
**Method of evaluating the UV dose to
airborne microorganisms transiting
in-duct ultraviolet germicidal
irradiation devices**

*Méthode d'évaluation de la dose d'UV pour les microorganismes
en suspension dans l'air transitant par des dispositifs d'irradiation
germicide aux ultraviolets raccordés*

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Contents

Page

Foreword.....	iv
Introduction.....	v
1 Scope.....	1
2 Normative references.....	1
3 Terms, definitions, symbols and abbreviated terms.....	1
3.1 Terms and definitions.....	1
3.2 Symbols and abbreviated terms.....	3
3.2.1 Symbols.....	3
3.2.2 Abbreviated terms.....	3
4 Configuration of the test rig.....	4
5 Test rig qualification.....	5
6 Preparation of test microorganisms.....	5
6.1 Test microorganisms.....	5
6.1.1 <i>Serratia marcescens</i>	5
6.1.2 <i>Bacillus subtilis</i>	5
6.1.3 <i>Cladosporium sphaerospermum</i>	5
6.2 Preparation of microbial suspensions.....	6
6.2.1 Acquisition of pure culture of test microorganisms.....	6
6.2.2 Cultivation and dispersion of the test microorganism.....	6
6.2.3 Dilution of the microbial suspensions.....	6
7 Testing procedure for an in-duct UVGI device.....	6
7.1 Determination of airflow rate, temperature and humidity.....	6
7.2 Production of the airborne test microorganism.....	6
7.3 Measurement of the test microorganism concentration without and with UV irradiation..	7
7.3.1 Sampling procedure.....	7
7.3.2 Test microorganism sampling methods.....	7
7.3.3 Test microorganism culture and enumeration.....	7
7.4 Repeating the tests at other flow rates.....	7
7.5 Determination of the UV susceptibility of the test microorganism.....	7
8 Safety and environmental considerations.....	7
9 Calculation, evaluation and reporting.....	8
9.1 Determination of the inactivation rate of the test microorganism.....	8
9.2 Determination of the UV dose of the UVGI device.....	8
9.3 Evaluation of the UVGI capacity.....	8
9.4 Results reporting.....	8
Annex A (informative) Recipe of culture medium for the test microorganism.....	9
Annex B (informative) Method for determining the UV dose-response curve and susceptibility constant of a test microorganism in air.....	10
Annex C (informative) Susceptibility constants of some typical microorganisms in air by the literature.....	13
Bibliography.....	16

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Airborne microorganisms including some pathogens in indoor air may cause different types of diseases or adverse health effects on humans. Among different air disinfection techniques, ultraviolet germicidal irradiation (UVGI) has been used for several decades to effectively inactivate the airborne microorganisms in indoor air and thereby prevent the transmission of a variety of airborne infections.

In-duct UVGI device is a primary form of air disinfection method by UV lamps mounted in heating, ventilation and air-conditioning (HVAC) systems to irradiate the microorganisms in air with high intensities. However, other than the power supply, there is no standard or index available to characterize or understand the performance of the UVGI products made by different manufacturers. In addition, effective parameters derived from a standard method are lacking to predict the performance of the UVGI device on microorganism inactivation in a real HVAC system.

As microorganisms in air are irradiated by UV-C light emitted by an in-duct UVGI device, the inactivation rate of a specific microorganism primarily depends on the UV dose given by the device and the susceptibility of that microorganism. If the UV dose under a specific condition is known, the inactivation capacity and disinfection performance of the UVGI devices can be compared. Furthermore, the inactivation rate for specific microorganism can be calculated with its susceptibility data known.

Therefore, the development of a standard method to evaluate the UV dose of the in-duct UVGI device is very useful and necessary.

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Method of evaluating the UV dose to airborne microorganisms transiting in-duct ultraviolet germicidal irradiation devices

1 Scope

This document describes a method in laboratory to assess the performance of ultraviolet germicidal irradiation (UVGI) devices which will be mounted in-duct in heating, ventilating and air-conditioning (HVAC) systems.

The method includes the detailed requirements for test rig, microorganisms, procedures, data calculation and result report to determine the UV dose to model microorganisms by an UVGI device at several airflow rates. By the testing results, the capacity of in-duct UVGI devices for air disinfection can be evaluated and compared reliably.

If the susceptibility constant of a given microorganism is known, the inactivation rate of that microorganism by the tested UVGI devices can be further calculated.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15858, *UV-C Devices — Safety information — Permissible human exposure*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1.1 airborne microorganism

microbial particle with an aerodynamic diameter up to 100 µm suspended in air

Note 1 to entry: Airborne microorganism includes bacterium, fungus, their spore or virus.

3.1.2 pathogen

infectious agent that causes diseases in its host

Note 1 to entry: Pathogen includes some virus, bacterium, prion, fungus, viroid, or parasite.

3.1.3

test microorganism

microbial surrogate representing the typical *pathogen* (3.1.2)

Note 1 to entry: Test microorganism is chosen to be safer than the real pathogen in order to prevent the infection of testers or analysts.

3.1.4

air disinfection

process that can remove, inactivate or destroy the *airborne microorganisms* (3.1.1), especially *pathogen* (3.1.2) in air

3.1.5

ultraviolet germicidal irradiation

UVGI

method for disinfection of air, water and object surfaces that uses radiation with wavelength in the range of 240 nm to 280 nm to kill or inactivate microorganism

Note 1 to entry: UV irradiation with a wavelength of 240 nm to 280 nm can cause damage to the DNA or RNA of the microorganisms.

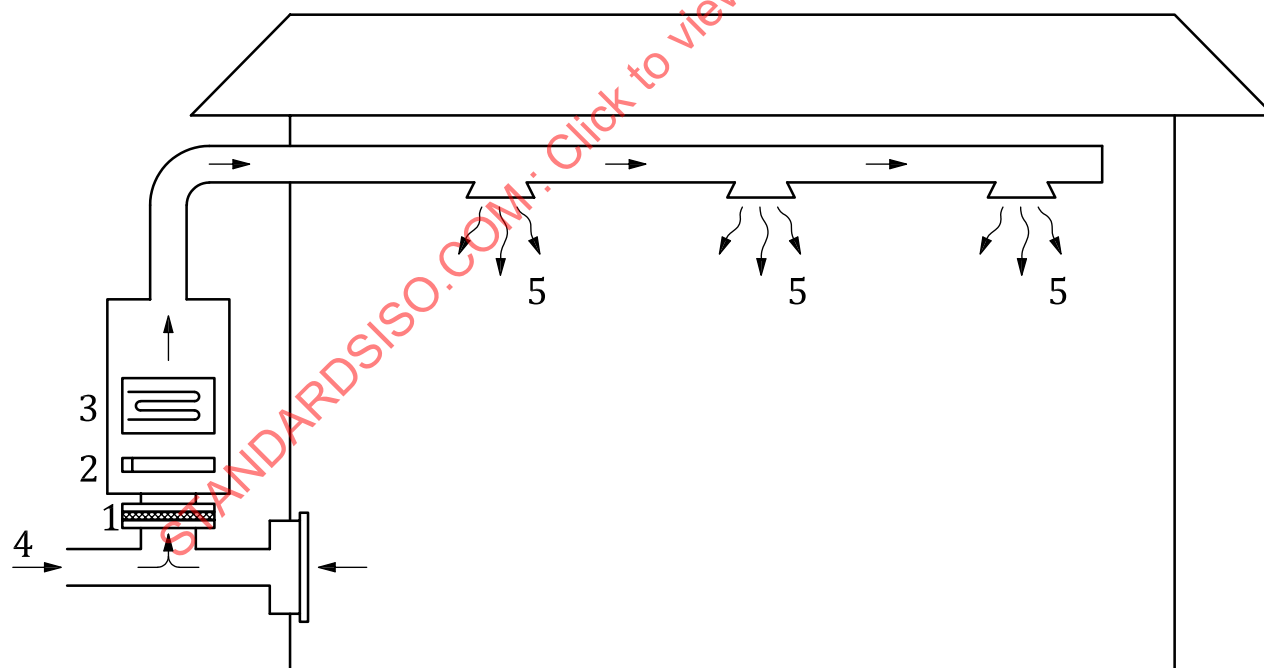
[SOURCE: ISO 29464:2017, 3.6.20, modified — Note 1 to entry has been added.]

3.1.6

in-duct UVGI device

device consisting of UV lamps, ballast and other accessories, all of which could be mounted in ducts of an HVAC system to disinfect the air or a surface

Note 1 to entry: A typical diagram of in-duct UVGI device in an HVAC system is shown in [Figure 1](#).



Key

- 1 filter
- 2 UV lamp
- 3 heating or cooling coil
- 4 fresh air
- 5 conditioned air

Figure 1 — Diagram of an in-duct UVGI device in an HVAC system

3.1.7**UV dose***D*

product of UV irradiance and specific exposure time on a given microorganism or surface

Note 1 to entry: UV dose is expressed in millijoules per square centimetre (mJ/cm²).

Note 2 to entry: The longer the time a microbe is exposed to UV light, the higher the UV dose it will receive. In a UVGI *air disinfection* (3.1.4) device, the UV dose to every single microbe is different. For the device with evenly distributed UV irradiation and airflow, the UV dose can be calculated based on the definition. But for most real *in-duct UVGI devices* (3.1.6), it is hard to evaluate the UV dose to each microbe but the average UV dose can be determined by the *inactivation rate* (3.1.9) and a known microbial susceptibility.

3.1.8**UV susceptibility**

extent to which a microorganism is sensitive to UV light or how easily it can be inactivated by UV irradiation

Note 1 to entry: UV susceptibility depends on the species and character of the microorganism. It can be described by a constant (*k*) with the unit of m²/J.

3.1.9**inactivation rate**

reduction in active microorganism concentration expressed as N_0/N (%) or $\log(N_0/N)$, in which N_0 is the original active microorganism concentration, N is the active microorganism concentration after disinfection

3.1.10**UV dose-response curve**

quantified relationship between the *inactivation rate* (3.1.9) of a specific microorganism and the average *UV dose* (3.1.7) it received

Note 1 to entry: In many cases, the relationship follows the equation as below:

$$\ln(N_0/N) = k D \quad (1)$$

in which D , k and $\ln(N_0/N)$ have been described in 3.1.7 to 3.1.9. In [Formula \(1\)](#), N/N_0 or D can be calculated with the other parameters known. In other cases, the relationship may not strictly follow [Formula \(1\)](#), but N/N_0 or D can also be determined according to the specific curve.

3.2 Symbols and abbreviated terms**3.2.1 Symbols**

Symbol	Definition
N_0	original active microorganism concentration
N	active microorganism concentration after disinfection
D	UV dose
k	susceptibility constant

3.2.2 Abbreviated terms

ATCC	American Type Culture Collection
BMBL	Biosafety in Microbiological and Biomedical Laboratories
BSL	biosafety level
CDC	Centres for Disease Control and Prevention of the United States

CFU	colony-forming unit
HEPA	high-efficiency particulate air
HVAC	heating, ventilating and air-conditioning
PDA	potato dextrose agar
UVGI	ultraviolet germicidal irradiation

4 Configuration of the test rig

4.1 In order to evaluate the disinfection capacity of an in-duct UVGI device, the inactivation performance for some specific test microorganism shall be measured through a standard test rig as shown in Figure 2.

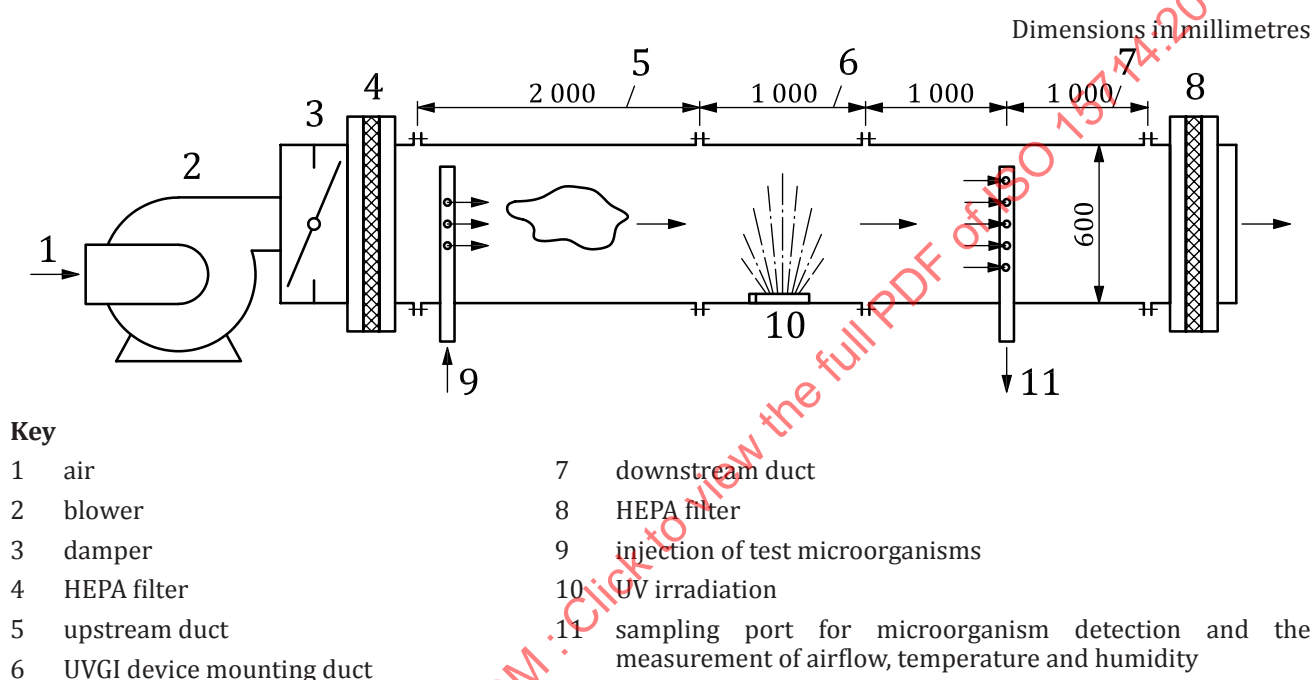


Figure 2 — Test rig for inactivation performance of in-duct UVGI device

4.2 The test rig includes a blower (installed in front or at the end of the test rig), a damper, a HEPA filter before the duct, an upstream duct with test microorganism injection port, a UVGI device mounting duct, a downstream duct with sampling port and an off-gas pipe with HEPA filter.

4.3 The ducts have a square cross-section and an inner side-length of 0,6 m. Galvanized steel or aluminium with a reflectivity of 50 % to 60 % shall be used to make the duct walls. The upstream duct and downstream duct have a length of 2,0 m and the UVGI device mounting duct has a length of 1,0 m.

4.4 In the test rig, a damper is used to control the flow rate of the test system. A subsequent HEPA filter shall be placed before the test microorganism injection port in order to remove the culturable microorganisms that may exist in the air to avoid their impact on test microorganism quantification.

4.5 In the upstream duct, a test microorganism injection port of 10 mm to 15 mm in diameter is set near the left flange of the duct (within 20 cm). The port can be set in the centre line of bottom or side wall.

4.6 In the UVGI device mounting duct, the UVGI device shall be installed following the instruction of the manufacturer and simulating its working conditions. If a new UV lamp is used, it shall be powered on continuously for 100 hours (called burn-in time) before it is tested.

4.7 In the downstream duct, a sampling port (Key 11 in [Figure 2](#)) of 15 mm to 20 mm in diameter is placed to collect the test microorganisms and to do measurements on the airflow rate, temperature and humidity by different sensors. The port can be set in the centre line of the bottom or side wall. Connected with the downstream duct, another HEPA filter is recommended to be installed to minimize the test microorganism emission to the environment.

5 Test rig qualification

Before launching the testing procedures, the test rig needs to be examined to insure that it is in a good condition and can provide reliable results. The methods for test rig qualification shown in Section 5 of ANSI/ASHRAE 185.1 are a useful reference. Tests on the velocity uniformity and duct leakage are recommended. All the qualification tests shall be operated at an air velocity of $(2,0 \pm 0,2)$ m/s.

6 Preparation of test microorganisms

6.1 Test microorganisms

6.1.1 *Serratia marcescens*

Serratia marcescens is a species of rod-shaped Gram-negative bacteria in the family Enterobacteriaceae. They are frequently used as typical test microorganisms for biodosimetry purposes and are good surrogates of those bacteria with high susceptibility to UV, especially many Gram-negative bacteria. The reported susceptibility constants (k) for *Serratia marcescens* range in $0,1 \text{ m}^2/\text{J}$ to $0,9 \text{ m}^2/\text{J}$. The recommended culturing media are nutrient agar (solid) which are commercially available and easy to prepare (the recipe is listed in [Annex A](#)).

Serratia marcescens is suitable for testing the UVGI device with an effective UV dose less than 25 J/m^2 .

6.1.2 *Bacillus subtilis*

Bacillus subtilis is a species of rod-shaped, Gram-positive and endospore-forming bacteria in the family Bacillaceae. They are frequently used as typical test microorganisms representing those bacteria with low susceptibility to UV, especially the Gram-positive bacteria. The reported susceptibility constants (k) for *Bacillus subtilis* (vegetative cells) range in $0,02 \text{ m}^2/\text{J}$ to $0,07 \text{ m}^2/\text{J}$. The recommended culturing media are nutrient agar (solid) which are commercially available and easy to prepare (the recipe is listed in [Annex A](#)).

Bacillus subtilis is suitable for testing the UVGI device with an effective UV dose from 25 J/m^2 to 120 J/m^2 .

6.1.3 *Cladosporium sphaerospermum*

Cladosporium sphaerospermum is a saprobic and spore-forming fungus that inhabits a variety of environments including the indoor and outdoor air. They are typical test microorganisms representing those fungi with very high susceptibility to UV. The reported susceptibility constants (k) for *Cladosporium sphaerospermum* spores in single-pass tests range in $0,0008 \text{ m}^2/\text{J}$ to $0,002 \text{ m}^2/\text{J}$. The recommended culturing media are potato dextrose agar (PDA) (solid) which are commercially available and easy to prepare (the recipe is listed in [Annex A](#)).

Cladosporium sphaerospermum is suitable for testing the UVGI device with an effective UV dose more than 120 J/m^2 .

6.2 Preparation of microbial suspensions

6.2.1 Acquisition of pure culture of test microorganisms

All the test microorganisms above are available for purchase through some national or global biological resource centres like American Type Culture Collection (ATCC) and have a biosafety level of 1 (not known to consistently cause disease in healthy adult humans) classified by the Centres for Disease Control and Prevention of the United States (CDC).

6.2.2 Cultivation and dispersion of the test microorganism

Inoculate the test organism onto solid media as indicated in the previous section, incubating the culture until mature, wiping a wetted sterile swab across the surface of the pure culture, and eluting from the swab into sterile deionized water to obtain a 600 nm absorbance of 0,8 to 1,0 with a 1 cm cuvette.

6.2.3 Dilution of the microbial suspensions

Dilute the microbial suspension to achieve a suitable test microorganism concentration typically ranging in 10^4 CFU/cm³ to 10^8 CFU/cm³. The exact concentration shall meet the requirement for producing an air stream with a desired concentration.

7 Testing procedure for an in-duct UVGI device

7.1 Determination of airflow rate, temperature and humidity

The performance of an in-duct UVGI device can be affected by airflow rate, temperature, humidity and other factors. Among these impacting factors, airflow rate is the most important one and a reasonable range shall be determined before the test. Adjust the airflow rate to the desired level by selecting a suitable blower and changing the angle of the damper. Three airflow rates at $(1\ 000 \pm 100)$ m³/h, $(2\ 000 \pm 100)$ m³/h and $(3\ 000 \pm 100)$ m³/h shall be selected for the inactivation test.

Air temperature and relative humidity are less important than the airflow rate but still need to be controlled within $(25 \pm 2,5)$ °C and $50\ \% \pm 10\ \%$ during the testing period. The exact level of air temperature and humidity with the UV irradiation switched on shall be noted as a reference condition while demonstrating the testing results.

At the sampling port in downstream duct indicated in [Figure 2](#) (Key 11), the airflow rate shall be measured by a portable anemometer (with a relative accuracy better than $\pm 10\ \%$) and the air temperature and humidity shall be measured by a digital hygrometer (with absolute accuracies better than $\pm 0,5$ °C for temperature and $\pm 3\ \%$ for relative humidity). The measurements of airflow rate, temperature and humidity shall be repeated twice and the relative difference in the same index shall be less than $10\ \%$ to ensure the testing system is stable.

All the three parameters shall be tested at the beginning and end of each test. The relative variations shall be less than $10\ \%$.

7.2 Production of the airborne test microorganism

The test microorganism with desired concentrations can be generated by a Collison nebulizer or ultrasonic air humidifier with fans and shall be injected into the airstream via a tube. Refer to [4.5](#) for the injection position. By adjusting the test microorganism concentration in suspensions and the setting of the generator, the microbe concentration in the air stream can be controlled. The suitable range shall be 10^3 CFU/m³ to 10^4 CFU/m³.

7.3 Measurement of the test microorganism concentration without and with UV irradiation

7.3.1 Sampling procedure

After the test microorganism concentration is adjusted to the desired level, the airborne microorganism shall be sampled with UVGI switched off at the sampling port in the downstream duct (Key 11 in [Figure 2](#)). The airborne microorganism concentration with UVGI switched off functions as a control to avoid the effect of air duct on microbe inactivation. After the sampling with UVGI switched off are completed, turn on the UV lamp and preheat it for 15 min. Then do the test microorganism sampling with UVGI on at the same sampling port with the same methodology.

7.3.2 Test microorganism sampling methods

The sampling of the test microorganism can be accomplished by an impaction type air sampler such as Andersen sampler or a commercial impinger. The device and procedure for all sampling shall be identical throughout the test. The sampling shall be repeated three times and at least two tested concentrations shall have a relative difference less than 50 %.

7.3.3 Test microorganism culture and enumeration

After agar plates are taken out of the impaction type air sampler or the suspension sample from an impinger is spread on agar plates, put them directly into an incubator at 32 °C for bacteria for 24 h to 48 h and 25 °C for fungi for 72 h to 120 h after which the number of colonies is counted. Then the airborne microorganism concentration can be calculated as the number of colonies in a certain volume of air (CFU/m³) considering the sampling flow rate and time. All the results with less than 50 % relative difference between any two of them shall then be averaged to do the performance calculation.

7.4 Repeating the tests at other flow rates

After completing the steps described above, the UVGI device can be turned off and a new airflow rate can be set to repeat the testing procedure from [7.1](#) to [7.3](#). All the tests under each designated flow rate shall be completed. If some mistakes are found or some results do not meet the requirements, some steps or measurement shall be repeated.

7.5 Determination of the UV susceptibility of the test microorganism

The UV susceptibility (UV dose-response curve) of the test microorganism shall be tested for calculating the UV dose of the UVGI device. The detailed method is described in [Annex B](#). Note that the exact same test microorganism, its generation and testing methods shall be used. Besides, all the other conditions such as air temperature, humidity and initial microbe concentration shall also be kept at the same level.

If the UV susceptibility test is not available, the citation of UV susceptibility constant is also acceptable (see [Annex C](#)) with the value and reference noted in the report.

8 Safety and environmental considerations

8.1 During the test, the first safety concern is the possible personal exposure to UV. The operation of the UVGI device shall follow ISO 15858. The exposure limits to UV at 254 nm shall be followed and personnel safety training shall also be considered.

8.2 Another concern is about the biological safety. All test microorganisms used in this method are in BSL-1 defined by the CDC in "Biosafety in Microbiological and Biomedical Laboratories" (BMBL). BSL-1 means the relative microorganisms are not normally associated with human diseases and present minimal potential hazards to the laboratory personnel and the environment. The operational guidelines described in BMBL need to be followed.

8.3 To minimize the impact to environment, an HEPA filter is used to remove the airborne microorganisms from the air stream with an efficiency of 99 % or higher.

9 Calculation, evaluation and reporting

9.1 Determination of the inactivation rate of the test microorganism

The averaged airborne microorganism concentrations before and after the UV irradiation shall be used to calculate the inactivation rate of the test microorganism according to its concept (see [3.1.9](#)).

9.2 Determination of the UV dose of the UVGI device

The UV dose of the UVGI device (D) can be determined by the inactivation rate derived in the UVGI device performance test and the UV susceptibility in [7.5](#). If the susceptibility constant (k) is available, D can be calculated according to [Formula \(1\)](#). If k is not available, D can be determined by the UV dose-response curve described in [7.5](#).

9.3 Evaluation of the UVGI capacity

After the UV dose under different airflow rates are calculated, plot the relative data to get the UV dose-airflow rate curve and use it as an indication for the UVGI device performance. The device with a higher UV dose under the same flow rate will have a higher capacity to inactivate microorganisms and disinfect the air. Obviously, the power shall also be considered when evaluating the performance.

9.4 Results reporting

The following information shall be included in the report to indicate the capacity or performance of the UVGI device being tested.

- a) Name and location of the test laboratory.
- b) Date of the test, test operators' names.
- c) Description of the UVGI device tested (brand, manufacturer, power, image, way of obtainment etc.).
- d) Description of the test rig including its size and materials (photos of the test rig indicating the position of UVGI device shall be included).
- e) Test microorganism used and its susceptibility constant adopted.
- f) Airflow rate, temperature in degrees, humidity.
- g) Original data for rig qualification and the inactivation results with UV on (indicating the input volts and watts) and off.
- h) Calculation procedure and result of inactivation rates and UV doses at each flow rate.
- i) UV dose-airflow rate curve of the UVGI device.
- j) Summary.

Annex A (informative)

Recipe of culture medium for the test microorganism

A.1 Nutrient agar

Beef extract	3,0 g
Peptone	5,0 g
Agar	15,0 g
Deionized water	1 000 mL

Mixed together and the final pH is $6,8 \pm 0,2$. Autoclave at 121 °C.

A.2 Potato dextrose agar (PDA)

Potato starch (from infusion)	4,0 g
Dextrose	20,0 g
Agar	15,0 g
Deionized water	1 000 mL

NOTE 1 The PDA is adjusted and/or supplemented as required to meet the performance criteria.

NOTE 2 The potato starch is from approximates 200 g of infusion from potatoes.

- 1) Mix thoroughly.
- 2) Heat with frequent agitation and boil for 1 min to completely dissolve the powder.
- 3) Autoclave at 121 °C for 15 min.
- 4) To alter the reaction of the agar medium to pH 3,5, cool the base to 45 °C to 50 °C and aseptically add an appropriate amount of sterile 10 % tartaric acid to each litre of medium. Mix well. Do not reheat the medium.
- 5) Test samples of the finished product for performance using stable, typical control cultures.

Annex B (informative)

Method for determining the UV dose-response curve and susceptibility constant of a test microorganism in air

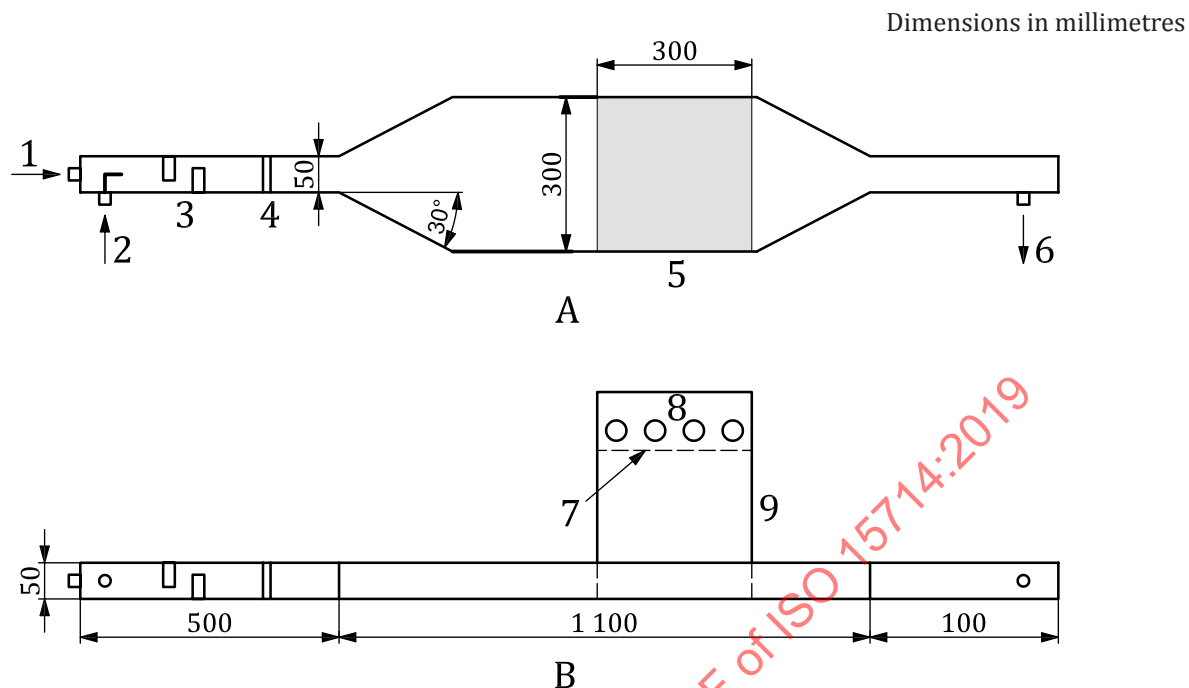
B.1 Aim of the UV dose-response curve and susceptibility constant test

The UV dose-response and susceptibility constant can be experimentally measured by exposing a test microorganism to controlled doses of UV-C irradiation. By determining the proportion of viable microbes at each dose it is possible to plot the relationship between the UV dose and the inactivation rate and calculate appropriate susceptibility constants when an exponential relationship applies. This test microorganism is supposed to follow the same UV dose-response relationship in an in-duct UVGI device under the same conditions (air temperature, humidity etc). Then the UV dose that the microorganism received in the in-duct UVGI device can be estimated after the curve is determined.

B.2 Test microorganism and apparatus

The test microorganism selected in this test should be identical to that used in the in-duct UVGI device test and even follow the same procedure in the preparation of the microbial suspension and the generation of the airborne microorganism.

An experimental apparatus developed by Noakes et al.^[6] is shown in [Figure B.1](#). The apparatus consists of an opaque low-reflectivity square-section duct that is widened in the centre to form a (300 × 300 × 50) mm UV exposure chamber. A panel of silica glass, 87 % transparent to UV-C light, forms the top surface of this chamber. Four UV bulbs (15 W) are mounted horizontally 640 mm above the chamber surface. The UV intensity within the chamber can be controlled by the number of lamps switched on and by inserting fine wire mesh panels between the lamps and chamber to attenuate the light.



Key

- | | | | |
|---|-------------------------------|---|-----------------|
| A | top view | B | side view |
| 1 | air inlet | 7 | wire mesh |
| 2 | nebulizer inlet | 8 | 4 UV tube lamps |
| 3 | baffles | 9 | shielding |
| 4 | air straightener | | |
| 5 | UV chamber | | |
| 6 | exit to microorganism sampler | | |

Figure B.1 — Geometry of the experimental flow apparatus

B.3 Test procedure and measurement method

B.3.1 Draw air through the apparatus at a constant 28,3 L/min and regulate the flow using a needle valve and a flow meter. Measure the temperature and humidity at the beginning and end of the experiment. Make sure that the air temperature and relative humidity are controlled within $25\text{ }^{\circ}\text{C} \pm 2,5\text{ }^{\circ}\text{C}$ and $50\% \pm 10\%$, respectively.

B.3.2 Measure the UV irradiance distribution by an UV radiometer at the points on the surface and bottom of the 300 mm × 300 mm chamber as shown in Figure B.2. The UV dose in the chamber is the product of the average value of 18 irradiances at different points and the area of the square section ($0,09\text{ m}^2$). Five UV dosages among the same range as the in-duct UVGI device test should be set to complete the inactivation test and get the UV dose-response curve.

Dimensions in millimetres

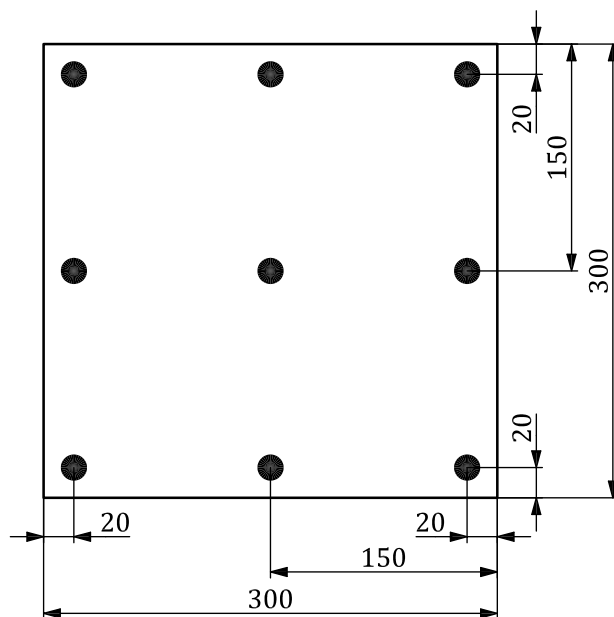


Figure B.2 — The UV irradiance measurement position on the surface or bottom of the 300 mm × 300 mm chamber

B.3.3 Inject the aerosolised test microorganism into the airflow at a constant rate in the inlet section to form airborne microbes of 10^3 CFU/m³ to 10^4 CFU/m³ and the total airflow in the chamber should be maintained at 28,3 L/min.

B.3.4 Use an airborne microorganism sampler to collect microbes in the air emitted from the apparatus with no loss to the external air, in the instance without UV irradiation and then with the five UV dosages. Five replicate samples at the port (Key 6 in [Figure B.1](#)) should be taken to determine an average colony count for each specific condition (without UV or at a UV dose). Use the average colony counts to calculate the inactivation rate as $\log(N_0/N)$, in which N_0 is the original active microorganism concentration, N is the active microorganism concentration after disinfection.

B.3.5 Plot the inactivation rates under each UV dose in a figure and get the UV dose-response curve by a data fitting method if the curve follows the [Formula \(1\)](#). Then, calculate the susceptibility constant of the test microorganism. In case the curve does not fit the [Formula \(1\)](#) well (R^2 is lower than 0,7, where R is the relative coefficient of the data fitting result), link all adjacent data points together to get a polyline, by which the UV dose can also be decided while the inactivation rate is known without a susceptibility constant.

Annex C (informative)

Susceptibility constants of some typical microorganisms in air by the literature

C.1 Table C.1 is adapted from Kowalski^[5] and lists published UV susceptibility constants (k , m²/J) for a range of microorganisms measured in air, together with the UV dose required to inactivate 90 % of the microorganisms (D90, J/m²).

C.2 The listed susceptibility constants enable people to estimate the inactivation rate of a specific microorganism with a known effective UV dose of a UVGI device tested by the method listed in this document. Or the data can also be used to estimate the required UV dose in case the desired inactivation rate for a specific microorganism is known.

C.3 For some microorganisms, several different values have been published due to that the specific strains and the irradiation conditions may differ a lot. Thus, the susceptibility constants data listed are just a reference and may have a big difference with the data observed under a real condition. It is important to treat these published values as representative behaviours and make allowances for the variability when using such values for design and performance assessment.

Table C.1 — Published susceptibility constants for various microorganisms in air (adapted from Kowalski^[5])

Type	Microorganism	State	k m ² /J	D90 J/m ²	Source
Bacteria	B. atrophaeus (B. globigii)	Sp	0,016	144	EPA (2006)
	Bacillus subtilis	Veg	0,168 58	14	Nakamura (1987)
	Bacillus subtilis spores	Sp	0,026	89	Peccia (2001)
	Bacillus subtilis spores	Sp	0,015 5	149	Ke (2009)
	Bacillus subtilis spores	Sp	0,027	85	Peccia (2001)
	Burkholderia cepacia	Veg	0,211 5	11	Fletcher (2004)
	Burkholderia cepacia	Veg	0,105 2	22	Fletcher (2004)
	Escherichia coli	Veg	0,723	3	Webb (1970)
	Escherichia coli	Veg	0,218	11	Webb (1970)
	Escherichia coli	Veg	0,219	11	Rentschler (1942)
	Escherichia coli	Veg	0,181	13	Rentschler (1942)
	Escherichia coli	Veg	0,156 11	15	Luckiesh (1949)
	Escherichia coli	Veg	0,965	2	Koller (1939)
	Escherichia coli	Veg	0,205	11	Koller (1939)
	Francisella tularensis	Veg	0,009	256	Beebe (1959)
	Francisella tularensis	Veg	0,008	288	Beebe (1959)
	Mycobacterium bovis BCG	Veg	0,242	10	Riley (1976)
	Mycobacterium bovis BCG	Veg	0,19	12	Peccia (2002)
	Mycobacterium bovis BCG	Veg	0,12	19	Ko (2000)
	Mycobacterium bovis BCG	Veg	0,07	33	Ko (2000)