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New device for air disinfection with a shielded UV radiation and ozone

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Abstract. Indoor air disinfection has become particularly relevant recently because of the Covid-19 pandemics. A shielded device for air and surface disinfection with UV radiation and ozone has been developed. It contains 28 low intensity (11 W) UV lamps (254 nm) in a specially designed three-dimensional grid to provide a large flow cross-sectional area and long path for the air particles to be irradiated. The device can be used in medical institutions, veterinary clinics, manufacturing plants, public premises, poultry, and livestock farms. It does not generate air-ions and ozone concentrations do not exceed the allowed 8-hour average values. The large number of UV lamps and powerful fans ensure air disinfection in large rooms in a relatively short time (400 m^3 h^{-1}). Simultaneously, the floor surface under the appliance is disinfected. Disinfection efficiency tests demonstrated 99.9999% reduction for *Escherichia coli*, *Staphylococcus aureus* and Pseudomonas phage Φ6 aerosols within a single transfer through the system (10 seconds of treatment). The housing of the device protects from direct UV radiation; therefore, people can be in the room during the operation of the device.

Key words: air ions, disinfection, ozone, prototype, UV radiation.

INTRODUCTION

Air disinfection to reduce the transmission of contaminants is generally practiced in medical environments and industries related to the storage of fruit, vegetables, eggs, dairy and meat products, animal and poultry farms and production sites. During the times of local epidemics and pandemics, e.g., COVID-19, H1N1 influenza, African swine fever, avian influenza, efficient indoor air and surface disinfection is of high importance to minimize the pathogen spread. Gaseous ozone, UV irradiation and liquid disinfectant aerosolization are the most widely practiced systems.

The effect of gaseous ozone to reduce microbial load is generally lower than that of aqueous ozone. Furthermore, it has been reported that the reduction is surface dependent. The reported doses for gaseous ozone range from 25 μg m^{-3} to 200 μg m^{-3}. Nevertheless, a 4–6 log_{10} reduction of bacteria can be achieved within 20 minutes of treatment (Wani et al., 2015; Hutla et al., 2020). The mode of action in microbial inactivation is related to the destruction of cell wall, damage of purines and pyrimidines and breakage of carbon-nitrogen bonds (EPA et al., 1999). At the same time it has been reported that exposure to elevated ozone concentration can cause dangerous effect on human health (Elvis & Ekta, 2011). Daily exposures to ozone increase mortality and respiratory morbidity rates. In 25 EU countries some 21,000 premature deaths per year are associated with ozone exceeding 70 μg m^{-3} of maximum daily 8–hour average (Amann et al., 2008).

As an alternative approach liquid disinfectant vaporization or aerosolization is applied. Hydrogen peroxide aerosols with particles from 2–12 μm are injected into rooms, followed by passive aeration. A 4 Log_{10} reduction of spores has been reported for these systems. A 'dry gas' vaporized hydrogen peroxide system that utilizes 30% hydrogen peroxide has been shown to be effective against a variety of pathogens, including *Mycobacterium tuberculosis, Mycoplasma, Acinetobacter, Clostridium difficile, Bacillus anthracis*, viruses, and prions (Boyce, 2016). Nevertheless, indoor spraying or fogging with disinfectants is not recommended, since spraying as a primary disinfection strategy is ineffective in removing contaminants outside of direct spray zones. Moreover, spraying disinfectants can result in risks to the eyes, respiratory or skin irritation and the resulting health effects (WHO, 2020).

Lately, the use of UV radiation for air, surface and materials, e.g., facial respirators (Yang et al., 2020), disinfection has become popular, and the number of various devices is increasing (Li et al., 2017; Guimera et al., 2018; Yang et al., 2019; Song et al., 2020). The germicidal effect in these systems generally results from UV–C causing damage to the cellular material of bacteria or viruses, including their DNA or RNA. At the same time, UV–C can also cause damage to human skin and eyes. To prevent human exposure to harmful levels of UV–C, precautions should be considered when the technology is operated (Chen & O`Keeffe, 2020), thus, open-type disinfection systems have a limited use in inhabitant-free rooms.

Irrespective of the selected disinfection technology, ergonomic parameters and sound level should be in the permissible range. The weighted equivalent continuous sound pressure level in schools and classrooms should not exceed 35 dB, in dwelling, indoors - 35 dB, inside bedrooms - 30 dB, in hospital wards during day - 35 dB, at night - 30 dB and in industrial, commercial, shopping and traffic areas, indoors and outdoors - 70dB (Berglund et al., 1999), cow farms - 90 dB (Phillips, 2010; Andrade et al., 2020).

Furthermore, if the technologies are operated in human presence, well-being will depend on the concentration and type of air ions. For example, the Sanitary and Epidemiological Rules and Regulations in the Russian Federation SanPin 2.2.4.1294-03 set limit values for the amount of air ions: 400–50,000 cm^{-3} for positive ions, 600–50,000 cm^{-3} for negative ions, and a unipolarity coefficient $0.4 \leq K \leq 1.0$ (SanPin, 2003). Artificial and natural ionizers can be used to control the concentration of air ions. Artificial ionizers are electronic devices, natural ionizers can be plants, such as *Pinus Mugo* producing negative, human-friendly air ions under daylight (Sinicina et al., 2015). Air ionizers can be also used to purify indoor air. Dust particles (including PM10)

combine with light air ions generated by the ionizer, obtain an electric charge, form heavier structures and settle to the floor as a result of gravity. If the PM10 concentration is > 0.1 mg m^{-3}, then the ionizers create heavy cluster ions that are harmful to health (Skromulis, 2019). In these cases, the indoor use of ionizers is prohibited. Therefore, all air disinfection equipment prior use should be tested if it is not acting as ionizer.

Many bacteria and viruses can be spread by air and liquid droplets / aerosols or can persist on surfaces. Among the systems currently available on the market, the devices generally have low number of UV-C lamps (Guimera et al., 2018) or are open-type (Yang et al., 2019), work on low throughput regime (Li et al., 2017) or employ design elements that require additional energy use, e.g., cooling of light source (Song et al., 2020), thus, there is still a lack in the equipment that is both effective and safe for the end-user, especially in the cases when humans are unable to leave room during the disinfection process, e.g., hospital wards. The aim of this research was to construct an effective UV–ozone disinfection device that can be used in the presence of humans and has a high throughput. Disinfection efficacy against Grampositive and Gramnegative bacteria that are representatives of healthcare-associated infections and Pseudomonas phage Φ6 (candidate surrogate for enveloped viruses such as EBOV, influenza virus, coronavirus (SARS-1), Venezuelan equine encephalitis virus, and other pathogenic enveloped viruses (Whitworth et al., 2020)) aerosols have been tested with the developed device. Furthermore, the presence of ozone and air ions have been evaluated to ensure end-user safety.

MATERIALS AND METHODS

UV–ozone device configuration

The UV–ozone disinfection device was designed and constructed by engineers of Rezekne Academy of Technologies, Latvia. The device (400×400×670 mm, 25 kg total weight, 4 wheels for mobility, Fig. 1) was equipped with 28 mercury lamps (11 W, 16 mm in diameter, 200 mm long) emitting UV radiation at 254 nm and ozone. The shaft mirrored walls were coated with silver to increase the generated radiation and reduce any potential accumulation of microorganisms during the device standstill. The mercury lamps were placed horizontally in a 200×200×200 mm vertical shaft in 6 individually controllable rows. The number of lamps in each row are placed in the following quantities: 5–4–5–5–4–5. Thus, a large flow cross-sectional area (min 240 cm^2, max 400 cm^2) and a long path (20 cm) is provided. From the outside, the UV–ozone disinfection device is coated with steel plates to prevent direct contact of UV light with human skin and eyes. As a result, people can safely stay in the room during the disinfection tests; as well, without using the UV protective glasses. At the same time, the open 200×200 mm shaft under the device ensures simultaneous surface disinfection.

To determine the particle flow and distance from lamps during irradiation, simulation tests with SolidWorks 2020 Flow Simulation were performed.

To ensure air flow through the device, four fans with a flow capacity of 200 m^3 h^{-1} at no-load running were installed at the top of the device and operated in a manner that air enters the device shaft from the top, moving down along the UV radiation lamps, and flow out at the bottom of the equipment. If required, each fan can be run individually. To estimate the exposure distance and velocity field, calculations were performed in an

empty 12×6×4 m (length, width, height) space with SolidWorks 2020 Flow Simulation. The disinfection unit was located in the middle of the room.

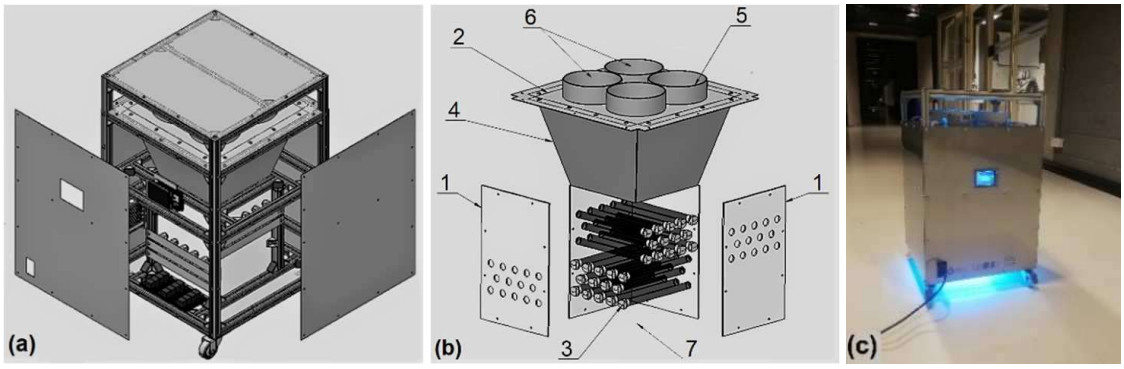

Figure 1. The schematic diagram of the UV–ozone disinfection device: (a) the 3D model; (b) the equipment elements: 1 – inner wall; 2 – inner top wall; 3 – UV lamps; 4 – truncated square pyramid; 5 – fans (WKA 125 TURBO); 6 – air inlet zone; 7 – air outlet zone; (c) a photo of the pilot-scale UV–ozone disinfection device.

UV irradiation of the individual lamps was measured with spectrometer Avantes AVS-PC2000. Further, the intensity of the UV irradiation at a distance b from lamp surface was calculated according to the equation (1):

$$I = \frac{\eta \cdot P}{\pi \cdot (D + 2 \cdot b) \cdot L} \quad (1)$$

where η – UV lamp efficiency coefficient; P – power; D – lamp diameter; L – lamp length.

To test the sound level, sound measurements were performed with VOLTCRAFT SL-451 (measurement error 1.4 dB) at 1 m distance from the device and 1 m above the floor.

Microbial strains and growth conditions

Antibacterial activity of UV–ozone disinfection device was assessed using *Escherichia coli* ATCC®10536 and *Staphylococcus aureus* ATCC®6538. Overnight cultures in Luria–Bertani (LB) broth (10 g L^{-1} tryptone, 10 g L^{-1} NaCl, 5 g L^{-1} yeast extract, pH 7.0) were thrice washed with sterile peptone water (0.1%) by centrifugation (6000 rpm for 2 minutes, Minispin, Eppendorf). The final bacterial pellet was re-suspended in sterile peptone water (0.1%) to obtain a stock solutions of *E. coli* and *S. aureus* (approximately 10^6 colony forming units (CFU) mL^{-1}). For cell enumeration 0.005 mL of the stock suspensions were filtered through a 25–mm-diameter 0.2–µm-pore–size filter (Polycarbonate Track- Etch Membrane, Sartorius, Germany) and fixed with 3–4% formaldehyde for 10 minutes, washed with sterile distilled water and stained with 10 µg mL^{-1} DAPI (4',6-diamidino-2-phenylindole, Merck, Germany) for 5–10 minutes. Cell concentrations were determined with epifluorescence microscopy (Ex: 340/380; Em: > 425, dichromatic mirror 565 nm, Leica DM6000B, Germany) by counting of 20 random fields of view.

For antiviral efficacy tests Pseudomonas phage Φ6 (DSM 21518, CsCl-purified from actively growing culture) was used. Estimated concentration ~ 3×10^9 plaque forming units (PFU) mL^{-1}.

Disinfection efficiency tests

To test the disinfection efficiency *E. coli, S. aureus* or Pseudomonas phage Φ6 suspensions were sprayed into 2 or 4 air inlets (before the ventilators). Each spray dose contained 0.13–0.15 mL of the microbial suspension, thus, ~ 10^6 CFU of bacteria and ~ 10^9 PFU of bacteriophage was introduced in each run. To measure the amount of organisms released from the system, simultaneously four 90 mm diameter Petri dishes of Tryptone soya agar (TSA, Oxoid Ltd) were placed at an air outlet zone of each side of the device (Fig. 1, b. 7). For surface disinfection one 140 mm diameter Petri dish representing ~ 39% of the treated surface was placed under the system. All samplings were performed for 10 or 30 sec by holding the dish exposed at the respective air or surface zone. Each run was repeated 4 times, each time placing the Plates at different sides of the device air outlet zone or at the surface exposure zone. Directly after the contact time the dish was removed. In-between the runs, the system was operated for 5 minutes at full regime to exclude cross-contamination from previous runs. Tests have been performed for 1) 4 ventilator and 28 UV lamp regime; 2) 2 ventilator (suspensions were sprayed twice to ensure the same concentration) and 28 UV lamp regime, and 3) 4 ventilator and 16 UV lamp regime. After the treatment, the plates from bacterial tests were directly incubated at 37ºC for 24 hours. Plates with Pseudomonas phage Φ6 were covered with top agar and *Pseudomonas spp.* overnight culture, gently mixed and solidified, then the plates were incubated in an upright position for 24 h at 25 °C. The results are expressed as log reduction of CFU or PFU.

Direct plating of suspensions prior tests was performed to obtain suspension controls (initial viability). Negative controls were obtained by running the device with 4 ventilators and switched-off UV lamps and collecting air and surface samples after 60 sec of exposure. All test results that were used for efficacy calculations had no growth in prior negative control tests.

Ozone concentration measurements

Ozone concentration was measured with 'Gas Detector PLT300-O3' (measurement error ± 10 mg m^{-3}) in an auditorium (12×6×4 m) with forced ventilation. The UV-ozone disinfection device was placed in the middle. The measurements were performed for 2 h before the device is switched on and during 4 h of operation (4 ventilators and 28 UV lamps).

Air ion concentration measurements

To determine air ion concentration bipolar light air ion counter Sapfir-3M was used. All measurements were performed in an auditorium (12 m × 6 m × 4 m; 18 °C room temperature; 55% humidity) with no forced ventilation. Two days before the measurements all windows were closed with tight blinds. Overall test time (100 min) was divided into 6 steps. First air ion counters were placed on 2 tables at 1 m distance from the UV–ozone disinfection device and 1.5 m apart from each other (1, 2, 4–6 measurement steps). In 3rd measurement step air ion counters were placed on the floor 60 cm apart from the UV–ozone disinfection device at different sides. During the experiment steps 1–5 the measurements were performed in the dark, at step 6 – under artificial daylight (16 luminescent bulbs). During the test time there was 1 person in the room at a distance of 3 m from the experimental stand, except when it was necessary to turn on / off the UV–ozone disinfection device or place the air ion counters on the floor

or on a table. Windows and doors were closed during the test time. When the disinfection device was switched on all 28 UV lamps and 4 fans were operating. All other electronic equipment (excluding 2 air ion counters) was switched off during the test period. Each counter showed the average amount of air ions measured during 64 s. The concentration was calculated as the average of the results reported by the 2 air ion counters.

RESULTS AND DISCUSSION

System design and operational features

During the design of an air UV disinfecting device, the placement of UV lamps is essential, as it is one of the main factors determining the effectiveness of the process. The particles should flow as close as possible to the UV source and contact time should be as long as possible. Airflow simulations (Fig. 2) of the device demonstrated that the maximum distance of all airflow particles from the lamps do not exceed 5 mm, thus, ensuring sufficient irradiation efficiency.

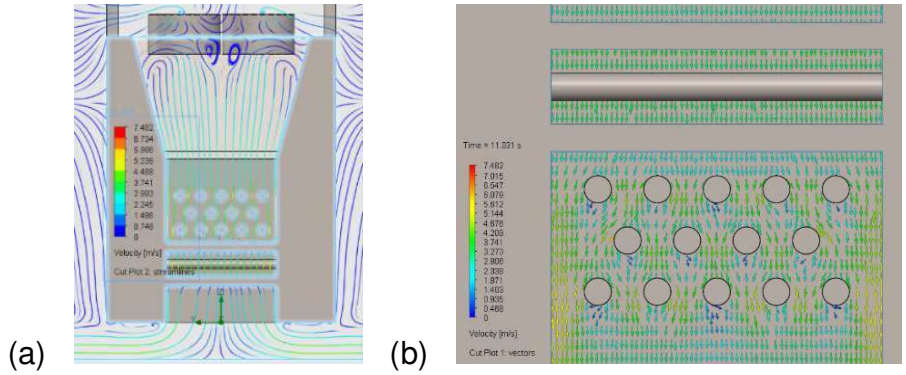

Figure 2. Airflow in the device at time moment 11 s after its switching on. (a) cross-section in yz axis; (b) cross-section in xz axis. Produced with SolidWorks 2020 Flow Simulation.

At the same time, an intensive flow of air is required to ensure high throughput. It is practically impossible to achieve all these conditions simultaneously with one or a few UV lamps, because by reducing the maximum distance of the flowing air particles to the surface of the lamp, the cross-section of the flow must be reduced; this in turn increases the flow rate and reduces the UV exposure time. Devices with one (Guimera et al., 2018) to six (Yang et al., 2019) lamps, air velocity below 1.5 m s^{-1} (Guimera et al, 2018) have demonstrated germicidal efficiency. However, not all aspects related to throughput, efficiency or ergonomics can be addressed simultaneously. Often, the lamps in the devices are open, thus, can cause serious damage to eyesight. Here all 28 UV radiation lamps were placed in a 20×20×20 cm three-dimensional grid of a shielded shaft to ensure efficient irradiation and high flow rate. Furthermore, the irradiation is not directly emitted into the room.

Internal shaft airflow simulations (Fig. 2) resulted in 2.8 m s^{-1} average outlet velocity from the disinfection zone, which corresponds to a unit productivity of 400 m^3 h^{-1} (4-fan regime), 450 W maximum power at the moment of switching on, 250 W during the operation mode and exposure time of 0.07–0.28 s depending on the amount of operating fans. During the full capacity operation, the measured sound level of the system reached 57.3–58.5 dB (registered background noise was 30.5–33.5 dB). A

minimal decrease is observed if only a single ventilator is running. In these cases, the noise level was 54.2–55.0 dB. Thus, at current setup the device cannot be used in bedrooms and hospital wards during the night. However, in industrial, commercial, shopping and traffic areas, indoors and outdoors, animal and poultry farms it can be operated without limitations.

To estimate the exposure distance of the disinfection device, simulations in an empty space were performed. The results after 300 seconds of the device operation showed that air particles attained speed throughout the whole room volume (Fig. 3). The observed particle trajectories were vortices that start at the outlet of the device and end at the inlet of the device.

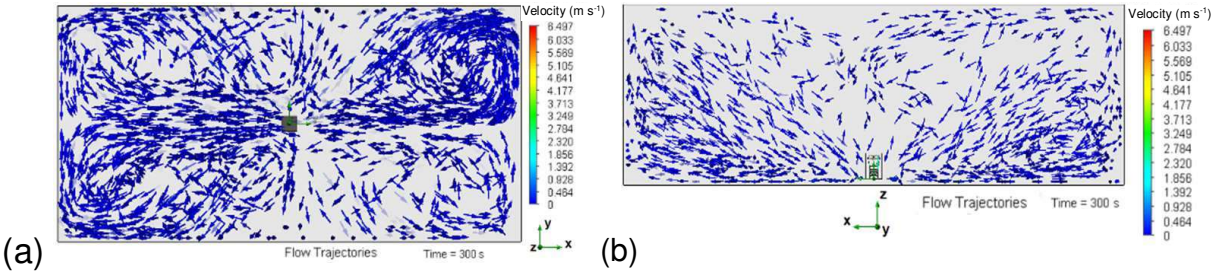

Figure 3. Airflow in the room (12×6×4 m) at time = 300 s after switching on of the device. (a) top view in xy axis; (b) side view in xz axis. Produced with SolidWorks 2020 Flow Simulation.

To estimate the time it takes for the exhaust air to reach the far wall, rise to the ceiling and return to the unit, a velocity distribution in the selected perimeter direction was used. Calculations showed that an air particle can pass a given perimeter of 1,020 s (if the perimeter is selected at a distance of 50 mm from the floor, wall and ceiling) or 620 s (if the perimeter is selected at a distance of 100 mm from the floor, wall and ceiling).

Furthermore, to reduce the possibility of dust rising and exposing human or animal airways to microbial pollution, the airflow after the exhaust at the bottom of the unit is directed in a horizontal direction along the floor (Fig. 2, Fig. 3). The dust in the vicinity of the device is drawn into this stream and blown away in a radial direction. In the periphery of the room, as the flow rate decreases, the particles settle on the floor.

Air ion concentration

In rooms with PM10 concentration above 0.1 mg m^{-3}, devices that generate light air ions can form heavy cluster ions that are harmful to health (Skromulis, 2019). Alternatively, if the device does not generate air ions, it can be used also in dusty rooms. To determine if the UV-ozone disinfection device during operation forms any ions, measurements were performed under 6 regimes (Fig. 4)

Some positive and negative air ion increase was observed from ion counters (1st regime, no other electronic devices are operating, no light is present and impossible that natural radiation background is changing so rapidly during the 100 min test time). Then, when the UV-ozone disinfection device was switched on, a certain decrease in ion concentration was observed (2nd regime). This could be explained by the movement of the person that was switching on the system, since human body absorbs air ions near the measuring equipment. Near the floor (3rd regime) the concentration of air ions was low since the floor surface adsorbed them. When the ion counters were placed back from the

floor to the table (4th regime), first a low concentration of air ions is registered (the person is close to the ion counter; the human body adsorbs ions), but then, as the process stabilizes, the ion concentration increases. When 1st and 4th regime is compared (Fig. 4), it can be seen that the results are similar. When the UV–ozone disinfection device is switched off (5th regime), a low air ion concentration is observed (human body is absorbing those), then the ion concentration increases. When the artificial light is switched on (6th regime), an increase in the concentration of positive air ions is observed. The obtained tests demonstrated that UV–ozone disinfection device practically does not generate light air ions, thus, it can be used in all rooms, regardless of the concentration of dust particles.

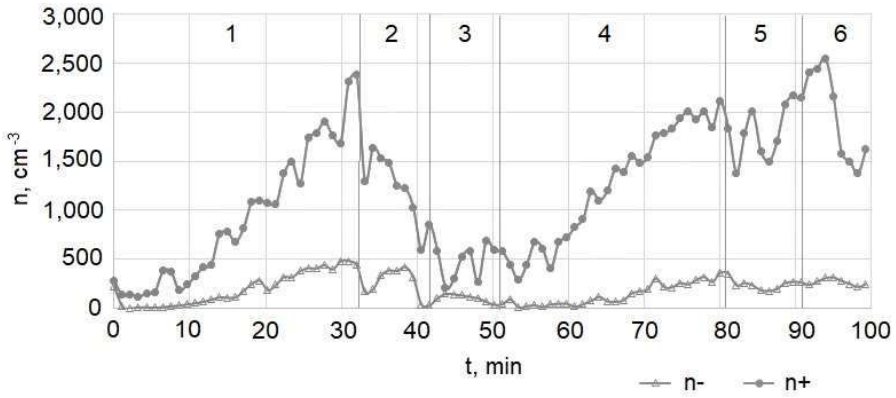

Figure 4. Positive and negative air ion concentration changes in the room with UV–ozone disinfection device present during 6 tested regimes: 1 – the device is switched off, in the dark; 2 – the device is switched on, in the dark; 3 – the device is switched on and ion counters are placed on the floor; in the dark; 4 – the device is switched on, in the dark; 5 – the device is switched off, in the dark; 6 – the device is switched on, artificial light.

Ozone generation and UV irradiation quality of the system

To further assess the efficiency and safety of the device, ozone generation and UV irradiation assessment was performed. According to the WHO recommendations maximum daily 8-hour average ozone concentration should not exceed 100 µg m^{-3} (Amann et al., 2008). Finnish Society of Indoor Air Quality and Climate sets more strict requirements, especially for rooms that reside elderly people, people with allergies or respiratory illnesses. There, ozone concentration cannot exceed 20 µg m^{-3}. In rooms with good indoor climate, the norm is set to 50 µg m^{-3} and satisfactory indoor climate should have not more than 80 µg m^{-3} of ozone (Säteri, 2002). At the same time Republic of Latvia Cabinet Regulation No. 1290 'on ambient air quality' set that maximum daily 8-hour average ozone concentration should not exceed 120 µg m^{-3}. If the one hour mean concentration reaches 180 µg m^{-3} information should be distributed. Alert threshold is reached when the ozone concentration exceeds 240 µg m^{-3} (Cabinet of Ministers, 2009). Within this study ozone concentration was measured in an auditorium before and during the operation of the UV–ozone disinfection device. The estimated background concentration of the ozone in the room was 40–70 µg m^{-3}. During the operation of the device, the ozone concentration in the air ranged from 50–100 µg m^{-3}. At certain short-term moments it reached the value of 120 µg m^{-3} meaning that short operational period of the device (15–30 min) will not affect the 8-hour average ozone concentration. Prolonged operation time should be evaluated on case to case basis and according to national or local regulations.

Furthermore, the device can be equipped with ozone meters that automatically control the operation of the UV device based on the ozone levels in the room.

To assess the operational quality of the system, UV lamp efficiency was calculated based on the obtained spectra from individual lamps (Fig. 5). The spectral range of the mercury lamps was in the range from 185–855 nm. The calculated area under 254 nm peak accounted for 24.9% from the total spectral area, meaning, that the UV irradiation (254 nm) intensity is around 25% from the total irradiance. Based on the available information (Chen & O`Keeffe, 2020) efficient germicidal effect is produced only at 254 nm UV irradiation. Infrared, visible light or near UV irradiation has no significant effect on disinfection. Thus, the efficiency of UV lamps was $\eta = 0.25$.

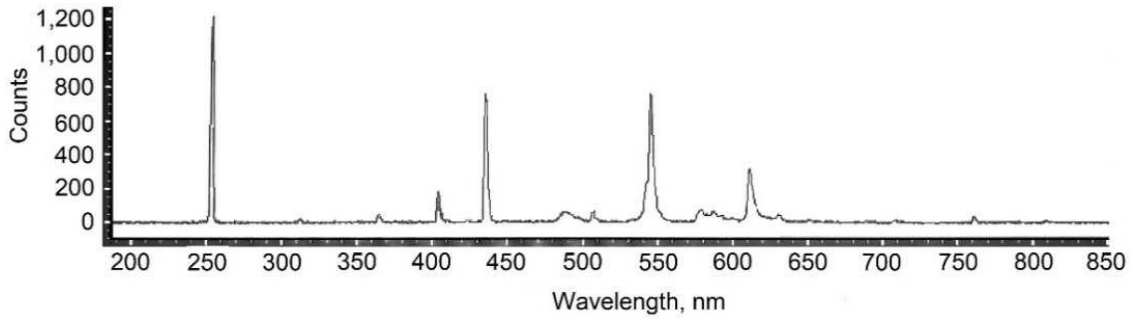

Figure 5. UV irradiation spectrum of the lamp used in UV–ozone disinfection device.

Use of more efficient UV lamps would allow to install more powerful ventilators and, thus, increase the throughput of the device without minimizing the germicidal efficiency. Lately alternative UV irradiation lamps filled with As, Tl or other elements have been described (Zorina et al., 2020). They have UV peaks at wavelengths below 254 nm (up to 190 nm). Meaning that the photons emitted by these lamps have a higher energy. Thus, their biological effect must be more effective than that of widely used 254 nm mercury lamps. So far, these high frequency electrodeless lamps (spherical shape) have only been described in experimental research with a diameter of 10 mm. If cylindrical UV lamps of such innovative filling electrodes will become commercially available, then they can be installed in the given equipment to significantly increase the air flow and reduce the operating time of the equipment in large rooms.

In the UV–ozone disinfection device the lamps are arranged so that the flowing air particles approach the surface of the lamps at a distance b = 0–5 mm. Thus, airborne microorganisms receive the minimum UV irradiance (I_{min}) of 16.8 mW cm^{-2} if b = 5 mm and maximum intensity (I_{max}) of 27.4 mW cm^{-2} if b = 0 mm. 28 lamps that are arranged in 6 layers inside the device, significantly increase the disinfection time of the flowing air. Furthermore, the shaft has silver-plated mirror walls. The upper part of the shaft has a steel plate, the lower part is open to additionally disinfect the surface of the floor. The reflection coefficient for 251 nm UV irradiation of a polished silver surface is 24.1%, and 32.9% for a steel surface (Hulburt, 1915). The reflection coefficient for UV irradiation of floor coverings: 8% for concrete, 22% for white concrete tile and 11.5% Ceramic tile (Turner & Parisi, 2018). Considering these factors, it can be concluded that the intensity of UV irradiation in the disinfection shaft of the device increases by 30–35% as a result of multiple reflections. Thus, the irradiance in the disinfection shaft is in the range of 21.9–36.9 mW cm^{-2}. Operation of all 4 ventilators will result in the

flow of 2.8 m s^{-1} and exposure time of 0.07 s. This will result in the irradiance dose of 1.5–2.6 mJ cm^{-2}. Similar doses have been reported for 90 % reduction of SARS-CoV-2 (Sabino et al., 2020).

Disinfection efficacy tests

Similar research with disinfection equipment (Heimbuch et al., 2011) has shown that 254 nm UV irradiation from one 80 W lamp with total intensity of 1.6–2.2 mW cm^{-2} can reduce 4 $\log_{10}$ of viable H1N1 virus within 15 minutes. Alternatively, UVC irradiation for 120 seconds demonstrated ≥ 99.95% bacterial CFU decrease in simulated healthcare surface disinfection tests (Guridi et al., 2019). In the UV–ozone disinfection device designed within this study UV irradiance is around 15 times higher. The increase in power and irradiance results in the increased efficiency of the system. The disinfection time is reduced significantly and 5 $\log_{10}$ reduction can be obtained for both bacteria and virus within 10 seconds of contact time (Fig. 6.) in air quality tests. Only minor increase in the efficiency is observed if the sample contact time is increased to 30 seconds. However, the reduced counts could more account to certain UV irradiation at the air exit zones than efficiency as such. Higher efficiency in bacterial neutralisation was observed for 28 lamp regime than for 16 lamps (Fig. 6, a, b).

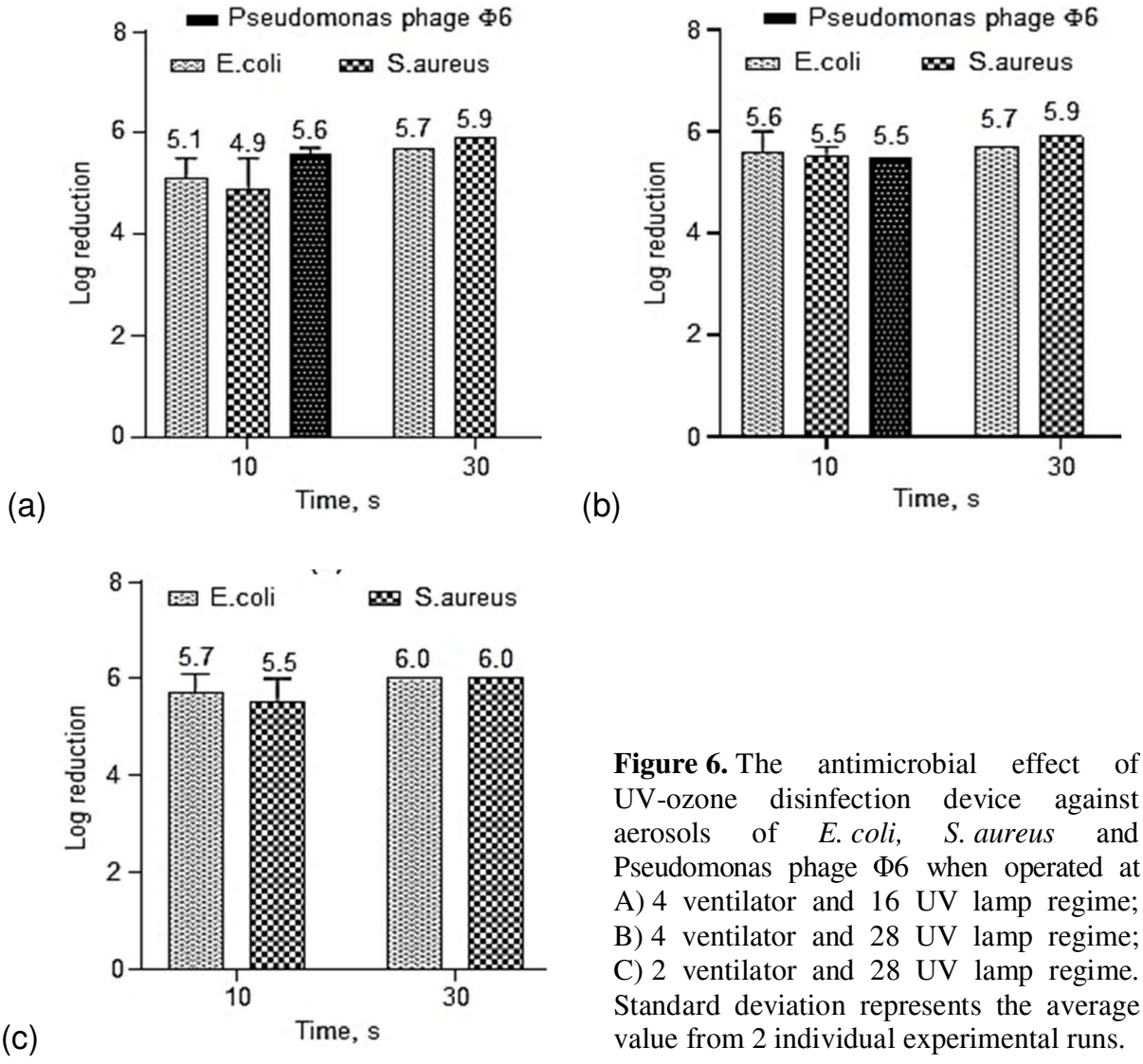

Figure 6. The antimicrobial effect of UV-ozone disinfection device against aerosols of *E. coli, S. aureus* and Pseudomonas phage Φ6 when operated at A) 4 ventilator and 16 UV lamp regime; B) 4 ventilator and 28 UV lamp regime; C) 2 ventilator and 28 UV lamp regime. Standard deviation represents the average value from 2 individual experimental runs.

Surface disinfection tests demonstrated no growth (> 6 $\log_{10}$) of either *E. coli* or *S. aureus* at the exposed area of the device irrespective of the amount of lamps used. Some viral particles were detectable after 10 sec treatment, however, it still accounted for more than (> 7 $\log_{10}$) reduction.

No significant impact of the lamp quantity was observed for the neutralisation of Pseudomonas phage Φ6. Nevertheless, more than 5 $\log_{10}$ reduction was observed after 10 seconds.

Use of 2 ventilators decreased the air flow rate and resulted in an increased contact time of the particles in the system, thus higher efficiencies were observed (Fig, 6, c).

The observed decrease is sufficient for a system to perform air-disinfection. A mere 6 $\log_{10}$ reduction can be obtained under simulated conditions with high aerosol doses of healthcare-associated microorganisms. To a large extent, the high increase in disinfection efficiency can be associated with the use of many but smaller UV lamps, their correct placement (the air flow is as close as possible to the surface of the lamps) and installed mirror walls.

CONCLUSIONS

The shielded UV-ozone disinfection device with 28 UV lamps demonstrated high efficiency to reduce aerosols of Grampositive and Gramnegative bacteria and virus. More than 99.999% CFU or PFU were neutralized within 10 seconds of system operation.

At the same time the system causes ozone concentration increase only for 10–50 μg m^{-3} from the background level and practically does not produce light air ions, so it can be used in dusty rooms with PM10 concentration above 0.1 mg m^{-3}.

Slight increase in operational noise, excludes the use of the equipment during the night, at the same time it operates at 400 m^3 h^{-1} throughput to efficiently treat the air at 6 m distance (empty room).

The shielded construction allows to operate the equipment in human presence.

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