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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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Foreword

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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.

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 micro-organism 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

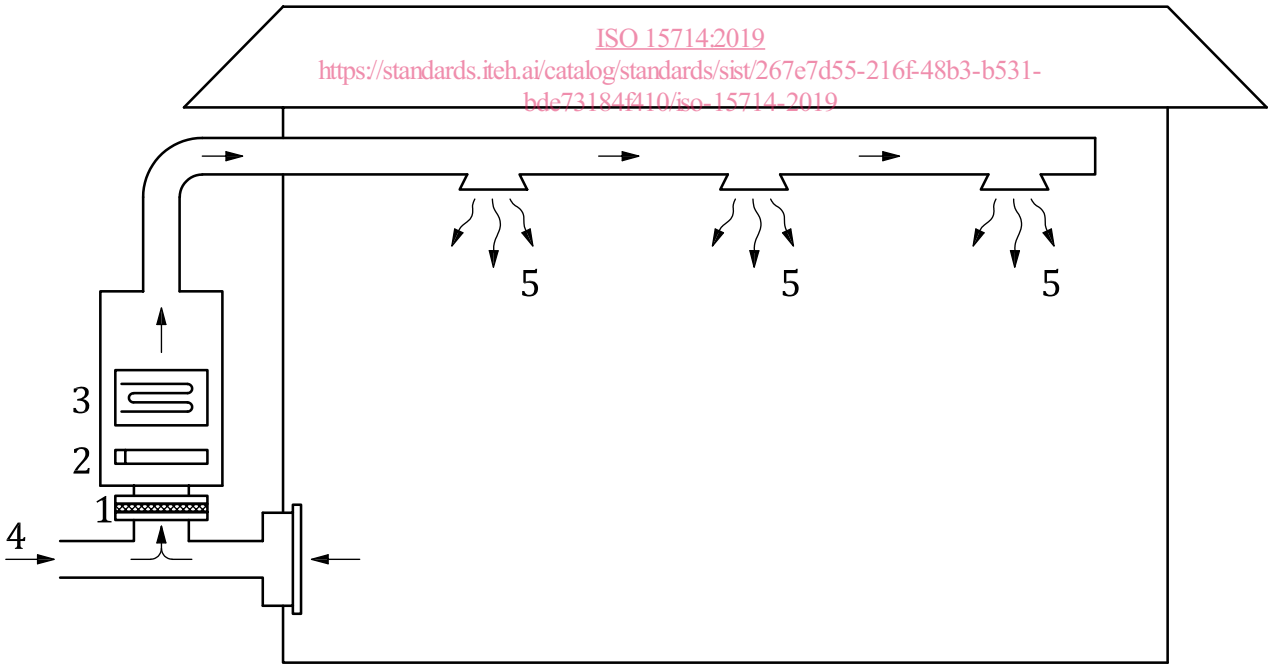
3.1.5
ultraviolet germicidal irradiation
UVGI
method for disinfection of air, water and object surfaces that uses radiation with wavelength in the range of 240 nm to 280 nm to kill or inactivate microorganism

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/cm^2).

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 m^2/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:

$$\ln(N_0/N) = k\,D \tag{1}$$

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

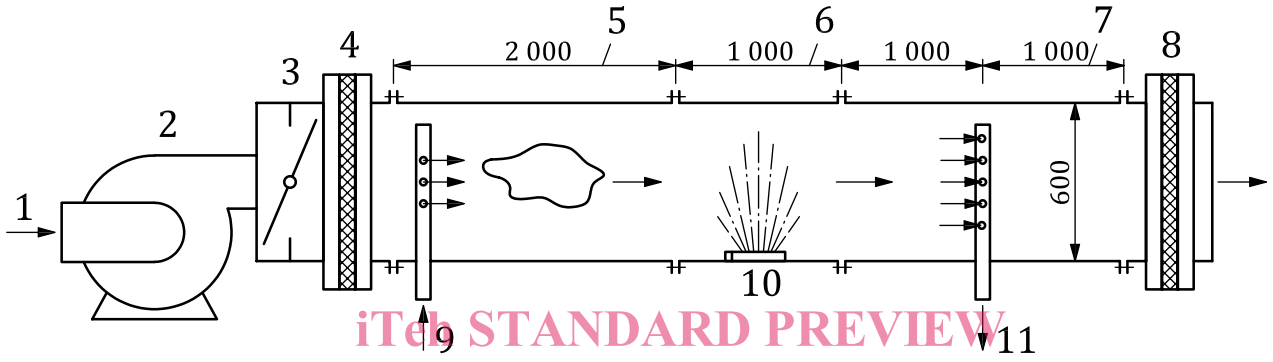
ATCC	American Type Culture Collection
BMBL	Biosafety in Microbiological and Biomedical Laboratories
BSL	biosafety level
CDC	Centres for Disease Control and Prevention of the United States

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.

Dimensions in millimetres



Key

1 air
2 blower
3 damper
4 HEPA filter
5 upstream duct
6 UVGI device mounting duct
7 downstream duct
8 HEPA filter
9 injection of test microorganisms
10 UV irradiation
11 sampling port for microorganism detection and the measurement of airflow, temperature and humidity

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 ± 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 m^2/J to 0,9 m^2/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 m^2/J to 0,07 m^2/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 0,000 8 m^2/J to 0,002 m^2/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.