GLOBAL LIGHTING ASSOCIATION

## Position Statement on UV Germicidal Irradiation

# GUIDELINES FOR QUANTIFICATION OF AIRBORNE PATHOGEN INACTIVATION BY UVGI TECHNOLOGIES

**April 2023**

# FOREWORD

### *About the Global Lighting Association*

The Global Lighting Association (GLA) is the voice of the lighting industry. GLA shares information on political, scientific, social and environmental issues of relevance to the lighting industry and advocates the position of the global lighting industry to relevant stakeholders in the international sphere. See www.globallightingassociation.org.

### *UV-C and urgent need for quantification guidelines*

Ultraviolet germicidal irradiation (UVGI) air disinfection technology is an established method to reduce infection risks caused by a wide range of contagious airborne diseases. However it does raise the following questions: 1. Does it work? and 2. Is it safe?

The Global Lighting Association answered the safety question with its 2020 publication *UV-C Safety Guidelines* (reproduced by the International Electrotechnical Commission in *IEC PAS 63313*), which concludes that the technology is safe if installed correctly, and the first question is answered by GLA in its 2022 *Guidelines for Quantification of Airborne Pathogen Inactivation by UVGI Technologies*.

Given the rapid developments and new insights, GLA has reconvened the same technical task force to update its 2022 *Guidelines for Quantification of Airborne Pathogen Inactivation by UVGI Technologies* resulting in this April 2023 edition.

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# 1. INTRODUCTION

Pathogens spread by touch (direct person-to-person or indirect via surface transfer), spray (ballistic droplets) and inhalation of airborne aerosols are exacerbating diseases such as SARS-CoV-2. The spread of pathogens by touch and the transmission of droplets can be reduced by surface cleaning including washing hands, use of personal protective equipment (PPE) such as face masks and appropriate behaviours such as social distancing. The spread and inhalation of pathogens by aerosols can be reduced by use of medical PPE and/or air cleaning. Air cleaning can be achieved by air replacement utilising ventilation (either natural and/or mechanical) and/or air disinfection technologies such as Ultraviolet Germicidal Irradiation (UVGI) and ionisation.

UVGI air disinfection technology is an established method to reduce infection risks caused by a wide range of highly contagious airborne diseases. During the last 80 years, the capability of UVGI technology to inactivate pathogens responsible for airborne diseases such as measles, influenza and tuberculosis has been proven over and over again, as shown in studies by Wells [1] and McLean [2] which identified 74% and 90% transmission reduction in these diseases respectively. It follows that UVGI technology is also one of the key tools to reduce the level of indoor air contamination [3] and thereby contribute to improving human health in general, including during and beyond the current COVID-19 pandemic. The corresponding fundamental pathogen inactivation theory and mathematical modelling are well established and described in existing UVGI documentation.

Section 2 describes the scope of this guidance document and Section 3 illustrates the UVGI working principles of the products in scope. In Section 4, the Global Lighting Association endorses the standardisation of a microbial clean air delivery rate which can be determined in a defined test chamber, and which is an unambiguous UVGI product specification. In Section 5 it is explained how these UVGI product specifications can be used to quantify the microbial cleaning capabilities of the UVGI products in a real application/room.

The Global Lighting Association recommends this document for use as reference material by international standards development organisations such the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO).

## 2. SCOPE OF THIS GUIDANCE DOCUMENT

This document describes quantification of the active airborne pathogen inactivation capabilities of UVGI technologies with wavelengths in the UV-C range of 200 nm to 280 nm. It does this at product and application level.

This document is applicable to:
- UVGI air cleaners
- UVGI luminaires

See Section 3 for illustrative examples.

This document is not applicable to:
- UV-A, UV-B and 405 nm technologies
- UVGI lamps, UVGI light-sources and UVGI control-gear
- Water disinfection and surface disinfection technologies
- UVGI devices which will be mounted inside heating, ventilating and air-conditioning (HVAC) ducts since these devices are already standardised in ISO 15714 (Method of evaluating the UV dose to airborne microorganisms transiting in-duct ultraviolet germicidal irradiation devices).
- UVGI devices combining UVGI with microbiological filters (e.g. HEPA[1] filters), chemicals and/or additives.
- Ionisation air cleaning technologies
- UVGI devices intended for use in medical treatment locations such as surgical suites, laboratories and medical treatment rooms

The document does not describe UVGI safety requirements since they appear in existing international standards IEC 62471:2006 (Photobiological safety of lamps and lamp systems), IEC PAS 63313:2021 (Position statement on germicidal UV-C irradiation - UV-C safety guidelines), ISO 15858 (UV-C Devices - Safety information - Permissible human exposure), IEC 60335-2-65 (for closed UVGI technologies) and IEC 63086-1:2020 (Household and similar electrical air cleaning appliances - Methods for measuring the performance - Part 1: General requirements).

[1] High Efficiency Particulate Air

# 3. EXAMPLES OF UVGI OPERATING PRINCIPLES

This Section illustrates examples where no disinfection measures are taken (§3.1) and the operating principles of UVGI air cleaners (§3.2) and UVGI luminaires (§3.3)

## *3.1 No disinfection measures*

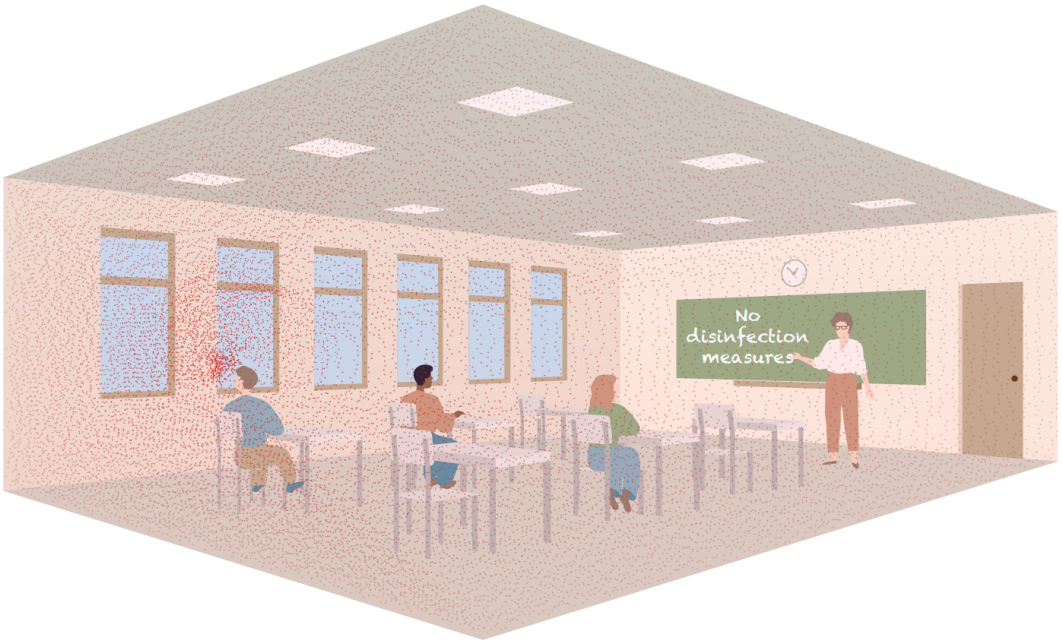


Figure 1: Illustrative example where no disinfection measures are taken

## *3.2 UVGI air cleaners*

Figure 2: Illustrative example of UVGI air cleaner application, combined with natural ventilation

### *3.3 UVGI luminaires*

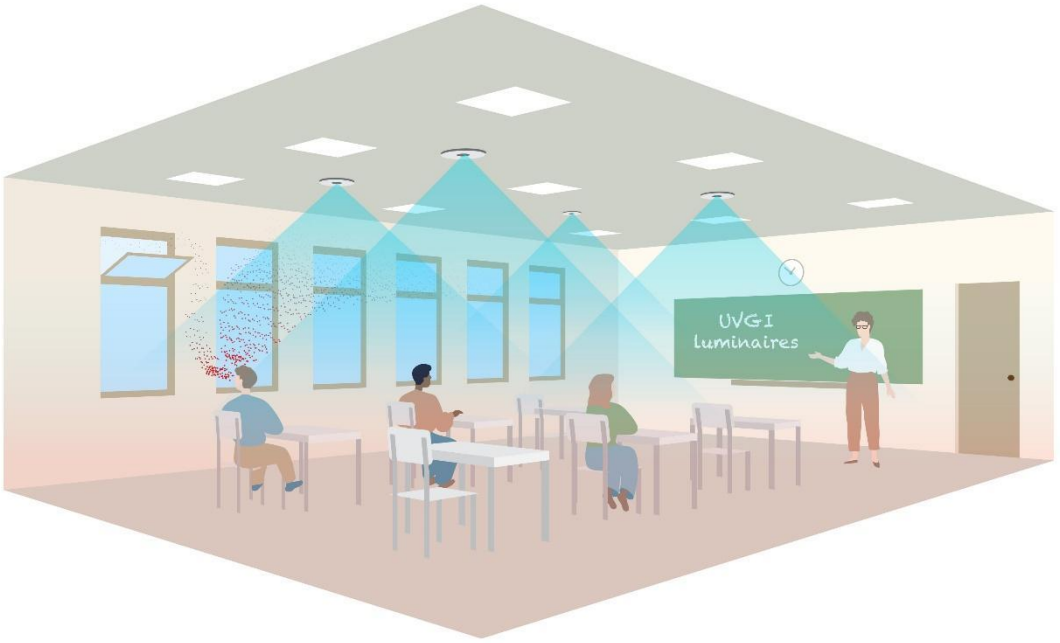


Figure 3: Illustrative example of a UVGI luminaire application, combined with natural ventilation

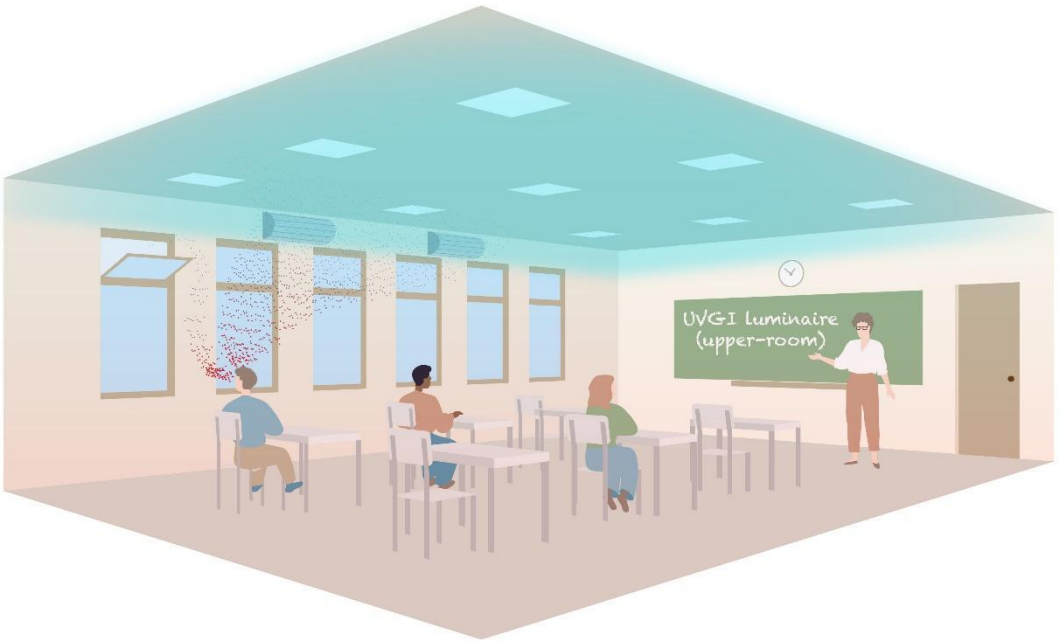


Figure 4: Illustrative example of UVGI upper-room luminaire application, combined with natural ventilation

# 4. QUANTIFICATION OF MICROBIAL CLEANING CAPABILITIES OF UVGI PRODUCTS IN A TEST CHAMBER

In the 1980s, the Association of Home Appliance Manufacturers (AHAM) published the ANSI/AHAM AC-1 standard which defines the Clean Air Delivery Rate (CADR) metric and a test method to quantify the reduction rate of airborne particles (smoke, dust, pollen etc) by portable air cleaners in a test chamber.

In 2022, AHAM published the ANSI/AHAM AC-5 standard in addition to ANSI/AHAM AC-1. The ANSI/AHAM AC-5 standard defines the microbial Clean Air Delivery Rate (*mCADR*) metric and a test method to quantify the reduction rate of key bioaerosols by portable air cleaners using an aerobiology test chamber.

GLA encourages the use of AHAM AC-5 for the quantification of the reduction rate of key bioaerosols by portable air cleaners.

Note 1: The ANSI/AHAM AC-5 standard will also be published as IEC PAS 63086-2-3 ED1 standard.

GLA also encourages standards development organisations to develop a standard using a similar test method to AHAM AC-5 and an equivalent microbial Clean Air Delivery Rate (*eqmCADR*) metric for the quantification of the reduction rate of key bioaerosols by UVGI luminaires. Further guidance for this standardisation work is provided in Annex A.

# 5. QUANTIFICATION OF MICROBIAL CLEANING CAPABILITIES OF UVGI PRODUCTS IN A REAL APPLICATION

Quantification of the microbial cleaning capabilities of UVGI products in a real application such as a room can be determined by scaling-up the test chamber results of Section 4 to the volume and target pathogen of the room.

Section 5.1 below lists the various reduction mechanisms for active airborne pathogens in a room, including their quantification by a decay rate. Recommended ventilation rates for different applications are given in 5.2. Determination of the number of UVGI air cleaners required to meet the recommended UVGI equivalent ventilation rate in a room is given in 5.3. Determination of the number of UVGI luminaires required to meet the recommended UVGI equivalent ventilation rate in a room is given in 5.4.

## *5.1 Reduction mechanism for active airborne pathogens in a room and their generic quantification*

Reduction of active airborne pathogens in a room can be achieved by:

- Dilution of the active airborne pathogens by conventional (natural and/or mechanical) fresh-air ventilation, quantified by a decay rate called the ventilation rate, with the unit $ACH_{fresh\text{-}air}$
- Natural decay of the active airborne pathogens, quantified by a decay rate called the natural-decay rate, with the unit $ACH_{natural\text{-}decay}$
- Inactivation of the active airborne pathogens by engineering methods such as UVGI, quantified by a decay rate called the equivalent ventilation rate, with the unit $eqACH_{UVGI}$ [2]
- A combination of the above, quantified by the total ventilation rate, with the unit $ACH_{tot}$.

Note: In general [4], the overall ventilation rate ($ACH_{tot}$) is the sum of the ventilation rate ($ACH_{fresh\text{-}air}$), the natural-decay rate ($ACH_{natural\text{-}decay}$) and the equivalent ventilation rate of the UVGI technology ($eqACH_{UVGI}$).

In general, the reduction is expressed in a decay rate with the unit Air Changes per Hour (ACH) in $h^{-1}$. The relationship is given in Equation 1.

$$Decay\ Rate = \frac{-\ln\left(\frac{N_t}{N_0}\right)}{t} \qquad \text{(Equation 1)}$$

Where:

$N_t$ is the number of active airborne pathogens after $t$ minutes
$N_0$ is the initial number of active airborne pathogens at $t$ = 0 minutes
$t$ is time in minutes

Note 1: A decay rate of 1 *ACH* equals a 63.2% airborne pathogen reduction in one hour (source: Wikipedia).

Note 2: The above formulas assume that no further pathogen generation source is present in the room.

Note 3: The exponential decay of a microbial population in response to UV can be subject to a slight delay, also known as 'shoulder effect'. In many cases it can be neglected, especially for susceptible microbes or for high UV doses.

[2] In the technical literature, equivalent air changes per hour is variously abbreviated as *eACH, ACHeq* or *EAC*.

The relation and inverse relation between the reduction levels and reduction times on the one hand, and the decay rates (*ACH*) on the other, are given in Table 1 and Table 2 respectively.

| Decay rate (*ACH) in $h^{-1}$* | | | |
|---|---|---|---|
| Reduction time [min] | Reduction level | | |
| | 90% (Log 1) | 99% (Log 2) | 99.9% (Log 3) |
| 10 | 13.8 | 27.6 | 41.4 |
| 20 | 6.9 | 13.8 | 20.7 |
| 30 | 4.6 | 9.2 | 13.8 |
| 40 | 3.5 | 6.9 | 10.4 |
| 50 | 2.8 | 5.5 | 8.3 |
| 60 | 2.3 | 4.6 | 6.9 |

Table 1: Relation between reduction levels and reduction times, and the decay rates

Note: A log reduction is a measure of how thoroughly a decontamination process reduces the concentration of a contaminant. It is defined as the common logarithm of the ratio of the levels of contamination before and after the process, so an increment of 1 corresponds to a reduction in concentration by a factor of 10. So for example, a 0-log reduction is no reduction at all, while a 1-log reduction corresponds to a reduction of 90 percent from the original concentration, and a 2-log reduction corresponds to a reduction of 99 percent from the original concentration (source: Wikipedia).

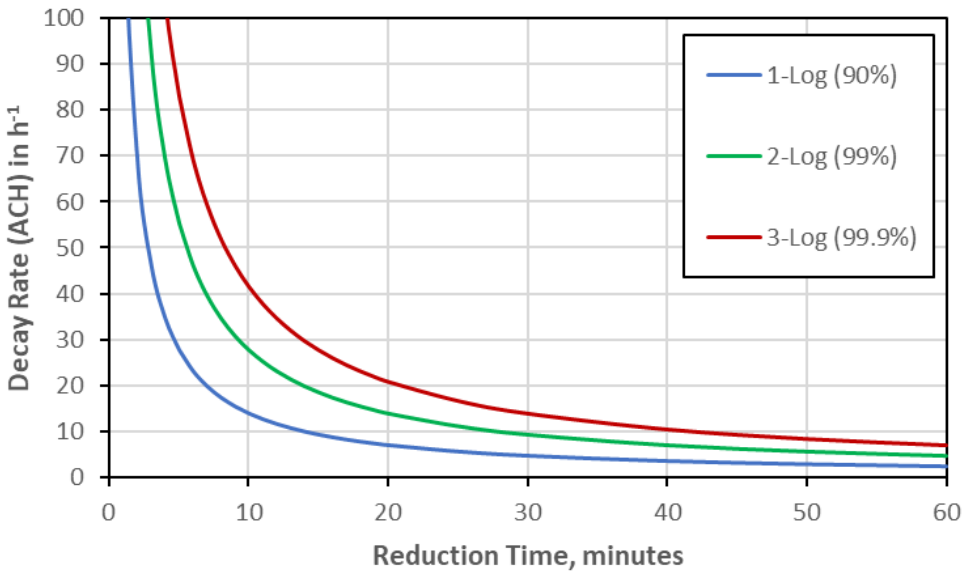


Figure 5: Relation between reduction levels and reduction time, and the decay rates

| Reduction time [min] | | | |
|---|---|---|---|
| Decay rate (ACH) | Reduction level | | |
| | 90% (Log 1) | 99% (Log 2) | 99.9% (Log 3) |
| 1 | 138 | 277 | 415 |
| 2 | 69 | 138 | 207 |
| 3 | 46 | 92 | 138 |
| 4 | 35 | 69 | 104 |
| 5 | 28 | 55 | 83 |
| 6 | 23 | 46 | 69 |
| 7 | 20 | 40 | 59 |
| 8 | 17 | 35 | 52 |
| 9 | 15 | 31 | 46 |
| 10 | 14 | 28 | 41 |
| 11 | 13 | 25 | 38 |
| 12 | 12 | 23 | 35 |
| 13 | 11 | 21 | 32 |
| 14 | 10 | 20 | 30 |
| 15 | 9 | 18 | 28 |
| 16 | 9 | 17 | 26 |
| 17 | 8 | 16 | 24 |
| 18 | 8 | 15 | 23 |
| 19 | 7 | 15 | 22 |
| 20 | 7 | 14 | 21 |
| 25 | 6 | 11 | 17 |
| 30 | 5 | 9 | 14 |
| 35 | 4 | 8 | 12 |
| 40 | 3 | 7 | 10 |
| 45 | 3 | 6 | 9 |
| 50 | 3 | 6 | 8 |

Table 2: Relation between decay rates and reduction levels and reduction times

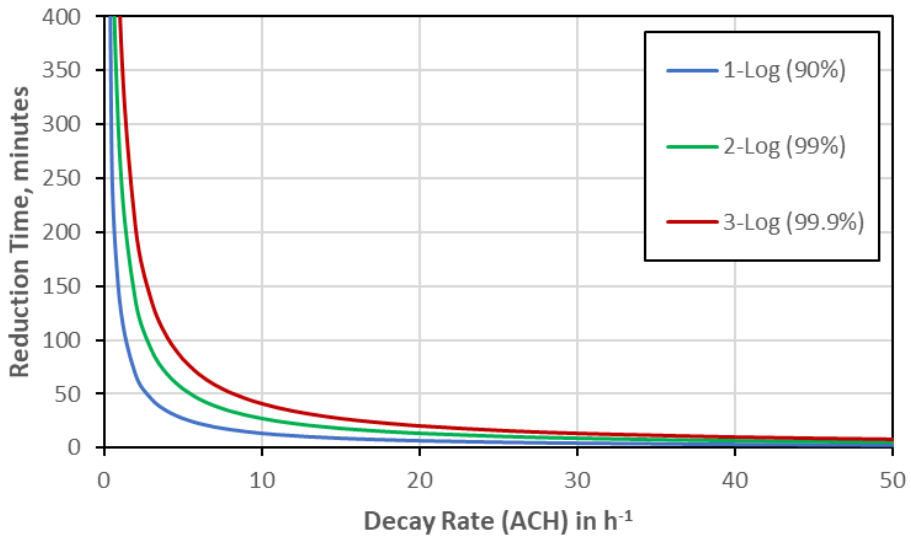


Figure 6: between rates and reduction and reduction

decay

levels

times

### 5.2 Recommended ventilation rates

The recommended total ventilation rate in a room ($ACH_{tot,\ required}$) varies according to application and depends on the required reduction level and reduction time for the airborne pathogens.

To reduce the contamination risk of viral infections like influenza, tuberculosis and SARS-CoV-2 in buildings, GLA recommends the decay rates in Table 3 during a viral outbreak. These recommendations are based on references [5, 6].

| Application | Recommended total ventilation rate ($ACH_{tot,\ required}$) | Recommended fresh-air ventilation rate ($ACH_{fresh\text{-}air}$) | Natural-decay rate ($ACH_{natural\text{-}decay}$) | Required UVGI equivalent ventilation rate ($eqACH_{UVGI}$) |
|---|---|---|---|---|
| Health-care facilities (such as hospitals, elderly care) | ≥ 15 | 3 | 0 | ≥ 12 |
| Buildings inhabited by many people for extended periods (such as offices, shops, schools) | ≥ 10 | 3 | 0 | ≥ 7 |
| Other buildings | ≥ 6 | 2 | 0 | ≥ 4 |

Table 3: Recommended decay rates per application

Note 1: Above recommendations apply to the applicable areas/rooms in the building

Note 2: Above fresh-air ventilation rates are always recommended since fresh-air ventilation serves multiple purposes other than dilution of airborne pathogens, including removal of harmful gases and vapours such as $CO_2$ and VOCs, control of humidity levels (including condensation prevention) and reduction of undesirable odours.

Note 3: Key parameters driving the natural decay rate are ambient temperature, relative humidity and ambient UV-index. In the technical literature, natural decay rates reported for SARS-CoV-2, at UV-index 0, typically range from 0.2 to 2 $ACH_{natural\text{-}decay}$. However by setting the natural decay rate to zero, a worst-case situation is emulated.

### 5.3 UVGI air cleaner - relationship between required UVGI equivalent ventilation rate and mCADR

As a first order approach, the number of UVGI air cleaners needed to achieve the required UVGI equivalent ventilation rate in Section 5.2 in an arbitrary room with volume V depends on the *mCADR* of the UVGI air cleaner and can be determined with Equation 2.

$$\#\ of\ UVGI\ air\ cleaners\ =\ \frac{eqACH_{\ UVGI}\cdot V}{mCADR}. \qquad \text{(Equation 2)}$$

where:

| | |
|---|---|
| *# of UVGI air cleaners* | is number of UVGI air cleaners needed to achieve the required UVGI equivalent ventilation rate in the room |
| $eqACH_{UVGI}$ | is required UVGI equivalent ventilation rate (Section 5.2) in $h^{-1}$ |
| *V* | is volume of the room in $m^3$ |
| *mCADR* | is microbial Clean Air Delivery Rate of the UVGI air cleaner as determined in Section 4 in $m^3/h$ |

Note: Equation 2 does not consider application details, including objects within the space and non-uniform placement of air cleaners.

### *5.4 UVGI luminaire - relationship between required UVGI equivalent ventilation rate and eqmCADR*

As a first order approach, the number of UVGI luminaires needed to achieve the required UVGI equivalent ventilation rate in Section 5.2 in an arbitrary room with volume V and a certain target pathogen depends on the *eqmCADR* of the UVGI luminaire and can be determined by Equation 3.

$$\#\ of\ UVGI\ luminaires = \frac{eqACH_{UVGI} \cdot V}{eqmCADR} \cdot \frac{k(\lambda)_{test-pathogen}}{k(\lambda)_{target\ pathogen}} \qquad \text{(Equation 3)}$$

where:

| | |
|---|---|
| *# of UVGI luminaires* | is number of UVGI luminaires needed to achieve the required UVGI equivalent ventilation rate in the room |
| $eqACH_{UVGI}$ | is required UVGI equivalent ventilation rate (Section 5.2) in $h^{-1}$ |
| *V* | is volume of the room in $m^3$ |
| *eqmCADR* | is the equivalent microbial Clean Air Deliver Rate of the UVGI luminaire as determined in Section 4 in $m^3/h$ |
| *k(λ)* | is spectral susceptibility factor of airborne pathogens ($m^2/J$) as given in Table 4 |

Note: Equation 3 does not consider application details including room/surface reflection, objects within the space and non-uniform placement of luminaires.

The classification and spectral susceptibility factors, *k(λ)*, of some actual airborne pathogens at a relative humidity (*RH*) below 68% are listed in Table 4.

| UVGI Peak wavelength *λ* in nm | Airborne pathogen | Classification | *k(λ)* in $m^2/J$ | Source |
|---|---|---|---|---|
| 254 | Coliphage PhiX-174 | Non-enveloped DNA virus | 0.620 | [7] |
| | Phi6 | Enveloped dsRNA virus | 0.31 - 0.43 | [8] |
| | MS-2 | Non-enveloped RNA virus | 0.380 | [7] |
| | Corona-type (MHV) | Enveloped RNA virus | 0.377 | [9] |
| | Corona-type (HCoV-229E) | Enveloped RNA virus | | |
| | Corona-type (OC43) | Enveloped RNA virus | | |
| | Corona-type (SARS-CoV-2) | Enveloped RNA virus | | |
| | Influenza A (H1N1) | Enveloped RNA virus | 0.119 | [8] |
| | Tuberculosis (TBC) | Bacteria | 0.472 | [7] |
| 222 | Coliphage PhiX-174 | Non-enveloped DNA virus | | |
| | Phi6 | Enveloped dsRNA virus | | |
| | MS-2 | Non-enveloped DNA virus | | |
| | Corona-type (MHV) | Enveloped RNA virus | | |
| | Corona-type (HCoV-229E) | Enveloped RNA virus | 0.410 | [10] |
| | Corona-type (OC43) | Enveloped RNA virus | 0.590 | |
| | Corona-type (SARS-CoV-2) | Enveloped RNA virus | | |
| | Influenza A (H1N1) | Enveloped RNA virus | 0.180 | [10] |
| | Tuberculosis (TBC) | Bacteria | | |

Table 4: Classification and spectral susceptibility factors, *k(λ)*, of some actual airborne pathogens

Note 1: More spectral susceptibility factors are given by ISO 15714 [7] and Kowalski [8]

Note 2: Spectral susceptibility factors at a relative humidity above 68% are given by Kowalski [8]

Note 3: Missing spectral susceptibility factors, *k(λ)*, in Table 4 are a subject for research

# 6. TERMS AND DEFINITIONS

**Ultraviolet germicidal irradiation (UVGI)**

Method for disinfection of air, water and object surfaces that uses radiation with a wavelength in the range 200 nm to 280 nm to kill or inactivate microorganisms and viruses

Note: UV irradiation with a wavelength of 200 nm to 280 nm can cause damage to the DNA or RNA of the microorganisms or viruses.

[Source: ISO 15714:2019, 3.1.5 modified by lowering 240 nm to 200 nm and extended to viruses]

**UVGI air cleaner**

Electrically powered household, or similar, appliance that employs UVGI technologies to inactivate one or more types of airborne pathogens using a forced air flow through a closed UVGI compartment.

[Source: IEC 63086-1 modified]

**UVGI luminaire**

Apparatus which distributes, filters or transforms UVGI from at least one UVGI radiation source to the external environment of the apparatus, and which includes all parts necessary for fixing and protecting the UVGI source and, where necessary, circuit auxiliaries together with the means for connecting them to the power supply.

[Source: IEC 60050-845; 845-30-001: 2020 modified]

**UVGI upper-air luminaire**

UVGI luminaire mounted underneath room ceilings with UVGI directed to the upper part of the room with adjustable louvers to keep UVGI above eye and head level.

[Source: ISO 15858: 2016 modified]

**UVGI radiation source**

Apparatus or a material emitting or capable of emitting UV germicidal radiation.

Note to entry: A UVGI radiation source can be a UVGI lamp, or UVGI LED module designed to be connected by terminals, connectors or similar devices.

[Source: IEC 60050-881; 881-03-01: 2020 modified]

**Microbiological filters**

Microbiological filters are considered to be filters that are capable of separating micro-organisms from the fluid being treated (e.g. HEPA filters).

## 7. REFERENCES

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[2] McLean, R.L., “The effect of ultraviolet radiation upon the transmission of epidemic influenza in long-term hospital patients”, American Review of Respiratory Diseases 83(2): 36–8, 1961

[3] Anca Maria Moldoveanu, “Biological Contamination of Air in Indoor Spaces”, Current Air Quality Issues, IntechOpen, DOI: 10.5772/59727, 2015

[4] Shelly Miller, “EFFICACY OF ULTRAVIOLET IRRADIATION IN CONTROLLING THE SPREAD OF TUBERCULOSIS”, CDC/NIOSH report 2002

[5] IES-CR-2-20-V1, “IES Committee Report: Germicidal Ultraviolet (GUV) – Frequently Asked Questions”

[6] Centers for Disease Control and Prevention (CDC), ‘‘Appendix B. Air – Guidelines for Environmental Infection Control in Health-Care Facilities’’, 2003. Available at https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html

[7] ISO 15714, “Method of evaluating the UV dose to airborne microorganisms transiting in-duct ultraviolet germicidal irradiation devices”

[8] W. Kowalski, “Ultraviolet Germicidal Irradiation Handbook – UVGI for Air and Surface Disinfection”, ISBN 978-3-642-01998-2, e-ISBN 978-3-642-01999-9, DOI 10.1007/978-3-642-01999-9, Springer Heidelberg Dordrecht London New York

[9] Christopher M. Walker and Gwangpyo Ko, “Effect of Ultraviolet Germicidal Irradiation on Viral Aerosols”, ENVIRONMENTAL SCIENCE & TECHNOLOGY / VOL. 41, NO. 15, 2007

[10] Manuela Buonanno, David Welch, Igor Shuryak & David J. Brenner, “Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses”, Scientific Reports | (2020) 10:10285 | https://doi.org/10.1038/s41598-020-67211-2

# ANNEX

## Determination of the *eqmCADR* of an UVGI luminaire

As stated in Section 4, the Global Lighting Association encourages standards development organisations (SDOs) to develop a standard using a similar test method to AHAM AC-5 and an equivalent microbial Clean Air Delivery Rate (*eqmCADR*) metric for the quantification of the reduction rate of key bioaerosols by UVGI luminaires.

This informative Annex provides the basic principle and steps for the *eqmCADR* determination. The measurement details must be worked out by the responsible SDOs. GLA anticipates that SDOs may improve the steps outlined in this informative annex and welcomes enhancements in test efficiency, accuracy, repeatability and reproducibility.

**Basic Principle**

The *eqmCADR* of a UVGI luminaire is determined by a test using nebulised and homogeneously distributed active (or surrogate) airborne test pathogens inside an enclosed aerobiology test chamber with a volume of at least 20 $m^3$ at controlled air temperature and relative air humidity. The *eqmCADR* is calculated by the reduction rate of the airborne test pathogen in a defined period of time, considering the natural decay rate of the airborne test pathogen and the volume of the test chamber.

Note 1: An air stirring fan in the enclosed test room is required to maintain a homogeneous distribution of the airborne pathogens in the test room during the test.

Note 2: GLA recommends the use of an active Coliphage PhiX-174, Phi6, or MS2 surrogate pathogen since they are fully benign bacteriophage viruses that are well studied, easily accessible and commonly used in microbial labs worldwide [7, 9, 10, 11, 12 and 15]

**Step 1: Pathogen selection and test setup**

1.1 Select target pathogen, or a surrogate pathogen with comparable UVGI susceptibility to the target pathogen.
1.2 If applicable, apply burn-in time of the UVGI luminaire as prescribed by the manufacturer.
1.3 Select an enclosed test chamber with:
- defined volume of test room
- defined UV-C reflectance (%) of walls, floor and ceiling
- controlled air temperature
- controlled relative air humidity.

1.4 Install the UVGI luminaire in the selected enclosed test chamber following manufacturer's installation instructions and approximate the intended application.

**Step 2: Determine natural decay rate without operating the UVGI luminaire**

2.1 Close the test-chamber and control and record air temperature and relative humidity inside the test-chamber.
2.2 Nebulise the test-chamber with a quantified initial concentration colony forming units (CFU), $N_0$ (CFU/$m^3$), of the selected pathogen using a calibrated nebuliser.
2.3 Determine the measurement time ($t$) to assure a good natural decay value.

Note: The standard should include methodology for determining measurement times that assure good natural decay value - for example, with specific standard times and/or a standardised approach for determining test-specific times.

2.4 Activate the test-chamber's stirring fan to assure a homogeneous pathogen concentration in the test chamber

Note: To achieve an initial homogenous mixing of the pathogen in the test chamber, a period of mixing before step 2.5 is required. Any additional mixing throughout the test should be carefully specified by the SDO to ensure consistent and unbiased results.

2.5 Take a sample at measurement time t.

Note: The standard should standardise the sampling method (quantity of samples, duration etc.) in a manner that best represents conditions throughout the chamber and be repeatable and reproduceable.

2.6 Determine the concentration CFU of the pathogen, $N_t$ (CFU/$m^3$), at time t.

2.7 Calculate the natural decay rate with Equation 4.

$$ACH_{natural\ decay} = (60/t)(\ln N_0/N_t) \qquad (4)$$

where:

*t* is measurement time at time point t in minutes

$N_t$ is CFU concentration of the pathogen at time point t, in CFU/m3

$N_0$ is initial CFU concentration of the pathogen, in CFU/$m^3$

2.8 Deactivate the chamber's stirring fan.

2.9 Ventilate/disinfect the test-chamber.

**Step 3: Determine decay rate of the pathogen when UVGI luminaire is operating**

3.1 Activate the UVGI luminaire and, if applicable, apply the stabilisation time of the UVGI luminaire as prescribed by the manufacturer, and nebulise the test-chamber with a quantified initial concentration CFU, $N_0$ (cfu/$m^3$), of the selected pathogen using a calibrated nebuliser.

3.2 Determine the measurement time (*t*) to assure a good natural decay value.

Note: The standard should include methodology for determining measurement times that assure good natural decay value - for example, with specific standard times and/or a standardised approach for determining test-specific times.

3.3 Activate the test-chamber's stirring fan to assure a homogeneous pathogen concentration in the test chamber

Note: To achieve an initial homogenous mixing of the pathogen in the test chamber, a period of mixing before step 3.5 is required. Any additional mixing throughout the test should be carefully specified by the SDO to ensure consistent and unbiased results.

3.4 Take a sample at measurement time *t*.

Note: The standard should standardise the sampling method (quantity of samples, duration, etc.) in a manner that best represents conditions throughout the chamber and be repeatable and reproduceable.

3.5 Determine concentration CFU of the pathogen, Nt (CFU/m3), at time t.

3.6 Calculate total decay rate, $eqACH_{total}$, with Equation 5.

$$eqACH_{total} = (60/t)(\ln N_0/N_t) \qquad (5)$$

where:

*t* is measurement time at time point t in minutes

$N_t$ is CFU concentration of the pathogen at time point *t,* in CFU/$m^3$

$N_0$ is initial CFU concentration of the pathogen, in CFU/$m^3$

3.7 Deactivate UVGI luminaire and the chamber's stirring fan.

3.8 Ventilate/disinfect test-chamber and open it.

**Step 4: Calculate the *eqmCADR* value**

4.1 Calculate UVGI decay rate, $eqACH_{UVGI}$, according to:

$$eqACH_{UVGI} = ACH_{total} - ACH_{natural\ decay}$$

4.2 Calculate equivalent microbial Clean Air Delivery Rate according to:

$$eqmCADR = eqACH_{UVGI} \times V_{test}$$

**Step 5: Reporting**

5.1 Report *eqmCADR* in ($m^3$/h) at each tested configuration

5.2 Report test condition details such as:

test laboratory details such as: name, location, date, operator.

test chamber details such as:

volume of the test-chamber, $V_{test}$ in $m^3$, and its length, width, and height in m
UV-C reflectance (%) of the test-chamber walls, floor, and ceiling
selected pathogen or surrogate pathogen and its susceptibility factor, $k(\lambda)$, in $m^2$/J
initial CFU concentration of the pathogen, in CFU/$m^3$
temperature, humidity
device mounting location and mounting details including photographs
pre-mixing fan airflow and in-test mixing airflow
time of overall test and sampling times
nebuliser details (particle sizes, locations, timing etc.)
sampling locations, time, sampling method/equipment, details on method of analysis
chamber ventilation details that could impact interpretation of the test including air filters
initial and during test air stirring fan details (airflow) and locations
chamber air clean-up method and disinfection method

5.3 Report UVGI luminaire details such as:

- manufacturer
- UVGI luminaire type and model number
- voltage in V, and power in W, and air flow settings in $m^3$/h
- peak wavelength(s) ($\lambda$) in nm
- inclusion of microbiological filter (if any)
- model and type of UVGI radiation source, in case of removable / replaceable lamps