Energy Efficiency Classification of Lighting Systems in Public Buildings

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Abstract – **This paper presents a methodology proposed for calculation of the expenses for electrical energy, consumed by lighting systems in public buildings. A proposal for energy efficiency classification of lighting systems, based on this methodology is presented. The lighting system's performance kWh/m^2/year, expressed in annual energy consumption per unit area (annual energy intensity) for typical premises is obtained. The present methodology complies with the criteria for energy efficiency recommended by European Union Directives and EN12464-1 2002 standard. The results presented are significant for estimation of the necessity for reconstruction of existing and the design of new lighting systems.**

Keywords – **Energy efficient lighting, energy consumption, annual lighting energy intensity.**

I. INTRODUCTION

In concern with the greenhouse gases emissions and the global climate change, a number of initiatives are implemented, aiming the reduction of energy consumption in the building sector. There are existing methodologies for estimation of the energy (electrical and thermal) and water consumption and the greenhouse gasses emissions of individual public buildings. These methodologies estimate the building performance as a whole, not the separate building's systems [14]. Proposals for energy certification of residential buildings exist as well. According to [4] the building's acoustic and lighting performance, the rational use of water, safety and technological devices have to be taken into account separately to form the global performance of the building. The criteria proposed for estimation of the separate building's systems is different, but the final class if given for the global building's performance.

For better estimation of the energy efficiency of public buildings and further reduction of the electricity consumption in the building sector, the building's systems have to be appraised separately. The estimation of the energy efficiency of building's systems has to be individual, using methodologies complying with the system's specifics. Thus it is possible to separate the efficient from the inefficient systems and take particular measures for improvement of the inefficient system's performance.

In the field of lighting systems there are methodologies for determination of the energy efficiency class of light sources and ballasts (energy classes A, B, C, D, E, F, G) [12, 13]. At the same time there is no general criteria defined for estimation of the energy efficiency of whole lighting systems. The definition of such criteria is necessary for appraisal of the energy efficiency in public buildings and its improvement.

II. THEORY AND METHODOLOGY

As a criterion for estimation of the energy efficiency of lighting systems in public buildings, in the methodology proposed, is used the minimum of the expenses for lighting [5]:

$$Z = C_{EN} + C_{MAINT} + C_A \Rightarrow \min \qquad (1),$$

where C_{EN} are annual expenses for electrical energy, consumed by the lighting system; C_{MAINT} are annual expenses for maintenance of the lighting system (expenses for relamping, cleaning, wages, est.); C_A are the annual instalments for credit return (taken for lighting system construction or reconstruction). The discount rate is taken into account for calculation of the instalments.

For estimation of the lighting system energy efficiency, using the proposed methodology the following algorithm is followed:

- The floor area, geographical exposure, and windows' area are specified for typical rooms in buildings, defined as public by European Union Directive 2002/91/EC [7];
- Different design variants of the lighting systems of the rooms mentioned above are prepared. The designs comply with the European standard for indoor lighting [8];
- The design variants are estimated according to the defined criterion. The lighting power density W/m^2 is calculated for each variant and the results are separated in seven classes;
- Based on the minimum values given in the literature [4] for the daylight factor, as well as on the annual change of this indicator [10], values of the daylight factor for all the working places in the rooms concerned are defined for the four trimesters of the year;
- The planned energy consumption of the lighting system is calculated, according to the average illuminance, geographical exposure, working days of

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the week, the beginning and the end of the working time [5];

- According to the calculated values of the annual lighting energy intensity, kWh/m^2/year, the results are arranged into seven classes.

III. Results

When new lighting systems are constructed or there is a necessity for reconstruction of existing, they have to be classified according to their economical efficiency.

For demonstration of the approach, presented in the current paper, a typical room of an office building will be reviewed. The floor area of the room is 48m^2, the area of the windows is 10m^2. The lighting requirements for this type of premises, according to EN 12464-1:2004 are: average illuminance Eav = 500lx; unified glare rating UGR<19; color rendering index of a light source Ra>=80.

For this typical room multivariant design of the lighting system has been done. Fluorescent lamps T8 and T5 with electrical power 18, 24, 28, 35, 36, 49, 54, 58W, fitted in luminaries with appropriate optical systems for common visual tasks in offices for 1, 2, 4 lamps, used as light sources. The luminaries used are fitted with electronic ballasts. As a result of the prepared designs different values for the lighting power density, W/m^2 for the room are obtained [6]. The minimal value of the lighting power density is considered as a basis for further estimation. The rest of the values for the lighting power density are analyzed and separated in six groups. The values of the lighting power density accepted for the current classification are as follows:

Basis (Class A) .... 1.06 W/m^2/100lx

Class B .... 1.99 W/m^2/100lx

Class C .... 2.39 W/m^2/100lx

Class D .... 3.34 W/m^2/100lx

Class E .... 3.86 W/m^2/100lx

Class F .... 4.25 W/m^2/100lx

Class G .... 5.21 W/m^2/100lx

Using a methodology for calculation of the daylight factors, according to one basic value, this indicator is calculated for the four trimesters of the year for north-east and south-west geographical exposure of the room [6, 10]. The value of the daylight factor (DF, e=100.E_{IN}/E_{OUT} for the working place, both illuminances are measured at the same moment) given in the literature e=>1.5 for the worst lightened with natural lighting working place is accepted as basic [4].

With the information of the lighting requirements given by the standard, the data for the lighting power density (received and separated into seven classes) and the values of the daylight factors, a procedure for calculation of the planned annual consumption of electrical energy for lighting is conducted [5]. The results obtained are for the annual lighting energy intensity. The values of this index vary according to the length, the beginning and the end of the working time as well as according to the geographical exposure of the room. The methodology used for calculation of planned consumption of electrical energy for lighting is based on the principles of automatic lighting control (daylight linked time switching), according to the daylight availability. Automatic control systems with dimming are also used for lighting control in public buildings, so they have to be considered in the methodology proposed for energy efficiency classification. A lighting control system with dimming of the light sources consume less energy than a system without dimming, because it complements the natural light, so that the requirements for average illumination are fulfilled [11]. That does not mean that a system for automating lighting control with dimming of the light sources is more efficient [1]. The lighting control systems, working on this principle have high prices of the elements and are expensive for installation and exploitation. These facts have to be taken in consideration when planning reconstruction or designing new lighting systems [2].

The methodology for energy efficiency estimation of the lighting systems, proposed in the current paper does not apply for circulation areas, corridors, bathrooms and warehouses, because there are no recommendations for daylighting of such premises.

All the procedures for appropriation of energy class to a building are systematized as an algorithm and are embedded for improvement of software product for calculation of planned consumption of electrical energy for lighting.

The results, obtained by using the described methodology for energy efficiency estimation of lighting systems in offices are shown on Fig. 1-6 and the corresponding tables.

TABLE I

Beginning	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	CLASS F	CLASS G
05:00	8,2	16,0	18,6	24,6	24,6	32,4	35,0
06:00	7,2	14,2	16,5	21,9	21,9	28,2	30,5
06:30	6,9	13,6	15,8	20,9	20,9	26,8	29,0
07:00	6,7	13,3	15,5	20,5	20,5	26,4	28,5
07:30	6,5	13,1	15,2	20,2	20,2	25,8	27,9
08:00	6,7	13,0	15,1	20,0	20,0	25,8	27,9
08:30	7,0	13,7	15,9	21,1	21,1	27,4	29,6
09:00	7,4	14,4	16,7	22,1	22,1	28,9	31,3
09:30	7,8	15,2	17,6	23,3	23,3	30,8	33,4

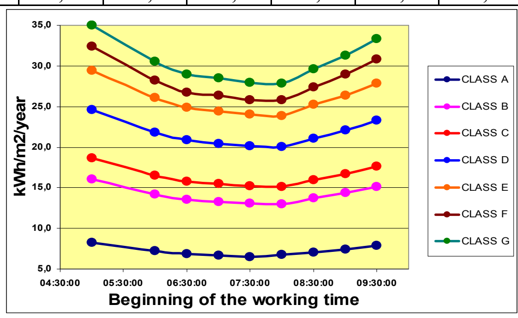

Fig. 1. Annual lighting energy intensity of a room with north-east geographical exposure, average illuminance 500lx, 11 hours working day and different beginning of the working time (Table I)

TABLE II

Beginning	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	CLASS F	CLASS G
07:00	5,7	11,3	13,1	17,4	20,7	22,0	23,8
07:30	5,4	10,8	12,5	16,6	19,8	21,0	22,7
08:00	5,3	10,7	12,5	16,5	19,7	21,0	22,8
08:30	5,5	10,8	12,6	16,6	19,9	21,1	22,9
09:00	5,7	11,1	12,9	17,0	20,3	21,9	23,7
09:30	6,2	12,1	14,1	18,6	22,3	24,2	26,2

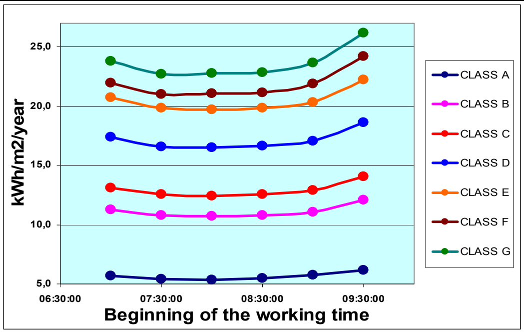

Fig. 2. Annual lighting energy intensity of a room with north-east geographical exposure, average illuminance 500lx, 10 hours working day and different beginning of the working time (Table II)

TABLE III

Beginning	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	CLASS F	CLASS G
08:00	4,4	8,7	10,1	13,4	16,0	16,7	18,0
08:30	4,2	8,5	9,9	13,1	15,6	16,3	17,6
09:00	4,3	8,8	10,2	13,5	16,1	17,1	18,5
09:30	4,6	9,2	10,7	14,2	16,9	17,9	19,4

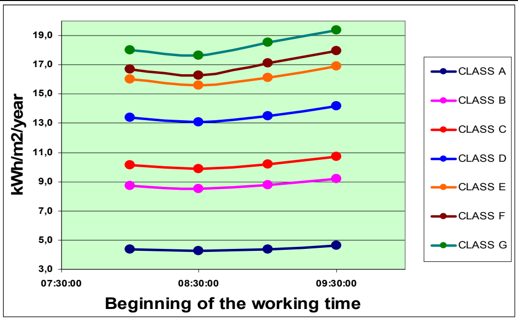

Fig. 3. Annual lighting energy intensity of a room with north-east geographical exposure, average illuminance 500lx, 9 hours working day and different beginning of the working time (Table III)

TABLE IV

Beginning	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	CLASS F	CLASS G
05:00	8,2	16,0	18,6	24,6	24,6	32,4	35,0
06:00	7,2	14,2	16,5	21,9	21,9	28,2	30,5
06:30	6,9	13,6	15,8	20,9	20,9	26,8	29,0
07:00	6,7	13,3	15,5	20,5	20,5	26,4	28,5
07:30	6,5	13,1	15,2	20,2	20,2	25,8	27,9
08:00	6,7	13,0	15,1	20,0	20,0	25,8	27,9
08:30	7,0	13,7	15,9	21,1	21,1	27,4	29,6
09:00	7,4	14,4	16,7	22,1	22,1	28,9	31,3
09:30	7,8	15,2	17,6	23,3	23,3	30,8	33,4

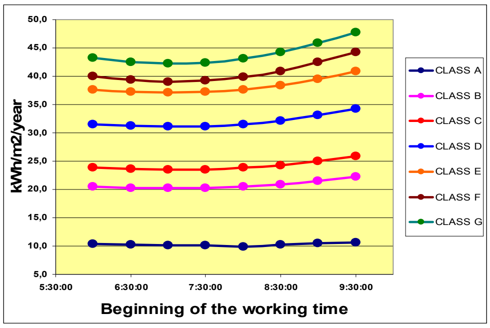

Fig. 4. Annual lighting energy intensity of a room with south-west geographical exposure, average illuminance 500lx, 11 hours working day and different beginning of the working time (Table IV)

TABLE V

Beginning	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	CLASS F	CLASS G
07:00	8,7	17,5	20,4	26,9	32,2	33,5	36,3
07:30	8,7	17,4	20,3	26,8	32,1	33,3	36,0
08:00	8,5	17,5	20,4	27,0	32,2	33,5	36,2
08:30	8,8	17,8	20,7	27,4	32,8	34,2	37,0
09:00	8,9	18,4	21,4	28,4	33,9	35,7	38,6
09:30	9,2	19,2	22,3	29,5	35,2	37,5	40,5

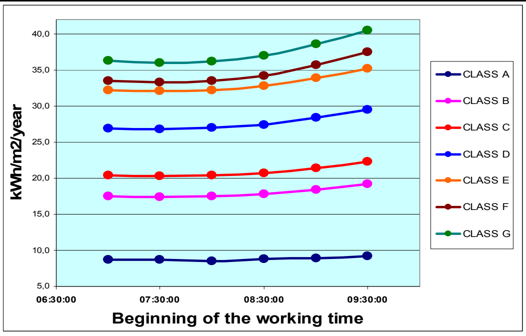

Fig. 5. Annual lighting energy intensity of a room with south-west geographical exposure, average illuminance 500lx, 10 hours working day and different beginning of the working time (Table V)

Table VI

Beginning	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	CLASS F	CLASS G
08:00	4,4	8,7	10,1	13,4	16,0	16,7	18,0
08:30	4,2	8,5	9,9	13,1	15,6	16,3	17,6
09:00	4,3	8,8	10,2	13,5	16,1	17,1	18,5
09:30	4,6	9,2	10,7	14,2	16,9	17,9	19,4

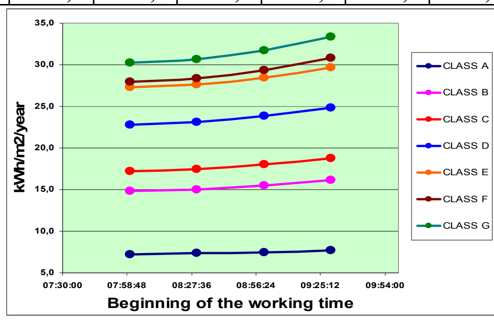

Fig. 6. Annual lighting energy intensity of a room with south-west geographical exposure, average illuminance 500lx, 9 hours working day and different beginning of the working time (Table VI)

The results, obtained for the annual lighting energy intensity of typical rooms in public buildings and shown in the current paper, lead to the following conclusions:

- The electrical energy, consumed by lighting systems depends not only on the length of the working day, but also on the beginning and the end of the working time;
- If the beginning and the end of the working time in a public building are changed and working hours are kept the same of reduced, the energy class of the premises may be improved;
- For rooms with same geometry and different geographical exposure, the premises with north-east exposure, no matter of the working time have lower energy consumption for lighting and annual lighting energy intensity, than those with south-west exposure.

IV. Conclusion

The existing methods for estimation of the energy efficiency in public buildings are not detailed enough and the building's installations are not appraised separately. They do not show the exact drawbacks of every installation and do not give straight recommendations for improvement. For more efficient use of the natural resources and reduction of the energy consumption, a more detailed and concrete analysis of buildings' systems specifics is recommended. For energy efficiency estimation of lighting systems in the current paper is used the criterion of minimal annual expenses for lighting. A methodology based on this criterion is proposed for classification of the lighting systems in public buildings. Lighting system using control strategy with programmable controllers switching every row of luminaries (control group) on and off according to the daylight availability and calculated according to the specifics of the premises is used as a basis of the methodology.

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