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THE ASSESSMENT OF LIGHT POLLUTION IN THE CITY OF KYIV

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Abstract. The analysis of environmental issues raised by the excessive artificial illumination in the selected areas of the central districts of Kyiv was conducted. The level of light pollution was measured using photometric equipment and compared to the levels of natural illumination. The instrumental measurements were amended with visual observation of sky glow levels and subjective perception of sunset timing. Based on the obtained results the possible health effects for the residents of affected districts were considered.

Keywords: light pollution, health effects, stellar visibility, photometry, Bortle scale.

1. Introduction

Nowadays, artificial light sources are an integral part of modern cities. However, the problem is that their number far exceeds that needed to provide a sufficient level of lighting in the city streets. Moreover, this issue is poorly regulated at the level of municipal authorities. Thus, it forms a new form of physical pollution–light pollution, able to violate natural living rhythms and cause anomalies in the lives of plants and animals.

The main cause of light pollution is outdoor luminaires that emit light upwards or sideways. This light spreads everywhere until a tree or building can block it, which will either become the final point of light pollution reception or cause further scattering throughout the atmosphere. This eventually makes the night sky brighter, thereby reducing the view of it. Particulate matter in the urban air is another reason for light scattering at night; this finally makes the amplitude of illumination in cities much lower due to atmosphere dimming. Some light is also reflected from the earth and other surfaces into the sky, but this component is milder due to the attenuation of light (Luginbuhl et al., 2009; McColgan, 2007).

The diversity of light pollution sources creates a wide range of problems due to peculiarities of light propagation and specific traits of affected objects. Thus, it is currently divided into:

Light clutter is excessive groupings of lights.

- Light trespass occurs when unwanted light enters one's property
- Glare is difficult to see in bright light such as direct or reflected sunlight or artificial light such as car headlamps at night.
- Over-illumination is lighting intensity higher than appropriate for a specific activity or above the need.
- Sky glow is the diffuse luminance of the night sky, apart from discrete light sources such as the Moon and visible individual stars (Mizon, 2001; Kyba et al., 2018). At the same time, outdoor lighting consumes up to 5 % of electricity demand in developed countries (Ożadowicz, Grela, 2017), much of which (from 20 to more than 50 %) contributes to light pollution (Luginbuhl et al., 2009).

2. Analysis of the previous research

The first concerns about light pollution were formulated by the astronomers as they have started

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losing the ability to watch the night sky normally because of illumination (Luginbuhl et al., 2009; Gallozzi et al., 2020). Thus, the Palomar Observatory of the California Institute of Technology, California, US, has lost part of its potential due to urbanization approaching the facility, chosen back in the 30s of the XX century for the completely dark sky. Over the last 50 years, as countries became affluent and urbanized, demand for outdoor lighting increased and light pollution sprawled beyond the city limits and into suburban and rural areas. This form of pollution is now prevalent in Asia, Europe, and North America. Most of the urban citizens around the world cannot see the Milky Way (Cinzano et al., 2001).

Further, the effect of photopollution on biota has become apparent through a range of research efforts by Smith M., Holker F. et al., Rich C. and Longcore T., Bennie J., Davies et al., Gaston, K. J. et al. Based on this, the light pollution problem has been split into purely physical component, preventing normal stellar visibility, and so-called ecological light pollution to describe the adverse effects of artificial night-time light to some plants and animals (Holker et al., 2010). The destructive effects of this pollution have also induced studies of the potential consequences for protected areas, having the highest level of demand for the conservation of pristine conditions, including photic conditions as a critical abiotic parameter for many sensitive species (Duriscoe, 2001).

Humans are also dependent on the light, despite living in strongly transformed conditions of urban areas. The evidence that indoor artificial light at night influences human health were already clear, but the clear interaction between light pollution and health disorders needed evidence. Light pollution has also been proved to cause health effects by a range of researchers, meeting for the first forum on the medical effects of exposure to light pollutants in 2006 (Stevens et al., 2007). The data coming from Stevens J., Longcore T. et al., Le Tallec T. et al., C. A. Wyse, Navara K. J. and Nelson R. J. show that health effects in the human population exposed to light pollution range far beyond circadian rhythms violation. Thus, living in cities apart from the other well-known health hazards involves night-time illumination, which may further induce the manifestation of detrimental changes in organisms.

Following the establishment of relations between light pollution and human diseases, a range of works containing an assessment of light pollution was published for cities like Las Vegas, Miami, Buenos Aires, Denver, Mecca and Medina, Helsinki, Chicago, Calgary. The research group headed by Cinzano P. and Falchi F. created a series of maps presenting the situation with light pollution in the world (Cinzano et al., 2001). As for Ukraine, the most polluted points are large cities such as Kyiv, Dnipro, Kharkiv and Odesa. The Environmental monitoring Committee of the Professional Association of Ecologists of Ukraine in cooperation with the Institute of Space Research of the National Academy of Sciences of Ukraine is conducting the first study on light pollution in Ukraine, based on satellite images - Night Light project. However, detailed studies of light pollution in the cities of Ukraine are still absent and the problem is usually considered as an architectural and energy-saving issue as in research for Odesa by Akopova A. (Akopova, 2016) while being considered negligibly small in most of the environmental assessments. However, the need for further research is formulated in the reports, dealing with visual pollution in cities (Bondarchuk, Petruk, 2016).

Thus, minimizing light pollution is an important environmental problem, as it will reduce potential negative impacts on living organisms, including humans, improve conditions for astronomic observations and provide significant energy savings. Therefore, Kyiv as one of the cities with a high level of light pollution in Ukraine was chosen for the study. The aim of the given research is to assess the level of light pollution in Kyiv and develop recommendations in terms of both health effects reduction and energy conservation.

3. Methods and Materials

Growing awareness of light pollution has increased the need for the development of measuring techniques. However, the technique to be applied depends on the form of pollution to be measured. In case of measuring excessive light coming from street illumination, the standard measuring equipment for light intensity can be used. This includes light (lux) meters of various configurations. It measures illuminance (light intensity within a space) in foot-candles or lux – it is the amount of light (lumens) falling on a surface.

Measuring sky glow to quantify its relationship to electric lighting is a much more challenging task. It must account for angular distribution of the light emitted from the luminaire, the light reflected from the ground, as well as atmospheric effects of humidity and the interaction of light with aerosols, all of which can change from moment to moment (McColgan, 2007). Since the beginning of the 90s, a number of metrics or calculation methods have been developed to estimate sky glow (Garstang, Walker, Lockwood et al., Upgren). One very

simple approach is to estimate sky glow by looking for the Plough (a large asterism consisting of seven bright stars of the constellation Ursa Major) and then counting how many stars are visible to the naked eye. However, none of the metrics directly relate electric lighting emissions to sky glow. But without the ability to model this lighting information, it is difficult to determine how to minimize sky glow while minimizing the impact on the use of light at night.

Considering the available methods, photometry with Luxmeter Yu-116 and visual observations to study the condition of the night sky were used for the analysis of light pollution in Kyiv. The results of visual observations were evaluated using the Bortle scale. The Bortle scale is a nine-level measurement system used to track the amount of light pollution in the sky. Level 5 or less is the amount needed to view the Milky Way, while level 1 is the "primitive", the darkest possible (Bortle, 2001). The levels of this scale differ in the following way:

- 1 is a really dark sky. A lot of technical details, such as stars and constellations, can be seen with the naked eye, but 1 is when you cannot see your car in the parking lot, even if it is right in front of you.
- 2 is when there is a faint light on the horizon, the Milky Way is visible, but it is not easy to see it.
- 3 is the sky that can be seen in any village.
- 4 is the sky that can be observed at the border of the countryside and the suburbs.
- 5 is the sky in the suburbs.
- 6 is also a "suburban sky", but brighter.
- 7 is a sky can be observed on the border of the city and suburban areas.
- 8 is the night city sky.
- 9 is when you can hardly see any stars or constellations at night, even with a telescope. You can only make out large celestial bodies, such as the Moon.

Another phenomena evaluated within the research framework was the subjective perception of the sunset, the time of which was personally noted in one of central points in Kyiv during a year and averaged for further analysis on a monthly basis.

4. Results and Discussions

4.1. Characteristics of the study area

For the analysis, light levels were measured at fifteen points in the city each season during the year. Measurements were performed in the central part of the city (Pechersk district) as the hot point of light pollution. The points at which the measurements were made belong to 3 categories: business area, natural area, residential area. The choice of the observation points was made so that they represent a maximal variety of illumination conditions or levels of light pollution; they were also chosen as easily accessible with no interference for light propagation from the source to the potential receptors.

Business areas are points near the outlets, which are typically the brightest places in this area of the city. This category includes 5 points:

1. IQ business centre is a business centre located at 15 Bolsunovska Street. Next to the building, there is a highway and residential buildings, and a park area across the road.

2. Gulliver Mall is a multi-storey shopping centre located at 1a Sportyvna Street, near the highway with heavy traffic and the concert hall "Palace of Sports".

3. Khreshchatyk Street – the central street of Kyiv, with shopping centres, catering establishments and a highway.

4. Embankment (Dnipro station) – the embankment of the Dnieper River, near the road with heavy traffic and the bridge for subway trains.

5. NSC Olympic – a stadium near the square and the road, as well as residential buildings and catering establishments.

The level of illumination near the points of this category was measured three times. The first measurement was taken at a distance of 25 meters from the building, the second – at the distance of 50 meters from the building and the third – at the distance of 100 meters from the building. Measurements were performed at different distances to track changes in the level of illumination of the territory depending on the distance to the point of interest.

The next category is natural areas. This category includes points with natural or artificial vegetation, namely, all major parks of the city district, where measurements were taken in proximity to the obvious light sources and as far from them as possible. Lighting levels were measured in 5 parks:

1. Navodnytsky Park is near the Dnieper River and a road with heavy traffic. The measurements were taken near the monument to the founders of Kyiv.

2. Mariinsky Park is in the city centre, near Independence Square, the waterfront and the city centre. The measurements were taken near the People's Friendship Arch.

3. Park of Eternal Glory is near the Arsenalna metro station. The Eternal Flame and the Monument to the World War II victims are located there. Nearby there is a road with heavy traffic and residential buildings. Measurements were taken near the monument.

4. Park of Fame is the park where the Motherland Monument is located. Measurements were made right next to the monument.

5. Taras Shevchenko Park is located near the central building of the Taras Shevchenko National University. High traffic roads and residential and public buildings are near the park.

The level of illumination at the points of this category was checked twice. The first measurement was taken directly under the trees, and the second measurement was taken on the path.

The third category of points covers residential areas – the measuring points near residential buildings, which were chosen randomly so that they are distributed relatively evenly over the study area. The following 5 points belong to this category:

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1. 5 John Paul II Street – the area near the grocery store, next to the road.

2. 16a Boulevard of People's Friendship – a residential building next to the road with heavy traffic.

3. Residential areas near Khreshchatyk Street – residential buildings located at 3 Shota Rustaveli Street, near the road with heavy traffic and catering establishments.

4. Residential areas near the University metro station – the area near residential buildings at 35 Pirogova Street, near the road.

5. Residential areas near the Arsenalna metro station – residential buildings at 4 Ivana Mazepy Street.

Measurements of light levels at these points were made three times. The first measurement was taken in the yard, the second – directly near the house, the third – near the road leading to the house (if any).

The measurement points were selected from the above categories to monitor how the level of light pollution changes depending on the point. After all, near shopping malls, in the central parts of the city and public places of the city, in addition to street lights, there is a large number of advertising banners and architectural lights, which causes high levels of physical pollution and impact on people and the environment. Measurement of the level of lighting in the parks was carried out to predict the possible effects of light pollution on flora and fauna.

4.2. Measurement results

The measurements were taken at the onset of complete darkness. The time of measurement, the nature of the underlying surface (dry, wet), the type of luminaries and the presence of greenery were taken into account. The nature of the underlying surface is an important indicator, because it affects the level of illumination through the reflection of light. To distinguish the light pollution from natural illumination and assess the magnitude of pollution it is necessary to choose the threshold value for which the intensity of illumination (luminance) at nights with the full moon (0.2 Lux) was chosen.

Analyzing the results of measurements (Fig. 1–3) a certain pattern of pollution was established. The first thing to note is that the level of light pollution in business areas is much higher than in other categories. It should also be noted that the level of illumination largely depends on the season: in winter the level of illumination is much lower compared to the indicators obtained in spring, but in general, the results of autumn and winter measurements are similar, with no sharp contrasts.

In the business areas, the main source of light pollution is the excessive number of lights installed along the roads, as well as a large number of illuminated advertising banners, architectural lighting and light from car headlights, because car traffic in these places is quite high. Sources of light pollution within the sites of natural areas are spotlights located along the alleys and the architectural lighting of monuments.

The results of measurements at the sites within the residential area during the year do not demonstrate considerable fluctuations and are normally below the accepted threshold value. As can be seen from the graph, the light level in these areas is normal. The sources of stray lighting in these areas are mainly light from the windows of residential buildings and street lights located in the neighbourhood.

The second part of the research included visual observations aimed at the assessment of sky glow and sunset delay (Table 1). On average, the state of the sky was scored 5–7 on the Bortle scale. The worst state of the sky by the Bortle scale is observed in cold months of the year, such as November, December, January, and February. The possible reason is that the humidity at this time of the year is quite high, which contributes to the scattering of light, especially from artificial sources.

Under the influence of light pollution in the city, the subjective perception of the sunset by population has changed. The citizens believe that the time when the sun has already set does not coincide with the astronomical time of sunset by 7–14 minutes on average. This difference is formed by the fact that people catch artificial lighting as natural, so it seems that the sun sets later than it really is (Table 1).

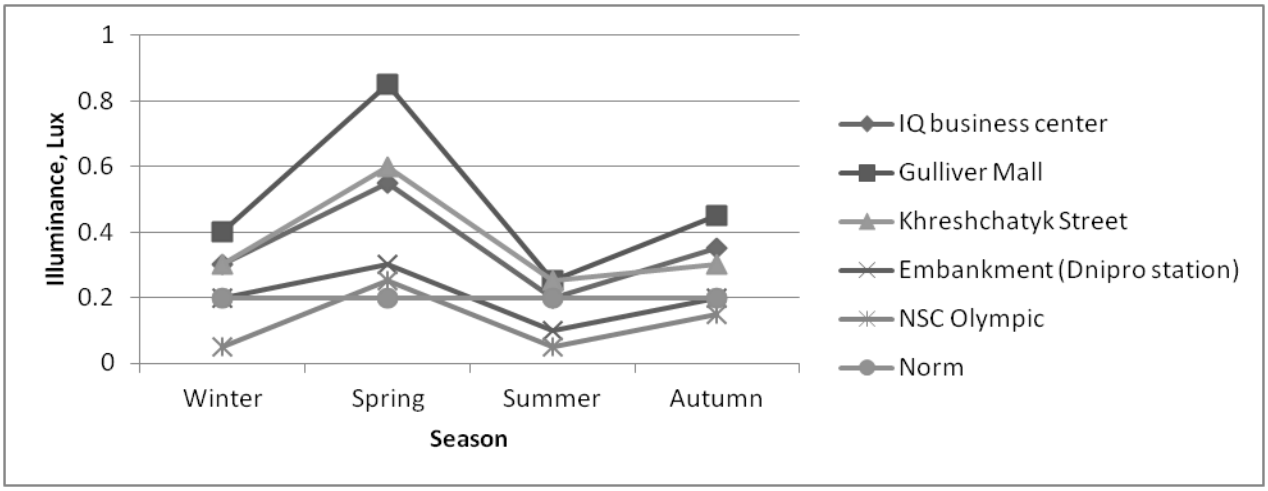

Fig. 1. The level of light pollution at the Business area sites

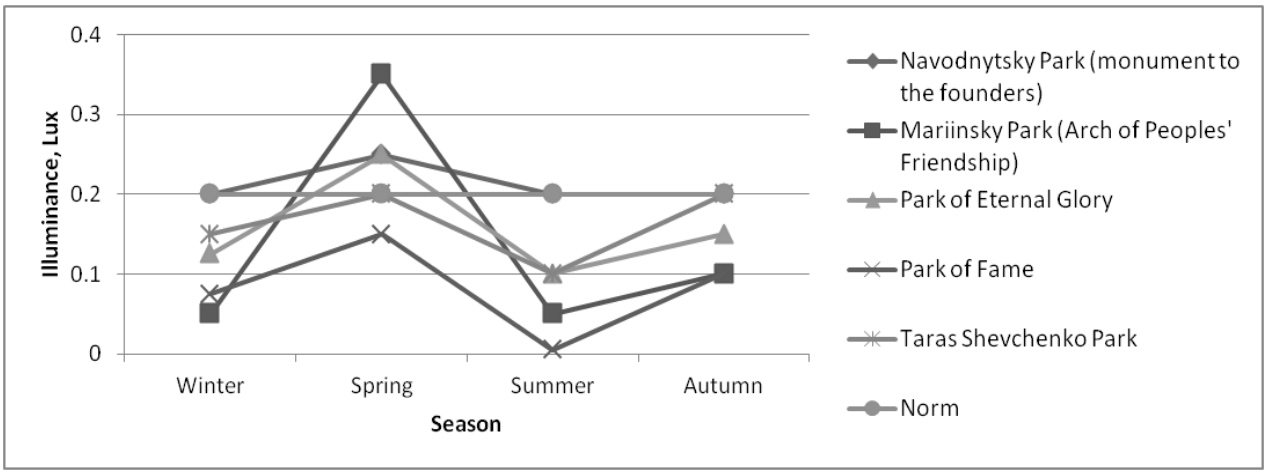

Fig. 2. The level of light pollution in the parks (natural areas)

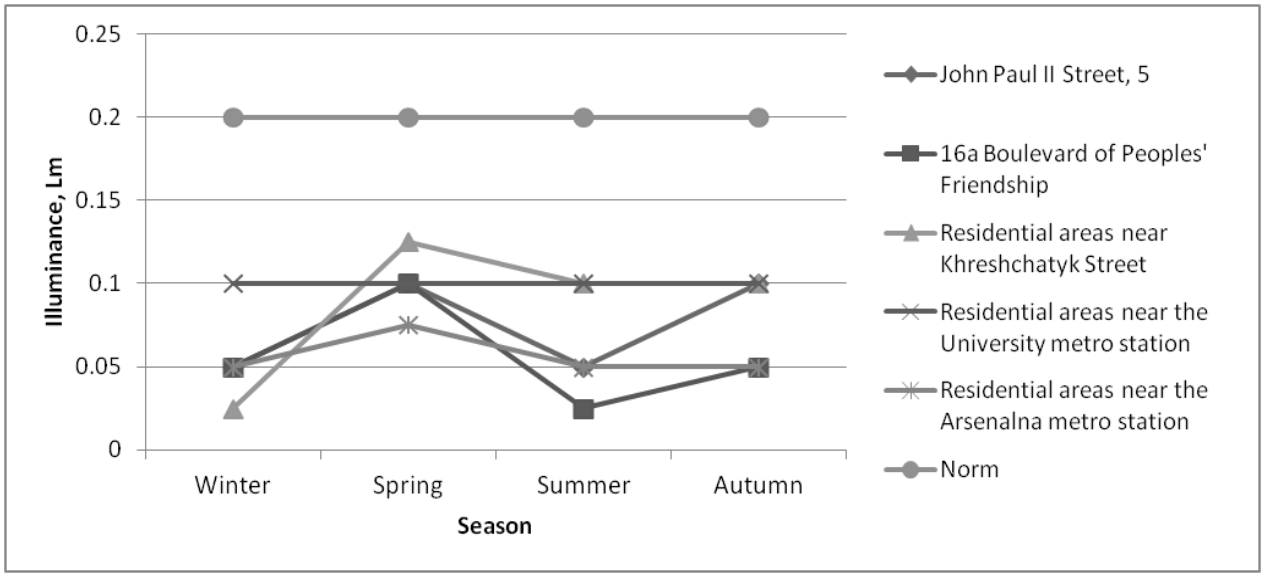

Fig. 3. The level of light pollution at the sites within the residential area

Table 1

Results of visual observations

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Parameter	Sky glow by the Bortle scale, average level											
Value	6.21	6.86	6.22	6.81	6.61	5.55	6.00	6.11	6.23	6.13	6.15	6.16
Parameter	Sunset time delay timing, time											
Value	07:00	07:53	06:07	14:10	07:00	08:04	08:06	06:00	09:08	06:34	07:53	06:36

Summing up the results of the analysis of the level of light pollution in the city of Kyiv, it was found that the level of lighting in the city exceeds the norm 10-100-fold. By the Bortle scale, the state of the sky in the city has an average rating of 7, which is typical for the city sky and the sky in the suburban area. Under the influence of high levels of illumination, the subjective perception of the sunset is different from the astronomical by 8 minutes on average. These deviations from the natural way of things might condition human health disorders and affect other living organisms negatively.

4.3. Results interpretation

The implications of the given level of light pollution are possible for all living organisms, inhabiting cities, but the significance and effects are quite different. Thus, plants will partially benefit from excessive illumination, as it will make them able to continue photosynthesis at night and compensate for nocturnal respiratory loss, but only in those plants that are directly illuminated above the minimal level necessary to initiate the process (Raven, Cockell, 2006). The urban fauna is probably less affected as common urban species are able to tolerate disturbance factors typical for cities either through avoiding mobility or adaptive plasticity.

Humans are considered to be the most affected with a wide spectrum of possible effects starting from visual effects to behaviour disorders (Chepesiuk, 2009). Thus, the meta-analysis of the observational and experimental studies applied to exposure assessment by scientists of various medical fields, done by Cho Y. M et al., show multiple evidence of increased breast cancer risks due to exposure to artificial light at night (Cho et al., 2015). Milder health effects proved by numerous researches are sleeping disorders, alertness, fatigue and negative effects on the psychological, cardiovascular and/or metabolic functions. The mechanism of the health disorders formation is based on the violation of circadian rhythms and melatonin secretion (Reiter et al., 2007).

To evaluate the possible health risk, the number of people living in the area affected by light pollution was defined. This figure included all sites of the business area with residential buildings, which made up 5726 people. According to the statistical data (Chepesiuk, 2009; Cho et al., 2015; Reiter et al., 2007), from 6 to 11 % of this population, depending on the intensity of exposure will experience headache and eye pain, fatigue, vertigo, sleeping disorder, depression, circulation disorders, and increased breast cancer probability by 5 %, which collectively means from 340 to 680 additional medical admissions a year. Thus, there is a real need for control and mitigation of light pollution within the central areas of the city, even though the overall level of photopollution is not very high in most of the purely residential blocks of the capital.

Still, the reduction of light pollution equals the improvement of energy efficiency, which is an intrinsic attribute of a sustainable city (Ovchynnikova, 2019). Living in a sustainable city is always a good choice for health due to decreased integral pressure on the environment resulted from lower demand for energy and consequently lowered power production volumes.

5. Conclusions

1. The city of Kyiv, like most modern cities, has significant problems with excessive lighting. The problem of light pollution is new in the field of environment and human health protection, and an integrated approach is needed to solve the issues of light pollution in the city. Despite being a new problem, the study of light pollution is supported with a variety of analytical methods based on the use of special instruments and visual observations.

2. The main drivers of this problem are inefficient lighting equipment, improper planning of lighting fixtures. Advertising and marketing trends also exacerbate the problem. Thus, there is a need to study the level of this type of pollution in the city of Kyiv, which is the largest urban area in our country.

3. In the course of our research, levels of light pollution were measured at 15 points in Kyiv. Measurements were performed during the year in each season. The study also assessed the state of the sky by the Bortle scale during the year, and subjective perception of the

sunset was observed during the year. The obtained results were compared to the background levels – the level of light at full moon.

4. Comparative analysis has shown that in general the level of lighting at all points is similar to the background levels except for the sites of business areas. The level of light pollution in business areas exceeds the background levels 10-100-fold.

5. According to the Bortle scale, the state of the sky in the city has an average rating of 7, which is typical for the city sky and the sky in the suburban area. Under the influence of high levels of light, the subjective perception of the sunset differs from the astronomical one by an average of 8 minutes. These deviations from natural phenomena can cause damage to human health and increase general morbidity and neoplasm incidence.

6. Thus, there is a need to develop regulations and establish standards for measuring light pollution and determine the permissible levels of impacts from this physical factor. It is possible to reduce the level of light pollution by introducing fairly simple legislation and restrictions.

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