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THE HYGIENIC PRINCIPLES OF USING BACTERICIAL ULTRAVIOLET MONOCHROME LED IRRADIATORS OF THE OPEN TYPE FOR PREMISES AIR DISINFECTING

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Introduction. The use of modern LED sources of bactericidal UV radiation is a promising direction for improving the air quality in different premises. In Ukraine and the world, there are standards for the use of bactericidal UV radiation to disinfect indoor air and surfaces, but there is a need for hygienic regulation of the use of open-type UV irradiators.
The aim of the study is to determine the hygienic principles of using bactericidal ultraviolet monochrome light-emitting diode (LED) irradiators of the open type for air disinfection in rooms of various purposes.
Materials and methods of the study. Instrumental measurements of the intensity of ultraviolet radiation and evaluation of the photobiological safety of the ultraviolet monochrome LED irradiator of the open type UVC T5-5W-275NM were carried out in accordance with DSTU EN 62471:2017, taking into account the coefficient of biological action in the range of 210–310 nm, the exposure limit value (ELV) of UV radiation was calculated for human skin and eye and doses of 90.0 % and 99.9 % bactericidal action for the most common biological pathogens: Influenza viruses, *Streptococcus viridans, Corynebacterium diphtheria, Staphylococcus aureus, Mycobacterium tuberculosis.*
Results. The measurement results show that, in accordance with the safety criteria set by DSTU EN 62471, a person is allowed to stay at a distance of more than 2 m from the LED irradiator (UVC T5-5W-275NM) for 8 hours. At a distance of 1.0 m from a working LED irradiator, the time of stay is permissible, taking into account risks of dangerous effects on the skin and eyes should not exceed 60 min. The main condition for the use of open sources of UV radiation is that the effective bactericidal dose should not exceed the effective exposure limit value for human skin and eyes according to DSTU EN 62471:2017.
Conclusions. Ultraviolet bactericidal open-type LED irradiator UVC T5-5W-275NM is a source of monochrome UV radiation, subject to assessment of exposure risks for human skin and eyes according to DSTU EN 62471:2017 «Safety of lamps and lamp systems photobiological». The main condition for the use of open sources of UV radiation is that the effective bactericidal dose should not exceed the exposure limit value (ELV) 30 J/m^2 according to DSTU EN 62471:2017. When developing recommendations for the use of UV radiation sources in premises in the presence of people, it is necessary to take into account the specific sensitivity of microorganisms to UV radiation and its selected level of bactericidal efficiency. To disinfect Influenza viruses, *Streptococcus viridans, Corynebacterium diphtheria, Staphylococcus aureus,* with a bactericidal effect of 99.9 %, it is advisable to use monochrome LED UV emitters of the open type with a wavelength of 230 nm. With the aim of 99.9 % bactericidal effect in the case of the *SARS-CoV-2*, in the presence of a person, it is advisable to use open sources of UV radiation with a wavelength of 220–290 nm.

Key words: hygienic principles, bactericidal ultraviolet monochrome LED emitters of open type, indoor air disinfection

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Introduction

The bactericidal effect of artificial UV radiation is actively used to disinfect air and surfaces from various biological pathogens [1–3]. Taking into account the peculiarities of biological action, the risks of negative effects of UV radiation on human eyes and skin are determined [4–9]. According to DSTU EN 62471:2017 «Safety of lamps and lamp systems photobiological (EN 62471:2008, IDT; IES 62471:2006, MOD)» the maximum permissible exposure for effective energy exposure is 30 J/m^2 [5]. Directive 2006/25/EC establishes that for UV 180–400 nm with daily exposure of 8 hours the exposure limit value (UV-A, UV-B and UV-C) is 30 J/m^2 (risks of damage to the conjunctiva, lens and retina, skin) [6]. Biological efficiency coefficients (UV hazard functions) are used to calculate the effective energy exposure of UV radiation [7, 8].

In accordance with the Order of the Ministry of Health dated 06.05.2021 No. 882 on the use of ultraviolet bactericidal radiation for air disinfection and disinfection of surfaces in the premises of health care institutions and institutions for the provision of social services/protection of the population, bactericidal radiation in places where people stay (near beds of patients when they are on the bed and at workplaces of the staff – at eyes level) should not exceed 0.2 μW/cm^2. At the same time, the surface dose of bactericidal radiation at a wavelength of 254 nm for an exposure of 8 hours is 6000 mJ/cm^2 (60 J/m^2) [9].

In previous years and today, low-pressure mercury lamps are actively used in Ukraine for bactericidal purposes, which emit in a wide spectrum [10] and have the negative side effect of ozone formation, which requires appropriate safety measures. Instead, recently, monochrome UV light sources based on light emitting diodes have appeared on the market, which are an alternative to the use of mercury lamps. In terms of their power and functionality, they occupy an intermediate position between bactericidal lamps and sources of prophylactic UV radiation.

Different technologies of using bactericidal UV radiation during the Covid-19 pandemic to disinfect this pathogen are of special interest [11–13].

M. Buonanno et al. (2020) showed the effectiveness of UV radiation (222 nm) against human coronaviruses transmitted by airborne droplets [11]. At the same time, low doses of 17 J/m^2 and 12 J/m^2 inactivated 99.9 % of airborne coronavirus aerosol of alpha HCoV-229E and beta HCoV-OC43 types, respectively.

Thus, the use of modern LED sources of bactericidal UV radiation is a promising direction of improving the air in premises of permanent or temporary stay of people.

The aim of the work is to determine the hygienic principles of using open-type bactericidal ultraviolet monochrome LED irradiators for air disinfection in premises of various purposes.

Materials and methods of the study

The study of the parameters of ultraviolet radiation during the operation of the open-type LED irradiator UVC T5-5W-275NM manufactured by LLC «LED Azimut» (Kamyanske, Ukraine) was carried out in a specialized darkened laboratory premises (illumination level < 1 lux) at air temperature of 20.2 °C and relative humidity – 40 %. There are no sources of moisture and thermal radiation, there are no external electromagnetic interferences (EMF levels of 50 Hz and 10 kHz – 300 MHz were below the sensitivity of P3–50 and P3–31 meters).

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Nominal power of the LED irradiator UVC T5-5W-275NM was 5 W, the wavelength of radiation λ_{max} = 278.6 nm. The opening angle of the LED irradiator was 120°. Ultraviolet radiometers were used: «Argus-06» (UV-C), «Argus-05» (UV-B), «Argus-04» (UV-A); energy dosimeter Tensor-51 (Ukraine) were used to measure dose of UV radiation, also.

Evaluation of UV radiation doses that is necessary to achieve bactericidal efficiency of 90 % and 99.9 % for Influenza viruses, S*treptococcus viridans, Corynebacterium diphtheria, Staphylococcus aureus, Mycobacterium tuberculosis* was carried out on the basis of the data of Methodical Recommendation No. 11-16/03-06 [2] taking into account the relative efficiency coefficients of UV radiation at wavelengths of 210–310 nm in accordance with GOST R 8.760-2011 [3].

Results of the study and their discussion

The radiation spectrum of LED irradiator UVC T5-5W-275NM in the range of 200–400 nm is presented in Figure (measurements were carried out on Inventfine CMS 3000 S/UV equipment presented by Inventfine Instrument Co, Ltd).

The UV radiation intensity at distances from 5 cm to 2.5 m is presented in Table 1 during UVC T5-5W-275NM irradiator's work. This Table 1 also presents the values of UV radiation exposure calculated according to Appendix ZB 3.1. to DSTU EN 62471:2017 «Safety of photobiological lamps and lamp systems».

The data presented in Table 1 show that the safe distance for the UV-C range (200–280 nm), at which the value of the actual UV exposure with the regulated duration of exposure time for 480 minutes (8 hours) does not exceed the exposure limit value of (ELV) is the distance 2 m or more from the UV irradiators.

In the UV-B (280–315 nm) and UV-A (315–400 nm) ranges, at a distance of 0.5 m, the intensity of UV radiation (mW/m^2) is below the sensitivity of the measuring device.

Thus, the results of measurements indicate that at a distance of more than 2 m from the LED UVC T5-5W-275NM irradiator, a person is allowed to stay for 8 hours in accordance with the safety criteria according to DSTU EN 62471.

At a distance of 1.0 m from a working LED irradiator, the permissible time taking into account the risks of dangerous effects on human skin and eyes, the stay should not exceed 60 minutes.

The main condition for the use of open sources of UV radiation is that the effective bactericidal

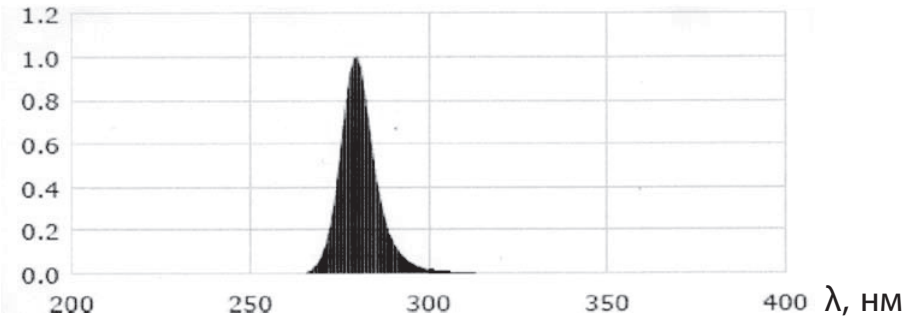

Figure. Emission spectrum in the range of 200–400 nm of LED irradiator UVC T5-5W-275NM

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Table 1

Intensity of UV radiation, exposure value and permissible exposure time during UVC T5-5W-275NM irradiator's work

Distances from UV irradiator, m	Intensity of UV radiation, mW/m²			Exposure value accord. to DSTU EN 62471:2017, J/m²		Permissible UV exposure time, min
	UV-C (200–280 nm)	UV-B (280–315 nm)	UV-A (315–400 nm)	UV-irradiation time 480 min	Exposure limit value	
0.05	550	37	70	13 939	30	1.03
0.2	128	11	15	3242		4.5
0.5	32	b.s.m.d.*	b.s.m.d.*	806.4		17.8
1.0	9.5	b.s.m.d.*	b.s.m.d.*	240.8		60.0
1.5	4.5	b.s.m.d.*	b.s.m.d.*	114.0		126.3
2.0	1	b.s.m.d.*	b.s.m.d.*	25.3		480
2.5	b.s.m.d.*	b.s.m.d.*	b.s.m.d.*	–		–

Note. b.s.m.d. – below the sensitivity of the measuring device.*

dose should not exceed the effective exposure limit value (ELVeff.) for human skin and eyes according to DSTU EN 62471:2017. In this regard, Table 2 shows the energy dose of UV-C with a wavelength of 254 nm for a bactericidal efficiency of 90 % and 99.9 % for certain microorganisms according to the data from the literature [1] and the time required for 90 % and 99.9 % efficiency at distances of 1 m and 2 m when using a UV irradiator LED UVC T5-5W-275NM.

Taking into account the coefficient of relative biological efficiency of ultraviolet radiation $K(\lambda) = 0.500$ at a wavelength of 254 nm in relation to risks for human eye and skin according to the standards of DSTU EN 62471:2017 [5] and ACGIH (1977, 2017) [7, 8], the exposure limit value for this wavelength of UV radiation is 60 J/m².

Table 3 shows the doses of UV radiation at a bactericidal efficiency of 90 % and the exposure limit value (EEL) at different wavelengths, taking into account the bactericidal efficiency coefficients of GOST R 8.760-2011 [3].

It can be seen from the data shown in the Table 2 for influenza virus, the bactericidal dose of 90 % does not exceed the ELV in the wave range of 220–260 nm, which makes it possible to use open sources of UV radiation such as LED UVC T5-5W-275NM at workplaces for 8 hours a day. It is possible to use UV radiation sources with a wavelength of 220–270 nm for the disinfection of *Streptococcus viridans*, 230–280 nm for *Staphylococcus aureus* and 230–254 nm for *Mycobacterium tuberculosis*.

Table 4 shows the UV doses for the bactericidal efficiency of 99.9 % and the exposure limit value (ELV) for human skin and eyes at different wavelengths from 210 to 310 nm.

For Influenza viruses, bactericidal exposures with a 99.9 % effect do not exceed the ELV only at the radiation wavelength of 220 nm, which makes it possible to use an open-type UV irradiator in such conditions in presents of people. For *Coronavirus types 229E* and *OC43*, for this purpose, it is advisable to use UV radiation with a wavelength of

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Table 2

The dose of the bactericidal efficiencies of 90 % and 99.9 % for individual microorganisms and the time required to achieve it

Microorganisms	UV-C exposure value, J/m²			The time required for 90 % efficiency of UV exposure, min		The time required for 99.9 % efficiency of UV exposure, min		The time required for ELVef. accord. to DSTU EN 62471:2017, min	
	Bactericidal efficiency		ELVeff. for human skin and eyes						
	90 %	99.9 %		by 1 m	by 2 m	by 1 m	by 2 m	by 1 m	by 2 m
Influenza viruses	36	66	30	72	683	132	1252	60	480
Streptococcus viridans	20	38		40	380	76	721		
Corynebacterium diphtheria	34	65		68	645	130	1233		
Staphylococcus aureus	49	66		98	930	132	1252		
Mycobacterium tuberculosis	54	100		108	1025	108	1897		

220–290 nm. It should be noted that UV radiation with a wavelength of 280–290 nm is presented in the spectrum of sunlight [12, 13]. Thus, the presence of direct sunlight is important in the prevention of *SARS-CoV-2*. This confirms the fact that in summer there is a significant decrease in the incidence of *SARS-CoV-2* [14].

For 99.9 % destruction of such microorganisms as *Mycobacterium tuberculosis* and *Corynebacterium diphtheria*, it is impractical to use only open sources of UV radiation in presence of people. It is necessary to include closed type UV irradiators (recirculators), which could clean effectively the air [15].

Thus, the use of modern LED sources of bactericidal UV radiation is a good perspective for improving the air in the premises of permanent or temporary stay of people, but the existing regulatory and methodological base for the use of bactericidal UV radiation for disinfection of air and surfaces in premises needs improvement in the direction of hygienic regulation of use Open-type UV irradiators.

Conclusions

1. Ultraviolet bactericidal LED irradiator UVC T5-5W-275NM is a source of radiation in the ranges of UV-C (200-280 nm), UV-B (280-315 nm), UV-A (315-400 nm), which is subject to assessment of exposure risks for the human skin and eyes according to DSTU EN 62471:2017 «Photobiological safety of lamps and lamp systems».
2. The main hygienic principle for the use of open sources of UV radiation is that the effective bactericidal dose should not exceed exposure limit value exposure limit value (ELV) according to DSTU EN 62471:2017 – 30 J/m² (taking into account the spectral function of the severity of UV danger for the skin and eyes). To comply with this condition, it is necessary to install UV irradiators at a safe distance and control the time of human exposure, which must be included in the manufacturer's instructions.

Table 3

UV dose at the bactericidal efficiency of 90 % and the exposure limit value (ELV) at different wavelengths (λ)

Microorganisms	UV dose (254 nm), J/m²	UV dose at a bactericidal efficiency of 90 %, J/m² at different wavelengths (nm)										
	Bactericidal efficiency 90 %	λ = 210	λ = 220	λ = 230	λ = 240	λ = 254	λ = 260	λ = 270	λ = 280	λ = 290	λ = 300	λ = 310
Influenza viruses	36	3442	193	86	56	36	32	32	41	94	1033	30 960
Streptococcus viridans	20	1912	108	48	31	20	18	18	23	52	574	17 200
Corynebacterium diphtheria	34	3250	182	81	53	34	31	30	38	89	976	29 240
Staphylococcus aureus	49	4684	264	117	76	49	44	43	55	128	1406	42 140
Mycobacterium tuberculosis	54	5162	290	129	84	54	49	48	61	141	1550	46 440
ELV for human skin and eyes		**400**	**250**	**158**	**100**	**60**	**46**	**30**	**34**	**47**	**100**	**2000**

*Note. *Sanitary indicator microorganism according to MI No. 11-16/03-06; (green background indicates UV dose for bactericidal efficiency of 90 %, which do not exceed the ELV for human skin and eyes).*

Table 4

UV dose at a bactericidal efficiency of 99.9 % and the exposure limit value (ELV) at different wavelengths

Microorganisms	UV dose (254 nm), J/m²	UV dose at a bactericidal efficiency of 99.9 %, J/m² at different wavelengths (nm)										
	Bactericidal efficiency 99.9%	λ = 210	λ = 220	λ = 230	λ = 240	λ = 254	λ = 260	λ = 270	λ = 280	λ = 290	λ = 300	λ = 310
Influenza viruses	66	6310	355	158	103	66	59	58	75	172	1894	56 760
Coronavirus 229E	17	1617	91	41	26	17	15	15	19	44	486	14 554
Coronavirus OC43	12	1147	65	29	19	12	11	11	14	31	344	10 320
Streptococcus viridans	38	3633	204	91	59	38	34	33	43	99	1091	32 680
Corynebacterium diphtheria	65	6214	350	148	101	65	59	57	73	170	1866	55 900
Staphylococcus aureus	66	6310	355	158	103	66	59	58	75	172	1894	56 760
Mycobacterium tuberculosis	100	9560	538	239	156	100	90	88	113	261	2870	86 000
ELV for human skin and eyes		400	250	158	100	60	46	30	34	47	100	2000

*Note. *Sanitary indicator microorganism according to MI No. 11-16/03-06; (green background indicates UV dose for bactericidal efficiency of 99.9 %, which do not exceed the ELV for human skin and eyes).*

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3. According to laboratory instrumental measurements, when the LED UVC T5-5W-275NM lamp is operating within the regulated time of 8 hours , the exposure limit value of 30 J/m^2 will not be exceeded at a distance of more than 2 meters from the UV irradiator.
4. When developing recommendations for the use of UV radiation sources in premises in the presence of people, it is necessary to take into account the specific sensitivity of various microorganisms to UV radiation and selected bactericidal effectiveness. It is recommended to use open-type monochrome LED UV emitters with a wavelength of 230 nm to disinfect a complex of common biological pathogens, such as Influenza viruses, S*treptococcus viridans, Corynebacterium diphtheria, Staphylococcus aureus,* with a bactericidal effect of 99.9 %. It is irrational to use open sources of UV radiation in order to achieve a 99.9 % bactericidal effect in a case of *Mycobacterium tuberculosis*.
5. In order to achieve a 99.9 % bactericidal effect in the case of the *SARS-CoV-2* virus, in the presence of people in premises, it is advisable to use open sources of UV radiation with wavelengths of 220–290 nm.
6. The normative-methodical base on the use of open-type UV irradiators for air and surface disinfection in premises of various purposes needs improvement, taking into account the sensitivity of microorganisms to UV radiation and the risks to human skin and eyes.

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