and far-UV-C attack the nucleic acid of a virus and renders it useless and eventually killing it off.

What are Bacteria?

Bacteria are single-celled microorganisms that can be found all over the earth, including in living hosts such as plants, animals and humans, and in water, soil and on surfaces. There are both beneficial and harmful bacteria that can positively or negatively affect plants, animals and humans if contact with bacteria is made. Bacteria are considered to be living organisms and harmful infections caused by bacteria are often easily resolved with the use of antibiotics. The DNA and RNA of bacteria float freely in

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[2] "What to know about viruses", https://www.medicalnewstoday.com/articles/158179

[3] "What are viruses?", https://www.medicalnewstoday.com/articles/158179
[4] "Virus: General Features & Definition", https://www.britannica.com/science/virus

[5] "What are viruses?", https://www.medicalnewstoday.com/articles/158179
[6] "Inactivation of viruses on surfaces by ultraviolet germicidal irradiation", https://www.ncbi.nlm.nih.gov/pubmed/17474029

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cytoplasm and features a cell wall and cell membrane. Bacteria reproduces via fission, a form of asexual reproduction[7].

When comparing viruses to bacteria there are many differences, which makes it clear that there are several different ways to kill each – the strain or type of bacteria or virus also can determine the measures taken to eliminate them in humans, in the air and on surfaces. Below is a brief comparison between the two most common entities that cause infections in humans.

Differences Between Viruses and Bacteria

	BACTERIA	**VIRUS**
Brief overview	Constitute large domain of prokaryotic microorganisms; a few micrometers in length; have different shapes (rods, spirals, spheres, etc.)	A small infectious agent that replicates only inside the living cells of other organisms.
Ribosomes	Present	Absent
Cell wall	Peptidoglycan/Lipopolysaccharide	No cell wall. Protein coat instead.
Living attributes	Living organism	Differing opinions on whether viruses are life forms or organic structures that just interact with living organisms.
Nucleus	No	No
Number of cells	Unicellular – one cell	No cells; not living (?)
Structure	DNA & RNA float freely in cytoplasm. Has cell wall and cell membrane.	DNA or RNA enclosed in a coat of protein.
Reproduction	Fission – a form of asexual reproduction.	Invades host cell and takes over cell enabling it to make copies of its DNA/RNA and destroys host cell in releasing new viruses.
Treatment	Antibiotics	Vaccines prevent spread; antiviral meds slow reproduction, but cannot stop it completely; UVGI kills viruses on surfaces and in the air before infecting a host.
Enzymes	Yes	Yes
Infection	Localized	Systemic

[7] "Bacteria vs. Virus", https://www.diffen.com/difference/Bacteria_vs_Virus

Benefits	Some bacteria are beneficial (i.e. gut bacteria in humans).	None
Size	Larger (1000nm)	Smaller (20-40nm)

Adapted from Diffen.com, Bacteria vs. Virus, https://www.diffen.com/difference/Bacteria_vs_Virus

What is Mold?

Viruses and bacteria are not the only contaminants that can be found inside buildings. Molds are actually very common in homes and commercial and industrial buildings. Mold tends to grow in environments with a lot of moisture, such as bathrooms, around pipes or windows, in basements that flood and more. According to the Center for Diseases Control (CDC), the most common types of indoor molds are *Cladosporium, Penicillium* and *Aspergillus*. Mold can grow inside and outside, and when mold spores are deposited on places where excessive moisture can be found they will grow. Mold affects people differently depending on the type of mold and the sensitivity of the person[8].

In terms of contaminating the air, mold is no different than viruses or bacteria in that they do not originate by themselves on a surface. The mold spores have to come from somewhere and be deposited onto a moist area in order to grow and further contaminate the environment.

How Does UV Light Kill Viruses, Bacteria and Mold?

The effect of UV light on human skin becomes obvious during the warmer months of summer when people experience sun burn when exposed to direct sunlight for too long. UV light from the sun can also cause skin cancer, which damages cells in the body. Considering these effects of UV light from the sun on humans it makes sense that UV light on a shorter and stronger wavelength can be just as effective, if not more effective, in immobilizing and killing viruses and bacteria.

In order to inactivate and kill a virus, it has to be directly exposed to shortwave UV – UV-C at 254nm. When this happens in a constant and consistent manner, the UV irradiation bombards the virus with UV light and breaks down its cell walls[9]. This is crucial because as mentioned earlier a virus cannot produce its own protective shell of protein or other material, so once it is severely damaged by UV-C the virus cell itself cannot repair the damage.

More specifically, microorganisms such as viruses and bacteria suffer damage to their nucleic acids when bombarded with high-energy, short wavelength UV light – UV-C at 254nm. The UV light is

[8] "Basic Facts About Mold and Dampness," https://www.cdc.gov/mold/faqs.htm

[9] "How Can Light Kill Viruses?", https://science.howstuffworks.com/life/cellular-microscopic/light-virus1.htm

absorbed by the RNA or DNA creating new bonds between the UV energy and the virus' or bacteria's nucleotides. This bonding creates double bonds, or dimers, that typically affect the thymine molecules. This damage to the thymine molecule is the most common type of photochemical damage that occurs in this process. When the formulation of multiple thymine dimers occurs in the DNA or RNA of a virus, the virus cannot replicate and is unable to continue infecting the host.

If a virus cannot replicate it loses its ability to infect the host and eventually dies off. This is especially important when trying to contain a virus that can spread rapidly by physical contact with humans or surfaces or through the air. With bacteria, which is a single-celled microorganism that has both DNA and RNA, once the DNA or RNA is attacked by the UV light the bacteria is damaged and cannot replicate itself.

How Does UV Light Work on Evaporator Coils Inside an Air Conditioning Unit?

Killing viruses, bacteria, mold spores and other contaminants at the source before they can come into contact with more people is the best way to mitigate their spread and stop infections, allergies and illness. Generally, AC systems provide acceptable air quality and thermal comfort. These systems can be found in single-family homes, apartment buildings and condominiums, hotels, senior living facilities, hospitals, industrial facilities, schools and universities, office buildings and more. Given the wide use of AC systems and how many people around the world rely on them for clear and breathable air in warmer months, it makes sense that UV light would be used inside the system to kill bacteria, viruses, mold and other contaminants to make the air as clean as possible.

Air conditioning systems have two different types of coils – one that can be found on the outside of the system and another that lives inside the system. The coil inside the AC system can be found inside the air handler or above a furnace inside a home, for example. Inside the system where the coil sits tends to be dark and wet as water condenses on the coil throughout the cooling season, which could be several months. This wet, dark place inside the system is the perfect environment for breading all sorts of microbes, including mold and bacteria. However, it should be noted that mold, bacteria and viruses do not originate inside HVAC or AC systems. The contamination starts in the air, typically from an infected person and that person coughs or touches something in the room where the air is circulated. That air is then contaminated and circulated back through the AC system where the contaminant can land and stick to a coil and be recirculated through the air[10].

If and when biological contaminants, which originated before they circulated into the system, start to grow on the AC's coil, the blower fan will glow them out into the air inside the building it is installed in. The idea is to kill the bacteria and other contaminants before they have a chance to be blown back out into the environment where more people can breathe them in and be infected[11].

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[10] "Coronavirus and Other Contaminants: How Indoor Air Quality Can Affect Your Health", https://www.acca.org/news/guest-blog/coronavirus-other-contaminants-indoor-air

[11] Ibid.

The type of UV light used inside AC systems is called UVGI, which means ultraviolet germicidal irradiation. There are two ways HVAC UV lights are used inside systems: coil sterilization and air sterilization. Coil sterilization is the most common type of AV UV light method because it can run 24 hours a day, seven days a week to ensure maximum sterilization – this is referred to as 'coil bathing'. With this type of application, "a 'stick-type' light is installed inside the return air duct and it sterilizes the air handler coil,"[12]. By adding a UV light to the coil, the origin of the contamination is treated before any bacteria, virus or mold spores are able to become airborne and contaminate the air once more[13].

However, it should not be assumed that sticking a UVGI light inside of an AC system will be sufficient in cleaning the air. There are a few factors that need to be considered before installing a UVGI into an AC system, including the wavelength and intensity of the UV lamp (as discussed above – UV-A, UV-B, UV-C), the number of lamps installed, the position of the lamps inside the system, and the reflectivity of the air duct[14]. Once UVGI lights are installed inside the AC system, the UV-C light kills bacteria, viruses and mold spores as described above the sections explaining how UV light kills these contaminants. Again, it should be noted that in order for contaminants to be an issue inside AC units, the air inside the building must have already been contaminated as mold, viruses and bacteria always originate somewhere outside the AC system and is then circulated through the system via already-contaminated air. The air filters and coils trap the contaminants and this is where they can be killed with a UVGI solution so that the air can be cleaned and pushed back out into the building.

In conclusion, the use of UVGI light inside AC systems can be extremely effective in purifying and sterilizing the air inside homes, commercial buildings and industrial facilities to help mitigate the spread of airborne pathogens. As we have seen, UV light has been found to be a very effective method in killing viruses, mold spores and bacteria if used properly and within the germicidal wavelength of 254nm. As long as the AC system type and size, as well as the sterilization method being used, number of lamps needed, placement of lamps and strength of UV lamps are taken into consideration, UVGI is an ideal solution to air sterilization and airborne pathogen mitigation.

[12] "What to Know Before Installing UV Lights for HVAC System", Lincoln Tech Blog, https://www.lincolntech.edu/news/skilled-trades/hvac/what-to-know-before-installing-uv-lights-for-hvac-system

[13] Ibid.

[14] Ibid.

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How UV Light is Used in Hospitals and Medical Facilities

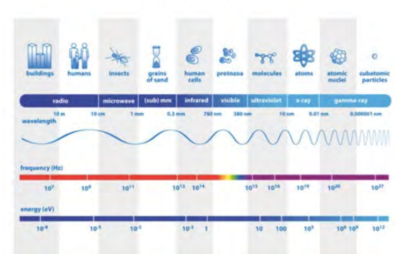
Ultraviolet (UV) light is a powerful disinfectant solution that can be used to clean surfaces, water and the air. The use of UV light can help mitigate the risk of contracting an infection from a virus if one comes into contact with a contaminated surface. One industry that benefits dramatically from UV lights for disinfection is the medical industry. Hospitals, Urgent Care centers, doctors' offices, labs and other medical facilities use UV lights to help disinfect surfaces, clean equipment and machines, clean the air, and keep their patients safe.

This paper will address several different topics to help the reader understand more fully how hospitals and other medical facilities harness the power of UV light to kill germs and other pathogens, such as the different types of UV light and which is best for disinfection, what viruses and bacteria are and the differences between them, and examples of ways hospitals and medical facilities use UV lights to sanitize their surfaces, equipment and environment.

Understanding UV Light Wavelength Ranges and Their Uses

In its natural form, UV light is generated by the sun and falls in the center of the light spectrum. At the beginning of the light spectrum is radio waves with infrared light next, then visible light and then ultraviolet light. Following UV is x-rays, gamma rays and then cosmic rays. Most sources of light generate some level UV light. The light spectrum chart below shows the different types of light, the type of wavelength (short or long), and where each falls in relation to the rest.

UV Light



Stanford Solar Center, http://solar-center.stanford.edu/about/uvlight.html

The intensity and source of UV light is determined by the wavelength range it falls in. There are four ranges, including UV-A, UV-B, UV-C and UV-V. The first type is UV-A (blacklight UV) and this is found within the wavelength range of 400nm to 315nm; UV-B (dangerous UV) is found within the wavelength range of 315nm to 280nm; UV-C (germicidal UV) is found within the wavelength range of 280nm to 200nm with 253.7nm (254nm) being the ideal wavelength to kill viruses and bacteria; and UV-V (vacuum UV) is found within the wavelength range of 200nm to 100nm.

Wavelength	Description
400nm-315nm	UVA – Blacklight UV
315nm-280nm	UVB – Dangerous UV
280nm-200nm	UVC – Germicidal UV at 254nm
200nm-100nm	UVV – Vacuum UV

If you notice on the chart above, UV-C is also known as germicidal UV and that's because it is the only type of UV that is effective at disinfecting air, surfaces and water. UV-C falls between 280nm and 200nm with the ideal for killing germs, viruses, bacteria, mold spores and other contaminants being 253.7nm, or 254nm generalized. A study published in 2018 by *Nature* in their *Scientific Reports* section claims that even far-UV-C light (207nm to 222nm) efficiently and effectively inactivates bacteria and viruses, such as tuberculosis and influenza, without harming exposed skin of mammals, including humans. It should be understood that far-UV-C is not as strong as germicidal UV-C, which can inactivate both multi-drug-resistant and drug-sensitive bacteria as well as various strains of viruses[1].

What is a Virus?

A virus is a microscopic organism that can be found almost anywhere on earth and can infect everything from plants to animals to humans and even fungi and bacteria. Viruses are complex in that there are many types and can affect different organisms in different ways. For example, a virus can have one specific type of effect on one type of organism, but a completely different effect on another type of organism. This explains why a virus that kills humans has no effect on dogs or cats. Viruses can also vary in their complexity with some having simple makeups while others have more elaborate compositions[2].

Viruses are considered to be the most abundant biological entity on the planet with no cure. The only way to prevent the spread of a virus is by using vaccines or disinfection methods. Viruses are parasitic, meaning they cannot replicate and spread without a host such as a human or animal. Viruses

[1] "Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases", https://www.nature.com/articles/s41598-018-21058-w

[2] "What to know about viruses", https://www.medicalnewstoday.com/articles/158179

are dependent on a host because they do not contain ribosome, which means they can't make their own proteins, a necessity for reproduction and spreading[3].

The genetic makeup of a virus consists of either RNA (ribonucleic acid) or DNA (deoxyribonucleic acid) that is surrounded by a coating of protein, fat (lipid), or glycoprotein. The purpose of the RNA and DNA is to encode the genetic information that is unique for each virus. "The true infectious part of any virus is its nucleic acid, either DNA or RNA but never both,"[4].

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Since the actual infectious part of a virus is the nucleic acid, either its RNA or DNA then this is the part of the virus that needs to be negatively affected in order to degrade and kill it. UV-C and far-UV-C attack the nucleic acid of a virus and renders it useless and eventually killing it off.

How Does UV Light Kill Viruses and Bacteria?

The effect of UV light on human skin becomes obvious during the warmer months of summer when people experience sun burn when exposed to direct sunlight for too long. UV light from the sun can also cause skin cancer, which damages cells in the body. Considering these effects of UV light from the sun on humans it makes sense that UV light on a shorter and stronger wavelength can be just as effective, if not more effective, in immobilizing and killing viruses and bacteria.

In order to inactivate and kill a virus, it has to be directly exposed to shortwave UV – UV-C at 254nm. When this happens in a constant and consistent manner, the UV irradiation bombards the virus with UV light and breaks down its cell walls[7]. This is crucial because as mentioned earlier a virus cannot

[3] "What are viruses?", https://www.medicalnewstoday.com/articles/158179
[4] "Virus: General Features & Definition", https://www.britannica.com/science/virus

[5] "What are viruses?", https://www.medicalnewstoday.com/articles/158179
[6] "Inactivation of viruses on surfaces by ultraviolet germicidal irradiation", https://www.ncbi.nlm.nih.gov/pubmed/17474029

[7] "How Can Light Kill Viruses?", https://science.howstuffworks.com/life/cellular-microscopic/light-virus1.htm

produce its own protective shell of protein or other material, so once it is severely damaged by UV-C the virus cell itself cannot repair the damage.

More specifically, microorganisms such as viruses suffer damage to their nucleic acids when bombarded with high-energy, short wavelength UV light – UV-C at 254nm. The UV light is absorbed by the RNA or DNA creating new bonds between the UV energy and the virus' nucleotides. This bonding creates double bonds, or dimers, that typically affect the thymine molecules. This damage to the thymine molecule is the most common type of photochemical damage that occurs in this process. When the formulation of multiple thymine dimers occurs in the DNA or RNA of a virus, the virus cannot replicate and is unable to continue infecting the host.

If a virus cannot replicate it loses its ability to infect the host and eventually dies off. This is especially important when trying to contain a virus that can spread rapidly by physical contact with humans or surfaces or through the air. Hospitals and medical facilities are places where viruses and bacteria can thrive since many people who become severely ill end up in Urgent Care, the hospital or their doctor's office.

How do Medical Facilities Utilize UV Sanitation Devices?

There are many different types of UV sanitation devices, including but not limited to UV sanitation carts, handheld UV sanitation wands and devices, UV doorway and door handle sanitation kits, UV sanitation lights for HVAC systems, UV boxes/ovens for sanitizing packages and other small objects, and even UV machines that a person can walk through – similar to a metal detector found at an airport. Hospitals and medical facilities can use any of these devices to ensure their facilities, surfaces and environment are clean.

Combined Cleaning Methods: UV-C and Traditional Cleaning Methods

A study by Duke Health researchers showed that hospitals that use UV-C are seeing a decline in transmission of super bugs, such as Methicillin-resistant Staphylococcus aureus (MRSA)[8]. The study

[8] "UV Light Helps Duke Hospitals Fight Transmission of Superbugs", https://www.dukehealth.org/blog/uv-light-helps-duke-hospitals-fight-transmission-of-superbugs

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showed that UV-C light "can cut transmission of four major super bugs by a cumulative 30 percent,"[9]. It's vital for hospitals and other medical facilities that see patients with various types of infections on a regular basis to have alternative ways of disinfecting rooms and surfaces because traditional cleaning is not enough. "Some of these germs can live in the environment so long that even after a patient with the organism has left the room and it has been cleaned, the next patient in the room could potentially be exposed," said Dr. Deverick J. Anderson, M.D. from Duke Health[10]. Duke utilizes enhanced disinfection methods, which combine traditional cleaning with bleach and/or quaternary ammonium with UV light. These enhanced methods "successfully reduce the risk of germs spreading through the environment," said Anderson[11].

UV-C Systems in HVAC Units for Air Disinfection

Another way that hospitals and medical facilities harness the power of UV disinfection is by installing UV-C lights into the HVAC system in their building. When UV-C is installed in an HVAC system it helps kill bacteria, viruses and other pathogens on the condenser coils before they enter the air or they kill them in their air inside the HVAC system, but before the air enters inhabited environments and rooms.

A couple of examples include a United States Invitro Fertilization Laboratory that installed a UV-C disinfection system in their HVAC unit and it actually "increased the clinical pregnancy rates from 38.9 to 62.3 per cent... [and] the Women's & Children's Hospital of Buffalo, NY reported… 'eUVGI eradicated microbes in HVACs and was associated with a decrease in NICU environmental pathogens and tracheal colonization. Significant reductions in VAP and antibiotic use in NICU high-risk patients were associated with eUVGI in this limited study,"[12].

UV-C Devices for Surface Disinfection

In some hospitals, smaller UV sanitizing devices are placed around for staff and doctors to use as a supplement to traditional cleaning methods. A common use is the disinfection of smartphones and

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[9] Ibid.
[10] Ibid.
[11] Ibid.
[12] "Ultraviolet and HVAC: Keys to reducing hospital acquired infections", https://hospitalnews.com/ultraviolet-hvac-keys-reducing-hospital-acquired-infections/

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other wearables, such as the Vocera Badge, used to communicate with staff and patients[13]. Contact with unclean hands and equipment like respiratory machines as well as smartphones and medical wearables aid in the spread of infections in hospitals. Even though the machines are cleaned, bacteria and contaminants can still hide in crevices and hard-to-reach places that traditional cleaning may miss. It is also not advisable to clean smartphones and other electronic devices with alcohol wipes, so to fix this problem, a UV sanitation device can be extremely helpful[14].

In a study done at a Canadian hospital it was found that when swabbing devices before they went into a UV sanitizer, 20% of the devices had bacterial growth compared to less than 5% after they went through a UV cleaning[15]. Although this was a small study, it shows the effectiveness of UV-C sanitization devices and how they can aid in disinfecting medical devices and other devices touched throughout the day, such as smartphones.

In conclusion, the use of UV light has been found to be a very effective method in killing viruses, bacteria and other pathogens in the healthcare industry. There are several factors that have led hospitals and other medical facilities to adopt the use of UV sanitation devices, including the inadequate level of clean by way of traditional methods alone, the increase in super bugs that are antibiotic resistant and resistant to certain cleaning methods, the increased use in smart and wearable technologies, and the faster pace inside some hospitals and medical facilities making thorough cleaning between patients less achievable. The use of UV sanitation devices alongside traditional cleaning methods is the best way to lower the infection rates and spread of disease in a fast and effective manner inside medical facilities.

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[13] "UV lights in hospitals could help limit bacteria on phones", https://www.reuters.com/article/us-health-hospitals-uv-sanitizers/uv-lights-in-hospitals-could-help-limit-bacteria-on-phones-idUSKBN1Y82L4

[14] Ibid.

[15] Ibid.

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LARSON ELECTRONICS LLC
9419 E US HWY 175
KEMP, TX 75143

Web: larsonelectronics.com
Email: sales@larsonelectronics.com
Phone: 1-800-369-6671
Intl: +1-214-616-6180
Fax: 903-498-3364

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