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SPECIAL SECTION

Strategies influencing energy efficiency of lighting solutions

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Abstract. Lighting technologies developed significantly in the last decade. New LED light sources, dedicated luminaires and improved lighting control techniques gave rise to new possibilities in improving energy efficiency of lighting solutions. The article is an overview of interior, road and exterior architectural object lighting design strategies. It also presents design considerations that directly impact lighting conditions and energy efficiency. Practical examples of the application of basic design strategies, accompanied by the obtained energy results, are also depicted. Issues discussed in the article may be useful in researching and designing interior and road lighting, as well as floodlighting. They can also be useful in planning and implementing strategies aimed at improving lighting conditions and energy efficiency of lighting solutions.

Key words: lighting technology, interior lighting, road lighting, floodlighting, energy efficiency.

1. Introduction

Interior, road and exterior architectural object lighting should meet many requirements and follow multiple recommendations in order to satisfy its users' expectations and demand of the society. Introducing electric light into private and public space allowed people to carry out a majority of their daily life activities, both work-wise and as regards their free time, without daylight, both at night and during the day. Good lighting involves good design and relevant execution. Critical decisions regarding the illuminated object, lighting conditions, energy efficiency, influence on the natural environment or investment and maintenance costs are made at the design stage. The design team is responsible for the lighting results, correct system functioning and the involved costs.

The 21st century brought about important changes in lighting technologies, lighting techniques and computer aided lighting design. New light-emitting diodes (LEDs) and a dedicated optical system were introduced on a wide scale and lighting control possibilities were improved. Improving energy and economic efficiency of lighting solutions by meeting lighting condition requirements is possible thanks to new lighting technologies and techniques. Changes as regards computer aided design make it possible to analyse and forecast lighting conditions in a precise manner. The objective of the article is to present technological and technical opportunities as regards energy-efficient lighting solutions that provide high luminous environment quality.

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2. Energy efficiency as a lighting quality element

The concept of high quality lighting was brought up in 1990s and has been promoted and developed ever since [1]. Its principle assumption is the need to consider whether each specific lighting solution satisfies human needs [2]. What this means in practice is the need to analyse lighting on the basis of multiple criteria. First of all, due to visual impact, lighting should provide effective and comfortable vision, on top of the safety aspects [3]. Satisfying these needs constitutes basis for defining normative lighting requirements for interiors [4], roads and other areas involved in communication [5], exteriors [6], sports facilities [7] and emergency systems [8]. Economic and energy efficiency are also important elements in evaluating lighting solutions [9]. Their psychological, architectural and aesthetic impact are additional evaluation criteria, relevant for many lighting situations [10, 11].

In the 21st century, due to the appearing results of research on non-visual lighting impact [12, 13], interest in introducing new criteria for evaluating lighting solutions surged [14, 15]. It should be anticipated that the next decade will see such requirements finally defined and included in the standards. HCL (Human Centric Lighting) concept is associated with this trend [16, 17].

The 21st century also brought about great interest in the impact of lighting onto the environment [18–21]. It is connected with a significant increase in global carbon dioxide emissions. Today, China, USA, EU-28, India and Russia emit the most CO_2 into the atmosphere. The world's largest per capita CO_2 emitters are the major oil producing countries, particularly those with relatively low population size [22]. A number of actions has been taken around the world to deal with this problem.

The reduction of electric energy consumption (and due to that, CO_2 to the atmosphere) is a high priority for the authorities of the European Union. This policy resulted in the agreement in Kyoto in 2005 [23]. The Kyoto Protocol stands that industrialised countries are obliged to reduce overall greenhouse gases emission.

The next pro-ecological step was the Paris Agreement, signed in 2015 [24]. This agreement can be determined as a global agreement of the international community on limiting climate change. It indicated in actions to rein up a global warming at the level "much below 2°C".

Another initiative took place in 2018 in Katowice, Poland [25]. The result of the UN Global Climate Conference – COP24 was that negotiators from 196 countries and the European Union finalized the next climate agreement implementing the 2015 Paris Agreement. The final report from this conference states that one should strive to reduce the global warming increase by 1.5°C instead of 2°C, as it was stated in the Paris Agreement. The call to increase efforts after 2020 and to mobilize $100 billion is also repeated. There is also a call for the participating countries to present their environmental commitments by 2020 and every five years. Despite CO_2 emissions reduction, the agreement presents other ways to prevent the climate change, including the absorption of CO_2 by living natural resources, e.g. forests. Moreover, according to the latest settlement of the European Commission, the European Union is to become "climate neutral" by 2050 [26]. It means that CO_2 emissions should be equal to their absorption. Therefore, the carbon dioxide emission into the atmosphere will be reduced by 45% by 2030.

According to another report from the International Energy Agency (IEA), energy use for lighting purposes is connected with around 19% of the total electricity produced in the world [27]. In the private, public and individual sectors there is a huge potential for reducing electricity consumption, and thus reducing CO_2 emissions to the atmosphere and, consequently, minimizing climate change. In order for this paper the impact of reducing electricity consumption on the environment, the calculation of CO_2 emissions have been made, and results presented in chapter 4, based on the assumption that the production of 1 kWh causes 765 kg CO_2 emissions. This data can be applied to Polish conditions [28].

The notion of energy efficiency in lighting can be referred to specific devices the lighting system is composed of (energy efficiency of the light source, power supply system, control system and of the luminaire) or to the lighting solution. Energy efficiency of lighting solutions defined as energy efficiency of interior, road or architectural object lighting, was considered in the conducted analysis. Efficiency of creation and distribution of the luminous flux to the illuminated surface and the level to which the lighting is maintained during use should be taken into consideration in evaluating energy efficiency of a lighting solution.

Evaluating energy efficiency of a lighting solution must involve evaluation of the applied means and the obtained results [29]. The obtained result is the level of lighting of the place involving visual work (e.g. average illuminance level on the corridor floor, average luminance level of the road surface, average luminance level of the illuminated building façade). The applied means are the lighting system power or energy. Therefore, energy efficiency of a lighting solution is measured with installed power or energy demand (usually in reference to a unit surface area of the illuminated plane) compared to the reference (or actual) illuminance or luminance level [5, 9]. These measures can be used to analyse factors that influence energy efficiency of the lighting solutions, factors which the designer has direct (design strategies) or indirect influence on (general design considerations).

3. Design strategies and considerations

Design strategies which we describe in our paper should be understood as technological and technical means and the other factors that influence lighting conditions and energy efficiency of lighting solutions. Technologies are light sources, luminaires, supply and control equipment whereas techniques are related to the equipment use. Design strategies are presented in this chapter in the order of lighting design stages.

The right choice of design strategies and ability to manipulate the other factors determine the desired lighting conditions and high energy efficiency. The search for optimal strategies is only a part of the entire, creative design process for developing lighting solutions for safe, productive and comfortable use. Design process, well known in architecture, covers all actions (not only strategy selection) that lead to the final solution appropriate in terms of quantity and quality of lighting, energy, environment, cost, aesthetics and more aspects [30].

Factors related to the illuminated object, criteria regarding lighting conditions and energy efficiency of the lighting solution, strategies regarding lighting equipment and its application are presented in detail. The economic, social and political approaches to lighting energy efficiency issue are not developed in this paper.

3.1. Object characteristics. The first stage of lighting design is a detailed analysis of all conditions regarding the illuminated object and its surroundings. Regardless of the illuminated object type (e.g. room, road, building façade), its geographic location determining the principal weather conditions (state of the sky, temperature, humidity) is crucial. The spatial location of the object is, however, crucial as its adjacency to other objects, their density, ambience brightness and geographic orientation of the building's windows are equally important. What is also important is the size of the object itself, its principal dimensions and mutual position of various zones, and location of equipment in the illuminated space. Another essential factors are the photometric characteristics of the principal surfaces of interiors, roads, exterior areas, architectural objects. Each of these factors has indirect impact on the obtained lighting conditions and energy efficiency. The principal factors related to the illuminated object and its surroundings are presented in Table 1.

Table 1
Factors related to the illuminated object and its surroundings

Interior lighting	Road lighting	Floodlighting
Building location (geographic, window size and orientation, adjacent objects)	Road location (geographic, ambient luminance, adjacent objects)	Object location (geographic, ambient luminance, adjacent objects)
Size and geometry of the building and rooms	Size and geometry of the traffic zone and environment	Size and geometry of the object and adjacent zones
Photometric characteristics of the illuminated surfaces and environment	Photometric characteristics of the illuminated surfaces and environment	Photometric characteristics of the illuminated surfaces and environment
Weather conditions, state of the sky, solar heat level, ambient temperature	Weather conditions, visibility, ambient temperature, humidity	Weather conditions, visibility, ambient temperature, humidity

Table 2
Basic criteria of evaluating interior, road and architectural objects lighting

Interior lighting	Road lighting	Floodlighting
Average illuminance on task area	Average luminance on road surface	Average luminance on object (e.g. building façade)
Uniformity on task area	Overall and longitudinal uniformity on road surface	–
Average illuminance on immediate and background area	Road surround ratio (relative illuminance on roadside)	Ratio of average object and background luminance
Uniformity on immediate and background area	–	–
Discomfort glare index	Disability glare index	–
Average illuminance and uniformity on ceiling and walls	–	–
Average cylindrical illuminance and uniformity; modelling index	–	–
	Vertical illuminance in intrusion place and luminaire luminous intensity towards the intrusion place. Luminaire/lighting upward luminous flux Average luminance of objects located near illuminated objects, including signs, adverts.	
Correlated colour temperature and colour rendering index		

3.2. Criteria of evaluating luminous environment and energy efficiency. Criteria of evaluating lighting conditions have the nature of requirements and recommendations. They are formulated by specific set of parameters and their criterion values. The same or similar aspects are evaluated despite the application of various parameters and criteria in designing interior, road and architectural objects lighting. The so-called task area (also the immediate and background areas) are subject to evaluation. Average values and uniformity of illuminance or luminance for specific areas are evaluated. Moreover, discomfort, disability and reflected glare phenomena are also assessed. What is also evaluated in interior lighting is the ceiling and walls illumination, visual communication and modelling, and in road and architectural objects lighting is the light pollution. An essential evaluation element is light colour and rendering, however, in evaluation of road and architectural objects lighting, this is not obligatory. Criteria of evaluating interior, road and architectural objects lighting are presented in Table 2.

The basic quantitative and qualitative criteria presented in Table 2 are used in lighting solutions analysis and design practice. Important elements of subjective evaluation in road lighting are visual guidance [31] and assessing the degree to which floodlighting rules of external objects have been met [32, 33].

Evaluation of energy efficiency of lighting solutions must be based on analysis of the applied means and the obtained results. The following indexes can be applied to evaluate energy efficiency of lighting solutions [5, 9, 29]:

- Installed power demand of the lighting system;
- Energy demand of lighting system;
- Installed power density (or energy density demand) of an interior (road, illuminated object), when the unit surface area and actual lighting level are the points of reference;
- Normalized power density (or normalized energy density) of an interior (road, illuminated object), when the unit surface area and normalized lighting level are the points of reference.

Applying these measures to analysis and evaluation of the energy efficiency of lighting solutions in interiors and roads is quite common.

In interiors, the annual energy density demand and also the installed power density are used [9]. These measures are determined for the whole building (e.g. office, school, hospital, etc.) and the requirements are different for different building types. The installed power density is a simpler measure but auxiliary only. The annual energy density demand (known as LENI – Lighting Energy Numeric Indicator) gives full information about energy on lighting purposes in an analysed building.

In roads, the normalised power density and the annual energy density demand are used [34]. These measures are determined for different road classes and the benchmark values are given for different road situations (geometry and used lamps). Both the normalised power density (known as the Power Density Indicator) and the annual energy density demand (known as the Annual Energy Consumption Indicator) should be used to assess the lighting energy efficiency on the analysed road. In contrast, the evaluation of energy efficiency of illuminated objects may result from the comparison of different parameters for lighting solutions, e.g. Floodlighting Utilization Factor, Oversizing Luminance etc. [35].

Criteria for evaluating energy efficiency of lighting solutions for interiors, roads and architectural objects are presented in Table 3.

Table 3
Criteria of evaluating energy efficiency of interior, road and architectural objects lighting.

Interior lighting	**Road lighting**	**Floodlighting**
Installed power density Energy density demand Normalized power density Normalized energy density		Floodlighting Utilization Factor, Maximum Floodlighting Utilization Factor, Coefficient of Floodlighting Utilization Factor, Oversizing Luminance

The main factors determining the power (energy) of lighting are as follows:

- the level of average illuminance on task area in interiors or the level of average luminance on road surface or the level of average luminance on the illuminated object;
- luminous efficacy of the applied lighting system;
- utilization factor;
- maintenance factor;
- lighting operation time.

3.3. Lighting equipment. Selection of lighting equipment is an essential design strategy impacting lighting conditions and energy efficiency of the solution and should not be accidental. Proper selection of light sources to interior and road lighting, also floodlighting is of great importance as regards meeting the lighting requirements and obtaining energy- and cost-saving lighting. Effective use of the lighting equipment is essential in all lighting areas. Light sources with the greatest possible luminous efficacy should be used to obtain considerable energy saving of a lighting device. As regards obtaining the lowest possible lighting utilization costs, lamp life and decrease of luminous flux value over time should also be taken into consideration. The issue of quality of the produced light, characterized by the correlated colour temperature and the general colour rendering index should not be overlooked. The development of light source constructions is LED technology-oriented nowadays. This is mainly due to high luminous efficacy and long lamp life of LEDs. The growing use of LED technology is also due to the wide range of LED luminaires and LED lamps offer today [36]. Manufacturers of lighting equipment have abandoned the production of traditional luminaires (for incandescent lamps, halogen lamps, fluorescent lamps and discharge lamps) in favour of the new LED technology. The availability of traditional light sources and traditional luminaires is significantly reduced on the market. For this reason, designers and users of lighting equipment mainly choose LED lamps and LED luminaires [37].

LED lamps, which are retrofits of traditional incandescent lamps and halogen lamps are the most common solutions for lighting living spaces (households). LED lamps can be used in practically all luminaires of incandescent and halogen lamps used in households. LED luminaires without interchangeable light source are now used in the general lighting of public places, which substituted the previously popular linear fluorescent lamps. The use of fluorescent lamps is avoided, even though they offer an alternative solution to LED tubes. Using LED tubes as an alternative to linear fluorescent lamps is, however, limited. This results from the need to interfere with the power supply system used in fluorescent luminaires and to change the luminaire luminous intensity distribution.

Luminaires for sodium (SON) and metalhalide lamps (MH) are still used in road lighting, even though LEDs have already gained advantage here. This results mainly from greater luminous efficacy of LEDs [28] and their longer life, as well as greater precision of optical systems construction [38–40]. Moreover, thanks to the possibility of controlling the LED luminaire luminous flux, it is possible to precisely match the luminaire with the given application (oversizing of the lighting level can be limited) [41–43]. An additional advantage of using LED luminaires is the easy adjustment of light colour to a specific application (e.g. changing light colour from warm white to cool white in the area of pedestrian crossings to additionally highlight that area).

Traditional light sources in the form of sodium or metalhalide lamps are also being supplanted by LED sources in floodlighting. This is mainly due to LEDs smaller size and mass but also advantageous photometric parameters. Luminaires that use LED sources, in particular low-power ones, are becoming more and more compact. A great advantage of this technology is the possibility to use it in linear luminaires. So far, linear luminaires have been executed mainly by fluorescent luminaires. The size of such luminaires, both when it comes to the power supply system and the need to create the luminous intensity distribution using a reflector, have often been anything but compact. Another disadvantage was also the standard length which resulted directly from the length of linear fluorescent lamps. When it comes to substitutes of high-power luminaires, the situation is still challenging. In such cases LED luminaires, mainly for thermal reasons, are relatively large. It should be considered, however, that LED technology is changing rapidly. Application of LED sources in luminaires is well-grounded also due to easy power (luminous flux) and colour of the produced light (RGB and RGBW systems) control. Table 4 presents basic electric, photometric

Table 4
Basic electric, photometric and operational parameters of selected light sources

Light Source	Power [W]	η* [lm/W]	CRI** [–]	B_{50}*** [kh]	B_{10}*** [kh]	L_{70}*** [kh]
LED	16–95	113–137	60–90	–	–	50–70
SON	50–400	80–150	20	40–48	28–34	–
MH	35–250	106–125	70–90	24	18	–

*Luminous Efficacy; **Colour Rendering Index; ***Lamp Life

and operational parameters of selected light sources used in interior and road lighting, as well as floodlighting. Summary of design strategies regarding choice of lighting equipment is included in Table 5.

Table 5
Lighting strategies connected with lighting equipment

Interior lighting	Road lighting	Floodlighting
Using light sources with high luminous efficacy and life, and low luminous flux drop in time		
Using energy efficient power supply systems		
Using luminaires with useful luminous intensity distribution (lighting class) according to the application, as well as high light output ratio		
Using luminaires with low susceptibility to receiving and maintaining contamination		

3.4. Lighting solutions. Having selected the lighting equipment, the ways in which it can be used in terms of the illumination method, layout, lighting control and the maintenance efficiency are analysed. The lighting control has the highest potential within these aspects.

Lighting control is used more frequently for two reasons. The first one is the desire to save on lighting operation costs by reducing luminaires power, at the same time meeting the lighting requirements. The second reason is obtaining comfort lighting that allows for the possibility to change the obtained illuminance/luminance levels and the colour of light (RGB and RGBW system) [44, 45].

Various light control systems are used in households, whose principal goal is to save electric energy. Users of homes and apartments more and more often use LED modules or LED luminaires power control to obtain additional lighting effects, e.g.: light colour control using RGB or RGBW systems. The so-called "smart home" technology, where the control takes place via an external application (e.g. installed on the user's mobile phone), has been growing rapidly in this area.

In public utility interiors and road lighting, lighting control is used mainly to limit the lighting operation costs [46] but comfortable conditions are of high importance too [47].

In floodlighting, lighting control is often used to obtain a variety of lighting effects (changing and adjusting luminance levels and distribution, and the colour of light) [32], even though energy-saving aspects are also important [35].

Lighting control systems allow users to decrease the lighting operation costs mainly by reducing luminaire power and their temporary shutdown. For instance, luminaires power can be reduced in interior lighting by using light sensors that maintain a constant illuminance level on the working surface depending on the amount of available daylight [48–50]. Proper selection and placement of such sensors is critical in the interior and road lighting design. Temporary luminaires shutdown occurs via presence or motion sensors. Individual luminaires or luminaire groups can be shut down over a workstation when there are no people around. Such a solution is often used in workplace lighting in offices, corridors and traffic routes in warehouses and industrial facilities. In case of road lighting, traffic/presence sensors are used with adaptive lighting. Lighting control use must always satisfy lighting requirements. For this reason, lighting design and lighting control project (selection of control devices) must be carried out comprehensively.

The level of savings on electric energy consumption resulting from lighting control application, usually refers to traditional lighting solutions. Level of power reduction, and therefore savings in lighting operation, depend on a variety of factors. The principal factors that influence the level of energy savings in using lighting control systems include:

- in rooms – availability of daylight in rooms and the timetable of the task areas use (e.g.: task areas used temporarily or constantly; daily and seasonal absence),
- in road lighting – traffic intensity on the road on basis of which luminaire power (luminous flux) can be reduced at night time or the possibility to use adaptive lighting,
- in floodlighting – luminous flux reduction or shutting part of the luminaires off from a specific night hour and application of various illumination scenes depending on the circumstances (daily, weekend, special occasion illumination etc.).

Summary of design strategies related to the use of lighting equipment and execution of the expected lighting conditions are presented in Table 6.

Table 6
Design strategies with regards to the applied lighting solutions

Interior lighting	Road lighting	Floodlighting
Satisfying requirements regarding lighting a task, immediate and background areas, roads and roadsides, architectural objects without significant over-illumination		
Satisfying requirements regarding cylindrical lighting, ceiling and walls lighting without significant over-illumination	Satisfying recommendations regarding light pollution limits	
If possible, using localized or local lighting, instead of general lighting	Applying luminaire layout system contributing to high light utilization	If possible, using floodlighting method contributing to high light utilization
Applying optimum geometric luminaire arrangement contributing to high light utilization		
Applying the highest possible maintenance factor based on a rational lighting maintenance system and low lighting costs		
Applying effective lighting control system		

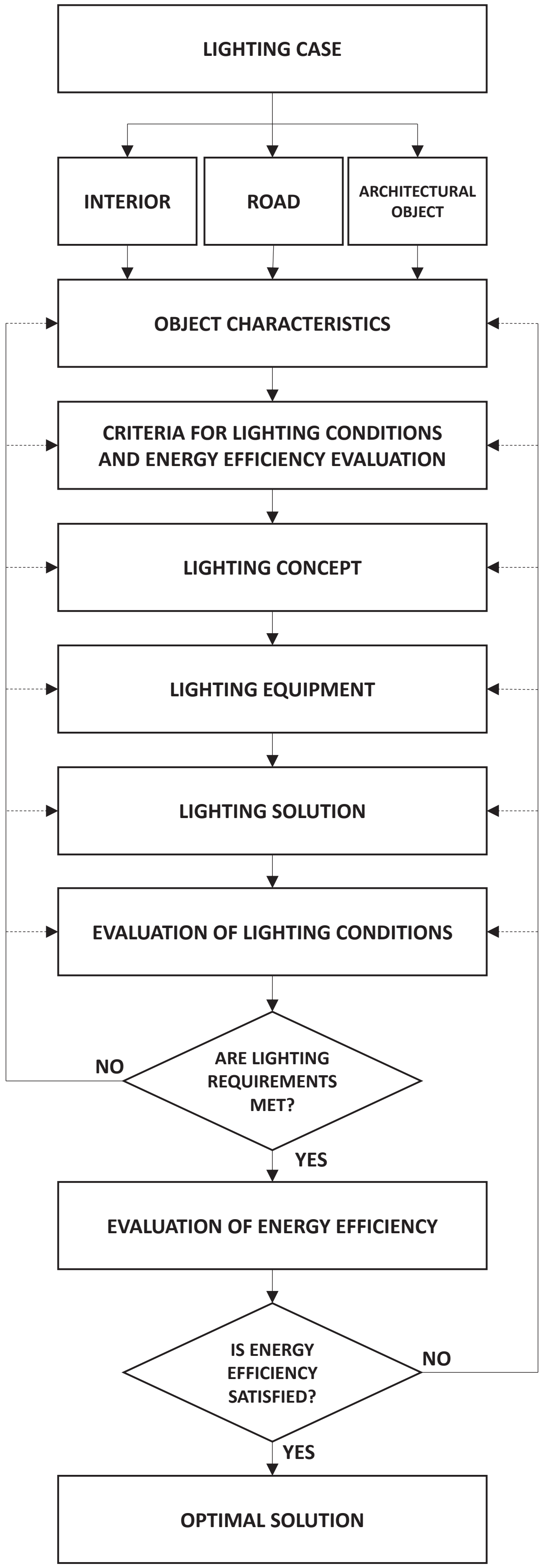

Fig. 1. Flowchart illustrating the order of lighting solutions analysis to meet lighting and energy efficiency requirements

3.5. Summary. To summarise the discussed strategies and factors that influence both lighting conditions and energy efficiency of lighting solutions a flowchart was elaborated and is presented in Fig. 1.

Regardless of the lighting case (interior, road or exterior architectural object), the order of lighting analysis and design is the same. Such ordering results from the lighting design stages, it is common around the world and comprehensive for lighting designers, planers and strategists as well as scientists dealing with illuminating engineering issues.

Strategies or factors that need to be considered to get the best lighting solution are available at each level of the analysis. The initial lighting solution is first assessed in terms of lighting and then energy efficiency requirements. Finally, the optimal lighting solution, considering lighting conditions and energy efficiency, is obtained.

4. Examples of design strategies applications

4.1. Use of luminaires with effective luminous intensity distribution (interior lighting). The leading interior lighting producers offer nearly exclusively LED systems today. With the same light source, the lighting and energy effects are highly dependent on the luminaire luminous intensity distribution. Table 7 presents the results of electric energy consumption in a large-size store with a surface of 1000 m^2. Results were compared for luminaires of II and III lighting class. The luminaires have identical power (41 W) and luminous flux (5006 lm). To calculate the electric energy consumption it was assumed that in each case full luminaire power is used and the annual lighting operation time is 5000 h.

Table 7
Differences in electric energy consumption in the store resulting from the use of luminaires with different lighting classes

Applied means	Energy consumption in III class luminaires solution [kWh/year] (CO_2 emissions [kg])	Energy consumption in II class luminaires solution [kWh/year] (CO_2 emissions [kg])	Difference [%]
Use of lower lighting class luminaires	30 135 (23 053)	27 265 (20 858)	9.5

4.2. Use of lighting control in a building (interior lighting). The application of lighting control systems in buildings is gaining popularity. Using the developed calculation methods [51], savings on electric energy in selected building areas as a result of using lighting control systems were presented. Table 8 presents differences in electric energy consumption for annual lighting system operation time of 4000 hours, using selected types of lighting control systems in reference to solutions without control. In case of using an astronomical clock, the energy consumption reduction is significant and results directly from shutting part of the luminaires down.

Table 8
Differences in electric energy consumption for different lighting control systems

Control system	Energy consumption in a solution without control [kWh/year] (CO_2 emissions [kg])	Energy consumption in a solution with control [kWh/year] (CO_2 emissions [kg])	Difference [%]
Reduction of power in an office hall at night time, using astronomical clock	6 716 (5 138)	1 812 (1 386)	73.0
Using electric lighting supplementing daylighting in an office room, using light sensors	2 144 (1 640)	1 632 (1 248)	23.9

Table 10
Differences in electric energy consumption on the analyzed street [52]

Applied means	Energy consumption in the solution without control [kWh/year] (CO_2 emissions [kg])	Energy consumption in the solution with control [kWh/year] (CO_2 emissions [kg])	Difference [%]
Use of concurrent lighting and 50% luminaires power reduction with fading traffic	16 714 (12 786)	12 974 (9925)	22.4
Use of concurrent lighting and luminaires shutdown with fading traffic	16 714 (12 786)	2134 (1632)	87.2

4.3. Use of LED luminaires (road lighting). In recent years the most common and "simplest" design strategy (modernization) involved LED equipment for lighting. The possible advantages of this strategy result not only from higher LED sources luminous efficacy but also from optimum luminaires luminous intensity distribution. In the presented road lighting example, electric energy consumption for sodium and LED lighting was compared (for one kilometre) for a 7-meter wide road (Table 9). In both cases modern solutions that provide high energy efficiency were used. Both LED luminaires and the traditional ones with high pressure sodium lamps were placed in a 40 m spacing and on similar height. Both luminaire types came from a popular European luminaires producer and provided M1 lighting class. The LED luminaire had the power of 165 W, while the sodium luminaire had the power of 269 W. Annual lighting operation time of 4000 hours was assumed for the analysis.

Table 9
Differences in electric energy consumption for the road resulting from the use of modern luminaires with different light sources

Applied means	Energy consumption in sodium lamps solutions for 1km road lighting [kWh/year] (CO_2 emissions [kg])	Energy consumption in LED lamps solutions for1 km road lighting [kWh/year] (CO_2 emissions [kg])	Difference [%]
Application	26 900 (20 579)	16 500 (12 623)	38.7

4.4. The use of concurrent lighting (road lighting). Introduction of control to road lighting is quite common nowadays. Control systems are used in road lighting mainly to improve energy and economic efficiency of lighting solutions. In the presented example, Table 10 demonstrates the benefits of using concurrent lighting on the road. Lighting power/energy reduction results from adjusting the lighting conditions (decreasing the average luminance on road surface) to the actual situation on the road. Electric energy consumption was compared for the lighting system working overnight with full power (without control) with electric energy consumption of a lighting system operating in a concurrent system mode, with a 50% luminaires power reduction and luminaires shutdown (when the traffic intensity fades) [52].

4.5. The use of effective floodlighting method and control (floodlighting). Differences in electric energy consumption can be significant also in case of floodlighting, depending on the applied strategy. They can result both from application of different floodlighting methods, and thus directly from the amount of lighting equipment used for a specific method [53], and application of lighting control for luminaires used in the project [35]. Table 11 presents both strategies using two examples.

Table 11
Differences in electric energy consumption for different lighting methods.

Applied means	Energy consumption with the accent/ mixed method [kWh/year] (CO_2 emissions [kg])	Energy consumption with the planar method [kWh/year] (CO_2 emissions [kg])	Difference [%]
Application of effective floodlighting method	16 600 (12 699)	5 520 (4223)	66.7
Changing the floodlighting method through control	38 512 (29 462)	16 800 (12 852)	56.4

In the first case, the application of a different floodlighting method is illustrated. The same average object luminance of 12 cd/m^2, both for the planar and the accent method, was obtained as a result of the calculations. It turned out that the accent method had greater installed power and energy consumption for the annual lighting operation time of 4000 hours. We should, however, bear in mind that multiple factors influence energy efficiency of lighting in floodlighting. These involve, among others: the lighting concept, luminous efficacy of the light sources, layout and orientation of luminaires and adjusting the luminous intensity distribution to the given lighting task [54].

The second case illustrates a situation where lighting control was used. The control was supposed to change the floodlighting method, depending on the needs [55]. The main purpose of floodlighting objects is to boost their attractiveness and that of their surroundings. These objects are, however, quite frequently illuminated until dusk despite limited traffic. The reason for this is the indirect role of floodlighting, which is to protect the object and its surroundings. In such cases one might shut down some of the luminaires or reduce the luminous flux for the entire object on specific days or hours. This does not necessarily entail failing to satisfy requirements regarding the average luminance. The third, mixed floodlighting method consists of illuminating the object using luminaires both providing luminous highlights and demonstrating the object outlines as a whole. Shutting down the highlighting luminaires obviously decreases the average luminance level, however, the level still often fits into the recommended range.

5. Conclusions

The development of illuminating engineering in recent years offers multiple opportunities as regards new lighting technologies and techniques, in terms of providing high quality lighting environment and improved energy efficiency in lighting interiors, roads and exterior architectural objects. The article presents design strategies and other factors that influence lighting conditions and energy efficiency of lighting solutions. Presentation of these issues based on a comprehensive literature overview and in an ordered manner can be useful in analysing and designing interior lighting, road lighting and floodlighting. It can also be of assistance in planning and implementing strategies for improving lighting conditions and energy efficiency of any lighting solution. The elaborated flowchart, presented in Chapter 3, summarises the order of lighting solutions analysis to meet lighting and energy efficiency requirements.

Obtaining high quality and energy efficiency of lighting involves a professional lighting design and its execution in line with the design results. The basic activities that directly or indirectly influence the obtained lighting and energy effect are:

- the analysis of the object and all conditions in terms of lighting,
- adopting rational design requirements and recommendations,
- elaborating reliable lighting concept,
- selecting high quality effective lighting equipment,
- finding optimum arrangement of lighting equipment in the illuminated space,
- using control systems that provide optimum use of lighting during its operation.

Application of the design strategies presented in the article should result in improved lighting conditions and energy efficiency of lighting solutions.

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