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LIGHT POLLUTION FROM LED LIGHTING SYSTEMS AND WAYS OF REDUCING ITS ENVIRONMENTAL CONSEQUENCES

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Introduction. Light pollution (LP) is recognized as a global environmental problem. The need of reducing the level of LP is emphasized not only for the external environment, but also for residential premises.

The aim of the study – is to analyze the literature data and normative-methodological acts regarding LP, its negative impact on the environment and human health, prevention measures of justification of measures to reduce the levels of light pollution from outdoor lighting systems, and development of recommendations for their further improvement.

Materials and methods of the research. An analytical review of scientific publications over the past 20 years was performed using the databases EuroPub (Great Britain), Science Direct – Scopus – Web of Science – Core – Google Scholar "Google Academies", Hinari Access to Research for Health, National Library of Medicine, U.S. Environmental Protection Agency, National Library of Ukraine named after V. I. Vernadskyi, as well as scientific publications taken from open sources.

Results. Light pollution is a broad concept that refers to all problems caused by unnecessary, excessive or ineffective use of artificial light. With regard to the impact on people, light pollution is proposed to be considered as the presence of an excessive amount of light (over-illumination), which exceeds the regulatory documents for a given territory, room, time of day and lighting regime. In addition to the "glow" of the sky (sky glows), which is caused by the light scattered in the lower layers of the atmosphere from outdoor lighting systems, buildings, illuminated advertising, vehicles, etc., the following forms of light pollution are qualified: glare caused by excessive brightness of light; penetration of light (light trespass) beyond the necessary limits and negatively affects the living environment of people; "clutter" caused by powerful light sources that create excessive lighting. Light pollution is also widespread indoors, which increases the risks to people's health. The most negative consequence of artificial lighting at night for a person is the violation of biological rhythms due to the inhibition of nighttime melatonin secretion. Measures to mitigate the negative impact of light pollution in connection with the transition to LED lighting were considered taking into account the characteristics of the parameters of light-emitting diode (LED) light sources. To reduce the level of light pollution, the concept and principles proposed by the International Dark Sky Association (IDA) are taken as a basis. A list of measures to reduce the level of light pollution carried out in Ukraine is recommended.

Conclusions. Based on the analysis, conclusions were drawn regarding the need for further research on reducing the level of light pollution and its impact on the environment and human health, improving regulatory documents on LED lighting systems and implementing outdoor lighting projects according to the principles recommended by IDA.

Key words: light pollution, LED sources of light, circadian rhythms, spectrum of light, brightness, lighting, photo-biological danger of light

Introduction

The creation of artificial light sources is one of the most significant achievements of mankind. But night lighting also has negative consequences. Most of them are caused by so-called light pollution. The growing awareness of the scientific community about the negative effects of artificial lighting at night and the lack of natural darkness in nocturnal ecosystems has contributed to the recognition of light pollution as a global environmental problem. One of the main tasks of this review is to provide concise information about modern ideas about light pollution and its impact on the environment and human health.

Life on Earth developed in accordance with the natural cycle of day and night. At the same time, most organisms, including humans, have developed internal functional "oscillators" that are precisely tuned to

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daily (circadian) changes in lighting. The behavior and physiology of the majority of living organisms is controlled by this cycle. It should be noted that the natural level of night darkness has significantly worsened in recent years in large cities due to irrational artificial lighting, especially after the widespread introduction of energy-saving LED light sources. Today, the "glow" of the sky, which is created by the external lighting of cities, illuminated advertising, lighting of buildings, transport, etc., exceeds the level of natural twilight. Rapid changes in light levels at night have a devastating effect on organisms, populations, and ecosystems [1]. The potential impact of light pollution on human health extends from sleep disorders to many serious diseases [2].

An urgent problem for research is also the assessment of the features of the nighttime impact on people of light not only from lighting systems, but also from the use of electronic displays, the impact of artificial light penetrating into the home during the period of rest and sleep.

The aim of the research – is to analyze the directions of light pollution research and its impact on the environment and human health, as well as to develop proposals for improving the regulatory framework regarding the environmental friendliness and safety of LED lighting in Ukraine.

Materials and methods of the research

An analytical review of scientific publications over the past 20 years was performed using the terms "light pollution", "LED lighting", "circadian rhythms" according to the databases EuroPub (Great Britain), Science Direct – Scopus – Web of Science – Core – Google Scholar "Google Academies" Hinari Access to Research for Health, National Library of Medicine, U.S. Environmental Protection Agency, National Library of Ukraine named after V. I. Vernadskyi, as well as scientific publications taken from open sources.

Results of the research and their discussion

Light pollution (LP) is a broad concept that refers to all problems caused by unnecessary, excessive or ineffective use of artificial light. There is still no generally accepted definition of the concept of "light pollution". The International Dark-Sky Association (IDA) gives the following definition: light pollution is an artificial change in the level of illumination created by inappropriate or excessive use of artificial light. Light pollution is often understood as an increase in the natural brightness of the night sky due to artificial light emitted into the lower layers of the atmosphere [3]. A negative feature of LP is also the deterioration of darkness, which is caused by excessive or unwanted use of light. Some researchers suggest distinguishing between the astronomical concept of LP, which impairs the visibility of celestial objects, and ecological LP, which has negative consequences for wildlife and people due to the disturbance of the night environment [4]. With regard to the impact on people, light pollution can be considered as the presence of an excessive amount of light, exceeding the amount regulated by the relevant regulatory documents for a given territory, room, time of day and lighting mode.

In addition to the "glow" of the sky, IDA qualifies several other forms of LP: excessive and unnecessary use of light (over-illumination); glare caused by excessive brightness of light, which creates visual discomfort or blinding; penetration of light (light trespass) beyond the necessary limits, which creates unnecessary lighting and negatively affects the living environment of people; "light mess" (light clutter) caused by powerful, bright, randomly placed light sources, which creates excessive illumination and light scattering.

It is recognized that LP has a negative impact on the environment and is the most distorting element at night [2–5]. Since the corresponding physiological processes are triggered by natural light stimuli, research on the impact of artificial lighting at night on human health is mainly aimed at studying the mechanisms that lead to negative biological, medical and environmental consequences and determining preventive measures. Research on improving the quality of light and its photobiological safety, preventing such negative phenomena as brightness flickering, the occurrence of stroboscopic effect is also ongoing.

The most negative consequence of artificial lighting at night for men is a violation of biological rhythms, due to the suppression of the night secretion of melatonin. Disruption of circadian rhythms caused by night lighting is associated with an increased risk of developing various diseases, including cancer and diabetes, affects sleep, digestion, causes migraines, headaches, irritability, chronic fatigue, and others [2, 3, 6, 7–10].

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Light pollution is also widespread in office, industrial and household premises, which directly increases the risk to human health. The number of digital devices (computers, smartphones, tablets, etc.) that use LED matrices and emit a significant amount of blue light, which can significantly affect the human visual system, is increasing in everyday life and at workplaces. The use of LED light sources with a high correlated color temperature in residential premises also causes concern. The potential impact of light pollution on human health can manifest itself in sleep disorders, excess weight [11], mental disorders [12], and cancer [13]. Some studies indicate a potential connection between light pollution at night and early symptoms of Alzheimer's disease [12]. Considering the biological aspects of the effects of light pollution, circadian rhythms are the most important target, which is associated with a variety of health consequences. Studies of the impact of light pollution over the past five years (2018–2022) indicate a strong connection between this factor and human health risks [2].

In addition to the biological activity of light, which depends on the radiation spectrum, people's health and psychological state can be affected by high brightness of light, which creates visual discomfort and temporary blindness [14, 15], and the photobiological danger of blue light with a wavelength of 435–440 nm, which creates risks of damage to the retina [16,17]. Photobiological risks to the eyes that blue light can cause depends on the accumulated dose, which can be formed both during short-term intensive exposure and as a result of low-intensity exposure to light for a long time. At the same time, children and workers whose activities take place in conditions of a high level of lighting by sources with a high correlated color temperature (CCT) are at greater risk.

One of the negative effects created by artificial light sources is the flickering of light brightness. The biological impact of this factor on men is a function of modulation depth, flicker frequency, brightness, and other factors. The studies [18–20] summarize the results of the influence of flickering on biological processes and the conditions of their occurrence. It is noted that in the frequency range of 3–70 Hz, potential risks include convulsions, especially in persons with a diagnosis of epilepsy, as well as some specific neurological symptoms, including headache. Biological effects that occur under the action of invisible flickering (beyond the frequencies of visual perception) are less obvious. They include eye strain, fatigue, and headache. Point light sources are less likely to cause seizures and headaches than diffuse light that covers most of the retina. Insignificant risks also occur at low brightness (< 1 cd/m^2) and increase monotonically with increasing brightness. Red flicker with a large modulation depth and alternating red and blue flashes can be particularly dangerous.

Flickering brightness causes a negative impact not only on the well-being and health of people, but also on other living organisms. In [21] it is shown that diurnal species are primarily at risk, since in the studied nocturnal species, the threshold frequencies at which animals stop perceiving light flickering as a series of flashes (Critical Fusion Frequency – CFF) are very low to perceive flickering, and many nocturnal species avoid places illuminated by artificial light. It was found that flickering affects behavior and movement patterns, the visual system and stress level. A. Jechow et al. (2020) established that brightness flicker from light pollution has an active impact on the environment and requires further research [22].

There is no doubt that LP is a growing environmental problem. The gradual "loss of night" spreads over large areas of unlit regions as a result of the return of light scattered in the atmosphere to the Earth's surface. The brightness of the sky can in some cases exceed the brightness of the light of the full moon [22], and the direct radiation of the outdoor lighting system at night creates illumination on the Earth's surface hundreds of times higher than that caused by the glow of the sky. The consequences of artificial lighting at night (created by both direct light from lighting systems and the glow of the sky) are important at all levels of biodiversity - from individuals to ecosystems [5]. Interventions in biological processes may be associated with unnatural levels and duration of illumination, spectral composition of light, time of day, which leads to disruption of biological rhythms [23]. In addition, artificial light at night can increase susceptibility to other stressors. In urban settings, light pollution usually occurs simultaneously with heat and noise pollution, and often with water pollution with nutrients, synthetic chemicals, and heavy metals. All these stressors can affect physiology, behavior, abundance, as well as species interactions and ecosystem processes. To date, it is not clear how artificial lighting and these stressors

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interact and whether the results are additive, synergistic or antagonistic [24].

Light is of fundamental importance for all living organisms, being a source of energy and information for them [24]. The most important processes caused by light for animals and humans are vision and regulation of biorhythms due to changes in daily, monthly and seasonal cycles [25]. Almost all organisms have genetically determined internal clocks that are adjusted by periodic changes in lighting to balance the body's functions and behavior depending on the time of day, the phase of the month, or the season of the year. The most important are circadian rhythms, which play a central role in ensuring homeostasis in the body, including the restoration of physiological functions and are controlled by the daily change of light and darkness and control the synchronization of the sleep-vigor cycle, changes in body temperature and heart rate, hormonal balance, etc. [7, 26].

Artificial light at night affects the circadian clock, shifting it back. When circadian rhythms are synchronized with the solar day – they cause alertness during the day and sleepiness at night, and when they are desynchronized due to artificial lighting at night – alertness can occur at inappropriate times, and sleepiness may not coincide with the time allotted for sleep. If the light perceived at night is brighter than a certain level, it will affect the biological clock, which is designed to respond to sunlight. The level of illumination before bedtime is important for the quality of sleep [26]. A reasonable limit for suppression of melatonin secretion at night would be approximately 30 minutes at 30 lux. However, any given limit value will vary depending on the spectral composition of the light [27]. Suppression of the secretion of melatonin, the main marker of the circadian rhythm, occurs most intensively for the spectral range of light 446–477 nm [28]. This means that a light source with a high proportion of blue light will have a high potential to shift circadian rhythms and affect sleep if such light is used at night.

Measures to mitigate the negative impact of light pollution

Mitigation of the negative impact of light on the environment at night must be considered taking into account that there is no safe level at which anthropogenic light will simultaneously satisfy humans and not have any negative impact on the ecological system. Circadian rhythms in wildlife can be synchronized at light levels well below the threshold for effective human vision. Thus, mitigation is the task of providing a sufficient amount of light, which is necessary for human safety and minimizing the impact on the environment [29].

Outdoor lighting systems are one of the biggest sources of light pollution. The levels of illumination created by them range from 5–10 lux to 150 lux, which is much more than necessary [30]. Artificial light, scattered in the lower layers of the atmosphere, due to the increase in the brightness of the sky, creates illumination on the Earth's surface up to 0.15 lux. At the same time, the area illuminated on the Earth's surface due to the increase in sky brightness is much larger than the area of the radiation source.

Due to the mass transition to LED lighting, which is relatively new compared to other types of lighting, it is important to consider any potential impact on the environment and human health [27]. One of the specific properties of LEDs used for general lighting is that they have intense radiation in the blue region of the spectrum, which roughly coincides with the maximum of the spectrum of suppression of melatonin secretion (446–477 nm) and the spectrum of photochemical damage to the retina by blue light (photo maculopathy), with a maximum at 435–440 nm [16]. At the same time, LED lamps and lamps, if light diffusers are not used, can have high brightness (>1 Mcd/m^2), which creates a feeling of discomfort and blinding lightning [17, 27].

One of the negative effects created by LED lamps and lamps for general lighting is brightness flickering and stroboscopic effect. The problem of flickering has gained new relevance after the widespread introduction of LED lighting technology, especially when using pulse width modulation (PWM) to control the power of LED lamps. To limit the levels of flickering and the visibility of the stroboscopic effect, the Commission Regulation (EU) 2019/2020 [31] sets new requirements for LED light sources: short-term flicker index (Pst LM) < 1; stroboscopic effect visibility index (SVM) < 0.4.

The use of lamps with LEDs for outdoor lighting has caused concern among supporters of the fight against environmental and astronomical light pollution due to their following characteristics [27,29]:

– a large proportion of blue light in the light flux. LEDs, even with CQT 3000 K, have a radiation spectrum that is more dangerous for the environment than the spectrum of high-pressure sodium

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lamps, which were mainly used for outdoor lighting (in sodium lamps, there is practically no radiation in the blue region of the spectrum, which makes their light less biologically active) [30];
- LEDs differ from sodium lamps in the level of flickering and the size of the emitting surface with high brightness of blue light, which can negatively affect the environment, well-being and health of people [20, 21];
- LED lighting becomes less expensive and people have increased the use of LED light sources, which becomes a serious problem in reducing light pollution [29, 32].

The following outdoor lighting principles have been adopted by the International Dark Sky Association (IDA) to mitigate the negative impact of light pollution on the environment:
- the light should be directed only where it is necessary;
- the light should not be brighter than necessary;
- light should be used only when it is useful;
- if possible, it is necessary to use light of warm tones;
- external lighting must comply with the recommendations of EN 12464-2 standards, EN 13201, EN 12193.

In [30, 33] it is noted that not all minimum levels of illumination are established by standards developed on the basis of reliable empirical data, so in some cases it is advisable to establish scientifically based minimum levels of illumination.

For outdoor lighting, IDA also recommends the use of shielding, which allows you to direct light more precisely to the illuminated surface, while reducing illumination in areas where lighting is not needed. The light should not be directed upwards from the lighting area (at an angle of more than 900) and at angles of 80–900 from the vertical, as the radiation at these angles can spread over long distances. It is also undesirable to illuminate billboards and signs with spotlights. It is recommended to use reflective signs and signs with internal illumination.

Recommendations for outdoor lighting provide for minimum levels of illumination that are several orders of magnitude higher than the limit levels of influence on the synchronization of circadian rhythms in wildlife. Therefore, any reduction in the level of illumination will be useful for reducing the negative impact of light pollution on living organisms of wildlife. Ensuring the required level of illumination is achieved due to lamps with the required light distribution and light flow, lighting systems with automatic control, etc. It is possible to ensure the use of light when it is useful through the use of timers, motion sensors, automatic lighting control systems. This is one of the most effective ways to reduce the level of light pollution. Recommendations regarding the use of light sources with warmer light tones are justified by several reasons:
- sources with warm tones of light have more long-wave (green, yellow, orange, red) light compared to short-wave (violet, blue). Short-wavelength light is more intensively scattered in the atmosphere and, accordingly, makes a greater contribution to the glow of the sky;
- the peak sensitivity of the circadian systems of most species, including humans, falls on blue light with a maximum at a wavelength of 470 nm. Avoiding the use of blue light reduces the impact on the circadian system, especially for species with a low threshold for impact on the synchronization of circadian rhythms;
- in most groups of wild animals, the visual response is more sensitive to light with shorter wavelengths compared to human vision [30]. The peak sensitivity of the human eye, at which light is mainly perceived, corresponds to a wavelength of 555 nm, although people also see well in the yellow and red regions of the spectrum. Therefore, the absence of blue light in the spectrum does not significantly affect the sensitivity of people's vision to external lighting and reduces the impact on the circadian systems of people and living organisms of wildlife. IDA recommends the use of light sources with SST not higher than 3000 K for outdoor lighting.

In real conditions, light pollution affects the environment not separately, but in combination with air pollution by solid particles, chemicals, physical effects of electromagnetic fields, noise, etc. Combined pollution can increase the effects of individual types of pollution due to synergy.

Considering the prospects of LED lighting, the Lighting Europe association, which unites more than 1,000 companies in the field of lighting, has identified 4 most important areas of research [7]:
- replacement of traditional light sources with LED ones;
- development of intelligent lighting systems;
- human-oriented lighting;
- closed cycle economy.

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The introduction of LED technology makes it possible to replace analog lighting technology with digital and implement the concept of intelligent lighting systems. Human-oriented lighting systems together with the implementation of an intelligent lighting system are of fundamental importance. They are aimed at minimizing the negative effects of artificial light on a person's normal circadian rhythm and will help increase work productivity, improve sleep quality, and ensure comfortable visual function. Lighting design aimed at the needs of visual perception will be carried out by determining the lighting necessary for various types of activities and the environment. Circadian lighting, depending on the environment, dynamically adapts to prevent circadian stimulation in the evening and night hours and to promote it during the day when there is insufficient daylight.

The concept of a closed-loop economy is used to create a system that is self-regenerating and in which material resources, energy consumption, waste and emissions to the environment are minimized. The goal of the concept is to reduce the impact of artificial lighting on the environment, including reducing the level of light pollution.

The International Association of Lighting Designers (IALD) also published a technical document aimed at achieving the goals of creating human-centered lighting [8]. The central role here is also given to the topic of circadian lighting; among other topics – innovations of LEDs, reduction of the flickering level, improvement of photobiological safety of light and quality of color rendering [34, 35].

Modern achievements in the development of LED technology have made it possible to solve a number of important problems, such as replacing low-efficiency incandescent lamps and environmentally hazardous discharge mercury lamps in almost all areas of their use, improving the quality of artificial light, creating intelligent lighting systems, and getting closer to solving the problem of creating circadian systems lighting. As for reducing the level of light pollution and mitigating its impact on the environment and human health, a lot of attention is paid to these issues, although there are still no significant achievements here. On the contrary, the expansion of the use of LED sources for outdoor lighting has increased the level of light pollution. To solve this problem, a large amount of research is currently being conducted, legislative decisions are being made to limit the impact of light pollution on the environment and human health, limit levels of illumination are being established, and lighting equipment is being improved. In Ukraine, measures are also being taken to reduce the level of light pollution:

- for outdoor lighting, national standards of Ukraine have been implemented, harmonized with European standards (DSTU EN 12464-2:2016 [36], DSTU EN 13201-2:2015 [37], DSTU EN 13201-4:2016 [38]);
- the State Building Regulations of Ukraine DBN V.2.2.5-28:2018 [39] were developed, which set requirements for the maximum permissible parameters of external lighting installations to prevent light pollution. These requirements are harmonized with the European standard EN 12464-2;
- the National Standard of Ukraine DSTU 8546:2015 [40] was developed, which sets requirements for light distribution, protection angles, maximum values of light forces and brightness, and other parameters of LED lamps for indoor and outdoor lighting.

The main parameters of outdoor lighting installations, which are subject to control in order to prevent light pollution of the environment, are: vertical illumination of the object, the power of light in a potentially blinding direction, the light flow into the upper hemisphere, the average brightness of facades and signs [39]. It should be noted that the maximum allowable parameters of outdoor lighting installations depend on: a) the type of illuminated area; b) lighting mode.

All requirements related to light pollution were developed almost 20 years ago and from the point of view of extreme studies of the impact of LED light sources on the environment and human health do not correspond to the current level of knowledge. In particular, there are no requirements for the spectrum of radiation (for the biological activity of light) for sources used in outdoor lighting, too high a proportion of light emitted into the upper hemisphere (up to 25%) and high values of light intensity in the blinding direction (up to 25,000 cd), no new requirements have been established for the level of brightness flickering and stroboscopic effect, in accordance with the EU Commission Regulation 2019/2020, the method of determining brightness using the generalized discomfort index (UGR) does not meet the CIE recommendations for LED lamps with non-uniform brightness [31].

Current issues for Ukraine today are the organization of scientific research aimed at reducing

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the level of light pollution, the establishment of scientifically based limit values of parameters for LED outdoor lighting systems, the use of automatic lighting control systems. Since light pollution also affects residential premises, it is necessary to establish safe limit levels of light pollution during rest and sleep. An important task is the substantiation of the integrated assessment of light pollution, taking into account stationary and moving light sources.

For the successful solution of these actual problems in Ukraine, it is very relevant to establish scientific cooperation with European scientific institutions and use their best experience in reducing the impact of light pollution on the environment in EU countries.

Conclusions

1. Over the past 20 years, there has been a significant increase in research on the ecological consequences of light pollution on the environment and human health.
2. The most negative effects of artificial lighting at night with the use of LED light sources is the disruption of biological rhythms due to suppression of the nocturnal secretion of melatonin.
3. In addition to light pollution of the environment caused by outdoor lighting, illuminated advertising, lighting systems of buildings, vehicles, etc., this factor can also be present in premises during work, rest or sleep, which increases the risks to people's health.
4. Norms regarding the limitation of light pollution were developed almost 20 years ago (without taking into account the peculiarities of LED light sources) and do not correspond to the current level of knowledge: they lack requirements for the radiation spectrum/biological activity of light, for the level of brightness flickering and stroboscopic effect, and no methodology is presented brightness determination using the generalized discomfort index (UGR) for LED lamps with non-uniform brightness.
5. In order to reduce the negative impact of outdoor lighting on the environment and human health, it is necessary to establish the maximum permissible values for the parameters of LED lighting systems that determine the level of light pollution, and to implement innovative outdoor lighting projects taking into account the principles recommended by the International Dark-Sky Association.

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СВІТЛОВЕ ЗАБРУДНЕННЯ ВІД СВІТЛОДІОДНИХ СИСТЕМ ОСВІТЛЕННЯ ТА ШЛЯХИ ЗМЕНШЕННЯ ЙОГО ЕКОЛОГІЧНИХ НАСЛІДКІВ

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Вступ. Світлове забруднення (light pollution) визнане глобальною екологічною проблемою. Підкреслено актуальність зниження рівня світлового забруднення не тільки для зовнішнього середовища, але й для житлових приміщень.

Мета дослідження – аналіз даних літератури та нормативно-методичних актів щодо світлового забруднення, попередження наслідків його негативного впливу на довкілля та здоров'я людини, обгрунтування заходів щодо зниження рівнів світлового забруднення від систем зовнішнього освітлення та розробка рекомендацій щодо їхнього подальшого удосконалення.

Матеріали та методи дослідження. Аналітичний огляд наукових публікацій за останні 20 років виконано з використанням баз даних EuroPub (Великобритания), Science Direct – Scopus – Web of Science – Core – Google Scholar «Академії Google» Hinari Access to Research for Health, National Library of Medicine, U. S. Environmental Protection Agency.

Результати. Світлове забруднення – це широке поняття, яке відноситься до всіх проблем, викликаних непотрібним, надмірним або неефективним використанням штучного світла. Стосовно впливу на людину світлове забруднення запропоновано розглядати як наявність надмірної кількості світла (over-illumination), що перевищує регламентоване нормативними документами для даної території, приміщення, часу доби та режиму освітлення. Крім «світіння» неба (sky glows), що спричиняється розсіяним у нижніх шарах атмосфери світлом систем зовнішнього освітлення, будівель, світлової реклами, транспортних засобів та інше, як форми світлового забруднення кваліфікуються: відблиски (glare), що викликаються надмірною яскравістю світла; проникнення світла (light tresspass) за межі необхідного, що негативно впливає на середовище проживання людини; «світловий безлад» (clutter), викликаний потужними джерелами світла, що створюють надмірне освітлення. Світлове забруднення поширене й у приміщеннях, що збільшує ризики для здоров'я людини. Найнегативнішими наслідками штучного освітлення в нічний час для людини є порушення біологічних ритмів через пригнічення нічної секреції мелатоніну. Заходи щодо пом'якшення негативного впливу світлового забруднення в зв'язку з переходом на світлодіодне освітлення розглядались з врахуванням особливостей параметрів світлодіодних (LED) джерел світла. Для зниження рівня світлового забруднення за основу взята концепція та принципи, які запропоновані Міжнародною асоціацією збереження темного неба (IDA). Рекомендовано перелік заходів зі зниження рівня світлового забруднення, які проведені в Україні.

Висновки. На основі проведеного аналізу зроблені висновки щодо необхідності подальших досліджень стосовно зниження рівня світлового забруднення та його впливу на навколишнє середовище та здоров'я людини,

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вдосконалення нормативних документів на системи світлодіодного освітлення та реалізацію проєктів зовнішнього освітлення за принципами, які рекомендовані IDA.

Ключові слова: світлове забруднення, світлодіодні джерела освітлення, циркадні ритми, спектр випромінювання, яскравість, освітленість, фотобіологічна небезпека світла

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