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ASSESSMENT OF ROAD LIGHTING PERFORMANCE FOR TRAFFIC INTENSITY AND TRAFFIC DETECTION BASED LIGHTING ADAPTATION

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Abstract

Amongst many road lighting design criteria, energy performance plays an important role as it has a direct link to operational costs, potential reduction of carbon dioxide emissions, mitigation of obtrusive light, and its impact on the night-time environment in urban and con-urban settlements. The energy energy performance of road lighting is conveniently described by the pair of normative numerical indicators PDI and AECI established in European standards. This paper aims to present typical values of the AECI (Annual Energy Consumption Indicator) for different combinations of road arrangements, road widths, lighting classes and light source technologies to illustrate what benchmarks can be expected using this assessment system. Essential part of this paper is focusing on assessment of the performance for traffic intensity and traffic detection based lighting adaptation.

Keywords: Road lighting, public lighting, adaptive lighting, energy efficiency, energy performance, lighting control, energy savings, luminous efficacy

1 Introduction and background

Road lighting, as defined by the International Lighting Vocabulary ILV [1], is lighting provided for the purpose of illuminating public roads, cycle tracks, footways and pedestrian movement areas within public parks and gardens. This public service has to simultaneously fulfil various functions, such as good visual conditions closely related to traffic safety, personal safety and assurance [2], safety to properties, visual performance at amenities other than those used for transportation, and not of less importance, is its contribution to increase the attractiveness and enjoyment of the urban environment in the evenings.

Photometric requirements for road lighting are established in CIE 115:2010 [3], in European countries implemented in the standard EN 13201-2 [4] with a selection of lighting classes guided in the CEN/TR 13201-1 [5]. For the M lighting classes (M1 to M6) used for motorized traffic, the photometric parameters are the maintained luminance, overall and longitudinal uniformity, threshold increment TI, and edge illuminance ratio EIR. For the P lighting classes (P1 to P7) intended predominantly for pedestrians and low-speed traffic, it is essential to assess the maintained average and minimum illuminance. For collision areas, the C classes (C0 to C5) based on the maintained horizontal illuminance and overall uniformity should be used.

Careful determination of lighting classes in different periods of operation time is essential to ensure that only the necessary light level is provided at the right time, just when it is needed. Classification of road sections and similar structures should be carried out considering all relevant circumstances like visual needs of the users, varying traffic volumes, weather conditions, traffic compositions, background brightness, etc. During the design stage, care should be taken to ensure that the criteria specified in EN 13201-2 are achieved without excessive overlighting and redundant spill light falling outside boundaries of the area to be lit. Luminous flux distribution can be now quite well controlled by the selection of proper optics for luminaires, and overlighting can be reduced by variable lighting control including compensation of the decay of luminous flux emitted from luminaires throughout their lifetime, compensation of the lighting design excess over the lighting requirements in the applicable standards etc.

Holistically and properly designed lighting is a powerful tool helping to reduce electricity consumption, as highlighted by Skoda & Baxant [6]. Besides accordingly designed new lighting installations, refurbishment of obsolete inefficient old lighting systems constitutes massive

potential for energy savings, emphasized by Boyce et al. [7] as well as by Sokansky & Novak [8]. Problems of energy efficiency in road lighting have been dealt by Pracki [9] who proposed a particular classification method for expressing the level of energy performance.

The energy efficiency of lighting products is subject to European directives specifying ecodesign requirements [10] and energy labelling [11]. In the field of public lighting, assessment of the energy performance of lighting systems has been introduced by EN 13201-5:2015 [12], where the performance is described by means of two compound indicators PDI and AECI. The indicators are related to illuminance as a universal quantity regardless of what is the target photometric parameter, i.e., also for luminance-based lighting classes.

The problem with proper assessment of the energy performance of lighting systems taking into account the efficiency of the technologies implemented and the performance of the lighting controls is that the two compensate for each other. It means that systems with energy-efficient luminaires operated at full power with no dimming can have a similar energy performance rating like some inefficient systems with aggressive dimming strategies. To make the evaluation fair, two key aspects of the energy performance are split, and thus, there are two mutually dependant indicators that should be always evaluated and presented together (side by side): PDI (symbol D_P, in $W.lx^{-1}.m^{-2}$) stands for *Power Density Indicator* and accounts for the efficiency of the implemented lighting products as well as how well the lighting system is designed to fulfil the bunch of criteria; generally speaking, this indicator is describing the quality of the lighting design from a static perspective. AECI (symbol D_E, in $kWh\ m^{-2}$) is the *Annual Energy Consumption Indicator* accounting for factors influencing the electricity consumption which is the input power and the operation time, both varying in the course of operation; this indicator is describing the behaviour of lighting systems in response to lighting controls from a dynamic perspective. It is obvious that the PDI should be calculated and presented for all discrete light levels considered while the AECI is only a single number.

2 Motivation and specific objectives

Massive development of advanced LED technology during the last decade in diverse areas of lighting, including road lighting, is the driving force for the need for more frequent update of technical standards specifying even more stringent requirements to both the quality of light and its energy performance. LED technology already brought to urban lighting a number of benefits: high luminous efficacy, tailored optics, free choice of colours, dynamic control. The efficiency of lighting equipment is still being improved.

However, LEDisation is just the first step towards sophisticated, efficient, sustainable, tailored and integrative (human-centric) lighting. In the time being, we are witnessing that adaptive lighting control is taking over the relay for the middle lap of the development. By implementation of the so-called 'smart lighting' elements, systems and technologies, the lighting becomes part of a superior smart city network and tends to integrate with other infrastructural subsystems, such as traffic monitoring and control, telecommunication, utility services and others. Interactions having a direct influence on setting up the target lighting parameters are especially significant: weather conditions, visibility level, traffic conditions (density, volume, speed), user presence or movement, the composition of users, etc. Adaptive lighting is the technical precondition to provide lighting on demand – where, when and how much it is needed. Optimization of road lighting has many benefits and goes far beyond energy savings, just to mention obtrusive light mitigation as one of the key driving force of adaptive lighting.

The European standard EN 13201 Part 5 was published in 2015. Typical values of PDI and AECI are based on lighting products available in Q1/2014 as referenced in the standard. Since that time, the luminous efficacy of luminaires has been increased, optics have been improved, selection of light distributions has been enhanced and tailored to a broad range of arrangements (narrow/wide roads, short/ /medium/long spacings, road profiles with or without footpaths, etc.). Lighting control profiles are now practically exploiting potentials to dim down the lighting to almost any level and to consider the presence or movement of the traffic users. It is evident that the typical values indicated in the standard are obviously not typical anymore, and their update is urgent. Suggesting newer typical values based on lighting products and solutions available in Q4/2020 is the primary goal of this paper, focusing on operation related aspects of

lighting systems, i. e. the AECI indicator. Study on PDI and static operation of lighting from the above mentioned perspective has been previously carried out by Gasparovsky et al. [13].

Aim of this paper is to derive typical values of the lighting operation factor c_{op}, which is a measure and simplification of the AECI indicator, for a series of assumptions which can be assigned to common situations in road lighting, and to estimate the savings potential due to traffic detection. It is also worth illustrating how development in light source technologies affects the value of the AECI indicator, including difference in energy performance between LED technologies in the span of 7 years (Q1/2014 versus Q4/2020). Note that comparisons between different technologies arising for public lighting have been experimentally investigated by Rodrigues et al. [14].

3 Methods of investigation

Energy performance of road lighting can be described by various parameters such as simple wattage or energy density, luminous efficacy of the installation, installation lighting factor, utilance or, the most preferrably, by the pair of compound numerical indicators PDI and AECI established in the European norm EN 13201-5, also used in many non-European countries worldwide.

3.1 Energy performance indicators

Power Density Indicator PDI (of a lighting installation in a given state of operation, for an area divided into sub-areas) D_P, in $W \cdot lx^{-1} \cdot m^{-2}$, is the value of the system power divided by the value of the product of the surface area to be lit and the calculated maintained average illuminance value on this area according to EN 13201-3 [15]:

$$D_P = \frac{P}{\sum_{i=1}^{n} (\overline{E_i} \cdot A_i)} \tag{1}$$

where

- D_P is the power density indicator, $W \cdot lx^{-1} \cdot m^{-2}$;
- P is the system power of the lighting installation used to light the relevant areas, W;
- E is the maintained average horizontal illuminance of the sub-area 'i', lx;
- A_i is the size of the sub-area 'i' lit by the lighting installation, m^2;
- n is the number of sub-areas to be lit.

Annual Energy Consumption Indicator AECI (of a lighting installation in a specific year) D_E, in $Wh \cdot m^{-2}$, is total electrical energy consumed by a lighting installation day and night throughout a specific year in proportion to the total area to be illuminated by the lighting installation, calculated by the formula:

$$D_E = \frac{\sum_{j=1}^{m} P_j \cdot t_j}{A} \tag{2}$$

where

- D_E is the annual energy consumption indicator for a road lighting installation, $Wh \cdot m^{-2}$;
- P_j is the operational power associated with the jth period of operation, W;
- t_j is the duration of jth period of operation profile when P_j is consumed, over a year, h;
- E is the maintained average horizontal illuminance of the sub-area 'i', lx;
- A is the size of the area lit by the same lighting arrangement, m^2;
- m is the number of periods with different operational power P_j.

For the calculation of AECI, it is necessary to assume some lighting control profile. Operation hours of road lighting systems are dealt e.g., in [16]. Full power operational profile is typical for many existing lighting installations with simple switching devices like time switchers or

photosensors where luminaires operate constantly at full power throughout the night time each day. For the full power operational profile, it is common to take the annual operation time 4 000 hours.

In regulated and sensing systems, tri-power or even quadri-power detector-driven operational profile, like the example shown in Figure 1 (daily course), can be used to control lighting levels. Daily course of the operational profile is then divided into several discrete light levels corresponding to particular lighting classes depending on and taking into account criteria set in the CIE 115. Road traffic intensity monitored over a suitable time span is influencing selection of lighting classes which can vary throughout the night. In quiet periods with lower traffic intensity the lighting can be dimed down and in late night hours it can be even reduced to a lowest maintained level if no traffic is detected. Here the role of movement detectors is to switch between consecutive (or other) light levels if a user appears in the area of interest. To predict this behaviour in order to estimate the potential of light savings it is necessary to account for some detection probability parameter for each of the lighting levels. This can be derived from normalized traffic data for typical road categories acquired from long-term monitoring of traffic. Estimation of the probability can be a hard task, particularly for new installations where no historical data are available; the value can be established by comparison with similar and neighbouring installations and/or derivation from higher class major roads. In systems with flat lighting levels without drop downs, the probability is 100 % by default. For detection of lone vehicles further assumptions are specified to estimate the duration of locally increased illumination.

Key

detection probability (%)

Figure 1 – Example of a quadri-power detector-driven operational profile

NOTE Switching times in Figure 2 (ON at 18:00, OFF at 06:00) depend on the day of the year, the geographical location and how the actual lighting control system (simple timer, astronomical clock timer, photocell etc.) takes the seasonal changes into account.

Assuming a road profile with carriageway and footpaths on both sides, a luminaire oriented towards the right footpath in addition to the main luminaire, and four lighting levels in four specific periods of time (full power FP, low traffic LT, late night LN and maintained M), formulae (1) and (2) for the calculation of energy performance indicators become the forms:

$$D_P = \frac{k_P \cdot (P_R + P_F)}{k_E \cdot (E_{FL}.A_{FL} + E_R.A_R + E_{FR}.A_{FR})} \tag{3}$$

$$D_E = \frac{(P_R + P_F) \cdot \left[t_{FP} + t_{LT} \cdot (k_{P,LT} \cdot \delta_{LT} + k_{P,LN} \cdot (1 - \delta_{LT})) + t_{LN} \cdot (k_{P,LN} \cdot \delta_{LN} + k_{P,M} \cdot (1 - \delta_{LN}))\right]}{A_{FL} + A_R + A_{FR}} \tag{4}$$

where

P is the system power of the main luminaire (R) and auxiliary luminaire for illumination of the right footpath (F) in the lighting installation, W;

A is the area of the carriageway (R), left footpath (FL) and right footpath (FR), m^2;

E is the calculated average maintained illuminance on the carriageway (R), left footpath (FL) and right footpath (FR), lx;

t is the annual operation time of the full power lighting level (FP), reduced lighting level in the low traffic period (LT) and reduced lighting levelin the late night period (LN), in h;

k is the illuminance reduction coefficient (E), power reduction coefficient (P) for the reduced lighting level in the actual time period (-), low traffic period (LT), late night period (LN) and the maintained lighting level in the late night period (M);

δ_{LT} is the detection probability coefficient in the low traffic period (LT) and the late night period (LN).

Power Density Indicator D_P should be calculated using formula (3) for all time periods (full power, low traffic, late night and maintained lighting levels), with actual values of reduction coefficients k_E and k_P. In Formula (4), the same operational profile is applied for both luminaires.

NOTE If there is no data on relation between the illuminance reduction coefficient k_E and the power reduction coefficient k_P or when these coefficients do not differ significantly then for the sake of simplicity it is sufficient to calculate the Power Density Indicator D_P only once, preferrably for the full power lighting level.

3.2 Typical values of energy performance indicators

Values of energy performance indicators PDI and AECI depend on many factors like the actual lighting class, road profile arrangement, width of carriageway and concurrent footpaths, type of the light source and luminaire implemented, spatial distribution of luminous flux from luminaires, etc. In the case of AECI, switching and control profile may strongly affect the value of this indicator. Assuming that the lighting system is optimized according to the target photometric parameters, lighting designs may still differ in energy performance. The lower is the value of PDI and/or AECI, the better is energy performance.

Indicative values of energy performance indicator AECI presented in this paper are based on numerous calculations of lighting systems for different combinations of road profiles, road widths, lighting classes, and luminaires (having luminous flux and type of optics appropriate for particular arrangements) that are common in practice.

Additional input data and boundary conditions for seeking the optimum geometry of the lighting system are listed below:

- six typical road profile arrangements considered;
- width of footpaths and grass strips, where applicable, equals to 2 m;
- maintenance factor is set to 0.80 for all types of luminaires and road profiles;
- for road reflection properties, the R3 table is considered;
- mounting height is optimized within the range 6 m to 12 m (step: whole numbers);
- spacing of lighting poles is optimized and sought between 20 m to 60 m (step: 1 m);
- arm overhang is ranged from 0 m to 2 m (step: 0,5 m);
- luminaires are not tilted;
- annual operation time 4 000 h at full power.

The arrangement of the lighting system is single-sided in all cases. In the framework of the investigated road widths, application of the opposite (or other double-sided) arrangement was not necessary. Within each calculation, the lighting system geometry has been optimized with preference given to the spacing in order to enlarge the illuminated area as much as possible and to have thus the energy performance indicators as low as possible. Mounting height and arm length affect the indicators only indirectly. However, accounting for the lowest possible installation costs, the mounting height has been sought as minimum as possible in addition to the previously mentioned criteria.

Calculations are based on generic lighting products (luminaires) available in Q4/2020. The average luminous efficacy of LED luminaires is 125 lm/W with very small deviations within the product range (–4 %/+0,8 %). Exclusively warm white light sources with T_c = 3 000 K have been used.

Road profile arrangements are considered as follows: A – two-lane road for motorized traffic, B – road with mixed motorized and pedestrian traffic without footpaths, C – road with a footpath on the side of the lighting installation, D – road with footpath opposite to the lighting installation, E – road with two footpaths on both sides, F – road with two footpaths on both sides, separated from the carriageway by grass strips.

The range of values for the AECI indicator applies to the full-power operational profile with an annual operation time of 4 000 h. To consider different operational profiles, it is usually sufficient to combine the annual operation times of individual lighting levels with the associated system power and the detection probability (in systems with detectors) into a single **lighting operation coefficient** c_{op}. This coefficient can be used to multiply the AECI for full power operation to obtain the value of AECI for an actual operational profile. It can also be used as a self-standing indicator of energy-saving potential of a lighting control system.

3.3 Comparison of energy performance indicators for different light sources

High-pressure mercury vapour lamps, metal halide lamps, elliptical and tubular sodium lamps, LEDs on the technology level of 2014, and currently available LED products (2020) are included in the comparison. Values of energy performance indicators are determined for the selected (assumingly most typical) boundary conditions described as follows:

- width of the carriageway 7 m;
- lighting class M4;
- annual operation time 4 000 h at full power.

LED products available in 2014 used for derivation of typical values published in the standard EN 13201-5:2015 have had luminous efficacy 100 – 105 lm/W and correlated colour temperature T_c = 3 000 K. Overall luminous efficacy of luminaires with HID lamp types strongly varies with wattage of the lamps and quality of optics as it is common for this traditional lighting equipments. In the case of high-pressure sodium lamps, the overall luminous efficacy was 70 – 120 lm/W;, for metal halide lamps, it was 70 – 75 lm/W, for mercury lamps below 45 lm/W.

4 Results

4.1 Case stady for assessment of energy performance indicators

Results of calculation for the case study specified in section 3.1 are presented in Table 1 together with all input data used for the calculation. For convenience, the power density indicator D_P is expressed in mW·lx^{-1}·m^{-2} and the annual energy consumption indicator D_E is expressed in kWh·m^{-2}.

4.2 Typical values of the AECI indicator for contemporary LED products

Road profile A is the simplest arrangement consisting of a single carriageway. The values of AECI (kWh·m^{-2}) are presented in Figure 2. For the 7 m road the values are unfolded in Figure 3, ranging from 0,32 for M6 up to 2,70 for M1. Because AECI is free of reference luminous parameter, the value is strongly dependant on lighting class and this is true for all luminance-based lighting installations. As seen in Figure 2, the lines representing M-classes are flat; it means that AECI is almost not sensitive to the width of carriageway! The same is evident and applies to any road profile arrangement.

Road profile B is somewhat unusual compared to the other profiles in that the lighting design is fully based on illuminance, and the photometric requirements are associated with C lighting classes. The absence of an observer means that complex road surface reflection properties (the R-tables) are not applied what makes the design process and the results more predictable. Graduation of the required illuminance according to the lighting classes is naturally projected to typical values of AECI as this indicator is not normalized to any photometric quantity. For the

average 7 m road, the values (in kWh·m^{-2}) are ranging from 0,53 (C5) to 3,43 (C0) and they are slightly increasing (lighting worse performing) with smaller widths and decreasing (lighting better performing) for wider roads. These clear characteristics result from the straightness of the illuminance criterion.

Table 1 – Input data and the calculated energy performance indicators for the case study

System power				
	Road side [R]	Footpath [F]		
Operational power P (W)	65	9		
Illuminated area				
	Left footpath [FL]	Carriageway [R]	Right footpath [FR]	
Area to be lit A (m^2)	60	210	60	
Calculated illuminance E (lx)	7,53	16,0	7,55	
Operational profile				
	Full power [FP]	Low traffic [LT]	Late night [LN]	Maintained [M]
Annual operating hours t (h)	1 810	1 095	1 095	1 095
Power reduction k_P	1,00	0,76	0,52	0,14
Illuminance reduction k_E	1,00	0,75	0,50	0,10
Detection probability coef. δ	1,00	0,80	0,20	0,80
Energy performance indicators				
PDI D_P (mW·lx^{-1}·m^{-2})	17,4	17,6	18,0	24,3
AECI D_E (kWh·m^{-2})	0,626			

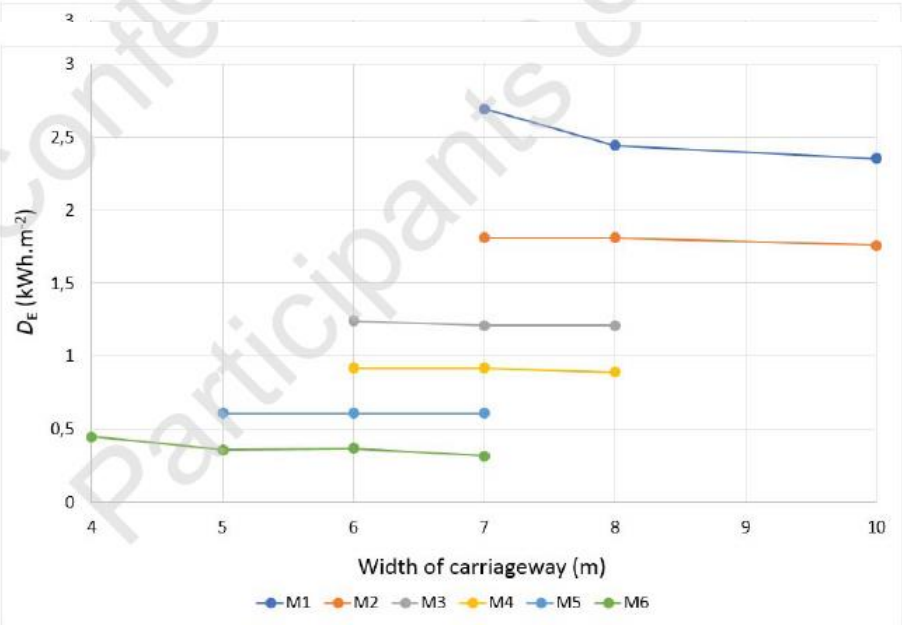

Figure 2 – Typical values of the Annual Energy Consumption Indicator AECI for road profile A

Road profiles C, D and E can be analyzed together. The AECI values (in kWh·m^{-2}) are very similar: for lighting classes M6/P6 to M3/P3 span from about 0,30 to 1,00 identically for the C and D profiles (the same target area), and from 0,24 to 0,82 for the E profile (the same area of

the carriageway and double area of the footpaths). Variation of the values over widths of carriageways is neglectable as for the A profile.

It is always essential to choose a luminaire with luminous flux distribution that suits the actual road profile arrangement, i. e., emitting some light to the nadir and behind (away from the carriageway) in case of the C profile, directing the light beam under higher angles of the asymmetrical light distribution curve in the C90-270 plane to reach the footpath opposite to the row of light points in case of the D profile and balancing these two in case of the E profile. It is always easier to illuminate the footpath on the side of the lighting installation than on the other side due to higher distance (inverse square law) and angles of incidence (cosine law).

It is important to emphasize that the results presented and discussed in the previous paragraphs are closely bound with the assumed road profile parameters. In real situations, however, the width of footpaths can be different from the assumed, even differing between each other on both sides of the carriageway, and the lighting class assigned to the footpaths can also be different (in many cases lower, typically P5 and P6 even for carriageways classified to M4 or M3). It is then obvious to expect different values of the PDI and AECI indicators at any deviations. The overall scheme becomes more complex. It would be beneficial to study these relations further.

Road profile F is even more complicated because grass strips separating footpaths from the carriageways can be almost arbitrary wide. In this case, with currently available lighting equipment, it is impossible to avoid light losses on the grass strips if all sub-areas are to be illuminated by one lighting installation. It can be noted that in practice, widths of grass strips up to 3 m can be acceptable, at 4 – 5 m, illumination of concurrent footpaths is inefficient and sometimes also hard to satisfy the lighting requirements; above 5 m, it has no sense to consider shared lighting installation and if the lighting of footpaths is inevitable or requested then it should be satisfied by a dedicated lighting installation.

Typical values for the road profile F should be deemed as very illustrative due to many assumptions specified for this case. The drop in performance is significant. The impact of the width of the carriageway must be treated with respect to the width of parallel footpaths and grass strips; the narrower carriageway, the more the indicators are influenced and, in general, the worse the energy performance. Typical values of AECI for the 7 m road are ranging from 0,29 (M6/P6) to 0,93 (M3/P3) with only small variations for other widths of the carriageway. Hence the values are 16 % to 36 % higher (depending on lighting class) than in the case of unseparated footpaths (road profile E).

4.3 Typical values of the AECI indicator for different light sources

Comparison of the AECI values for different light sources is graphically presented in Fig. 3. From the graph it follows that advances in LED technology within the last 6 years improved the AECI as much as by 20 %. LED lighting is performing twice better than its sodium technology predecessor and 4,5 times better than the obsolete mercury based technology.

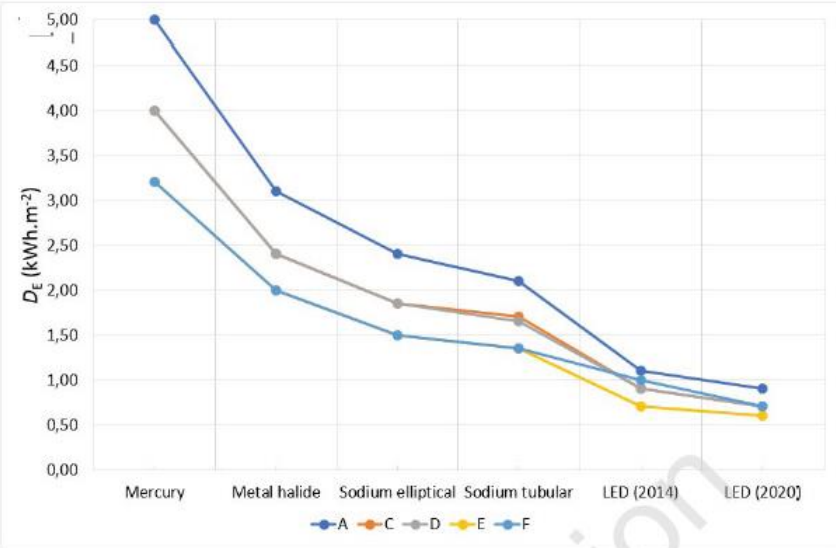

Figure 3 – Typical values of the AECI indicator for different light sources

It must be noted that not only higher luminous efficacy of the lamps (or luminaires) is responsible for this benefit but to much extent it is due to significantly different quality of optics – from modest diffusers in combination with bulky elliptical mercury bulbs through faceted reflectors combined with compact-size sodium lamp burners up to precise Fresnel lens optics attached to tiny LED chips.

4.4 Typical values of the AECI indicator for different operational profiles

Typical values of AECI presented in sections 4.2 and 4.3 apply to full power operational profile (see 3.1) with annual operation time 4 000 h. To consider different operational profiles, the lighting operation coefficient c_{op} explained in section 3.2 can be suitably used to describe the effect of lighting operation.

Table 2 shows typical values of the lighting operation coefficient c_{op} for different operational profiles. For values in this table it is assumed that difference between the illuminance reduction coefficient and the power reduction coefficient can be neglected ($k_E = k_P$).

Table 2 – Typical values of the lighting operation coefficient c_{op} in % for different operational profiles

OPERATIONAL PROFILE TYPE	DESCRIPTION OF THE PROFILE	c_{op} %
Flat full power	4 000 h operation at full power	100,0
Bi-power	2 175 h at full power and 1 825 h at 70 % of the system power typical for voltage control of sodium lamps	86,3
Bi-power	1 810 h at full power and 2 190 h at 75 % of the system power corresponding to reduction by one lighting class	86,3
Tri-power	1 810 h at full power, 1 095 h at 75 % of the system power and 1 095 h at 50 % of the system power, both steps corresponding to reduction by consecutive lighting classes	79,5
Tri-power with detectors	1 810 h at full power, 1 095 h of bi-level control between 75 % and 50 % of the system power with detection probability of 80 %, and 1 095 h at 50 % of the system power	78,1
Bi-power	1 810 h at full power and 2 190 h at 50 % of the system power corresponding to reduction by two lighting classes	72,6
Quadri-power with detectors	1 810 h at full power, 1 095 h of bi-level control between 75 % and 50 % of the system power with detection probability of 80 % and 1 095 h of reduced bi-level lighting control between 50 % and 10 % of the system power with detection probability of 20 %	69,3

Values of c_{op} in Table 2 assume for particular lighting levels and probabilities that are strongly dependant on the type of road and the nominal lighting class. Further analyses which are not in detail presented in this paper showed that compared to full-level operational profile, application of quadruple level profile by means of traffic detectors can lead to as high as 50 % savings and even more on mid-class roads. In quiet residential quarters the reduction is yet significantly higher, preliminary results showing savings of more than 60 % for entire quarters. However, for residential areas and neighbouring settlements harvesting and analysis of more data is needed to enhance accuracy of average probabilities and their dispersion.

5 Conclusions

Results showed considerable potential of light savings (electricity consumption and light pollution) by proper adaptation of light levels and simultaneously by introduction of the sustained minimum light level to be applied when no traffic user is detected in the area of interest, in order to provide additional functions. Thus, lighting adapting to actual traffic intensity and traffic detection should be promoted as a powerful tool to save electricity and to mitigate adverse effects of obtrusive light.

Typical values of the road lighting energy performance indicators have been updated to reflect the current level of technology referred to the end of 2020, in a simplified and streamlined structure. The results showed that in the span of the last 7 years the performance is biased to slightly better figures. Although the gain is not that significant for PDI, AECI values are improved by approximately 20 % in the case of the flat full-power operational profile what is not neglectable. It can be assumed that advances in lighting controls in recent years will boost the performances mile steps forward.

Comparison of the indicators for different types of light sources showed significant improvement of the performance with upraise of the LED technology, which is twice better than the preceding sodium lamp technology and yet little better than metal halide lamps. Heavily obsolete mercury lamps (that still can be found operating in some aged systems) perform 4,5 times worse than modern lighting products.

6 Outlook

Typical values of the lighting operation coefficient c_{op} have been calculated for different typical lighting control profiles under standard assumptions. Right the lighting control is promising a huge amount of energy savings, but this potential is unfortunately still exploited to a very little extent. Technological advances in the field of road lighting controls are very rapid but their implementation lacks a solid scientific background. Research should be focused on adaptive road lighting, intensifying the investigation of conditions that can be utilized to optimize the lighting according to various criteria and their combinations. The Technical Committee CIE/TC-42 is to study and report the state-of-the-art in adaptive road lighting.

Since introduction of the indicators PDI and AECI, their acceptance in practice is insufficient, in some countries fully neglected and this problem is still persisting. Nevertheless, the PDI/AECI system is a useful tool to the benefit of road lighting operators. Typical values are, in particular, intended to support and enhance the usage of this standard in practice.

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