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Energy performance of lighting systems

Abstract. *For a number of years, the attention has been drawn to the issue of energy saving not only in the field of lighting, but also in many other areas. A crucial moment in the process of dealing with this issue was the opening of the discussions on global warming. One of the effects of this discussion is that the pressure on a fast introduction of new technologies, procedures and new legislation, which would result in reducing energy performance of outdoor as well as indoor lighting systems, has been increasing. This paper deals with the relationship between the technical parameters of illumination and the energy performance of lighting and describes possible trends in achieving energy efficient lighting systems.*

Streszczenie. *Od wielu lat przywiązuje się dużą uwagę do zagadnień efektywności energetycznej, nie tylko w zakresie oświetlenia, ale także wielu innych dziedzinach. Istotnym momentem w tej dyskusji było włączenie tematyki globalnego ocieplenia. Efektem tych dyskusji jest wzmożenie działań w kierunku szybkiego wdrażania nowych technologii, opracowania nowych regulacji prawnych, co ma w założeniu skutkować poprawą efektywności energetycznej zewnętrznych i wewnętrznych urządzeń oświetleniowych. W artykule poruszono zagadnienie współzależności cech oświetlenia i charakterystyki energetycznej oświetlenia oraz trendy uzyskiwania oświetlenia wydajnego energetycznie.* ***(Charakterystyka energetyczna systemów oświetleniowych).***

Keywords: lighting systems, energy performance of buildings, power saving.
Słowa kluczowe: systemy oświetleniowe, charakterystyka energetyczna budynków, redukcja mocy.

Introduction

Energy performance of various types of buildings - office, industrial, healthcare, educational and other buildings - is a widely discussed issue at different levels. The solution of energy performance of lighting systems of these buildings is also a part of these discussions. The basis is provided by the newly drafted standard ČSN EN 15 193 Energy performance of buildings – Energy requirements for lighting and by technical national standards TNI 73 0327.

The lighting design of an interior as well as outdoor space is primarily determined by its use. The aim of the lighting design is to create suitable lighting conditions for a particular visual activity (e.g. reading, writing, metal cutting, surgery, etc.) A number of specialized studies and scientific experiments were realized in order to determine what illumination conditions are sufficient for a particular visual activity. Based on the statistical evaluation of their results, the technical parametric values were determined for the various visual activities, which then became a part of national and international standards. It is important to mention that the current technical parameters of illumination specified in the standards and recommendations do not represent the optimum values, but the compromise between economic capacity of the society and the optimum visual conditions [1].

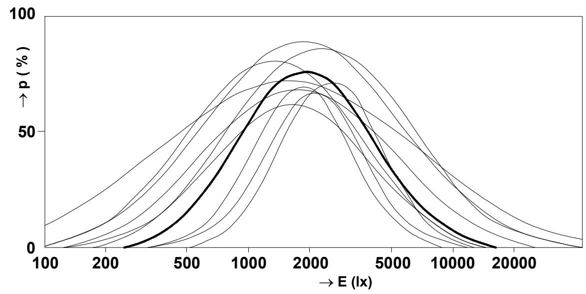

Fig. 1 The results of a research focusing on the subjective illuminance level assessment in interiors illuminated with fluorescent lamps showing the percentage of people's satisfaction depending on the illuminance level.

The optimum values of technical parameters of illumination are distinctly higher in comparison with the standard values. Figure 1 shows the results of some of the experiments focusing on illuminance level assessment in an interior space where people performed common office tasks. While the recommended standard values of illuminance for these visual activities are around 500 lx, the optimum values are around 2 000 lx.

Illumination and its charcter

Technical parameters of illumination are not the only aspects important for lighting design. There are other aspects to consider in order insuring a functional quality lighting solution:

- Visual aspect – relates to the visual design of the illumined space, i.e. the atmosphere created by the light and the design of the lighting system, i.e. visual application of lighting in space.
- Technical aspect of illumination – the selection of technical parameters of illumination according to the purpose and use of the space. These parameters primarily take into consideration physiological and security requirements, but also psychological requirements. In recent years, biological requirements have also become relevant.
- Operational aspect – includes energy performance of lighting system, its operation and maintenance as well as issues related to the investment and operational cost.
- Aspect of external influences – this aspect is connected with the fact that lighting can, apart from its primary function, produce side effects which may negatively influence the space itself, objects placed inside the space, or the adjacent space. This includes for example the control of UV radiation when illuminating sensitive objects in museums and galleries, dazzling of users in the adjacent space, etc.

The character of illumination in a space can differ not only according to the intended use of the space but also according to the role played by the physiological, psychological or biological requirements of its users. Illumination of a space where the main focus is on physiological aspects is based on the technical parameters of illumination specified in the standards. The example of this is the illumination of an office space, industrial buildings etc. Illumination which is primarily based on psychological aspects serves to create specific light atmosphere in the space and is usually a part of the artistic solution of the interior design. This type of illumination is typical for public cultural space such as theatres, cinemas, restaurants, etc. Fairly complex subjective nature of such illumination does not make a simplified objective specification of current technical parameters of illumination possible. Illumination determined by the biological aspects of the users does not primarily focus only on creating an environment for a specific visual task, but uses the illumination to influence the human biological system. This type of design is based on other than visual requirements, and the energy performance of such lighting systems is higher than that of common lighting systems.

When designing and assessing lighting systems, energy performance of lighting is only a secondary aspect which can be defined as follows: the required technical parameters of illumination should be satisfied in the most energy efficient manner. Requirements for lower energy performance of lighting cannot in any case be superior to the lighting requirements.

Energy performance of lighting

The approach to the issue of energy performance of lighting varies depending on whether we are assessing energy performance of a designed, eventually a newly realized building or the energy performance of an already existing building.

In case of a new building, the installed power of the lighting system is known, however, it is necessary to determine the operation time and the real operational power based on the information on the nature of the building operation, (i.e. standard operation). This simply means that the power consumption is estimated.

In case of already existing buildings, the energy performance of lighting can be determined from the measured values of power consumption. However, due to the fact that in most cases the measurement of power consumption of lighting system is not separate, the share of power consumption for lighting must be estimated (figure 2). Then, based on the installed load and the nature of building operation, it is necessary to try to determine the utilization of the power of the lighting system within a certain period of time, for example year.

In both cases, one works with estimated values. When looking for energy saving measures and determining their returnability, it is necessary to determine the inaccuracy of this estimate. In order to have the possibility to assess the energy performance of lighting objectively in the future, it is necessary to ensure a direct measurement of the power consumption for the lighting system (figure 3). Should the information on the utilization of different parts of a lighting system be required, it is necessary to use control lighting systems which are able to record the power consumption of the whole lighting system as well as individual lighting fittings (figure 4). For a more objective assessment of the energy performance of already existing buildings, sets of statistical data on the utilization and character of operation in various types of buildings are to be produced, which describe the behaviour of the users from the point of view of lighting control.

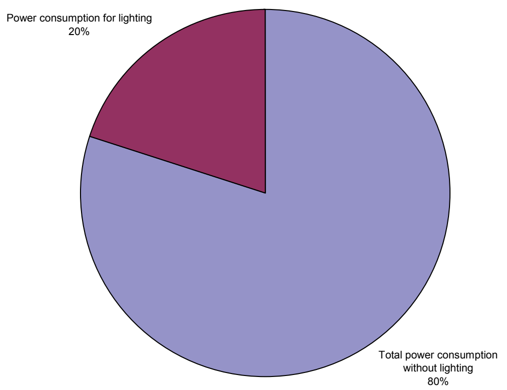

Fig. 2. An example of an estimate of energy performance of artificial lighting specified as the proportion from the total consumption of the building during a certain period of time (e.g. a year).

There are two problematic issues connected with the assessment of energy performance of lighting systems: One, a lighting system does not necessarily have to be utilized according to standard conditions and the power consumption can be far lower than the prescribed standard values [2].

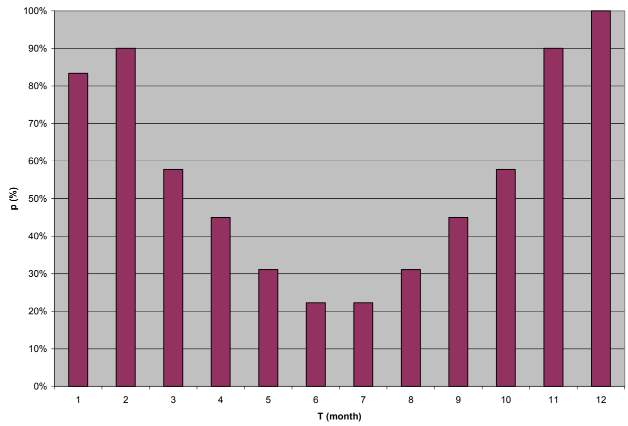

Fig. 3. An example of detailed processing of results of power consumption measurement for artificial lighting per month within one year period of testing.

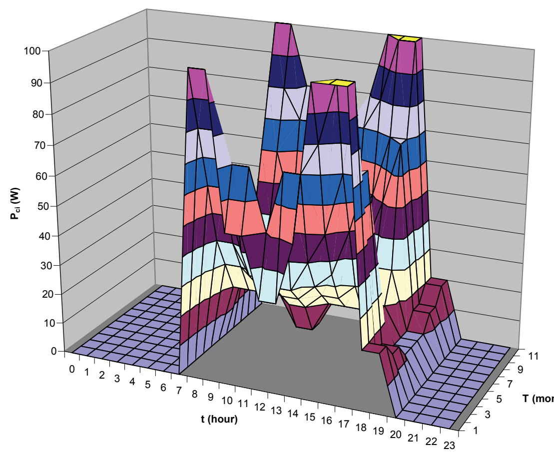

Fig. 4 An example of a detailed graph showing the results of the real power P_{ci} (W) of a selected lighting fitting which is a part of a tested lighting system.

This, however, does not rule out the possibility that the installed power of the lighting system can be distinctly higher than the prescribed standard values [2], [3]. If the behaviour of users changed, the standard values of the specific power consumption for lighting would be exceeded. A question therefore arises whether a possible proposal of energy saving measures, which may or may not become relevant depending on the behaviour of the users, has any significance. The other problematic issue is the complexity of separating the real operational power for lighting and the operation time of lighting fittings. A selection of effective energy saving measures depends on this information. If these information are not ascertained with sufficient accuracy, the inaccuracy rate when determining the efficiency and returnability of the proposed energy saving measures increases.

Energy saving strategy

In order to choose the right strategy when proposing energy saving measures, one can start from the basic relationship represented by the power consumption for lighting for a certain period of time, e.g. a year:

$$W = P_p \cdot t_o \qquad \text{(kWh/year)}$$

where: P_p - average operation power of lighting fittings (kW), t_0 - operation time (hour/year)

It is obvious from this relationship that the strategy for achieving power consumption savings in case of lighting can be based on the search for savings in operational power or in the operation time of the lighting system, possibly also in combining both parameters. Energy saving measures can be based on the following strategies:

- selection of a lighting system;
- selection of technical equipments;
- control of lighting system design;
- use of daylight;
- monitoring of the presence of people;
- use of time modes;

The assessment of energy performance of lighting makes sense provided the lighting and therefore also the technical parameters of illumination in a particular space correspond to the purpose and the use of that space. In the design phase, the protocols containing calculations of technical parameters provide the basic information about the parameters of illumination. In case of already realized buildings, such information can be found in the protocols on the measurement of illuminance levels drafted by an authorized body.

Selection of a lighting system

Lighting system for artificial illumination is a set of devices (lighting fittings, light sources, control gears, lighting control systems and accessories) which primarily serve to the creation of the required light environment. Lighting systems can be distinguished according to the type of device used and its characteristics. The type as well as the characteristics of a lighting system influences its energy performance. There are three basic types of lighting systems used when implementing the general lighting which is based on the physiological requirements of the users: general lighting, localized lighting and combined lighting (general + local lighting).

The utilization options of the individual types of lighting systems depend on the application area and the features of the space which is to be illuminated. A general lighting system has the highest energy performance whereas the combined lighting system the lowest. A general lighting system ensures the required horizontal illuminance with the prescribed equal distribution of light into the entire space. The required illuminance is in this case the prescribed illuminance for the most demanding visual task performed in the space. The design of a localized lighting system is based on the division of the space into zones. Zones are functionally defined sections of space which vary in the nature and intensity of the visual activity performed in those sections (figure 5). Each functionally defined section is to be accurately described in relation to the visual activity and required technical parameters of illumination. One of the supporting parameters that can make the division into zones easier is the distribution of the daylight in the space. An example of the application of the division into zones is an open-plan office the space of which can be divided into two type zones: working zones and communication zones. A combined lighting system is a combination of the general or localized lighting system and the local lighting. The combined lighting system is the most energy efficient system of lighting. This system is mostly used in spaces with a relatively small number of working zones in a large area, or in a space where high levels of illuminance are required due to the visual task performed there. Figure 5 shows an example of an open space office with an area of 20 x 6 m. The required illuminance of 500 lx in the working zone can be reached through the application of a general lighting system (variant a), a localized lighting system (variant b) or a combined lighting system (variant c). Merely from the simple assessment of the illuminated zone areas and the required illuminance levels one can ascertain that the energy performance of the combined lighting system is about half in comparison with the general lighting system.

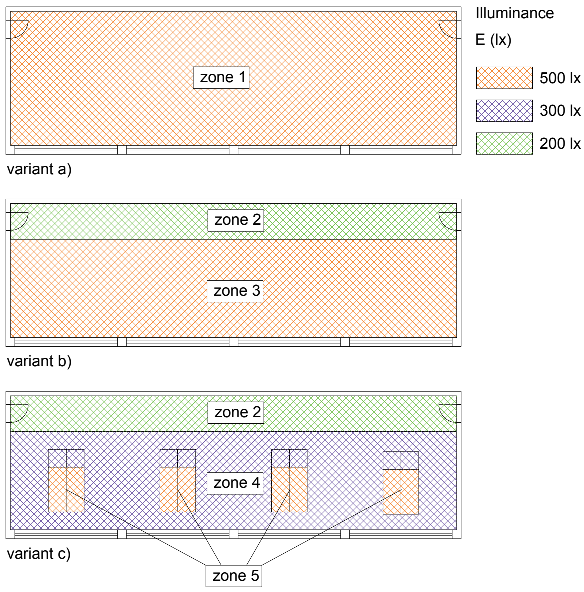

Fig. 5 An example of the floor plan of a open space office and its possible division into functionally defined zones:
Variant a) – general lighting system;
Variant b) – localized lighting system;
Variant c) – combined lighting system.
Energy performance of these options is in the following ratio: 100% : 80% : 48%.

In terms of the nature of illumination, the lighting systems can be divided into direct, direct/indirect or indirect. With regard to the satisfaction of quantitative parameters, the direct lighting is the most energy efficient; the indirect lighting is the least energy-efficient. When considering the selection or changes of the nature of illumination, it is important to consider its influence on the visual appearance of the illuminated space and qualitative parameters of illumination.

Selection of technical equipments

Basic technical equipments which form a lighting system and influence energy performance of lighting are light sources, control gears, lighting fittings and lighting control systems.

In terms of energy efficiency of the conversion of electric power into luminous flux, light sources are assessed by luminous efficacy η (lm/W – lumen per Watt). To asses energy efficiency of a group of light sources with its own reflector which are used for spotlight illumination for example in exhibitions or commercial spaces, it is not the luminous efficacy, but rather axial luminous intensity and the beam that are important. Technical parameters used to describe the light sources are stated for defined environment conditions, and their measurement is done outside the lighting fitting. When the lighting fitting is under operation, the parameters of some light sources change, for example due to the heat (fluorescent lamp). Some types of light sources may require a control gear which ensure the start and stable operation of the light source or adjust power supply voltage or current.

Control gears can be divided into electronic and electromagnetic according to their structure. In terms of energy, the electric ballasts are described with wattage losses P_Z (W). Wattage of the light sources is usually specified without the losses in the control gear. Therefore, when comparing the energy performance of various types of light sources, it is necessary to take into consideration not only the wattage of the actual light source but also the wattage of all electrical devices required for the operation of the tested light source.

Lighting fittings are technical devices, which by optical elements filter or change luminous flux from one or more light sources. Apart from light sources, lighting fittings contain all parts necessary for the installation and protection of light sources, possibly subcircuits, including devices required for their connection to the supply network. The efficiency of lighting fittings η_{sv} (%) is important in terms of their energy efficiency assessment. It specifies the ratio of output luminous flux of the lighting fitting and the luminous flux of the sources measured under given conditions outside the lighting fitting. Another important parameter is the lighting distribution of the luminous flux. This parameter is described with photometric curves which show the distribution of the luminous flux radiated from the lighting fitting into the space. When assessing energy performance of technical equipment for a specific purpose, it is desirable to assess the complete lighting fitting. Luminous efficacy of the lighting fitting LER (lm/W) [4] can be of certain help. It is defined as the ratio of output luminous flux (lm) to the power consumption (W) of the lighting fitting.

Fig. 6 An example of illumination of a open space office by a general lighting system with recessed lighting fittings.

Similarly, the entire lighting systems can be assessed by their luminous efficacy (lm/W) which is defined as the ratio of luminous flux (lm) emitted by all lighting fittings of the lighting system to their total power input (W). Illustration 6 shows the lighting of a large-space office with recessed lighting fittings. Energy performance of such lighting system which uses various types of recessed louvered lighting fittings is specified in table 1. The first variant uses 4x18 W lighting fittings with electromagnetic control gear, variant 2 and 3, lighting fittings with electric control gear for 4x14 W, or 2x28 W fluorescent tubes.

Table 1 Energy performance of lighting in an open-space office (figure 6) with the same illuminance level for various types of lighting fittings.

lighting fitting	number (pcs)	P_i (W)	p_1 (W/m^2)	p_2 (W/m^2/100*lx*)
4x18 W	27	2 376	20	3,7
4x14 W	27	1 755	15	2,7
2x28 W	21	1 300	10	2

When using lighting control systems for smooth regulation of lighting, the luminous efficacy of the lighting system decreases (lm/W). It is caused by the fact that the interdependency between the output luminous flux and the power consumption is not linear. Should the luminous flux be dramatically decreased with help of regulation under the level of 20% of the maximum value, the decrease in the luminous efficacy is so significant that the long-time operation of the lighting system set in this way is wasteful in terms of energy efficiency.

Control of lighting systems design

At the beginning of the lighting system operation, the resulting illuminance levels on a working plane or in places of visual task are always higher then the standard levels. The main reason for this is that the required parameters must be satisfied during the entire lifetime of the lighting system. Due to the fact that lighting systems depreciate due to the decrease in luminous flux of light sources, pollution of the lighting fittings and the decrease of the wall reflectance factor, the dimensions of the lighting systems must be overrated. To further justify higher parametric values of the lighting system, it is important to mention the fact that the light sources and lighting fittings are sold in certain product lines according to their power. This makes it almost impossible to reach the exact technical parameters of lighting. However, the closest higher power level of a particular device should be selected. There are types of spaces with flexible dispositional arrangement, for example, open space offices where various space units with various sizes can be created. An open space office can be for example rearranged into a number of cell offices and the other way around. In such space, the lighting systems should be designed to suit the worst scenarios. Should the spatial arrangement differ from the worst scenarios, the values of the technical parameters of lighting increase and therefore the dimension of the lighting system is further overrated. This over dimensioning of the lighting system can be eliminated by using dimmable lighting fittings connected to the lighting control system which is able to balance the constant decrease in luminous flux caused by depreciation of the lighting system through gradual increase of power input of the lighting fittings, or enables the setting of the luminous flux according to the current dispositional arrangement of the space.

Use of daylight

Illumination of the space as well as the place of visual task is not assessed according to whether it is done by artificial light or daylight. Therefore, a well designed daylight illumination of the space enables to reduce the requirements for the operation period of the artificial lighting systems. If there is a sufficient daylight in the designed space, there could be significant energy savings thanks to monitoring daylight illumination levels by a lighting control system. Information processed by light sensors helps reduce the operation time of the artificial lighting system, or its power, so that it would not produce light at the time of sufficient daylight illumination. Based on information from the sensors, the lighting system can be regulated by step or by a continuous regulation of the output luminous flux. The selection of the right regulation method depend on the the type light sources used, and determines how technically demanding and costly the proposed energy saving measures are going to be.

Monitoring the presence of people

A number of working spaces and working places are not used during all working hours. Often the lighting system remains in operation although the workers are not present. If the user of the room is not in, there is no reason why the lighting system should remain in operation. Movement sensors are used to monitor the presence of people in the room. Based on information processed by these sensors, the respective lighting fittings, lighting systems or their parts are switched on or off, eventually, their power may be limited. Monitoring the presence and monitoring the absence of people are the basic techniques for this energy saving measure. [2].

Use of time modes

Lighting systems perform its main function only during a certain part of the day. After the period of operation finishes, they no longer perform their function and it is possible to switch them off, or switch them into another mode in which they have a different function. Time controls are there to make sure the lighting system operates only during a defined period of time, or possibly switches automatically into another operational mode. Depending on their settings, these time controls can regulate the lighting system through a simple switch on/switch off function, or, they can be a part of a lighting control system which - based on information from the time controls - switches on the pre-set lighting scenarios. An example of such system is shop window, where a lighting system is used for promotion of products. Their function is performed up to a certain hour, for example, up to midnight. After that, the effect of lighting as a means of promotion is very little, therefore, it is possible to switch it off or switch it over to a limited mode, which may serve security purposes.

Conclusion

The intention of the authors of this paper was to point out the somewhat complex issues of assessing energy performance of buildings with regard to the design of effective lighting systems. It draws the attention not only to the importance of selecting energy efficient, and at the same time, technically efficient light sources and lighting fittings, but also to the significance of the utilisation time analysis of lighting systems and the use of daylight in particular interiors.

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