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(Research Article)

Advancing Healthcare Safety with UV-222 nm Disinfection Systems: Applications, Benefits, and Ethical Considerations

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Abstract

The COVID-19 pandemic has brought attention to the necessity of an adequate disinfection system to fight dangerous and contagious diseases. Current cleaning procedures are frequently laborious and time-consuming. Researchers are investigating the use of cutting-edge technologies to safeguard the worldwide populace against the spread of viruses and other illnesses to address this issue. A UV-222 nm light-based disinfection system has been suggested as a possible remedy in this regard to counteract the impacts of viruses and maintain a clean and secure environment. The implementation of UV-222 nm light-based disinfection systems and their prospective influence on healthcare technology are the main topics of this article. The technology can address issues with the spread of viruses and bacteria in a variety of contexts, including car headlights, public lighting, interior lights in homes, and other sterilising techniques. Additionally, the high-way geometry of UVC sterilisation has been theoretically formulated and investigated.

Healthcare professionals, medical physicists, biomedical and clinical engineers, and other associated groups are the target audience for this article. In order to enhance patient safety, disease surveillance, and management, the study discusses the potential advantages of UV-222 nm light-based disinfection systems. We also talk about the ethical, moral, and legal ramifications of using such technology.

In conclusion, this research offers a fresh viewpoint on UV-222 nm light-based disinfection systems and their prospective influence on medical technology. In order to improve patient care and safety, we hope that this conversation will promote additional research and development in the area of healthcare technology.

Keywords: UVC,222nm; KrCl; UVC-222nm; Headlight; DNA; UV Radiation; Street Light

1. Introduction

The World Health Organization first identified illness due to coronavirus (COVID-19) in December 2019 which was considered an epidemic initially and declared a pandemic on March 11, 2020. With more than 65.7Cr confirmed cases and more than 66.8L confirmed fatalities as of Dec 27, 2022, despite significant efforts to control its spread. According to statistics obtained from Johns Hopkins University's Center for Systems Science and Engineering, COVID-19 affected the entire world and caused several concerns such as health risks among people, resulting in about 66 lakh deaths worldwide by 2022.[1] The CDC (Center for Disease Control) states that UV (Ultraviolet light) plays a vital role in virus disinfection. In 1835, Wheatstone invented mercurial (Hg) vapor arc lighting that emits UV through gas discharging. UV was first employed to clean drinking water in 1906. Henri (1914) was the first to show that ultraviolet light had a photochemical impact on bacteria [2]

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KrBr 207 nm and FAR-UV KrCl 222 nm Beginning in 2000, far-UVC excimers were initially applied to chemicals and microorganisms to kill the virus and bacteria[3]. UV light is the focus of the current study. UV light with a wavelength of 222 nm is used in vehicle headlight systems to sterilize viruses and bacteria found on highways and in travel areas. That UVC with shorter wavelengths (207–222 nm) is safe for mammalian skin. When the light is distributed via the headlight and falls over the road or traveling locations, UV light kills viruses and bacteria by damaging the microorganism's DNA and RNA, which affects pathogens and slows their growth.

The process of deactivating viruses and bacteria by UV-C light with a wavelength of 222 nanometers (nm).

Absorption: UV-C light with a wavelength of 222nm is highly absorbed by DNA and RNA molecules within microorganisms, due to its high energy and the resonance of its wavelength with the molecular bonds in nucleic acids. According to a study by Sagripanti and Lytle, "the absorption of UV-C light by DNA and RNA depends on the wavelength of the light and the composition of the nucleic acid. At a wavelength of 222 nm, the absorption coefficient of DNA is about 15-fold higher than at 254 nm, which is the wavelength typically used for UV germicidal lamps."

Formation of Photoproducts: The excitation of electrons in nucleic acids by UV-C light leads to the formation of reactive intermediates called photoproducts, including cyclobutane pyrimidine dimers (CPDs) and pyrimidine- pyrimidone (6-4) photoproducts. According to a study by Cadet and Wagner, "CPDs are formed by the covalent bonding of adjacent pyrimidine bases (usually thymine or cytosine) in the DNA, causing a kink in the DNA helix that interferes with replication and transcription. 6-4 photoproducts are formed by the bonding of a pyrimidine base with an adjacent pyrimidine base in the opposite strand of DNA, leading to the formation of a bulge in the DNA helix."[3]

Damage to Genetic Material: The formation of CPDs and 6-4 photoproducts can cause significant damage to the DNA molecules within the microorganism. This damage can lead to mutations, strand breaks, and other forms of damage that interfere with the normal replication and transcription processes required for the microorganism's survival and reproduction. According to a study by Mouchet et al., "UV-C exposure causes a wide range of DNA damages including single and double-strand breaks, nucleobase modifications, and DNA-protein crosslinks."[4]

Deactivation: The damage to the genetic material of the microorganism ultimately leads to its deactivation. This is because the microorganism is unable to carry out its normal cellular processes due to the DNA damage caused by UV-C light. Over time, the microorganism may undergo further damage and die off completely. According to a study by Kowalski et al., "UV-C at 222 nm was shown to be more effective at inactivating bacterial and viral pathogens than conventional UV-C lamps, and caused minimal damage to human skin cells."[4-5]

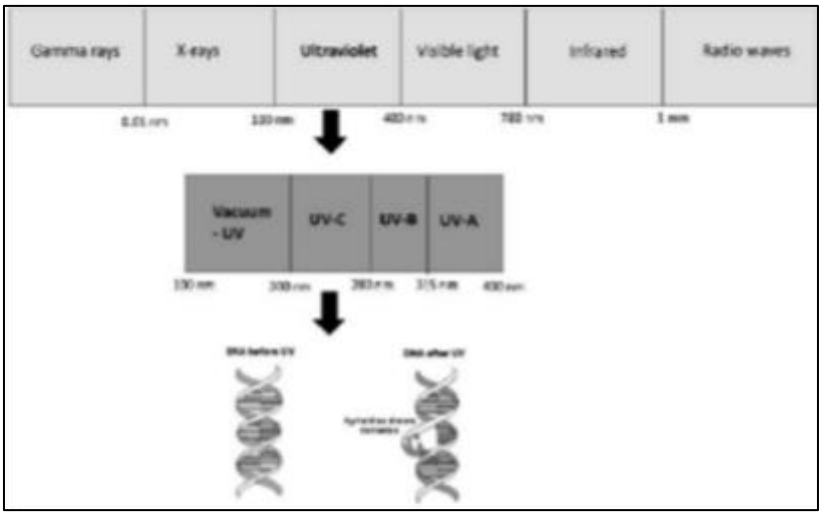


Figure 1 The UV headlights broad spectrum and genetically broken DNA of the virus and bacteria.[6]

Figure 2 demonstrates electromagnetic waves with frequencies ranging from 0.01 nm to 1 mm, which are included in the electromagnetic spectrum. The current vehicle headlight system focuses on germicidal UV Light with a wavelength of 222 nm, which has a wavelength between 100 nm and 400 nm. UV light is categorized into four categories based on wavelength where the current study demonstrates the utilization of UV-C germicidal. When viruses and bacteria are exposed to UV light from the UV headlamp, which causes the production of pyrimidine dimers in DNA, resulting in DNA lesions, cellular enzyme dysfunction, and cytoplasmic membrane integrity loss.[7] UV radiation from the UV headlamp has the ability to destroy viruses, bacteria, and microorganisms, as well as limit bacterial replicating abilities. Shorter wavelength UVC light has a narrower penetration range, so it cannot pass through the stratum corneum of the skin or the outer layer of the eye.[8] However, it is safe for deeper layers of living cells because it can still enter the bacterial cell nucleus. A study found that 222 nm UVC light is equally effective in killing bacteria and viruses without causing cyclobutane pyrimidine dimers (CPD) in the skin.[9]

Contrarily, it is possible to examine the effectiveness of this light against airborne human coronaviruses such as alpha-HCoV-229E and beta-HCoV-OC43. Transmission of SARS- CoV-2, the beta coronavirus that causes COVID-19, is thought to occur both through direct contact and airborne routes. Studies of SARS-CoV-2 have shown viability in aerosols for at least 3 hours. Low doses of 1.7 and 1.2 mJ/cm2 inactivated 99.9% of aerosolized coronaviruses 229E and OC43. It is crucial to investigate viable mitigation methods that may inactivate the airborne virus in the public road and traveling regions and reduce airborne transmission given the disease's fast spread, especially through asymptomatic carriers.[10]

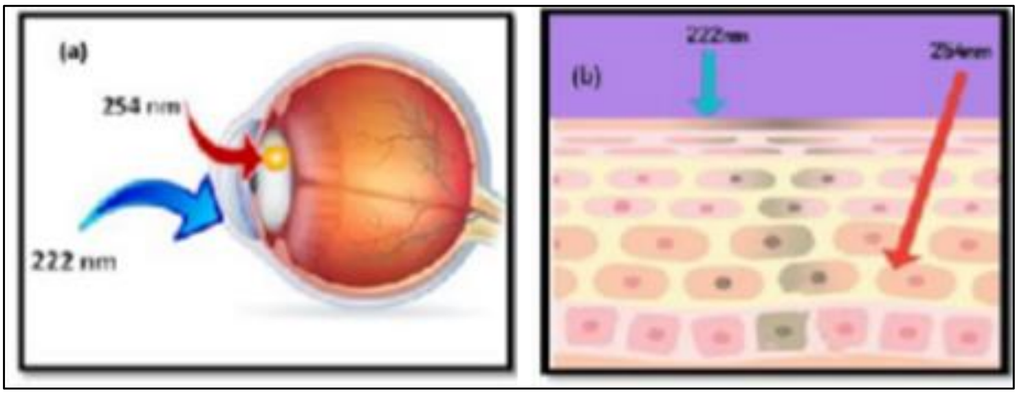


Figure 2 UV light penetration on the human eye and skin at various wavelengths (222 nm and 254 nm)

As shown in Figure 2 In comparison to other conventional UV light at different wavelengths[11], the study refers to the use of UV-222 nm light in vehicle headlight systems, which does not cause any effect in skin and eyes because the 222 nm wavelength has a narrow bandwidth[12], making it the germicidal UV light that is safer to use in a vehicle.[13].

Table 1 Human exposure to UV waves with different wavelengths and doses

Wavelength	Dosage	Effects	reference
Unfiltered Far UVC 207 nm	24mJ/cm2 150mJ/cm2	50%and 80% of cell death in human fibroblast cells cyclobutane pyrimidine dimer (CPD) formation.	[14] [5]
UVC 254 nm	150mJ/cm2 24mJ/cm2	45% human epidermal cell death and 90% fibroblast cells death	[14] [5]
UVC 220 Nm 230 nm 250 nm	10mJ/cm2 13mJ/cm2 8mJ/cm2	Affects the human eye cells by causing Cell deaths and Photokeratitis	[15]
UVC 210 nm 220 nm 230 nm 250 nm	327mJ/cm2 21mJ/cm2 22mJ/cm2 20mJ/cm2	Causes Photokeratitis In primate eyes	[15]
U V C - 2 2 2 nm	filtered-500 mJ/cm2 unfiltered- below50 mJ/cm2	No dangerous effects on the human skin or eye	[16] [17]

From table 1. Unfiltered Far UVC 207 nm at the dosage of 24mJ/cm2 and 150mJ/cm2 causes 50% and 80% of cell death in human fibroblast cells cyclobutane pyrimidine dimer (CPD) formation.[14] UVC 254 nm at dosages of 150mJ/cm2 and 24mJ/cm2 causes 45% human epidermal cell death and 90% fibroblast cell death.[14] UVC 220 nm, 230 nm, and

250 nm at tCausehe dosage of 10mJ/cm2, 13mJ/cm2, and 8mJ/cm2 will affect the human eye cells by causing Cell death and Photokeratitis.[15]

UVC 210 nm, 220 nm,230 nm,250 nm at the dosage of 327mJ/cm2,21mJ/cm2,22mJ/cm2,20mJ/cm2 will Causes Photokeratitis in primate eyes[16].UVC-222 nm filtered- 500 mJ/cm2 or unfiltered-below50 mJ/cm2 does not cause any dangerous effects on the human skin or eye.[17] As a result, UV-222 nm can effectively kill viruses and bacteria when employed in the headlight system of vehicles.[5], [18]- [19]

2. Headlight beam geometrical parameters.

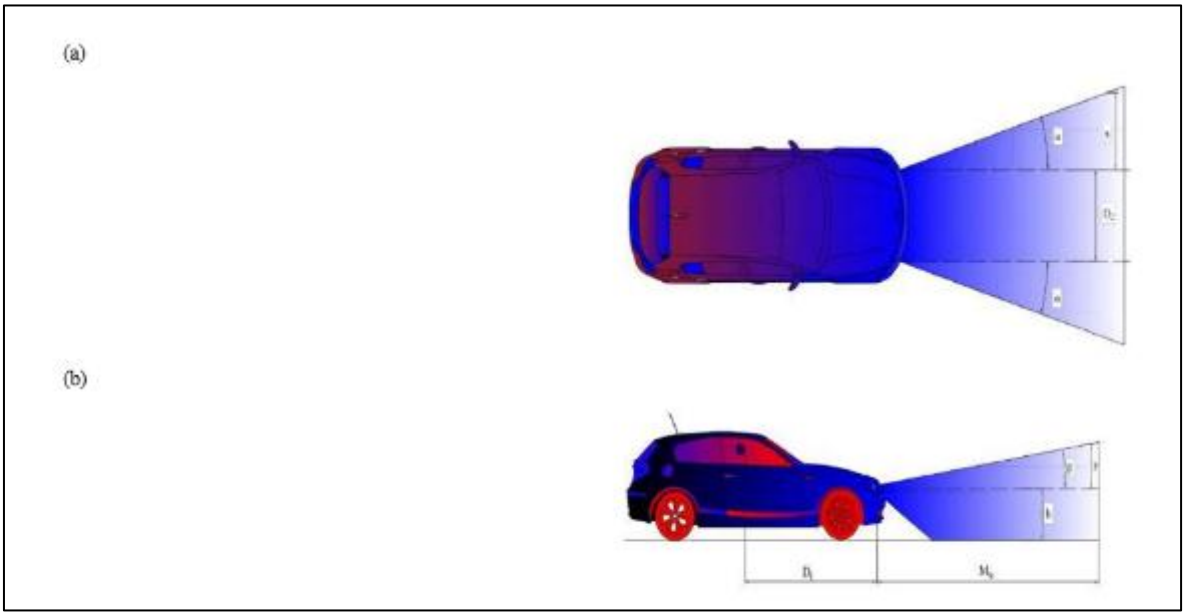


Figure 3 (a) (b)Headlight beam geometrical parameters

Figure 3(a) illustrates the headlight beam's top view and geometrical parameters. Figure 3 (b) shows the side view and geometrical parameters. It is essential to consider the following parameters before declaring a region to be virally and bacterially sterile:

- β- headlights' upward divergence angle α- headlights' horizontal spread angles Mlr- Maximum light range
- the height of the headlight mounting y-upward divergence length
- horizontal spread length w-width of light range
- Hh- Height of light range
- D2- offset distance between headlight
- D1- Distance between headlight position to the driver

From the above equation it is clear that headlight will cover the “w” distance during its journey, which is referred as driver's night-time sight distance, at these distance viruses and bacteria are sterilized. [20]–[22]

UV-C irradiation follows the inverse-square rule of light, which states that the intensity at a particular site is inversely proportional to the square of its distance from the light source and that the germicidal dosage is the product of time and intensity that is given by,

Dose = Intensity x Time.

μW × seconds = mj ……….. (12)

cm2 cm2

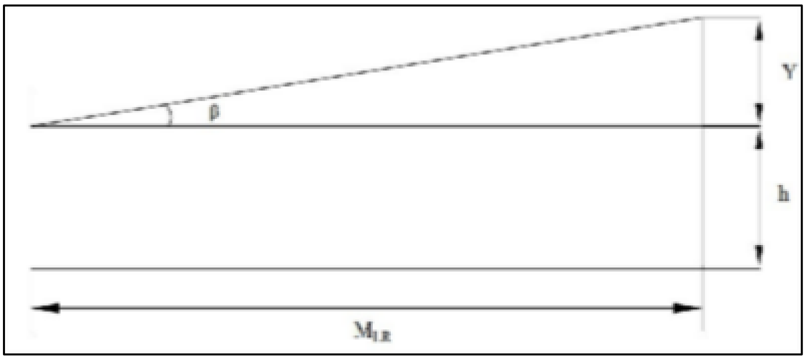


Figure 4 Headlight beam side views geometrical parameters

As shown in figure 4 normally the β is ranging from below 1 degree. To derive the Hh (Height of light range) the following calculations are made.

tanβ is given by the ratio of divergence length to the Maximum light range

In terms of fatal impact on bacteria, high intensities over a short period and low intensities over a long period are basically the same.As shown in figure 6. The inverse square law relates to germicidal UV light. As a result, as the lamp distance increases, the destructive power diminishes.[23]–[25]

tanβ y Mlr

The divergence length is given by the product of tanβ and Maximum light range

$$y = \tan\beta(Mlr) \qquad (2)$$

The height of the headlight mounted with upward divergence length is added to determine the height of the light range.

$$Hh = h + y \qquad (3)$$

From equations 2 and 3 it can be written as

$$Hh = h + (\tan\beta(Mlr)) \qquad (4)$$

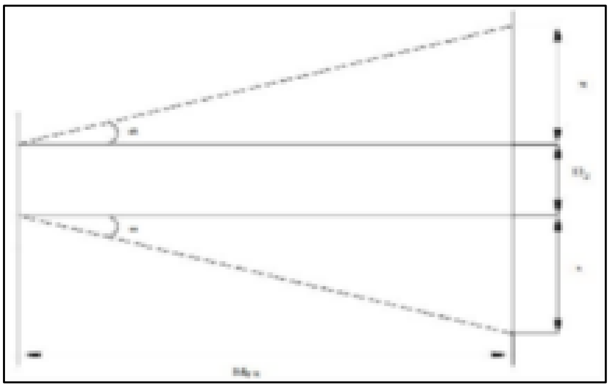


Figure 5 Headlight beam top views geometrical parameters

As shown in figure 5 normally the α ranges from (1-3) degrees. To derive the w (area of light range) the following calculations are made.

tanα is given by the ratio of horizontal spread length to the Maximum light range

$tan\ \alpha \quad \underline{x}$

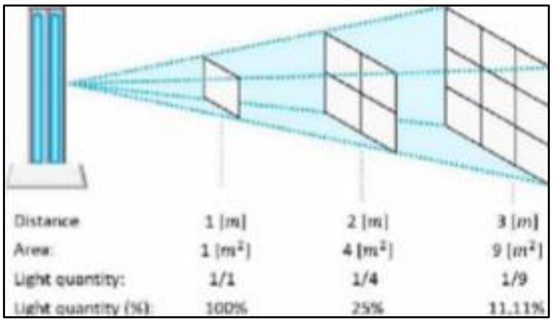


Figure 6 UV-C light propagation based on the inverse square law[25]

Viable SARS-CoV-2 was decreased by 99.7% with 222 nm UVC radiation at 3 mJ/cm2 (0.1 mW/cm2 for 30 seconds).[26]-[28] KrCl shows that even in the presence of quantitative reverse transcription polymerase chain reaction (in vitro culture medium) of SARS-CoV-2, it is not able to recover to the original number which concludes UV 222 nm is effective towards the surface decontamination process.[10], [29]–[31]

2.1. Circuit Diagram

$$\tan\alpha \quad x \ Mlr \ldots\ldots\ldots\ldots\ldots \quad (5)$$

The horizontal spread length is given by the product of tan α and Maximum light range

$$x = \tan\alpha(Mlr) \quad (6)$$

The offset distance between headlight with horizontal spread length is added to determine the width of the light range.

$$w = d_2 + (x + x)$$

$(x + x)$ can be written as 2x

$$w = d_2 + 2x \quad (7)$$

From equations 6 and 7

$$w = d2 + 2(\tan\alpha(Mlr)) \quad (8)$$

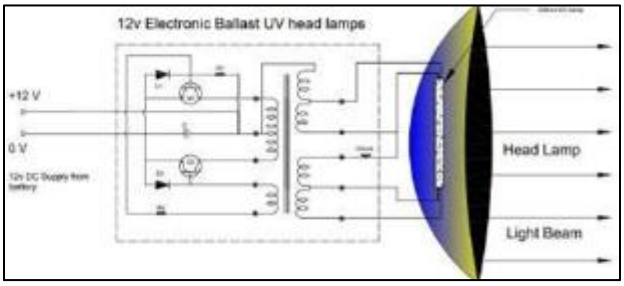


Figure 7 Circuit diagram of 12-V ballast with UV headlamps

Figure 7 illustrates the circuit diagram and connections of a 12-V electronic ballast with UV head bulbs. A self-oscillating inverter stage is created by the transistors Q1 and Q2 and the transformer T1. The main winding size, supply voltage, and core material all affect the circuit's working frequency. The inverter is configured as stated to oscillate at a frequency of around 2 kHz when the input supply is fed by a 12 V power source. The transformer's secondary side winding consists of two 4V windings for preheating the tube filaments, an 80V winding for supplying discharge current across the tube, and a 240V winding for producing an initial static voltage to kick-start the tube's conduction. To regulate the current flowing through the tube, choke L1 is observed to be linked in series with the transformer's 80

V winding. The choke L1 not only limits the tube's current but also stabilizes it to compensate for variations in the supply voltage. Choke impedance rises as the inverter frequency rises in response to an increase in input supply voltage and vice versa. In response to fluctuations in supply voltage between 10 V and 15 V, this automatically changing L1 impedance aids in maintaining lamp current steadiness.

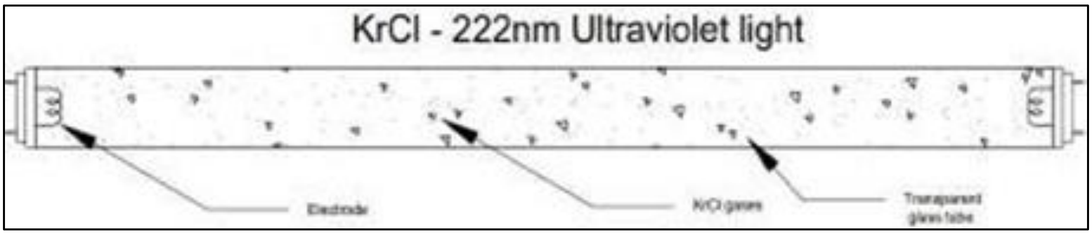


Figure 8 Structural diagram of the Krcl-222 nm UV lamp

When the vehicle's headlight switch is turned on, as shown in figure.8 a glass tube filled with inert gas, specifically KrCl, has an electrode heated by a current flowing through a significant voltage across the electrode, causing the electrons and other charged atoms to move across the tube. Some of these collisions excite the KrCl atoms and raise the electron's energy levels, and when the electrons return to their original level, the atoms are excited. Ballasts are used in lights to regulate current flow. An electromagnetic device resembling an inductor called a ballast lowers the current flow to stop KrCl lights from igniting nearby objects.[32], [33]

Krypton (Kr) and typically less than 3% chloride (Cl) gas are both filled in high-frequency discharge excimer lamps. Excimer lamps produce Kr/Cl emissions with peaks at 222 nm without using dangerous substances like mercury. In terms of the technical parameters of 222 nm Far-UVC light, it was discovered that 222 nm exclaims a very efficient system for performing far-ultraviolet c inactivation of viruses, bacteria, and pathogens. This was done using a narrow frequency band of EMR (Electro- magnetic Radiation) that was discovered to be human- safe at 222 nm wavelengths in a narrow part of the electromagnetic spectrum.[34] Through an experiment done on NCTC clone cell sheets, it was discovered that KrCl lamps of UV 222 nm are more friendly than conventional UV lights.[35] The study indicates that UV 222 nm exposure had minimal to no effect on the survival of the cells at the lower level of the sheet. This demonstrates that it can be utilized in regions where people are moving.[36]-[37]

Table 2 The inactivation rate of some airborne viral strains when exposed to the UVC 222 nm

SARS-COV-2	**1.42**	**1.52**
MHV	0.96	1.13
HCoV 229E	0.84	1.33
Phi6	0.36	0.27

The above table describes the inactivation rate of some airborne viral strains when it exposed to the UVC 222 nm light of 1.3 mJ/cm2 which is 3 cm away from virus [37] -[38]

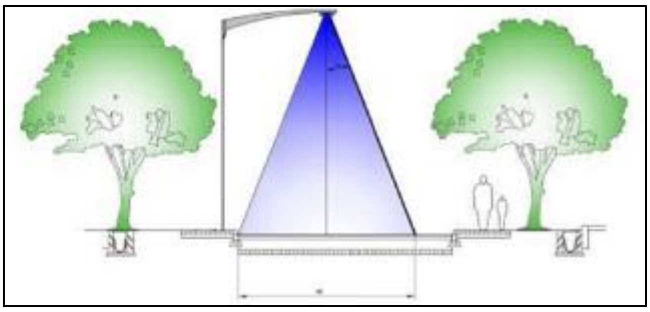
3. Street light design and installation

In order for people to use the roads safely, street lighting must be designed accordingly.[42] Although street lighting schemes can never replicate the appearance of sunshine, they can offer enough light for commuters to view crucial objects needed for navigating the roads. Utilizing ultraviolet C (UV- C) germicidal radiation for street lights, the unit may quickly and effectively deactivate the DNA of bacteria and viruses, stopping them from reproducing and causing disease. Time of exposure and UV-C radiance are the two elements that directly impact the efficiency of UV-C disinfection (intensity).[39] A nationally renowned laboratory that specializes in antibacterial, biocidal, and veridical effectiveness conducted tests on the device and found that five minutes of exposure to UV-C light eliminated >99.99% of common viruses and bacteria.[40]-[41]

KrCl 222 nm can produce ozone in the air under specific designing fixtures, But low-power 222 nm lamps (less than 15 W) do not generate a significant amount of ozone, Hence they can be applied in daily life without any hazardous damage to health.

4. Street Light geometrical parameters.

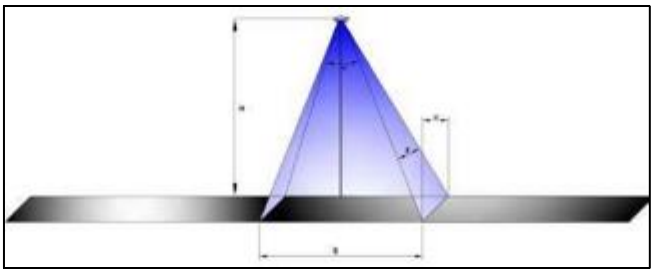
4.1. Side View



4.2. Isometric View

Viral Strains	Inactivation rate Filtered UVC 222 nm in cm2/mJ	Inactivation rate Unfiltered UVC 222 nm in cm2/mJ

4.3. Top View



- H - Height of the street light from the light source to the road surface.
- Ø - Luminous flux(measured in lumens).
- Q - Quantity of light emitted by the light source. t - Periodic time.
- E - illumination or lux. A - area (w x s).
- N - number of luminaries.
- LLF - light loss factor or maintenance factor.
- UF - utilization factor is the ratio of the utilized lumen to the installed lumen.
- Θ - is the angle between the incident angle at the road surface to the specific point.

The primary term for street lights is the intensity of the light source. The intensity distribution of the street light luminaire is measured using a mirror goniophotometer and as a result, the amount of light emitted by a light source over a period of time is known as the luminous flux is given by,

Ø = Q (13)

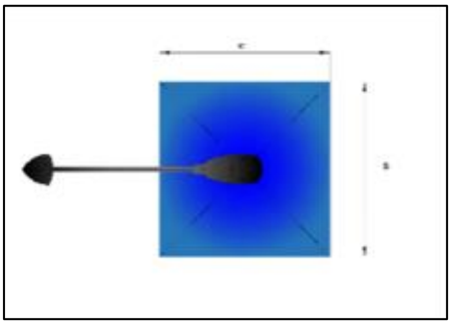


Figure 9 (a) (b) (c) Street Light geometrical parameters

The illumination or lux, which is determined by the number of lumens falling on the surface per unit square area, is given by

Figure 8(a) shows the Street light's side view and its E Ø

(14)

geometrical parameters whereas Figure 8(b) illustrates the isometric view of the Street light and Figure 8(c) represents the top view of the Street light radiation pattern. Before proclaiming a region to be virally and

And at a specific point the Lux is given by, E = I × coscos ϴ3

H2

(15)

Again, the lumen technique's illumination is given by bacterially sterile, it is crucial to take the following factors into account:

E N×Ø×LLF×UF

A

(16)

β - The spread angle of a luminaire which determines how it will direct light flux across a roadway

α - Throw angle is the angle at which the luminaire directs the flow of light toward the road.

S - length of the light range towards the road. w - width of light range across the road.

The aforementioned equation demonstrates that lighting is inversely proportional to the area that is illuminated. [42] To effectively eliminate viruses and bacteria, the intensity of UV-C radiation should also be raised as the height or distance is increased. [43]-[44]

Table 3 Comparison between different types of streetlights and UV-222nm street light

Feature	**UV-222nm Street Light**	**High Pressure Sodium (HPS)**	**Light Emitting Diode (LED)**	**Metal Halide (MH)**
Wavelength	Uses UV-C light with a wavelength of 222nm [45]	Emits yellow-orange light with wavelengths between 580-620nm [46]	Emits white light with a range of wavelengths [47]	Emits blue-white light with a range of wavelengths [48]
Illumination	UV-C light with a wavelength of 222nm cannot penetrate the atmosphere and reflect off of objects to produce visible light, so not effective at illuminating the road ahead	Effective at illuminating the road ahead	Effective at illuminating the road ahead	Effective at illuminating the road ahead
Microbial inactivation	UV-C light with a wavelength of 222nm has been shown to effectively inactivate bacteria and viruses [49]	No microbial inactivation	No microbial inactivation	No microbial inactivation

Human safety	UV-C light with a wavelength of 222nm is harmful to human skin and eyes and can cause damage with prolonged exposure or at high intensities, proper safety measures must be taken to avoid potential harm [50]	Generally safe for human eyes and skin	Generally safe for human eyes and skin	Generally safe for human eyes and skin
nergy consumption	UV-C light with a wavelength of 222nm may require higher energy consumption due to the specialized UV-C light source needed [51]	Lower energy consumption compared to UV-222nm street light	Lower energy consumption compared to UV- 222nm street light	Higher energy consumption compared to LED or HPS
Cost	UV-C light with a wavelength of 222nm may require a specialized light source and may be more expensive than other streetlights [52]	Lower cost compared to UV-222nm street light	Higher cost compared to HPS, but lower cost compared to UV- 222nm street light	igher cost compared to HPS or LED
Maintenance	UV-C light with a wavelength of 222nm may require additional maintenance and replacement of the specialized light source [53]	Standard maintenance for HPS and LED	Standard maintenance for HPS and LED	Standard maintenance for MH

It is important to note that while UV-222nm street light may be effective at inactivating bacteria and viruses, it is not a replacement for proper cleaning and disinfection practices. Additionally, proper safety measures and precautions must be taken to avoid potential harm to human eyes and skin from UV-C light. Each type of streetlight has its advantages and disadvantages, and the choice of which to use will depend on the specific needs and circumstances of the area being illuminated.

5. Conclusion

In this study, 222-nm UVC headlight irradiation was shown to be effective against SARS-CoV-2 contamination. As far as intensity and power consumption are concerned, UV-222 nm headlights are similar to standard headlights. In addition, UV-222nm lighting contributes significantly to the sterilization of viruses and germs while driving at night without affecting the human skin or eyes negatively. It will also be safer if you travel at night through infested areas. In addition to being used in vehicles, this technology is also capable of preventing and controlling COVID-19 infection. Irradiation with 222-nm UVC headlamps may have a positive effect on reducing contamination of real-world surfaces and the transmission of the SARS-CoV-2 virus, but further studies are needed to evaluate its safety and efficacy.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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