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ÚSTAV JAZYKŮ

LET THERE BE LIGHT? IMPACT OF LIGHT POLLUTION ON THE ENVIRONMENT

BUDIŽ SVĚTLO? DOPAD SVĚTELNÉHO ZNEČIŠTĚNÍ NA ŽIVOTNÍ PROSTŘEDÍ

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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DOPORUČENÁ LITERATURA:

1) Mizon, B. (2012). Light pollution: Responses and Remedies. (2nd ed.). New York: Springer.

2) Narisada, K., & Schreuder, D. (2004). Light Pollution Handbook. (1st ed.). Dordrecht: Springer. 3) Hollan, J. (2011). Venkovní osvětlení v obcích. Brno: ZO ČSOP Veronica.

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Abstract

Light pollution is one of many types of pollution that threaten our planet. The main reason for its creation is the fact that light pollution is a side effect of industrial civilization. The adverse effects of light pollution can have a serious impact on human health, wildlife and climate. The aim of this bachelor's thesis is to define the concept of light pollution, describe means of its measurement and its adverse effects. The theoretical part of this thesis deals with defining what the light pollution is and it describes how it is manifested. Furthermore, possibilities of how light pollution can be measured are discussed. Subsequently, impacts on human health, wildlife, economy, safety, and astronomy are described and discussed. Towards the end, common light sources used for public lighting and their parameters are defined. Lastly, basic practices that help to reduce light pollution are presented with examples of correctly designed luminaires for outdoor lighting. The practical part of the thesis is concerned with quantitative research, whose purpose was to identify the level of awareness of light pollution among the general public. The data were gathered by means of the questionnaire survey.

Key words

light pollution, skyglow, light intrusion, over-illumination, glare, luminaires, adverse effects, brightness, artificial light, wavelength, light source, colour rendering index, luminous efficacy, awareness

Abstrakt

Světelné znečištění patří mezi mnoho druhů znečištění, které ohrožují naši planetu. Důvod jeho vzniku je vedlejší efekt průmyslové civilizace a jeho negativní dopad ohrožuje lidské zdraví, zvěř, rostlinstvo a klima. Cílem této bakalářské práce je vymezit koncept světelného znečištění, popsat způsoby měření a negativní dopady. Teoretická část bakalářské práce se zabývá definováním pojmu světelného znečištění a popisuje způsoby, jakými se světelné znečištění projevuje. Dále řeší možnosti měření světelného znečištění, a také diskutuje negativními dopady na lidské zdraví, přírodu, ekonomiku, bezpečnost a astronomii. Navazující kapitola popisuje parametry běžně užívaných světelných zdrojů pro veřejné osvětlení, a nakonec jsou probírány základní praktiky, které napomáhají snížit světelné znečištění a jsou doplněny příklady správně navrženými svítidly pro venkovní osvětlení. Praktická část této bakalářské práce se zabývá kvantitativním výzkumem, který měl za cíl objasnit úroveň povědomí o světelném znečištění mezi širokou veřejností. Data pro tento výzkum byla shromážděna pomocí dotazníkového šetření.

Klíčová slova

světelné znečištění, světelný závoj, pronikání světla do nežádoucích prostor, nadměrné osvětlování, oslnění, svítidla, negativní dopady, jas, umělé světlo, vlnová délka, světelný zdroj, index podání barev, světelná účinnost, povědomí

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Prohlášení

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1 INTRODUCTION

Several thousand years ago when the first humans discovered fire the first artificial lighting was seen as a friend to humankind. It allowed its creators to see at night, frighten off predators and manage their households. The light itself represented an entity that helped them share their thoughts, ideas and opinions not only by day, but also by night. Therefore, it was a powerful tool that accelerated human evolution, it enabled them to prolong their day and complete more tasks. Thence, humankind sought more advanced sources of light, from ancient oil lamps and candles to kerosene lamps. All these inventions were still mainly used by individuals for their own use in their households, but after the discovery of gas, followed by the invention of electricity the artificial lighting expanded to every aspect of human life. Throughout the next 200 years, artificial lighting expanded exponentially, in many cases leaving no space for natural darkness, resulting in disruption of global ecosystems.

The whole thesis is divided into two parts: theoretical and practical. The aim of the theoretical part is to summarize the concept of light pollution. As it is not an easy task to simply define light pollution, considering that it is a broad term referring to multiple problems, the first chapter of the thesis will be focused on defining the concept of light pollution. It will discuss how is it created and manifested. Additionally, data about affected population will be presented and analysed. The second chapter will investigate every type of light pollution and describe its causes and behaviours. Further, the thesis will focus on measuring light pollution, hence defining what portion of light pollution can be measured and the chapter will as well go through different types of tools that can be used for measuring light pollution by general public. Moreover, the thesis will focus on adverse effects that light pollution creates. Firstly, it will focus on adverse effect on humans and how light pollution influence their sleeping patterns and production of hormones. Secondly, the major focus will be on adverse effects on wildlife as it is the largest group that is affected by light pollution in many ways. Subsequently, the thesis will focus on energy a money waste, where the importance of an appropriate light design will be shown. Furthermore, the connection between lighting and crime activity will be discussed, including the adverse effect related to astronomy and its interference with astronomic observations. Towards the end, common light sources used for public lighting and their parameters will be described, focusing mainly on the light spectrum

of the individual light sources. The final chapter is devoted to the reduction of light pollution, where basic practices for correct outdoor lighting are described and a few examples of correct luminaires are presented.

The practical part comprises of quantitative research based on an online questionnaire survey that was designed in order to identify the level of awareness of light pollution and its adverse effects among the general public. In the discussion chapter, the research questions that are outlined at the beginning are answered.

2 What is light pollution?

People are familiar with the concept of water pollution or air pollution, but the concept of light pollution is not yet in their subconscious, even though this phenomenon has existed for more than sixty years. That might be caused by the fact that not all the adverse effects of light pollution are easily noted. Further, light pollution is a phenomenon that refers to multiple problems and cannot be simply defined; universally it is understood as a description of all the adverse effects, caused by any type of artificial lighting. Another alternative term, mainly used in lighting technology for light pollution, is obtrusive light. However, the impact of light pollution practically concerns every citizen of the developed world, even though; most people do not even realize it. According to Dark Skies Awareness (2009), "It is a serious environmental concern that wastes money and resources while jeopardizing wildlife, our environment, health, and human heritage".

Light pollution is mainly manifested by sky glow, light intrusion, over-illumination, and glare. All these categories of light pollution are caused by a side effect of industrial civilization and will be discussed in more detail in later chapters. Furthermore, International Dark-Sky Association (2017c) (hereinafter referred to as IDA) states that its sources include: "building exterior and interior lighting, advertising, commercial properties, offices, factories, streetlights, and illuminated sporting venues". The IDA did not include vehicle lighting, but it should be mentioned as another source that contributes to light pollution. All artificial lighting inevitably creates an amount of light pollution, particularly in a form of reflected light from illuminated constructions. Nonetheless, majority of light pollution is formed utterly unnecessarily. The IDA (2017c) points out the fact that "much outdoor lighting used at night is inefficient, overly bright, poorly targeted, improperly shielded, and, in many cases, completely unnecessary". As reported by Falchi et al. (2016), more than 80% of the world and more than 99% of the U.S. and European populations live under light-polluted skies (see Figure 1). Further, the Milky Way is hidden from more than one-third of humanity, including 60% of Europeans and nearly 80% of North Americans. The countries with the least affected population are Chad, Central African Republic, and Madagascar. Three quarters of inhabitants of these countries live under pristine sky conditions. On the contrary, the most polluted country is Singapore, its entire population lives under skies so bright that the eye

cannot fully adapt to night vision.

Fortunately, light pollution, contrary to many other forms of pollution is reversible. Conjointly, throughout the last decade light pollution awareness has been increasing dramatically. An increasing number of scientists, dark-sky enthusiasts, environmental organizations, and civic leaders are taking action to restore the natural night. The leading organization combating light pollution worldwide is the IDA. Their work includes identifying and publicizing the negative impacts of artificial light, education, the Dark Sky Places Program and many other projects that help to reduce light pollution.

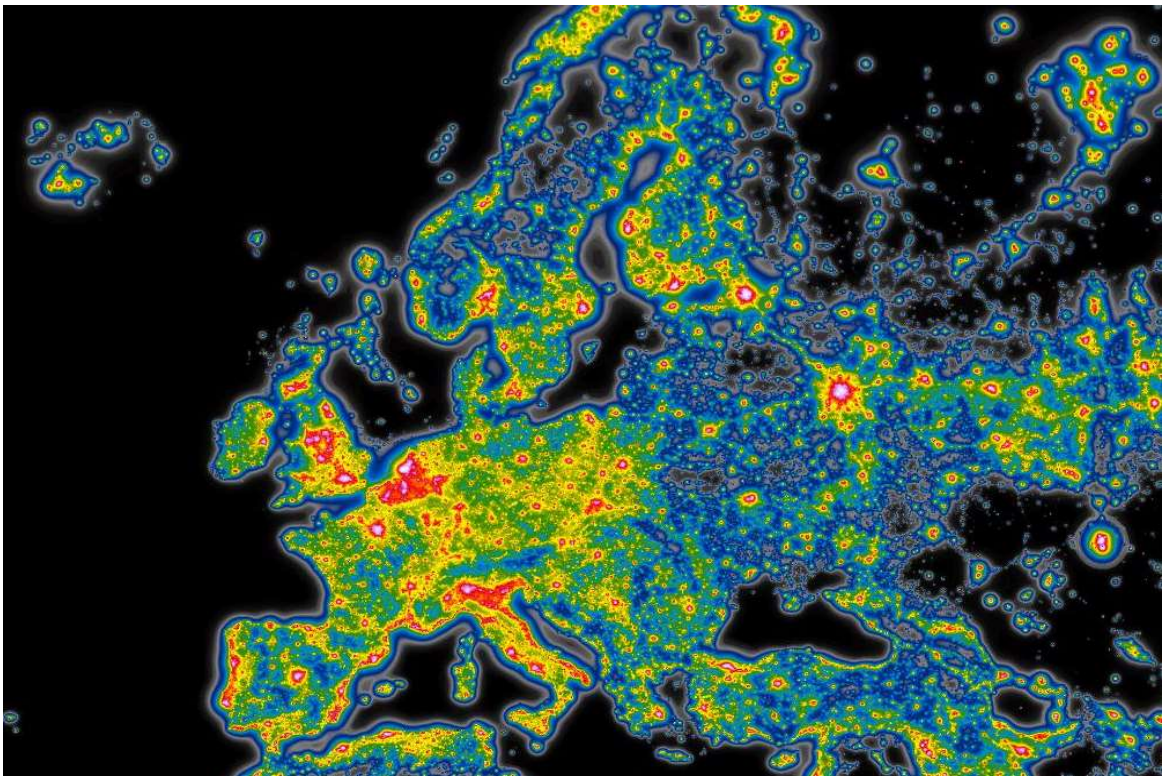

Figure 1. Illustration of light pollution in Europe.
Reprinted from Falchi, et al. (2016, p. 5).

3 Types of light pollution

Light pollution is a profoundly vast term that refers to numerous problems. Every problem related to light pollution is caused by inappropriate, excessive or unappealing use of artificial light. Light pollution consists of four main categories; light intrusion, skyglow, over-illumination, and glare. Light source in poorly designed luminaires often falls into more than one of these categories.

3.1 Skyglow

Skyglow is a type of light pollution that can be spotted effortlessly, furthermore, it is the most pervasive type, and is perceived as an orange glow over cities or towns (see Figure 2). The orange colour of the glow is due to sodium street lighting units that were the most common type of lighting installed in the past, however, the colour of skyglow above some cities might be different. The old sodium street lighting units are being replaced by new LED technologies that most commonly emit a white colour, therefore, the colour of skyglow is white. To some extent, every type of light pollution contributes to the extension of skyglow as well. The reason for that is the fact that every artificial lighting, regardless of what type of light pollution it causes or how well shielded or directed it is, the light will be always reflected from the surface of roads, buildings, and grass, upwards to the sky and contribute to the creation of skyglow. Nevertheless, the major cause of skyglow includes lights that are not properly shielded or are intentionally directed upwards. Mizon (2012) remarks that "skyglow is light that is being carelessly, or sometimes deliberately, projected from the ground or structure, colouring the night sky and reducing the visibility of astronomical objects" (p. 40). An alternative description for skyglow, as mentioned by The Royal Commission on Environmental Pollution (2009), is "a cloud of non-toxic, but visually impenetrable, artificial vapour" (p. 1). This "artificial vapour" can influence areas located tens kilometres away from the initial source. In some rare cases, it can stretch hundreds of kilometres through inhabited areas. This phenomenon can be observed in the Netherlands and Belgium, most densely populated countries of the European Union, where population centres are close together, and it is possible to travel at night for long distances without ever

escaping skyglow. Skyglow creates undesirable conditions for professional astronomers and for dark-sky enthusiasts who marvel the wonders of the sky, it brightens the sky and also makes it impossible for the eyes to adapt to the dark. Although reducing the visibility of astronomical objects is the most noticeable adverse effect, skyglow comprises of other adverse effects that include threats to wildlife and human health.

Skyglow is occasionally confused with airglow, a phenomenon manifested by a very faint luminescence ever-present in the night sky. However, airglow is caused, contrary to skyglow, by natural causes. This cause being the Sun's radiation reflected from particles within or beyond the atmosphere of the Earth. On the other hand, skyglow is caused by artificial lighting, hence, by unnatural causes.

Mizon (2012) states that:

> The cause of skyglow is nowadays well known. Upward light (especially traveling at low angles) from poorly designed lamps is scattered and reflected by aerosols in the atmosphere. It returns to the eye of Earthbound observers, so paradoxically it is light coming downwards that causes skyglow! (p. 40)

Aerosols are particles composed of dust, bacteria, pollen, spores, smoke, haze, mineral particles from deserts and waste products from industry. Therefore, the skyglow is worse in heavily polluted areas, and will always exist on some level when the air quality is poor.

Figure 2. Skyglow over Poole (town in England).
Reprinted from Mizon, B. (2012).

3.2 Light intrusion

Light intrusion, or light trespass (term mainly used in the United States), is another type of light pollution. The IDA (2017c) presents definition of light intrusion relatively plainly "light failing where it is not intended or needed". Therefore, its main cause is, as always, insufficient light design, which results in economic, environmental and health issues. Appropriate light design ensures that the light comes where it is needed, and does not spill elsewhere. However, if the actual luminaires are not properly designed, the light can cause unwanted spilling and result in annoyance, discomfort and disturbance of the private sphere; it intrudes into the living and private space of people who do not have any interest in the lighting. Furthermore, this kind of intrusion may result in serious health issues caused by altering biological cycles.

Light intrusion mainly occurs when outdoor street lighting is poorly designed, therefore, it directs very limited light onto the street where it is wanted. Instead, it sends wasted light at the sides of residential building where it may cause annoyance (shown in Figure 3). Generally, not enough thought is being put into the design of new street lighting, old sources of light are being replaced by newer technologies, but "new lighting columns are often taller than those they replace, increasing the likelihood of light intrusion into bedrooms" (Mizon, 2012, p. 66). What is more, private lighting of external space is an increasing problem. House of Commons Science and Technology Committee (2003) indicate that "security lights are the most common culprit." That can be supported by the fact that over the years there has been a growing number in the use of security lighting, which is now a feature of many private homes, commercial buildings and sporting venues. These are commonly mentioned problems, as well as advertisements that are shining into people's dwellings or onto their properties.

Some actions are taken against light intrusion, for example, in the United States, there are several towns and counties where local lighting regulations are in force. Conjointly, in 2005, exterior lighting also became subject to the criminal law in the United Kingdom. Nevertheless, if one's country does not have any exterior lighting laws, the IDA provides practical guide with steps that you should take to educate your neighbours and community to avoid light intrusion.

Figure 3. Example of light intrusion – wasted light spilled at the side of the residential building.

3.3 Glare

Another type of light pollution "glare", can be regarded according to Mizon (2012) as "the most safety-related aspect of light pollution" (p. 63). The main reason is the fact that it can exert an immediate and harmful effect on human health due to deterioration of driving condition.

Motta (2009) states that:

> The glare from bad lighting is a public-health hazard-especially the older you become. Glare light scattering in the eye causes loss of contrast and leads to unsafe driving conditions, much like the glare on a dirty windshield from low-angle sunlight or the high beams from an oncoming car.

This statement can be supported by the report by House of commons Science and technology (2003) stating that the effect of glare "can cause momentary blindness and bring safety risks for drivers moving rapidly form dark areas to relatively bright ones" (p. 19). However, it does not matter if the change is from a dark to illuminated area or vice versa. It always takes a certain time for a human eye to adapt during this time, so the risk potential of not spotting someone or something is rising. Generally, we can encounter this phenomenon primarily in smaller villages where the design of street lighting might be in a questionable condition (see Figure 4), but cities are no exception. The effect of glare, as mentioned before, can be also caused by a strong source of light whose brightness is far more intense than of the environment. If this happens, in some extreme cases human eyes cannot perceive anything else but the strong source of light, which results in a high level of risk. Additionally, the source of glare can vary from floodlights illuminating sporting venues and LED billboards to incorrectly mounted and dazzling security lights.

Furthermore, glare can be categorized into different types to which all the previously mentioned situations relate. Bob Mizon (2012) provides such classification.

- Blinding glare: A glare so intense that, for an appreciable time after stimulus has been removed, no object can be seen or easily distinguished.

- Disability glare: Glare causing reduced visual performance. Drivers in cities are confronted with ever-changing and conflicting light sources, many of them bright enough to cause disability glare; pupils constrict, trying to adapt to the brightest sources, and ability to see into shadowed areas is diminished.
- Discomfort glare: Glare producing discomfort or annoyance without necessarily interfering with visual performance.

Figure 4. Poorly designed street light that can dazzle drivers.

3.4 Over-illumination

The last type of light pollution "over-illumination" is rather self-explanatory. Chepesiuk (2009) defines it as "the use of artificial light well beyond what is required for a specific activity" (p. A22). Primarily it can be observed in a form of excessive light that is used to bring attention to important buildings or landmarks, such as town halls, museums, castles, and attention-seeking skyscrapers. People often install unnecessary lights to light up these constructions, and they stay turned on during the whole night, in hope to bring attention to them. However, at night there will be always a minimum people that are interested in seeing these constructions. This results in many adverse effects. For instance, it vastly boosts enlargement of skyglow as it is closely connected with its creation because most of the light that is illuminating these constructions escapes straight up to the sky, likewise, the intensity of the lightning is in some cases unnecessarily immense. Further, it brings economical disadvantages as it wastes a great deal of energy and creates enormous carbon emissions. In addition, it has an immediate impact on wildlife, mainly concerning birds and insects. Therefore, some metropolitan areas started applying new policy where architectural lighting is turned off during late night hours as shown in Figure 5 (e.g. the lighting of Prague castle is turned off at 1:00 AM).

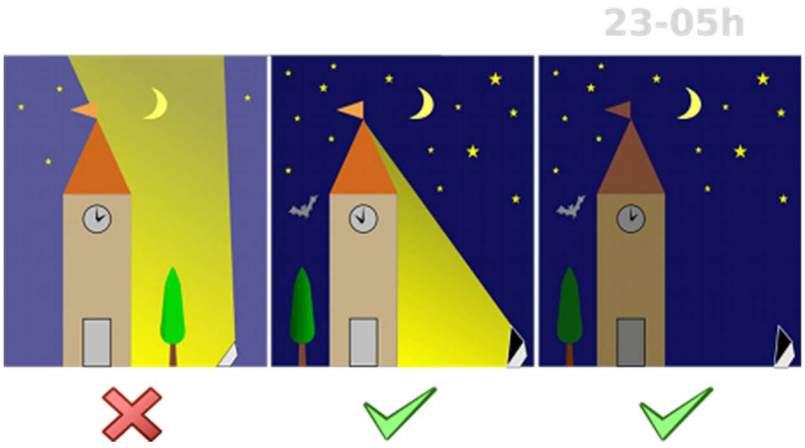

Figure 5. Example of acceptable, unacceptable architectonic lighting and part-night lighting. Reprinted from Odborná skupina pro tmavé nebe (2017d).

Although lighting up important buildings is probably the most iconic example of this type of light pollution, over-illumination may come in other forms. Conjointly, over-illumination includes streetlights turned too early or shining extremely intensively. It is obvious that in the late-night hours when the urban traffic is minimal it is not necessary to shine so intensively as during the evening rush hour. This problem can be seen in almost every city, even though relevant technical solutions are available. Another big contributor to over-illumination are lit up parking lots in front of shopping malls and other centres or offices in buildings not turning their lights off for the night. All these factors result in over-illuminating places that do not need to be illuminated, thus wasting energy and polluting the sky.

4 Measuring light pollution

As mentioned in previous chapters, light pollution refers to misdirected and misused lighting. Light pollution is the result of poorly designed luminaires that spill unwanted light into adjacent areas and up to the sky. This results in creation of skyglow, thus, brightening of the night sky, which hides the stars from our sight and makes it impossible to experience natural darkness. The level of the night sky brightness is the only aspect of light pollution that can be properly evaluated and measured. Professional astronomers use sophisticated tools to precisely measure skyglow. Recently, *The New Atlas of Artificial Skies* has been created using Visible Infrared Imaging Radiometer Suite (VIIRS) – a night-time sensor also called Day/Night Band (DNB) placed on the Suomi National Polar-orbiting Partnership satellite. However, experienced dark-sky enthusiasts can estimate the amount of light pollution by noting which celestial objects they can or cannot see using the Bortle scale. The most frequently used device to measure brightness of the sky among amateur astronomers and dark-sky enthusiasts is a Sky Quality meter. Other possibilities used as well by general public include smartphone applications or digital cameras.

4.1 Bortle scale

In 2001, John E. Bortle created the Bortle scale, which is a nine-level numeric scale that measures the night sky brightness at a particular location. According to Bortle (2006) the scale ranges from Class 1, the excellent dark-sky site, through Class 9, the inner-city sky. It evaluates the astronomical observability of celestial objects and the interference caused by light pollution. The usage of this scale does not depend on any measuring device. The key part is the visibility, respectively, invisibility of some celestial objects. Therefore, it is required to be familiar with the position of some celestial objects.

4.2 Sky quality meter

A sky quality meter (SQM) is an instrument used to measure the brightness of the night sky. It is mainly used by amateur astronomers, to quantify the skyglow. It uses units of "magnitude per square arcsecond" that are commonly used in astronomy. In general, as the scale of magnitude is reversed, the higher the measured value is, the darker the sky is. The sky without light pollution would result in the value approaching the number twenty-two, on the other hand, the highly polluted sky would result in the value close to the number seventeen.

The main part of the SQM is a sensitive chip that records how much light is coming from a particular location to which the SQM is directed. There are several types of the SQM, the two most widespread types are the basic SQM and the SQM-L. The difference between these two models is the angle at which they measure the luminance. The basic SQM measures at an angle of 120° and the SQM-L at an angle of 40°. With the wide SQM, it is possible to measure brightness of substantial part of the sky, however, it is not possible to determine in which direction the sky is brighter and in which darker. On the other hand, the narrow SQM measures only limited part of the sky, but it is possible to measure in different directions, thus determine where the sky is brighter and darker.

4.3 Dark Sky Meter application

A different possibility to measure the night sky brightness is the Dark Sky Meter application. This application makes use of the iPhone camera and collects light at night. To measure the brightness level the application needs to take two photographs; the first photograph is called a "dark shot" and its purpose is to calibrate the camera to complete darkness. Therefore, to take a "dark shot", it is required to accomplish a total darkness while taking the picture. Thereafter, it is required to point the camera to the zenith or directly up and take the second photograph of the sky. The application will return a number that indicates the quality of the night sky. It is also possible to submit the measured data. If submitted, the data is used for further scientific research. The aim of this application is to provide cheap alternative to

expensive light meters. In addition, it is possible to calibrate this application with the SQM or the SQM-L for better results.

4.4 *Loss of the Night* application

Loss of the Night is an android based application that helps monitor skyglow. It works on a different principle than Dark sky meter application, it does not use a phone camera to collect light, but it works on the principle of the Bortle scale. It is based on Google's Sky Map and human vision and the application requirements include a compass and the GPS to function. To evaluate the level of skyglow, the application will ask you to search for eight stars, while navigating you to their position. The search starts with the brightest one that can be seen even in large cities, continuing with stars that are dimmer and harder to be detected in polluted areas. Each time you detect a star, the application asks you if it is visible or not. If the star is not visible you will be asked to choose a reason. After reaching eight stars you can submit your observation, or continue to look for more stars to increase precision. When the observation is over the results are anonymously sent for scientific research and the application lets you know how faint the faintest visible star is and approximately how many stars are visible in your location.

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5 Adverse effects of light pollution

Before artificial lighting was introduced, nearly all life on the Earth had relied on a predictable rhythm of day and night. This rhythm is encoded in the DNA of all animals and plants. By introducing artificial lighting to prolong day time, humans excessively disrupted this cycle, thus, exerting negative and deadly effects on many creatures. However, it is not only the creatures that suffer from light pollution. The excessive use of lighting also causes immense energy loses. According to Globe at Night (2017), "lighting is responsible for at least one-fourth of all electricity worldwide", therefore, the use of unwanted or unneeded illumination inevitably contributes to the creation of a considerable amount of carbon footprint, which results in the extension of global warming, and consequently influences not only the creatures and plants, but also the entire planet. The extent of adverse effects does not stop there, because another considerable group influenced by light pollution are astronomers and general public interested in cosmos endeavours. As the interesting stars and constellations are increasingly more difficult to see through skyglow, people are forced to retreat to distant places, where they can make respectable observations. Furthermore, due to the extension of light pollution the night sky heritage is being lost. Our ancestors experienced a sky brimming with stars, an unprecedented spectacle that the current and future generation may never experience.

5.1 Impact on human life

A human body is adapted to twenty-four-hour circadian rhythm, whose integral part is sleep. Sleep is necessary for correct functioning of our body, especially for regeneration of the nervous system. Lack of sleep or its bad quality might lead to exhaustion, reduced attention and performance. Long term sleep problems might result in a significant reduction in the quality of life and may lead to the emergence of serious psychological problems. A particularly common reason that reduces the quality of sleep is the presence of excessive lighting at night.

During the synchronization of our internal biological clock, the "sleep" hormone melatonin plays the key role. Its important part is that it can be created only during total darkness.

Even a slightest night time exposure to artificial light suppresses melatonin production. Even though any kind of light suppresses the production of melatonin, the biggest suppressor is light with short wavelength and blue portion of the spectrum. The IDA (2017a) supports this by stating that "exposure to blue light at night is particularly harmful. Unfortunately, most LEDs used for outdoor lighting — as well as computer screens, TVs, and other electronic displays — create abundant blue light." Furthermore, melatonin not only affects many bodily processes including metabolism, and immune function, but as well balances reproductive, thyroid and adrenal hormones. A reduced level of melatonin, sleep deprivation and a disrupted circadian rhythm might result in many health issues, such as obesity, diabetes, heart diseases, hypertension, insulin resistance, and poor metabolism. Moreover, recent studies have shown that melatonin suppresses cancer cells because it acts as an antioxidant. Brest cancer and prostate cancer are two major concerns as well. This can be linked by the fact that long-term night workers have a higher risk of breast cancer than women who do not work at night. As the connection between light exposure at night and cancer risk is so strong, the International Agency for Cancer Research (2007) classified night work as a probable human carcinogen.

5.2 Impact on wildlife

Artificial light at night greatly influences not only humans, but also animals, plants and whole ecosystems. What might come as a surprise is the fact that more than half of animal species are at least partly active at night. Not all the species have the same reaction to the exposure of artificial light. Some species are instinctively attracted to light sources, conversely, some species are repelled by it. Furthermore, some species control their circadian rhythm according to day/night cycle or use natural sources of light for orientation and mating. Furthermore, by extension of artificial light, the natural protection of prey species is taken away, giving predators a great advantage, hence disrupting the natural flow of nature. Further, artificial light represents a great threat to plants that can result in prolonging of the vegetation period and can be harmful. The IDA (2017e) emphasizes that according to scientific evidence, artificial light at night has negative and sometimes deadly consequences on many animals including amphibians, birds, mammals, insects and plants.

Mizon (2012) remarks that "insects are the class with the largest number of species on Earth and represent the majority of the planet's biodiversity. They are very important pollinators of plants and an irreplaceable link in the food chain" (p.70). However, it is also a class which is experiencing the largest decline in numbers, The IDA (2017e) notes that this decline has a negative impact on all species that depend on insects for food or pollination, therefore influencing whole ecosystems. One of the reasons for the decline might be the fact that moths and other insect species are vigorously attracted to light sources, the attracted individual will then circle around the light source until it dies out of exhaustion or by contact with the lamp itself, and they also become a vulnerable victim to predators. Other insects that are greatly influenced by light pollution in other ways are bees, fireflies or dung beetles and many others. Light pollution disrupts bee's day and night patterns, "getting too little sleep and losing recovery time to repair their bodies alters reproductive cycles" (IDA, 2017f). Fireflies are known for their charming mating rituals, unfortunately, growing evidence suggests that these mating rituals are also influenced by light pollution and might be the reason for the sudden decline across the globe (IDA, 2017b). Lastly, dung beetle is one of the insects that can use astrological objects for navigation, however, light pollution obscures these objects, hence creating undesirable condition for navigation.

Disorientation by artificial light affects birds as well. Migratory birds perform their long-distance journeys exclusively at night, therefore, the navigation solely depends on bright astronomical objects and on the setting Sun. Fatal Light Awareness Program (2017a), hereinafter referred to as FLAP, acknowledges that "artificial, city lights interfere with this instinctive behaviour and draw night-migrating birds toward brightly-lit buildings in urban areas". The disorientation caused by artificial light can result in deadly collisions with numerous lit-up constructions – skyscrapers, monuments, lighthouses, or billboards. FLAP (2017b) points out that "the estimated number of migrating birds killed annually in collisions with buildings ranges from 100 million to 1 billion birds".

FLAP (2017a) additionally emphasize that:

Floodlights, lighthouses, festival lighting and airport ceilometers (light beams used to determine the altitude of clouds) are also dangerous to migrating birds. The birds get trapped inside the beams of light and are reluctant to fly back out into the dark. They continue to

circle inside the beams until they drop to the ground from exhaustion. Once on the ground, the stunned or injured birds become vulnerable to predation.

This phenomenon can be observed at *Tribute in Light* in New York City, at an annual memorial to the victims of 9/11, where two beams of light are projected to the sky, attracting thousands of birds that are trapped inside the light (see Figure 6).

Figure 6. Trapped birds in beam of lights at Tribute in light.
Reprinted from https://www.newsday.com

Additionally, artificial light might alter reproductive behaviour of songbirds (e.g. blackbird, tit, thrush). In natural conditions, early singing is a sign of quality in male songbirds. However, in environments with artificial lights, male songbirds commence their singing according to the distance of light and not according to their strength and health. Females are then attracted to males that can be less suitable for them, this reproduction may result in weakened descendants and may influence future generations. Moreover, due to this phenomenon, premature laying eggs may occur as well. It can have an adverse impact on survival or health of young birds.

Unfortunately, wildlife is the most influenced part of the environment by artificial light. Influenced species do not stop with insects and birds, the range of the impact is much greater. Different species can be found all around the globe that are influenced by artificial light. Well known species that are influenced by light pollution are bats, young turtles, fish, plankton, molluscs, frogs, rodents, trees, and countless more.

5.3 Energy and money waste

"Lighting that emits too much light or shines when and where it's not needed is wasteful. Wasting energy has huge economic and environmental consequences" (IDA, 2017d). Unfortunately, not enough is being done to avoid this unnecessary waste. According to Odborná skupina pro tmavé nebe (2017), public lighting in the Czech Republic consists of more than 1.3 million lighting units, and its total electric consumption is roughly equal to 700 GWh per year. With average price of 3CZK/kWh, operational costs of public lighting are equal to 2 billion crowns per year. However, as the public lighting in the Czech Republic is financed from budgets of cities and municipalities, most of the lighting is outdated and beyond its service life. This results in enormous energy losses, with appropriate reconstructions of public lighting the operational costs can be in most cases reduced by three quarters.

Additionally, Odborná skupina pro tmavé nebe (2017) provides other statistic, in which are evaluated direct financial costs of electric consumption of wasted light. Lighting worldwide is responsible for 20 percent of total electric consumption, in the European Union (EU) this share is 15.4 percent. Outdoor lighting in the EU forms roughly 21 percent of the total EU lighting energy consumption, hence, per capita 200 kWh annually. Costs for wasted energy in EU are estimated to be around 5.2 billion euro per year. Even though, EU is one of the most light polluted parts of the world, the United States level of pollution is very similar. IDA (2017d) points out that at least 30 percent of all outdoor lighting in the United States is wasted, and total costs for wasted energy are about $3.3 billion per year. Furthermore, this wastage results in release of twenty-one million tons of carbon dioxide per year. IDA (2017d)

additionally emphasizes that “to offset all that carbon dioxide, we would have to plant 875 million trees annually”.

Nowadays, there are accessible practices how to reduce this unnecessary waste. The new and appropriate installation of outdoor lighting could reduce energy use by 60-70 percent and also reduce carbon emissions. The appropriate outdoor lighting should be, as mentioned before, fully shielded and light is ought to be directed down where it is needed, the exact opposite of correctly designed luminaire is depicted in Figure 7.

Figure 7. Wasteful design in a street light: unnecessary illuminating of the trees above.

5.4 Lightning and crime activity

Light has always been perceived as a form of safety at night, it is a universal feeling. People think that brighter lights make them safer, therefore, they avoid dark alleys and parks because these places feel unsafe. Such dark places are often perceived as an ideal place for crime. Another assumption that has been stuck inside our heads for decades is that people often think that increased lighting prevents traffic accidents. However, these assumptions are not justified by any evidence.

Cities that are having difficulties with increased criminal activity are trying to solve the crime issue by a simple and well-established solution - increased lighting in the streets. Nonetheless, there is no clear evidence that increased lighting can reduce crime. A large number of studies and extensive research have been conducted, but no clear evidence supports the assumption that increased lighting prevents or even reduces crime. The same attitude towards lighting and crime is held by IDA (2017g) that states "there is no clear scientific evidence that increased outdoor lighting deters crimes. It may make us feel safer, but has not been shown to make us safer". Moreover, a research report conducted by Steinbach et al. (2015) in England and Wales found no evidence that switching off, dimming, or part-night lighting is associated with crime increase. There are numerous research studies on this topic that ended with no proof that increased lighting in the streets reduces crime activity. Mizon (2012) points out that "those who believe that bright lights deter criminals miss the important point that lighting is of use to anyone who needs to see" (p. 85). This argument is trying to support the fact that with increased street-lighting, the potential criminals have the ability to evaluate the situation and react accordingly. Furthermore, there are two sides to the argument. Riggs (2014) says, "the light may scare criminals away, but it can also tell them enough about a house or a street or a parking lot to know whether there is anything for them to be scared of". This topic is rather complex, so evaluation of the true nature of numerous aspects of lighting needs to be considered.

There are certain lights at night that are necessary, so it is obvious that turning off all the light is not the answer. However, it is crucial that the installed lights:

- are correctly positioned and angled
- are no brighter than it is needed
- illuminate only the required area
- should not be turned on for longer than necessary

If these four straightforward rules are violated, the desired outcome might be lost and can result in a better condition for criminal activity. Creating deep shadows, disability or blinding glare can be easily exploited by criminals. Therefore, the initial design of the light is crucial and must be well thought out individually. The relation to the light pollution is clear. With the increasing street-lighting, the substantial problem is that the design is not considered carefully and seriously. This results in an inefficient use of lighting that contributes to light pollution, carbon footprint and, as mentioned before, can create a more favourable environment for criminal activity.

5.5 Light pollution and astronomy

For many people, the greatest joy that comes from astronomy is simply just standing beneath a clear dark sky and marvelling at the beauties of our universe. Decades ago, numerous young enthusiasts became preoccupied with the mysteries of the universe and pursued their careers in astronomy. The IDA (2018h) points out that "until recently, for all of human history, our ancestors experienced a sky brimming with stars – a night sky that inspired science, religion, philosophy, art and literature, including some of Shakespeare's most famous sonnets". Unfortunately, nowadays most people can no longer see the true breath-taking beauty of the night sky from their home or even nearby surroundings. The natural night sky is our common and universal heritage, yet it is rapidly becoming unknown to the younger generations (IDA 2018h). Regrettably, the number of people who have never seen our own galaxy, the Milky Way, is increasing. One striking example of people losing the basic knowledge of the dark sky is the 1994 earthquake in Los Angeles. During this earthquake, the whole city lost its power; therefore, the whole city went dark, leaving the night sky without any light pollution. The residents of Los Angeles were so used to the bright night sky without any stars that the police department received numerous phone calls from frightened people reporting mysterious, shiny objects in the sky. The loss of awareness and excitement is one of the problems that astronomy is struggling with. Due to light pollution, astronomy became a natural science that lost all its beauty and romance.

Anyway, the root of all the problems is light pollution and how it interferes with our ability to study the skies. From the astronomy perspective two major problems emerge. Both problems are related to the frequently mentioned unshielded lights that send their light straight up and in all directions. Therefore, the first problem is related to sky glow that brightness the night sky. Sky glow creates a problem when observing dim objects in the sky. The brighter environment deteriorates the observational conditions and it is difficult to see these dim objects in the sky. This is the reason why we can no longer see the Milky Way or majority of the stars. In cities, depending on their population and the level of pollution, it is possible to see about one to three hundred brightest stars. If we compare this number to the actual number of stars that could be seen with the naked eye and no light pollution, the difference is alarming. Humans with no eye condition should be able to see more than 9,000

stars across the entire sky, which means both hemispheres. However, we are not able to see both hemispheres at once; therefore, the average number of stars is roughly divided by two.

The second way public lighting interferes with astronomy is much more insidious. Astronomy is not just an observation of stars with a naked eye. In most cases astronomers want to take a spectrum of an object because it is possible to learn much more from a spectrum of an object than from a simple picture. The spectrum of an object is a light that is captured with a telescope and split into its component colours. The spectra of galaxies, planets, stars, or nebulae can reveal a lot of information. Every element in the periodic table and its gaseous form will produce a series of bright lines in the spectrum according to its wavelength, unique to the particular element. From these lines it is possible to deduct the elements from which the object is composed of including its temperature, velocity and density. However, when the spectrum of fluorescing objects like galaxies, planets or nebulae is taken, it is not smooth, but made up of number of lines. Each line is a unique indicator of the presence of certain chemical compound. Astronomers than study these lines and can acquire the desired information. The problem is that urban lighting can interfere with these measurements. Every light source has its own spectrum according to its used material. Therefore, urban lighting can easily interfere with these spectral measurements if some of the light gets into the spectrograph. Every light source (light emitting diodes, high-pressure sodium, low-pressure sodium, etc.) that we use has a different spectrum. Some are friendlier to the astronomical observation because they can be easily filtered, but others are a real problem and will be discussed in the following chapter.

With the increasing pollution in urban areas, the astronomers are forced to move their expensive telescopes to more remote locations where there is a minimum interference caused by thick atmosphere and light pollution. These locations are usually deserts with high altitudes, or the finest place of all, the orbit of the Earth or outer space. With altitude reaching over five thousand meters, the Atacama Desert in Chile is a conventional location for telescopes on the Earth. The biggest advantage of telescopes at high altitudes is that with increasing altitude the atmosphere is thinner; therefore, it leads to less distortion. Orbiting around the Earth, the well-known Hubble telescope with a four-meter diameter is discovering a nearby universe. However, the Hubble telescope will soon be inferior to by far a more powerful successor. In 2019 the James Webb space telescope will be launched; this telescope

is four times larger in diameter and it will observe some of the most distant events and objects in the Universe. The remote locations of the telescopes are the reason why astronomy became an office job comparable to any other job. To observe the interesting phenomena in the Universe, one must rent these powerful telescopes and manage them from their office.

6 Types of light sources

The type of light is an important aspect when considering the reduction of light pollution and its impact on the environment. Nowadays, there are number of different light sources used for outdoor lighting. All these sources have different properties that are appropriate for different environments. In the Czech Republic, compact fluorescent, metal-halide, high-pressure sodium (HPS), low-pressure sodium (LPS) lamps and light emitting diodes (LED) are used for street lighting, however, most of the mentioned types are obsolete technologies that are used in small quantities. In 2015, high-pressure sodium lamps were according to Světloblog (2017) the most commonly used light source in the Czech Republic (85%). Nevertheless, there is an ongoing trend to switch from these obsolete sources and HPS to blue-white light emitting diodes.

Moreover, besides appropriate shielding, there are a few main parameters that need to be considered when choosing the correct light source for public lighting that will be efficient and not harmful to the environment. One of the most important parameters of a light source, when talking about light pollution, is the light spectrum, respectively the light wavelength that corresponds with the correlated colour temperature (CCT). This parameter is important due to the fact that light scatters differently according to its wavelength. This is known as Rayleigh scattering which says that light with a shorter wavelength scatters more easily than light with a longer wavelength (see Figure 8) which is also why the sky appears blue during the day.

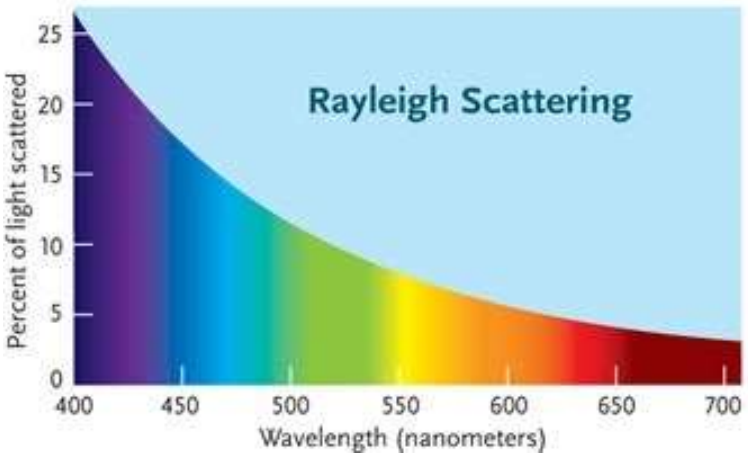

Figure 8. Rayleigh scattering.
Reprinted from Quora (2016).

Another factor to consider when talking about the wavelength of light is the energy of light. Light consists of individual photons that carries the energy of the light, the amount of energy is again proportional to the wavelength of the light itself. The shorter the wavelength, the higher the energy. Therefore, extensive exposure to the high energy light, especially at night, can have negative impact on biological rhythms and health. CCT or correlated colour temperature also corresponds with the spectrum of light, however, it has nothing to do with actual temperature. It is denoted in Kelvin (K) and with a higher temperature, the light becomes bluer, thus lower temperature lights are more suited for outdoor lighting. Light sources with colour temperature below 3000K are considered to be warm and light sources above 4000K are considered to be cool (see Figure 9). Other important parameters of light sources that are associated with light pollution and its economic consequences are luminous efficacy and lifespan. Luminous efficacy indicates how well a light source produces visible light using a given amount of power. It is expressed by luminous flux per watt (lm/W) and the higher the luminous efficacy, the better. Lifespan is a self-explanatory parameter; light sources with less maintenance and less frequent replacements are more economically beneficial. Lastly, a colour rendering index (CRI) is another parameter considered when designing public lighting. According to TopBulb (2018) it describes how a light source accurately renders a colour of an object to the human eye and its scale ranges from 0 to 100, the higher the CRI rating, the higher accuracy of the reproduced colours.

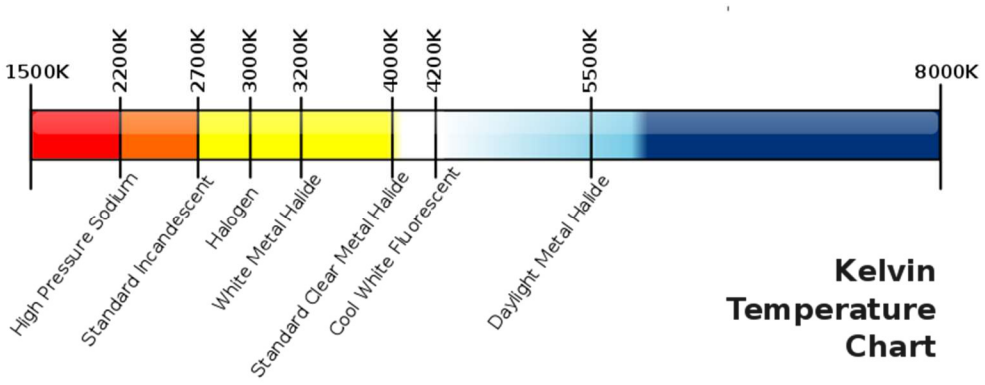

Figure 9. Kelvin temperature chart.
Reprinted from Wikimedia (2009).

6.1 Compact fluorescent lamp

Compact fluorescent lamps (CFLs) in the Czech Republic are mainly used for lighting of the secondary roads, firstly because their luminous flux decreases with decreasing temperature and secondly because the lamp dimensions are quite large and therefore not appropriate for precise optical routing. As mentioned in Světloblog (2017), their share in the Czech Republic in 2015 was only around 6 %. Originally, the light emits in the ultraviolet spectrum as an electric current is driven through a tube filled with argon and mercury vapour. Furthermore, the ultraviolet light excites with a phosphor coating that reacts and transforms the UV light into visible spectrum. As a consequence, CFLs have a narrow emission band around 435 nm, 545 nm and 615 nm (the blue, green, orange spectrum), which can be seen in Figure 10. Moreover, the luminous efficacy of the CFL is around 50-70 lm/W, a rendering index of about 80, and their lifespan can achieve up to 20,000 hours.

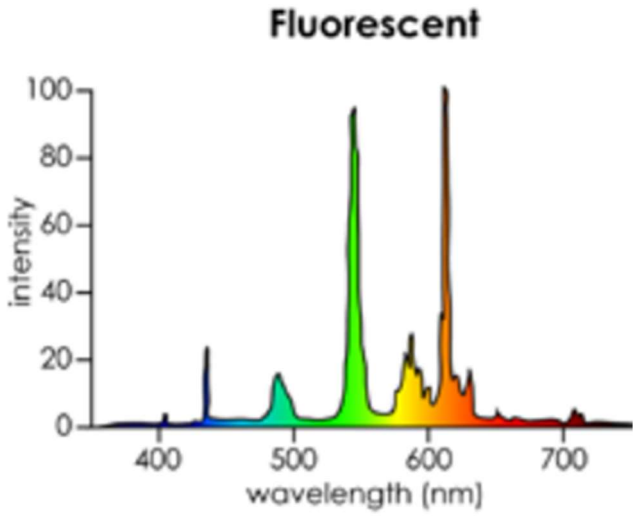

Figure 10. Light spectrum of fluorescent light source.
Reprinted from High Efficiency LED Tube Lights (2017).

6.2 Metal-halide lamp

A metal-halide lamp produces light by an electric arc through a gaseous mixture of vaporized mercury and metal halides. The spectrum of metal-halide lamps consists of all spectral colours; therefore, they produce white light that is often used for lighting of city centres, pedestrian crossings and intersections because they have a high colour rendering index of about 90. Nowadays, the share of metal-halide lamps in the Czech Republic is around 5 %. The luminous efficacy is around 70-100 lm/W and their lifespan can reach up to 20,000 hours.

6.3 Low-pressure sodium lamp

The sodium lamp working principle is based on the generation of an electric arc through vaporized sodium metal. Additionally, other materials and gases are used to help light the lamp and control the colour of the light. The low-pressure sodium lamps are among one of the most energy efficient lamps with luminous efficacy up to 200 lm/W. This is not only due to the fact that all the electric energy is converted into the visible part of light but mainly because the light wavelength is very close to the peak sensitivity of the human eye. However, LPS lamps have a poor rendering index of about 5 that might be found undesirable, therefore they are mainly used for road lighting where colour rendering is not that important. LPS are probably the best choice for lighting near astronomical observatories since LPS emits only a narrow spectrum of orange colour with the wavelength of around 595 nm (see Figure 11), which can be easily filtered, if necessary, when conducting spectrograph measurements.

Even though LPS are a friendly choice for astronomical observatories, the general public that enjoys the sight of the night do not favour this type of lights. It is due to the fact that the LPS tubes are rather lengthy and cannot be easily directed. For general public, "the direction in which the light is made to travel, and its intensity, are the most important factors" (Mizon 2012, p. 110). Moreover, lifespan of LPS lamps can achieve up to 18,000 hours. In the Czech Republic, LPS lamps are not widely used.

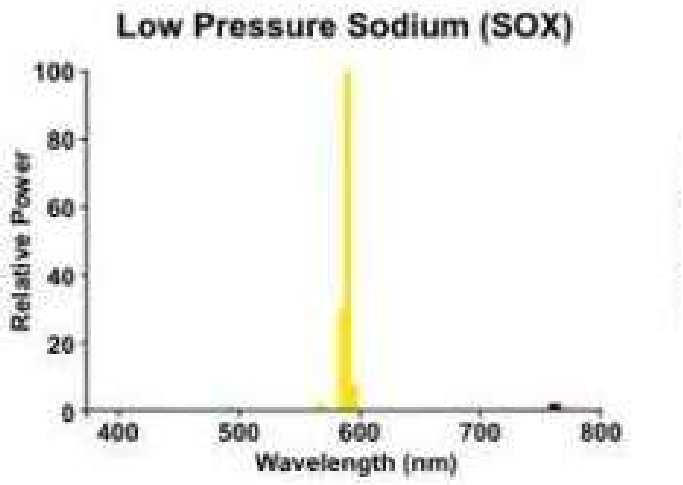

Figure 11. Light spectrum of LPS light source.
Reprinted from Lamptech (2011).

6.4 High-pressure sodium lamp

High-pressure sodium lamps are the most common type of light source in the Czech Republic which is used for lighting of all public roads and streets. In many countries, LPS lamps have been largely replaced by HPS lamps due to better colour rendering of 22, longer lifespan that can be up to 25,000 hours, and due to their smaller casings ensuring a better direction of the light. However, luminous efficacy is smaller than of LPS, reaching up to 150 lm/W. The spectrum of HPS is dominated by long-wavelength light spanning from 560 nm to 650 nm and some short-wavelength light around 500 nm (see Figure 12). Even though the light from HPS does not scatter that well and is not so harmful for the environment if properly shielded, in the Czech Republic the problem lies in the convenient design of the luminaires. The light source from HPS lamps or any other should not be seen if observed from higher ground; however, the reality is vastly different. If you are observing a city in the Czech Republic from a hill or top of a building, you will most likely see a sea of orange dots all around you, which should not happen.

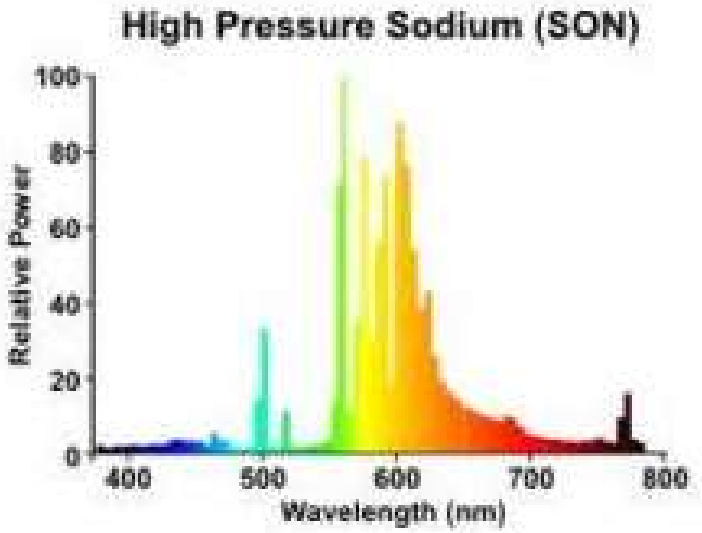

Figure 12. Light spectrum of HPS light source.
Reprinted from Lamptech (2011).

6.5 Light emitting diodes

Light emitting diodes are an emerging type of light source used in public lighting. They work on the basis of electroluminescence effect; “when a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in form of photon” (Jain, 2017). Furthermore, the colour of the light is determined by the energy band gap of the semiconductor. LEDs have a wide range of colours; therefore, their spectrum depends on the type of colour emitted. Moreover, blue-rich LED sources, which light can be seen as white, are the most efficient and that is why they are most widely used. The spectrum of these cool white LED is dominated by short-wavelength light between 420 nm to 500 nm and long-wavelength light spanning from 500 nm to almost 700 nm (see Figure 13). Nevertheless, since LED have such a wide range of colours, it is possible to use more warm colours that does not emit so much of the harmful blue light. However, their cost is much higher and the efficiencies are lower. The spectrum of warm white LED spans from 500 nm to 700 nm with almost no blue component (see Figure 14). One of the great advantages of LED is the fact that light from LED sources can be dimmed and properly directed. Their lifespan can reach up to 50,000 hours, the colour rendering index is about 70 or higher and luminous efficacy can vary from 150 to 200 lm/W, depending on the used material.

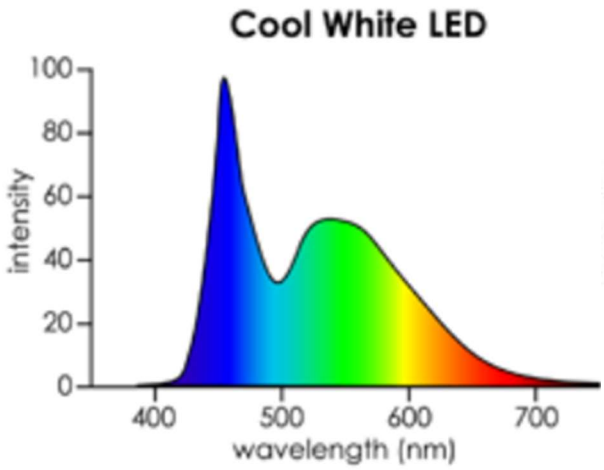

Figure 13. Light spectrum of cool white LED light source.
Reprinted from High Efficiency LED Tube Lights (2017).

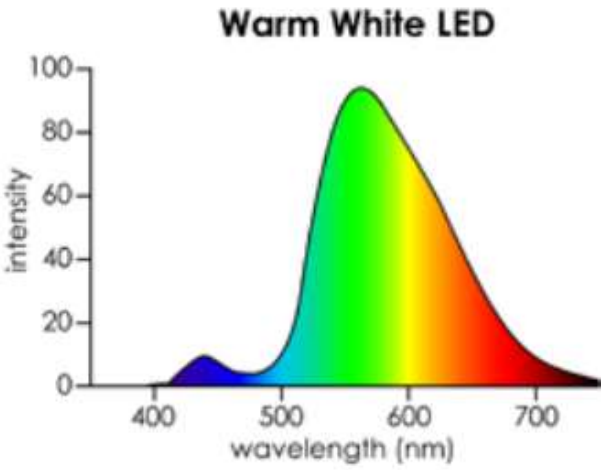

Figure 14. Light spectrum of warm white LED light source.
Reprinted from High Efficiency LED Tube Lights (2017).

7 Reduction of light pollution

A positive factor about light pollution is that it is a reversible kind of pollution, so the quickest and most effective solution would be to turn off all the lights. However, “modern society requires outdoor lighting for a variety of needs, including safety and commerce” (IDA 2018i). Therefore, getting rid of all light pollution is, unfortunately, impossible. On the other hand, the achievement of a significant reduction of light pollution is not that complicated. There are a few standard practices that should be followed. So that light pollution could be reduced significantly. Moreover, applying these practices would not only lead to reduction of light pollution, but also energy costs could be cut in half. Additionally, we could avoid human health risks and save numerous animal species. The most important aspect of the pursuit of reducing light pollution is the awareness of this issue. Anyone can contribute to the reduction of light pollution. The simplest action that anyone can take to fight light pollution is to be an engaged citizen that spreads the word and educates others about the seriousness of this issue; hence the awareness must be increased.

Anyone, even people living in flats that do not manage any outdoor lights can help to reduce light pollution by turning off unnecessary lights or closing blinds in rooms where the light is needed so that no light could escape into the sky. Since the colour of the light is very important, changing your light sources in homes to warmer, efficient colours will not only help your health, but it will also scatter less if some of the light escapes the room, and will not contribute so vastly to the extension of light pollution. In general, minimizing the use of lights at night is a great approach to commence an action against light pollution.

However, if one is managing outdoor lights, there are more aspects to consider. IDA (2018i) provides standard aspects that should be considered when using any outdoor lighting, including advertisements, private, street, and industrial lighting:

- lights should be fully shielded,
- blue light emissions should be minimized,
- lights should not be brighter than necessary,
- people should light only the area that needs it,
- lights should be on only when needed.

Firstly, as IDA (2018i) points out, it is vital to identify the proper, fully shielded luminaires from which the light will only point downwards and will not escape to the sky, attract insects or other animals from nearby area (see Figure 15). Secondly, warm light sources are preferable due to the fact that warmer colours are less harmful to the environment than cool lights with blue emissions and warmer lights also scatter less in the atmosphere. The brightness of the light source is very important too. It is not necessary to use lighting at full brightness when the light is not serving its purpose to anyone. Therefore, at least dimming the outdoor/street lights during night is a great way to reduce light pollution. The next aspect "only light the area that needs it" correlates with the appropriate luminaires that point or direct the light downwards and where needed, thus not upwards or into people's dwellings or onto private properties as discussed in previous chapters.

Figure 15. Example of acceptable and unacceptable outdoor luminaires. Reprinted from Odborná skupina pro tmavé nebe (2017c).

Lastly, when the light needs to be on, is an important question that must be considered when buying or designing outdoor lighting. For most of the night, lights are serving their purpose for minimum number of people, the use of movement detectors are a great possibility to help with this issue. Additionally, an increasing number of cities and villages are adopting part-night lighting policy, where the street lighting is switched off during late hours (usually between 11 p.m. and 5 a.m.). Nevertheless, this policy can be implemented not only to street lighting but also to any outdoor lighting that may include advertisements (see Figure 16) or architectural lighting. Part-night lighting helps to reduce light pollution vastly and on top of that it reduces the energy bills or carbon footprint.

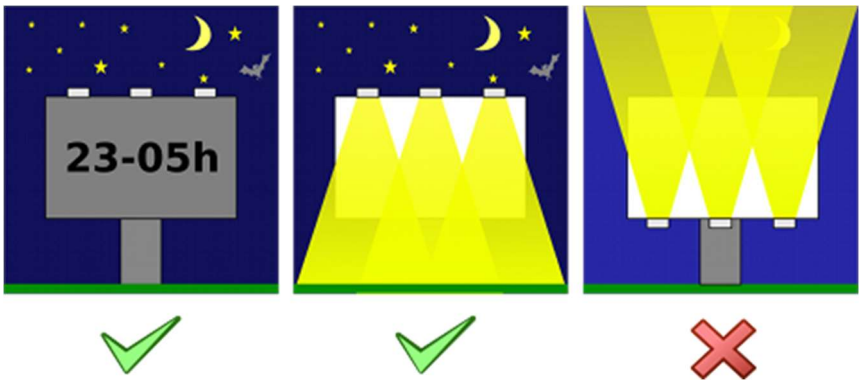

Figure 16. Part-night lighting policy implemented on advertisement lighting. Reprinted from Odborná skupina pro tmavé nebe (2017b).

Unfortunately, there are hundreds of different options available on the market when looking for outdoor lights, nevertheless not all products are designed to accommodate all the above-mentioned requirements. In the Czech Republic, no third party exists that would help with this issue. In the United States, on the other hand, the International Dark Sky Association provides objective, third-party certification for luminaires that minimize glare, reduce light trespass, and do not pollute the night sky. This program is called a Fixture Seal of Approval that considers all the important aspects for outdoor lighting and provides a database of all approved fixtures, some examples of approved fixtures are depicted in Figure 17.

Since the street lighting is by far the most expanded lighting, it has the largest impact on the extension of light pollution. Therefore, when it comes to the design of street lighting or other complex installations, the design should come from a qualified light designer who considers all the aspects of given environment. Unfortunately, not all light retailers/designers are experts in the field of lighting and will sell you the lights that look “beautiful”, not considering any of the above-mentioned standards.

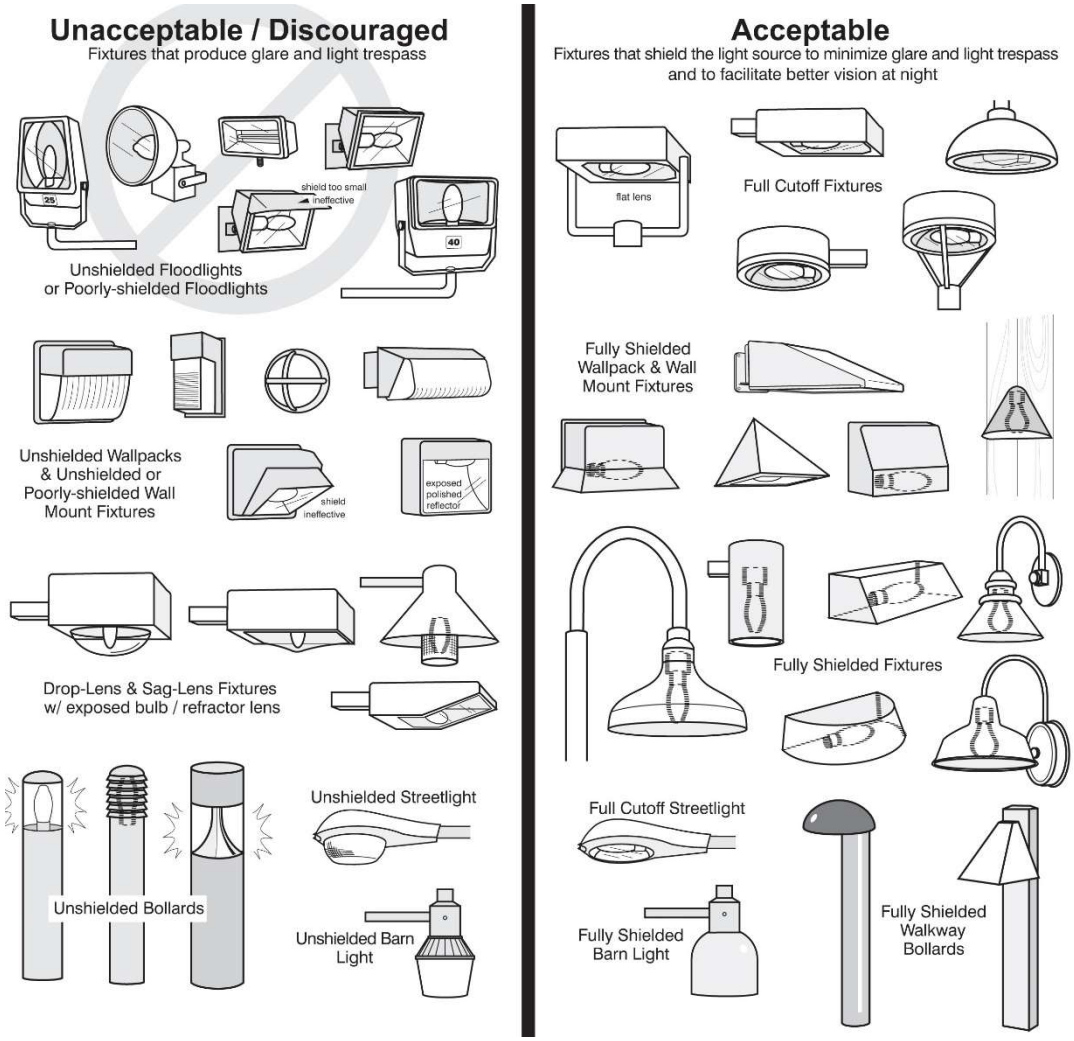

Figure 17. Examples of unacceptable and acceptable types of light fixtures. Reprinted from IDA (2017i).

8 Practical part

8.1 The research objectives and research questions

The practical part concerns quantitative research based on an online questionnaire survey, which provides a relatively quick and efficient way of obtaining large amounts of information from a large sample of people. The target group of respondents was general public, so a quantitative method of data collection was the best choice here.

The general objective of the research was to identify the level of awareness of light pollution and its adverse effects among general public.

The intermediate objectives were the following:

a) to identify whether the respondents are familiar with the dark sky and its celestial objects;
b) to identify to what degree the respondents are acquainted with the basic concept of light pollution;
c) to determine how many respondents have ever encountered or been affected by any type of light pollution;
d) to identify whether the respondents are aware of the possible health risks that can be caused by light pollution;
e) to determine whether the respondents are able to identify how the artificial light can influence wildlife.

Therefore, the following research questions for the objectives were defined:

a) Is the public familiar with the dark sky and its celestial objects?
b) To what degree is the public acquainted with the basic concept of light pollution?
c) How big percentage of the public has encountered or been affected by light pollution?
d) Is the public aware of the possible health risks that are caused by light pollution?
e) Is the public able to identify how the artificial light influences wildlife?

8.2 Research design

The research is divided into three main stages:

- Preparation stage
- Realisation stage
- Evaluation stage

8.2.1 Preparation stage

While writing the theoretical part of my bachelor's thesis, I addressed a number of people with questions about light pollution and found out that most of the addressed people had known relatively little about this problem. Therefore, I wanted to assess the level of awareness of a greater number of people - general public. That would create a slight idea of what people know about this issue.

The preparation phase involved:

- literary research;
- establishing the conceptual framework focused on the issue of light pollution (see the theoretical part of this bachelor's thesis);
- defining the research objectives and research questions;
- sampling procedure;
- selecting a data collection method.

The research sample selected by means of random sampling was a general public. Later I divided the research sample into sub groups according to their age, education and gender to identify any deviations within these sub groups. Additionally, a number of possible questions were put together during the preparation stage.

8.2.2 Realisation stage

The realisation stage aimed at designing a data collection tool (including its verification and elaboration) and its distribution. A pilot version of the questionnaire was distributed among a few respondents in order to identify any misunderstandings or problems that might occur throughout the questionnaire. The pilot version revealed a number of issues, mainly related to the formulation of open questions that had to be rephrased for better understanding.

Even though some of the early respondents recommended reducing the number of open questions, I decided not to proceed with that. The main reason for this decision was the fact that without the open questions the results would not be as comprehensive. The most crucial questions were open and it was vital that they remained open since the topic of light pollution is a vast area and every respondent could connect it with different problems.

Moreover, the aim was to get at least 150 respondents. Two methods of sharing the questionnaire were used: on my personal Facebook page and via emails distributed within the international company IBM and a non-profit organization Liga Vozíčkářů. Other possibilities were feasible, however, I achieved 150 respondents within the first four days, so additional distribution was not necessary.

8.2.3 Evaluation stage

The emphasis in the evaluation stage was on the analysis of the responses. Since the questionnaire consisted of a large number of open questions the main focus was on the evaluation of these open questions. Open questions were divided into groups of similar answers and linked together. If a sample response correlated with more groups, the response was put into all the appropriate groups. Further, responses that did not correlate with any of the groups or were incorrect were put into group of “I don’t know”.

8.3 Data collection tool

Since I wanted to use complementary questions that would only appear if a respondent answered to a question in a certain manner, I had to find an appropriate tool that would facilitate this condition. However, most of the online questionnaire tools did not have this option unless they are paid for. Alternatively, I decided to use Google Forms as a tool for designing the questionnaire because it had an option to continue to a certain section based on the respondent's answer. Even though the use of this option resulted in a need for more clicking through the questionnaire, it facilitated the required need. Another advantage of Google Forms is the fact that it is possible to save the responses to another file (sheet), besides the original form in which Google even creates two bookmarks (summary and individual answers) where you can freely manage the answers individually.

Since I wanted to address a general public, the questionnaire was an evident choice as a research tool because it enabled me to approach a lot of respondents easily in a short period of time and collected data could be quickly analysed and quantified.

The questionnaire consists of six main sections. *Light pollution* section is the largest section with three open questions and five closed. Additionally, three questions are accommodated with pictures to help the respondents recall some types of light pollution. *Star observation* section has four closed questions; *General* section has the same number of closed questions. Another section is related to *human health* with two open and two closed questions. Furthermore, the section about *a type of light* consists of two closed questions. The last section focuses on *wildlife* and consists of one open and one closed question. The total number of questions is twenty-four out of which eighteen questions are closed and six are open questions. Five out of six open questions are complementary.

8.4 Data analysis and interpretation

In this chapter, the collected data are presented, analysed, described and interpreted. The data from the questionnaires were statistically analysed using Microsoft Excel. The analysis and interpretation is further divided into 6 subchapters, including General section, Star observation, Light pollution, Human health, Type of light, and Wildlife.

8.4.1 General section

Question 1. What is your gender?

Table 1. *Gender of respondents.*

Gender	Absolute value	Percentage
Male	48	31.58 %
Female	104	68 %
Total	152	100 %

Table 1 shows that female respondents comprised the majority of respondents: 68%. Male respondents comprised a distinct minority of 32%.

Question 2. How old are you?

Table 2. *Age groups of respondents.*

Age group	Absolute value	Percentage
26 – 40	57	37.50 %
19 – 25	47	30.92 %
Above 40	44	28.95 %
Under 15	3	1.97 %
15 – 18	1	0.66 %
Total	152	100 %

As Table 2 indicates the vast majority of respondents were distributed almost evenly between the three age categories consisting of age above 19. Only three respondents were younger than 19.

Question 3. What is your highest level of completed education?

Table 3. *Level of education achieved by the respondents.*

Level of education	Absolute value	Percentage
Secondary[1] education	69	45.39 %
Tertiary education: Master's degree	50	32.89 %
Tertiary education: Bachelor's degree	26	17.11 %
Primary education	3	1.97 %
Doctorate degree or equivalent	2	1.32 %
Post-secondary non-tertiary education[2]	2	1.32 %
Total	152	100 %

Nearly half of the respondents finished at least secondary education (see Table 3). However, the fact that some respondents under 23 years might be finishing their bachelor's or master's studies must be taken into account. Therefore, more than a half of respondents have or will have a higher education. This circumstance might be reflected throughout the questionnaire by more accurate and complex answers.

[1] Secondary education refers to the stage preparing for tertiary education or providing skills relevant to employment.

[2] Post-secondary non-tertiary education refers to programmes providing learning experiences that build on secondary education and prepare for labour market entry or tertiary education.

Question 4. Do you think that public lighting in your city/village is used efficiently?

Table 4. *Opinion of respondents on the efficiency of public lighting.*

Answer	Absolute value	Percentage
Yes.	80	52.63 %
No.	48	31.58 %
Don't know.	24	15.79 %
Total	152	100 %

As can be seen in Table 4, more than half of respondents (80) feel that the public lighting is efficient. However, if we consider that the questionnaire was distributed only within the Czech Republic and according to Světloblog (2017), 95 % of public lights in 2015 were HPS it is possible to conclude that majority of the general public is not able to correctly deduct if the lights are efficient. This is totally acceptable, since it is not an easy task to deduct this information. Consequently, it was expected that more people would answer with "I don´t know".

8.4.2 Star observation

Question 1. Do you think there is a difference between the night sky in urban areas and rural areas?

Table 5. *Respondents' perception of the night sky in urban and rural areas.*

The level of difference	Absolute value	Percentage
A significant difference.	138	90.79 %
A small difference.	11	7.24 %
No.	3	1.97 %
Total	152	100 %

It can be seen that more than 90 % of respondents can recognize the significant difference, slightly more than 7 % of respondents are aware that there is at least some difference between the night sky in rural and urban areas. Only 3 respondents think that the night sky appears the same. It is a positive sign that almost all the respondents are aware of the contrast between the night sky in urban and rural areas.

Question 2. How many stars, in your opinion, can be seen with a naked eye in large cities?

Table 6. *Respondents' perception of visible stars in large cities.*

Number of visible stars	Absolute value	Percentage
Less than 500.	82	53.95 %
501- 1,500	34	22.37 %
1,501 - 3,000	28	18.42 %
3,000 - 4,500	6	3.95 %
More than 4,500.	2	1.32 %
Total	152	100 %

Even though the exact number of visible stars depends on a lot of factors, it is expected that no more than five hundred stars can be seen in large cities because of light pollution. Therefore, 82 respondents answered correctly and have excellent conception of the night sky. The second largest group of respondents (34) think that 501 – 1,501 stars can be seen, which is still quite an acceptable guess when we take into consideration a lot of factors. However, more than 23 % think that more than 1501 stars can be seen in large cities, which is totally inaccurate.

Question 3. How many stars do you think you are supposed to see with a naked eye without any interference?

Table 7. *Respondents' perception of visible stars without any interference.*

Number of visible stars	Absolute value	Percentage
More than 4,500	85	55.92 %
3,001 - 4,500	39	25.66 %
1,501 - 3,000	24	15.79 %
Less than 500	2	1.32 %
501 - 1,500	2	1.32 %
Total	152	100 %

As previously mentioned in the theoretical part, the number of visible stars without any interference should be close to five thousand. Consequently, if we compare the answers of the previous questions, it is possible to verify that most of the respondents (124) have a clear conception of the night sky. Nevertheless, the respondents that think only 1,501 – 3,000 or less stars can be seen without any interference have probably never seen the night sky without light pollution and are greatly influenced by it.

Question 4. Have you ever seen the Milky Way at night?

Table 8. *Respondents' experience with seeing the Milky Way.*

Answer	Absolute value	Percentage
Yes	95	62.5 %
No	19	12.5 %
I do not remember	19	12.5 %
I am not sure how to find it in the sky	19	12.5 %
Total	152	100 %

Table 7 shows that 62.5 % of respondents were lucky enough to see the Milky Way. On the other hand, 25 % respondents have never seen or cannot recall seeing the Milky way. The fact that 12.5 % of respondents probably do not even know how the Milky Way looks is quite alarming.

8.4.3 Light pollution

Question 1. Have you ever heard about light pollution?

Table 9. *Respondents' awareness of the term light pollution.*

Answer	Absolute value	Percentage
Yes, I heard about it.	74	48.68 %
Yes, I heard and I know what it is.	57	37.50 %
No.	21	13.82 %
Total	152	100 %

Table 8 illustrates that the majority of respondents (48.68 %) have at least heard about light pollution. What is greatly encouraging is the fact that 37.50 % of respondents additionally claim that they know what light pollution is. The fact that only 13.82% of respondents have never heard of light pollution is somewhat surprising.

Question 2. (Complementary) Can you describe in your own words what light pollution is?

Table 10. *Respondents' description of light pollution.*

Group of answers	Number of mentions	Percentage
All artificial light that brightens the night sky or deteriorate the astronomic observations	24	32.43 %
Any artificial light	13	17.57 %
Excessive artificial light that comes from cities or homes	12	16.22 %
Artificial light that disrupts rhythms or behaviours of animals	9	12.16 %
Artificial light that disrupts circadian rhythm	6	8.11 %
Excessive use of light that influences the quality of sleep	6	8.11 %
Excessive artificial light that has a negative impact on the environment	2	2.70 %
Don´t know	1	1.35 %
Reflected artificial light	1	1.35 %
Total	74	100 %
Number of respondents	57	37.5 %

The respondents that claimed they knew what light pollution is in the previous question were asked to elaborate on these claims. Considering that light pollution is a vast issue comprising of several problems, all the answers were in fact correct. However, most of the respondents mentioned only one problem. The total number of the respondents was 57, but only 74 answers overall (see Table 10). Therefore, large majority of respondents mentioned only one problem. The most frequent description of light pollution was connected to brightening of the night sky. Moreover, the remaining respondents associate light pollution usually with artificial light that can have negative impact on quality of sleep, environment, rhythms and behaviours of animals, or biological rhythms (see Table 10).

Question 3. Could you name some negative effects of light pollution?

Table 11. *Summary of* n*egative effects that are cause by light pollution according to the respondents.*

Group of answers	Number of mentions	Percentage
Poor observational conditions or no visibility of stars	34	19.10 %
Impact on animals and nature (bird migration, mating, etc.)	30	16.85 %
Don´t know	28	15.73 %
Can cause sleep disorders	27	15.17 %
Wastage of energy	17	9.55 %
Disruption of circadian rhythm	10	5.62 %
Adverse impact on humans (not specified)	9	5.06 %
Can result in decreased production of hormone melatonin	5	2.81 %
Absence of total darkness	5	2.81 %
Light intrusion	4	2.25 %
Safety issues	3	1.69 %
Glare	3	1.69 %
Can cause eye disorders	1	0.56 %
Causes global warming	1	0.56 %
Drought	1	0.56 %
Total	178	100 %
Number of respondents	152	100 %

All the respondents were asked to identify negative effects of light pollution, 28 respondents out of 152 were not able to come up with any answer (see Table 11). As expected, most of the respondents mentioned "Poor observational conditions or no visibility of stars" as the most

frequent answer. Overall, all the major negative effects were mentioned, including wastage of energy, impact on animals and nature, impact on humans, safety, and poor observational conditions (see Table 11). A few respondents even mentioned some negative effects in detail (sleep disorders, reduce production of melatonin, disruption of circadian rhythm, bird migration, etc.) and a handful of respondents even recognized some types of light pollution (light intrusion and glare). Even though, most of the answers were correct and a few even quite comprehensive, most of the respondents mentioned only one negative effect.

Question 4. Do you think that it is possible to reduce light pollution?

Table 12. Respondents' view on the possibility of light pollution reduction.

Answer	Absolute value	Percentage
Yes.	131	86.18 %
No.	20	13.16 %
I don't know.	1	0.66 %
Total	152	100 %

Table 11 shows the expected result that the big majority of respondents (131) are aware of the fact that light pollution can be reduced. A slightly surprising fact is that 20 respondents think that light pollution cannot be reduced.

Question 5. (Complementary) – Please describe how light pollution can be reduced.

Table 13. *Summary of possible practices mentioned by the respondents that would help to reduce the light pollution.*

Group of answers	Number of mentions	Percentage
By better design of public lighting that is effective and all light points downwards	35	19.34 %
By reducing the amount of lighting used for advertisements, landmarks, parking lots etc.	33	18.23 %
Reduce the amount of public lighting (including decorative/holiday lights)	26	14.36 %
Introduce part-night lighting policy	19	10.50 %
Introduce the use of dimmers and movement sensors	15	8.29 %
Elimination of lights that are not needed	11	6.08 %
Better choice of light source	10	5.52 %
Use of LED as a light source	8	4.42 %
Don't know	6	3.31 %
Limit the amount of light that escapes from human dwellings	6	3.31 %
Overall reduction of artificial light	4	2.21 %
By turning all the lights off	3	1.66 %
Use of candles	2	1.10 %
Introduce new laws enforcing better use of lighting	2	1.10 %
Reduce the amount of smog	1	0.55 %
Total	181	100 %
Number of respondents	131	86.18 %

The respondents that claimed that light pollution can be reduced were asked to give some examples of practices that would help to reduce light pollution. Overall, the respondents had a very good grasp of practices that would greatly reduce light pollution. All the essential practices were mentioned, including better design of public lighting (pointing downwards),

part-night lighting policy, use of dimmers and movement sensors, better choice of light source, and elimination of lights that are not needed (see Table 13). Additionally, the other practices were mentioned that mainly considered overall reduction of any artificial light or introduction of new laws that would enforce better use of lighting.

Question 6. Have you ever seen this phenomenon that is shown in the picture?

Table 14. *Respondents' experience of encountering skyglow*.

Answer	Absolute value	Percentage
Yes	83	54.61 %
Yes, I see it quite often	31	20.39 %
Sometimes	22	14.47 %
Never	16	10.53 %
Total	152	100 %

Skyglow is the most known phenomenon connected to light pollution and this fact is verified by the answers. As shown in Table 13, 83 respondents have at least encountered this phenomenon, 31 respondents recall encountering it often and 22 respondents are sometimes in contact with it. Only 16 respondents have never seen skyglow. It is possible to conclude that majority of respondents live in an area with high level of light pollution and are aware of the major phenomenon of light pollution.

Question 7. Have you ever been disturbed by a public lighting or any other outside lighting that shined into your home?

Table 15. *Respondents' experience of encountering light intrusion.*

Answer	Absolute value	Percentage
Yes	125	82.24 %
No	24	15.79 %
I don't remember	3	1.97 %
Total	152	100 %

Light intrusion can be considered as the most frustrating type of light pollution when it comes to a private sphere. Therefore, it is expected that the respondents would easily recall being influenced by it, this can be seen in table 14, 125 respondents have been disturbed by an outside lighting. Furthermore, 24 respondents have not been disturbed by an outside lighting and 3 respondents do not recall being disturbed.

Question 8. Have you ever been dazzled by a street light?

Table 16. *Respondents' experience of encountering glare.*

Answer	Absolute value	Percentage
Sometimes	108	71.05 %
Never	23	15.13 %
Yes, quite often	21	13.82 %
Total	152	100 %

The adverse effect of glare that is caused by inappropriate design of public lighting is remarkably perceived by 21 respondents and less frequently by 108 respondents (see Table 15). A very small portion of respondents (23) have never been dazzled by a street light. It can be concluded that glare is a type of light pollution that occurs regularly due to inappropriate luminaire design.

8.4.4 Human health

Question 1. Does the absence of total darkness have a negative impact on human health?

Table 17. *Respondents' views on the possibility of the negative impact that can be caused by the absence of darkness.*

Answer	Absolute value	Percentage
Yes, it does	108	71.05 %
I do not know	32	21.05 %
No, it doesn't	12	7.89 %
Total	152	100 %

Even though 108 respondents are aware of the negative impact that the absence of total darkness have on human health, a disturbing number of respondents are either not sure (32) or do not realize (12) that the absence of total darkness can have both short-term and long-term consequences on human health.

Question 2. (Complementary) – Try to describe how the absence of total darkness have a negative impact on human health.

Table 18. *Respondents' descriptions of negative impacts on human health caused by the absence of total darkness.*

Group of answers	Number of mentions	Percentage
Sleep disorders, poor quality of sleep or regeneration of metabolism	64	45.07 %
Can result in headaches, tiredness or depression	23	16.20 %
Reduced production of hormones (melatonin or generally)	21	14.79 %
Stress	13	9.15 %
Disruption of circadian rhythm	12	8.45 %
Don't know	6	4.23 %
Higher risk of cancer	3	2.11 %
Total	142	100 %
Number of respondents	108	71.05 %

Almost a half of respondents are aware of the most obvious negative impact that the absence of total darkness may cause – sleep disorders, poor quality of sleep or regeneration of metabolism. The second largest portion of respondents think that the absence of total darkness can result in headaches, tiredness or depression (see Table 18), which are to a certain extent caused by the consequences of poor quality of sleep or regeneration. A modest number of respondents associate the absence of total darkness with the decreased production of melatonin and disruption of circadian rhythm, both these negative impacts can further result in other health issues.

Question 3. Is there any connection between lifestyle diseases and light pollution?

Table 19. *Respondents' view on the connection between lifestyle diseases and light pollution.*

Answer	Absolute value	Percentage
I don't know	76	50.00 %
Yes	72	47.37 %
No	4	2.63 %
Total	152	100 %

As can be seen in table 18, only 72 respondents are confident that light pollution may result in lifestyle diseases. Furthermore, exactly a half of respondents are not sure whether there is a connection between lifestyle diseases and light pollution. The remaining 4 respondents feel that there is not connection at all.

Question 4. (Complementary) – Can you name some lifestyle diseases connected with light pollution?

Table 20. *Summary of possible lifestyle diseases connected to light pollution according to the respondents.*

Group of answers	Number of mentions	Percentage
Sleep disorders	33	26.40 %
Depression	20	16.00 %
Cancer	13	10.40 %
Stress	10	8.00 %
Don't know	8	6.40 %
Mental illness	8	6.40 %
Chronic tiredness	8	6.40 %
Obesity	6	4.80 %
Diabetes	4	3.20 %
Cardiovascular diseases	4	3.20 %
Stroke	3	2.40 %
Digestive tract, eye or concentration issues	3	2.40 %
Migraine	3	2.40 %
Hormonal disorders	2	1.60 %
Total	125	100 %
Number of respondents	72	47.36 %

It is a known fact that light pollution can have a negative impact on human metabolism and can result in number of lifestyle diseases. Sleep disorders are the most known amongst the general public, this can be confirmed by the fact that 33 respondents mentioned sleep disorders as one of the lifestyle diseases (see Table 20). Another well know lifestyle disease is depression, which was mentioned by 20 respondents. Cancer, more specifically breast and prostate cancer, is also linked to light pollution, even though cancer is one of the most serious illnesses, only 13 respondents are aware that light at night can increase the chance of cancer.

The other light pollution-related diseases are obesity, diabetes, or cardiovascular diseases. These three diseases were also mentioned by a few respondents (see Table 20).

8.4.5 Types of light

Question 1. Human organism reacts differently to different colours of light. Which colour has the least impact on human organism at night?

Table 21. *Colours of light with the least impact on human health, according to respondents.*

Answer	Absolute value	Percentage
Blue light	53	34.87 %
Red light	37	24.34 %
Yellow light	25	16.45 %
Orange light	24	15.79 %
White light	13	8.55 %
Total	152	100 %

Table 19 shows that a substantial portion of respondents consider blue light to be the least harmful type, however, blue light is on the contrary the most harmful type of light at night. White light has been chosen by 13 respondents, nonetheless, white light contains blue emission and thus is harmful. Moreover, yellow light might be identified as neutral and was chosen by 25 respondents. Orange light is the second least harmful type of light at night that has been chosen by 24 respondents. Nevertheless, only 37 respondents recognize red light as a light that has the least impact on human organism.

Question 2. There is an ongoing trend to switch from old street light types to cool white LED (light emitting diodes). Do you think that this transition is helping to reduce light pollution?

Table 22. *Respondents' perception of the ongoing transition to cool white LED and its possibility to reduce light pollution.*

Answer	Absolute value	Percentage
I don't know	72	47.37 %
No	54	35.53 %
Yes	26	17.11 %
Total	152	100 %

A considerable portion of respondents (see Table 20) recognize that cool white light emitting diodes does not help to reduce light pollution. However, 26 respondents consider white cool light emitting diodes to be a type of light that reduces light pollution. Nevertheless, almost half of respondents are not confident to answer.

8.4.6 Wildlife

Question 1. Do you think that the dark night sky is important for animals and plants?

Table 23. *Respondents' views on the importance of the dark night sky for animals and plants.*

Answer	Absolute value	Percentage
Yes	144	94.74 %
Maybe	5	3.29 %
No	3	1.97 %
Total	152	100 %

Table 23 indicates that a clear majority of respondents (144) realize that night sky is important to animals and plants. Additionally, 5 respondents think that there is some possibility and only 3 respondents feel that the dark night sky is not important for animals and plants.

Question 2. Can you describe why/how is the dark night sky important to animals or plants?

Table 24. *Respondent's descriptions of reasons why is the dark night sky important to animals or plants.*

Group of answers	Number of mentions	Percentage
They use dark sky for orientation	48	23.88 %
Necessity of regeneration (sleep)	35	17.41 %
Biological rhythms	31	15.42 %
It influences their life or vegetation cycle	19	9.45 %
Don't know	17	8.46 %
Same as humans	14	6.97 %
Hunting conditions for nocturnal animals	13	6.47 %
Absence of darkness can result in disruption of photosynthesis	10	4.98 %
Dark environment provides safety	5	2.49 %
They are used to darkness because of evolution	3	1.49 %
Mating	3	1.49 %
Absence of darkness can result in stress	2	1.00 %
Chemical processes of plants	1	0.50 %
Total	201	100 %
Number of respondents	144	94.74 %

Table 24 shows that a considerable portion of respondents (48) recognizes that the dark night sky is important to animals for their orientation; another two substantial groups of respondents realize that the dark sky is important to wildlife due to the necessity of regeneration (35) or due to the correct functioning of biological rhythms (31). The fourth largest group of respondents (17) were not able to come up with any answer. Another groups of respondents also connect the importance of the dark night sky correctly to the vegetation cycle, hunting conditions, disruption of photosynthesis, and safety (see Table 24). Unfortunately, only 3 respondents are aware of the importance of the dark night sky for the purpose of mating (e.g. fireflies).

8.5 Discussion

The positive fact that can be concluded from the findings is that most of the respondents are familiar with the night sky above them. They recognize the significant contrast that can be seen between the night sky in urban and rural areas. However, the conception of the visible stars both in large cities and without the pollution is less convincing, which might be caused by the frequent stay under the polluted skies. The most surprising finding regarding the celestial objects is that a large number of the respondents has either never seen the Milky Way or does not remember seeing it or even does not know how the Milky Way looks. This underlines the sad fact that light pollution is robbing us from one of the most spectacular views created by nature.

According to the findings, the respondents are considerably acquainted with the basic concept of light pollution, only a small number of the respondents have never heard about light pollution, on the other hand, a quite substantial number of the respondents not only heard about light pollution but additionally claimed that they know what light pollution is. The most frequent descriptions of light pollution consisted of answers connected to all artificial light that brightens the night sky and results in degraded observational conditions. Since the poor visibility of celestial objects is the most noticeable effect of light pollution this type of answer was expected. Even though all the answers were in fact correct, only a few respondents were able to describe light pollution in a comprehensive way. Additionally, the respondents were able to describe the basic negative effects that light pollution causes and quite encouraging was the fact that the respondents mentioned all the basic practises that help to reduce light pollution.

The research did prove the fact that most of the inhabitants in developed countries are vastly influenced by light pollution, this can be derived from the fact that a vast majority of the respondents stated that they have encountered or been influenced by all three main types of light pollution, including skyglow, light intrusion, and glare.

As the research shows, the respondents are aware that the absence of total darkness can cause health problems, however, most of the respondents associate it with more common and evident problems (e.g. sleep disorders, depression) and they do not recognize the connection

with more serious problems and diseases (e.g. cancer, diabetes, hormonal disorders, cardiovascular diseases).

Nevertheless, the respondents showed the most comprehensive understanding of the importance of the dark night sky for wildlife. Most of their descriptions comprised of quite diverse answers that correlated with the actual problems, which are caused by light pollution and generally pointed out the fact that the respondents are aware that the wildlife is much more influenced by this unnatural alteration than humans.

Even though the research has shown that the general public has greater knowledge about light pollution than expected, the majority of respondents have only basic understanding about light pollution, however, there were quite a few exceptions that proved their profound knowledge of the topic of light pollution and other related areas. This might be advocated by the fact that the large majority of respondents are studying at universities and colleges or they have reached the higher level of education.

9 CONCLUSION

This thesis focuses on light pollution and its impact on the environment. Light pollution is a type of pollution that is still unknown for most of the population. The reason for that might be the fact that most of the population has grown up alongside with light pollution and thus has got accustomed to it. Another fact is that people experience the adverse effects of light pollution every day without realizing it. Therefore, they have no reason to address this issue. Unfortunately, the incomprehension within this area among the public is the immense issue concerning light pollution.

The thesis deals with defining what the light pollution is. It describes how is it manifested and what kind of sources are responsible for its creation. Next, types of light pollution are presented as well as statistics of affected countries. In the chapters that follow every type of light pollution is individually discussed. The discussion includes their observation, behaviour and their effects.

Afterwards the thesis focuses on measuring light pollution. The only part of light pollution that can be measured is skyglow, hence, the brightness of the sky. Astronomers use special sensors placed on orbiting satellites to achieve maximal precision when measuring light pollution. However, this part of thesis discusses the affordable approaches to measure light pollution with minimal costs.

Furthermore, the thesis deals with the question of adverse effects. Firstly, the focus is on adverse effects on humans. It is obvious that the impact of light pollution concerns every citizen of the developed world in many different ways. The adverse effects concerning humans are mainly health related or related to astronomic observations. However, humans are not the only species influenced by light pollution, animal species of all kinds are much greatly influenced by light pollution, for the reason that their life circle depends vastly on natural light during night. Another adverse effect connected to light pollution is energy and money waste that is caused by inappropriate design of luminaires and its light sources. The operational costs of public lighting in the Czech Republic could be approximately reduced by three quarters if appropriate reconstructions of public lighting were made. Moreover, light

pollution has also a negative impact on safety, criminals can easily exploit deep shadows, disability or blinding glare that is created by inappropriate light design.

In chapter six, low-pressure sodium lamps and types of light sources that are used in the Czech Republic for public lighting are individually described with a focus on parameters that need to be taken into account when considering the reduction of light pollution, which include correlated colour temperature (light spectrum), luminous efficacy, colour rendering index, and lifespan.

Fortunately, light pollution is a reversible type of pollution, therefore, a few basic practises that help to reduce light pollution are described in the last chapter of the theoretical part, including a number of examples how outdoor luminaires (light fixtures) should be designed. However, the reduction of light pollution does not include only the people managing outdoor lights because people living in flats can help as well by turning off unnecessary lights or closing blinds in rooms where the light is needed.

The aim of the research in the practical part of the thesis was focused on the level of awareness of light pollution among the general public. The findings suggest that the general public has much greater awareness than excepted, however, most of the respondents demonstrated only basic understanding and recognized merely a fraction of related issues. Nevertheless, a small number of respondents demonstrated a profound knowledge about this issue. Nonetheless, the incomprehension even though it is decreasing is still the leading issue concerning light pollution. The increasing awareness is a positive element; however, it must be followed by the actions of individual people that can make a change. Hopefully, the research not only identified the level of awareness but also increased it.

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11 List of figures

12 List of tables

13 Appendices

Appendix: Light Pollution Awareness Survey

General section

1. **What is your gender?** *
   Mark only one oval.
   - ◯ Female
   - ◯ Male

2. **How old are you?** *
   Mark only one oval.
   - ◯ Under 15
   - ◯ 15-18
   - ◯ 19-25
   - ◯ 26-40
   - ◯ 40+

3. **What is your highest level of completed education?**
   Mark only one oval.
   - ◯ Elementary/primary education
   - ◯ High school/secondary education
   - ◯ Bachelor's degree.
   - ◯ Master's degree.
   - ◯ Doctorate degree or equivalent.
   - ◯ Other: _____

4. **Do you think that public lighting in your city/village is used efficiently?** *
   Mark only one oval.
   - ◯ Yes.
   - ◯ No.
   - ◯ I don't know.

Star observation

5. **Do you think there is a difference between the night sky in urban areas and rural areas?** *
   Mark only one oval.
   - ◯ A significant difference.
   - ◯ A small difference.
   - ◯ No.

6. **How many stars, in your opinion, can be seen with a naked eye in large cities?** *
Mark only one oval.

- ◯ Less than 500.
- ◯ 501- 1,500
- ◯ 1,501 - 3,000
- ◯ 3,001 - 4,500
- ◯ More than 4,500.

7. **How many stars do you think you are supposed to see with a naked eye without any interference?** *
Mark only one oval.

- ◯ Less than 500
- ◯ 501 - 1,500
- ◯ 1,501 - 3,000
- ◯ 3,001 - 4,500
- ◯ More than 4,500

8. **Have you ever seen the Milky Way at night?** *
Mark only one oval.

- ◯ Yes.
- ◯ No. *Skip to question 9.*
- ◯ I do not remember. *Skip to question 9.*
- ◯ I am not sure how to find it in the sky. *Skip to question 9.*

Light pollution - Part one

9. **Have you ever heard about light pollution?** *
Mark only one oval.

- ◯ Yes, I heard about it. *Skip to question 11.*
- ◯ Yes, I heard and I know what it is. *Skip to question10.*
- ◯ No. *Skip to question 11.*

Light pollution - Follow up question

10. **Can you describe in your own words what light pollution is?** *

Light pollution - Part two

11. Could you name some negative effects of light pollution? *

_____

_____

_____

_____

12. **Do you think that it is possible to reduce light pollution** *

Mark only one oval.

- ◯ Yes. *Skip to question 13.*
- ◯ No. *Skip to question 14.*
- ◯ I don't know. *Skip to question 14.*

Light pollution - Follow up question

13. Please describe how light pollution can be reduced. *

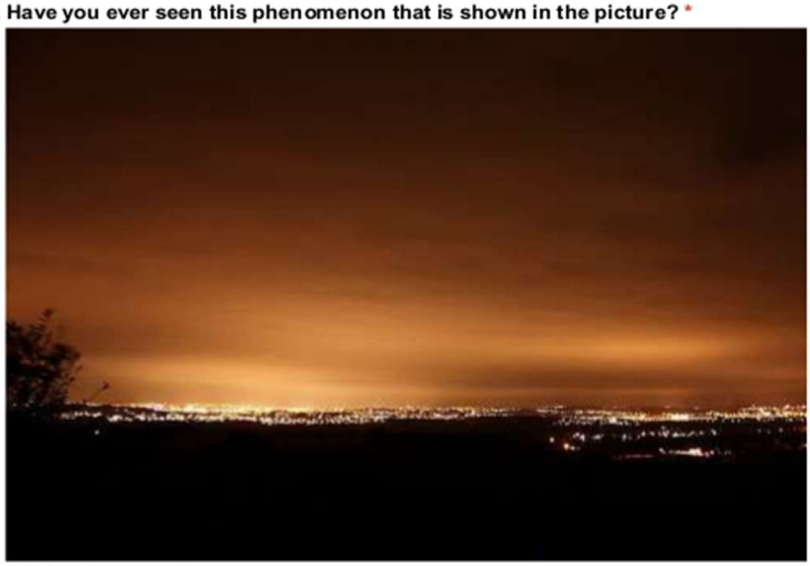
_____

_____

_____

Light pollution - Part three

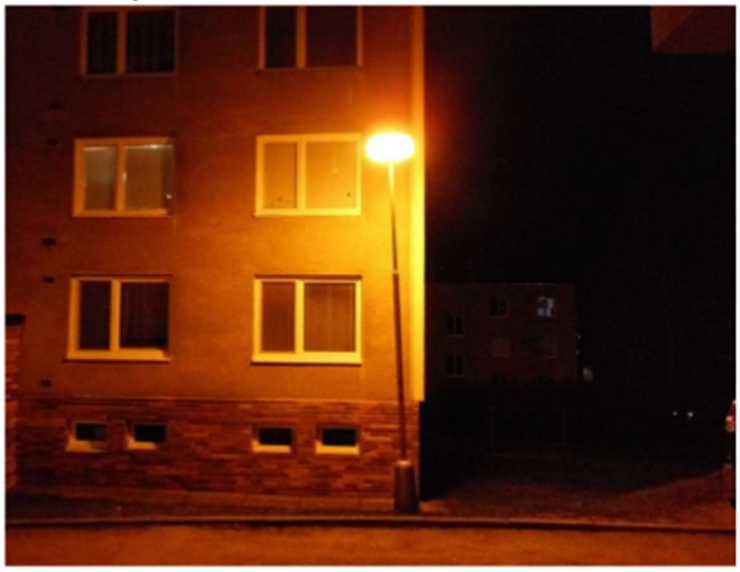
14. Have you ever seen this phenomenon that is shown in the picture? *



Mark only one oval.

- ◯ Yes.
- ◯ Never.
- ◯ Yes, I see it quite often.
- ◯ Sometimes.

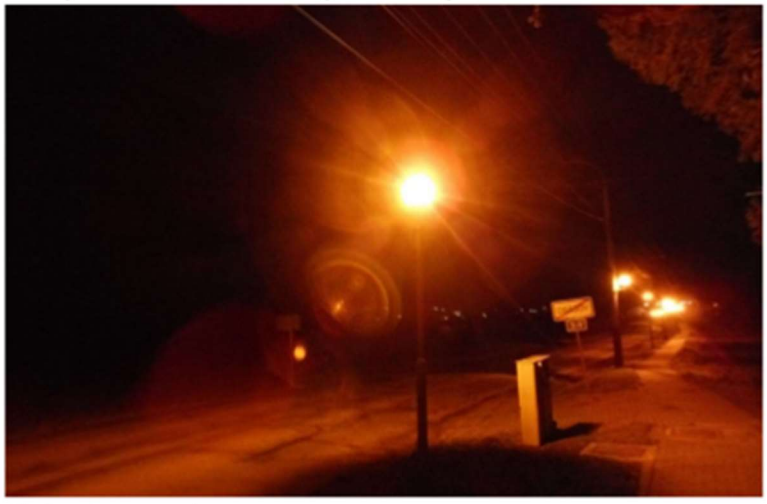
15. **Have you ever been disturbed by a public lighting or any other outside lightning that shined into your home?** *



Mark only one oval.

- ◯ Yes.
- ◯ No.
- ◯ I don't remember.

16. **Have you ever been dazzled by a street light?** *



Mark only one oval.

- ◯ Yes, quite often.
- ◯ Never.
- ◯ Sometimes.

Human health - Part one

17. **Does the absence of total darkness have a negative impact on human health?** *

Mark only one oval.

- ◯ Yes, it does. *Skip to question 18.*
- ◯ No, it doesn't. *Skip to question 19.*
- ◯ I do not know. *Skip to question 19.*

Human health - Follow up question

18. **Try to describe how the absence of total darkness have a negative impact on human health.** *

_____

_____

_____

_____

_____

Human health - Part two

19. **Is there any connection between lifestyle diseases and light pollution?** *

Mark only one oval.

- ◯ Yes. *Skip to question 20.*
- ◯ No. *Skip to question 21.*
- ◯ I don't know. *Skip to question 21.*

Human health - Follow up question

20. **Can you name some lifestyle diseases connected with light pollution?** *

_____

_____

_____

_____

_____

Type of light

21. **Human organism reacts differently to different colors of light. Which color has the least impact on human organism at night?** *

Mark only one oval.

- ◯ White light.
- ◯ Red light.
- ◯ Blue light.
- ◯ Orange light.
- ◯ Yellow light.

22. **There is an ongoing trend to switch from old street light types to cool white LED (light emitting diodes). Do you think that this transition is helping to reduce light pollution?** *
Mark only one oval.

- ◯ Yes.
- ◯ No.
- ◯ I don't know.

Wildlife

23. **Do you think that dark night sky is important for animals and plants?** *
Mark only one oval.

- ◯ Yes. *Skip to question 24.*
- ◯ No. *Stop filling out this form.*
- ◯ Maybe. *Stop filling out this form.*

Wildlife - Follow up question

24. **Can you describe why/how is dark night sky important to animals or plants?** *