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AUTOMATED METHOD FOR SEARCHING OPTIMAL SOLUTION IN STREET LIGHTING DESIGN

BY

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Abstract. This paper presents an automated method for street lighting calculation by using DIALux 4.13 softwareWizard. The study presents how a very big number of calculations can be done in a very short amount of time. For the advantages of the method and increased calculation speed to be acknowledged, a case study regarding lighting class parameters for footpaths considering different standards is presented. The Standards considered in the case study are: Romanian Standard, European, U.S.A. and from Denmark, which after extensive studies are considered to be the standards with the biggest differences. The first conclusion of the paper is that the automated solution can do a very big number of calculations in a relatively small amount of time, but there are limits for the program, which crashes if the number of lighting distribution curves is very high. The paper also proposes a new parameter to evaluate the energy efficiency, linear power density [W/km] which will be used in parallel with the one recommended by the standards, unitary power density [W/m^2/lx].

Keywords: lighting class; illuminance; overall uniformity; vertical illuminance; cylindrical illuminance; DIALux; Wizzard.

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1. Introduction

This paper presents a technical study regarding the automation of street lighting straight road calculation. The software used to do the calculation is DIALux 4.13. This software has a Wizard that can theoretically do countless number of straight road calculation. For the paper to have a more applicable role, the second part of the paper is a case study regarding lighting class parameters for footpaths around the world. The study consists in a parallel calculation for two footpaths, for each lighting class, considering 4 different standards: Romanian standard (NP 062, 2002), European standard (EN 13201-2:2015), U.S.A. (RP08, 2014) and Danish (Manual for Street Lighting Facilities and Planning, 2014). A similar case study for different roads is presented (Rusu, 2019a) and the same method was used to do a study for carriageway lighting classes (Rusu, 2019b).

2. Automatic Solutions for Street Lighting Straight Road Calculation

The software used to automate the calculations is DIALux 4.13. This software has a platform named “WIZARD” for inserting an optimised luminaire arrangement. Fig. 1 presents the parameters based on which the software does all combinations to find the best solution possible. Some of the parameters can be variable: distribution curves, distance between poles, height of pole, boom angle, length of the bracket arm, while others are fixed: distance of the pole to roadway, type of arrangement.

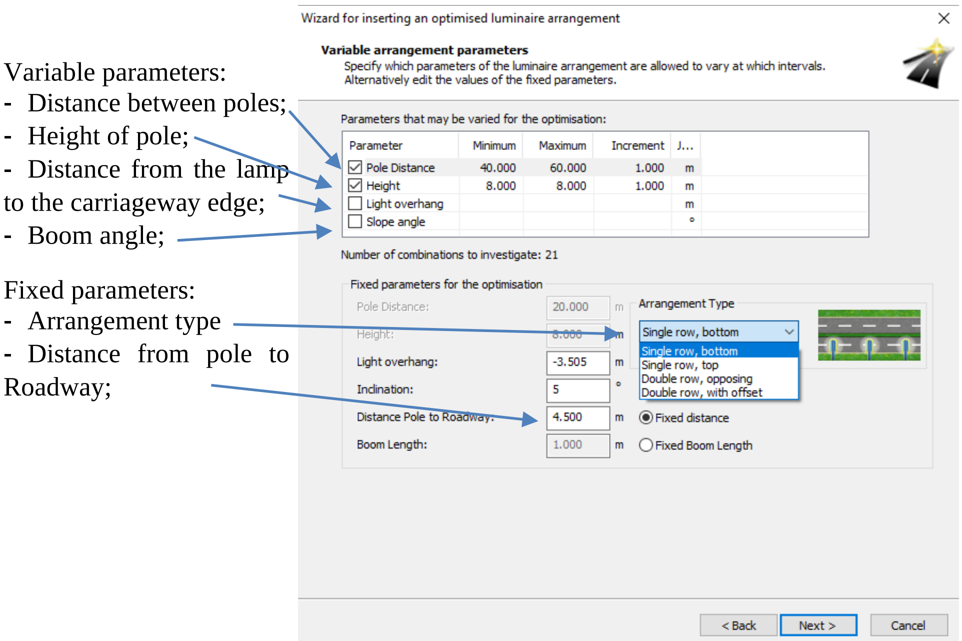

Fig. 1 – Selection of the parameters of the luminaire arrangement.

Analysing Fig. 2 one can see that based on the input, the program can do all combinations possible and export the solutions. Considering that the export is in excel it can be filtered and sorted based on any of the parameters from the table head.

Illumination class	Luminaire	Lamp	Result	Distance [m]	Height [m]	Overhang [m]	Slope angle [°]	Em [lx]	Emin [lx]
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407952	48 LEDs 350mA NW	Suitable	38	8	-4	0	15.19	6.65
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407962	48 LEDs 350mA NW	Suitable	38	8	-4	0	15.29	6.37
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407952	48 LEDs 350mA NW	Suitable	37	8	-4	0	15.59	7.05
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407962	48 LEDs 350mA NW	Suitable	37	8	-4	0	15.7	6.78
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407952	48 LEDs 350mA NW	Suitable	36	8	-3.5	0	15.15	6.63
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407962	48 LEDs 350mA NW	Suitable	36	8	-3.5	0	15.26	6.42
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407952	48 LEDs 350mA NW	Suitable	36	8	-4	0	16.03	7.55
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407962	48 LEDs 350mA NW	Suitable	36	8	-4	0	16.13	7.29
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407952	48 LEDs 350mA NW	Suitable	35	8	-3.5	0	15.57	7.04
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407962	48 LEDs 350mA NW	Suitable	35	8	-3.5	0	15.7	6.84
S1	SCHREDER TECEO 1 / 5136 / 48 LEDs 350mA NW / 407952	48 LEDs 350mA NW	Suitable	35	8	-4	0	16.47	7.99

Fig. 2 – Export example from DIALux Wizard.

3. Case Study on Footpath Lighting Classes Around the world

The scope of this chapter is not just to show the utility of the calculating method, but also to establish which of the standards are more or less restrictive when referring to pedestrian areas. Street lighting improves the safety of drivers, riders and pedestrians. It is well known that street lighting has a very big effect in reducing crime rate at night (Farrington and Welsh, 2008; Atkins *et al*., 1991) and pedestrian`s sense of security (Cellucci *et al*., 2016; Mattoni *et al*., 2017). Pedestrians suffer from decreased visibility in the dark, this is why a good street lighting system reduces the risk of accidents.

Table 1
Nomenclature

Parameter	Description
E, E_{avg}, E_{hm}, E_H	horizontal illuminance averaged over a road area [lx];
E_{min}, E_h	lowest illuminance value on a road area [lx];
E_{sc}	total luminous flux falling on the curved surface of a very small semi cylinder divided by the curved surface area of the semi cylinder [lx];
$E_{sc,min}$	lowest semi-cylindrical illuminance on a plane at a specified height above a road area [lx];
E_v	illuminance at a point on a vertical plane [lx];
$E_{v,min}$	lowest vertical plane illuminance on a plane at a specified height above the road area [lx];

A case study regarding lighting class parameters and the way of selecting the lighting classes considering different standards is presented. To reduce the number of calculations this method is used to try to determine the best solution possible. For the results to be more precise, the case study is done for two very different road arrangement, one of 16 m and one of 40 m width. The Standards considered in the case study are: Romanian, European, U.S.A. and from Denmark, which, after extensive studies are to be considered the standards with the biggest differences.

In Tables 2, 3, 4 and 5 there is a centralization of the lighting classes from each standard and the values that need to be met so that the solution is considered correct.

Table 2

P Lighting Classes for Pedestrian and Cyclists (NP062, 2002)

Class	E_H [lx]		E_{sc} [lx] Minimum value
	Medium value	Minimum value	
P1	*20.0*	*7.5*	*5.0*
P2	*10.0*	*3.0*	*2.0*
P3	*7.5*	*1.5*	*1.5*
P4	*5.0*	*1.0*	*1.0*
P5	*3.0*	*0.6*	*0.75*
P6	*1.5*	*0.2*	*0.5*
P7	*No imposed value*		

Table 3

P Lighting Classes for Pedestrian and Cyclists (**EN 13201, 2015)

Class	Horizontal illuminance		Additional requirements if facial recognition is necessary	
	E_{avg} [maintained] lx	E_{min} [maintained] lx	$E_{v,min}$ [maintained] lx	$E_{sc,min}$ [maintained] lx
P1	*15.0*	*3.0*	*5.0*	*5.0*
P2	*10.0*	*2.0*	*3.0*	*2.0*
P3	*7.5*	*1.5*	*2.5*	*1.5*
P4	*5.0*	*1.0*	*1.5*	*1.0*
P5	*3.0*	*0.6*	*1.0*	*0.6*
P6	*2.0*	*0.4*	*0.6*	*0.2*
P7	*Performance not determined*	*Performance not determined*		

Table 4
E Lighting Class (Manual for Street Lighting Facilities and Planning, 2014)

E-rank Lighting Class		E1	E2	E3	E4
Average Illuminance, minimum	E_{hr}, *lux*	*5.0*	*2.5*	*1.0*	-
Uniformity, minimum	*R*	*0.15*	*0.15*	*0.15*	-

Table 5
Maintained Illuminance Values for Walkways (RP08, 2015)

Road Area Classification		E_{avg} [lx/fc]	E_{vmin} [lx/fc]	E_{avg}/E_{min}
Pedestrian conflict area	Type of walkway			
High	*Low*	*10/1*	*5/0.5*	*4.0*
Medium	*Low*	*5/0.5*	*2/0.2*	*4.0*
Low	*Rural/Semi-Rural*	*2/0.2*	*0.6/0.06*	*10.0*
	Low Density Residential	*3/0.3*	*0.8/0.08*	*6.0*
	Medium Density Residential	*4/0.4*	*1/0.1*	*4.0*

In this case study the calculations are done for two particular arrangements. The main information of each road are presented in Table 6. Considering the high number of calculations, the height of the poles were considered fixed (8 m). The length and angle of the bracket arm, the lentil used in the calculation and the distance between the poles were chosen using the DIALux 4.13 Wizard in between some limits. Based on this limits, the program calculates and finds the best solution possible. The family of the luminaires used is TECEO from Schreder supplier and the overall maintenance factor is 0.7.

Table 6
Road Main Information

Road	Width [m]	Arrangement	Height of pole [m]	Footpath Width [m]	Distance Pole to edge of footway [m]
Arrangement 1	*40*	*Staggered*	*8*	*2.5*	*0.5*
Arrangement 2	*16*	*Staggered*	*8*	*2.5*	*0.5*

For a better understanding of the roads, in Fig. 3 and Fig. 4 there is an overview of the streets from the DIALux calculations.

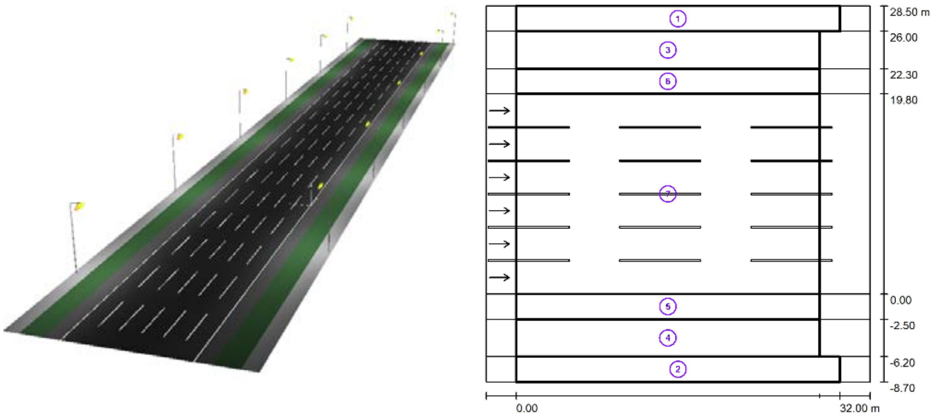

Fig. 3 – Road 1 Arrangement – 40 m width, 1,2 – footpath, 3,4 – parking, 5 – carriageway.

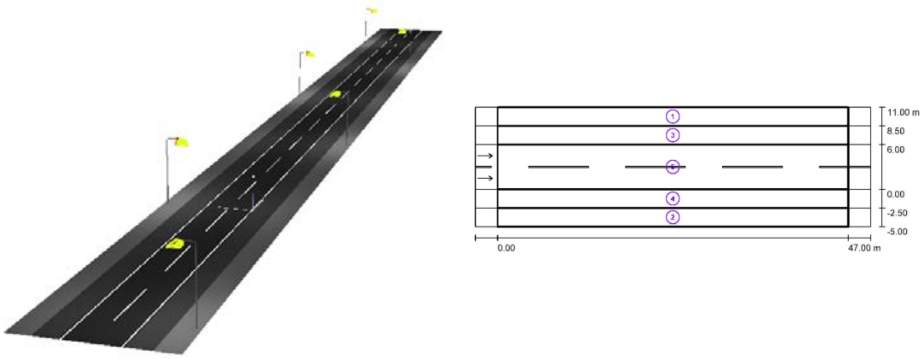

Fig. 4 – Road 2 Arrangement - 16m width, 1,2 – footpath, 3,4 – parking, 5 – carriageway.

The final scope of the Dialux calculation is to obtain the best efficiency of the system. The paper (Prachi, 2011) proposes that the efficiency of the system should be evaluated based on the power consumption per square meter per lux, [W/m^2/lx]. The scope is to get a solution with the smallest power density possible, but still comply with the values imposed by the standards. The results of the calculation are centralized in Table 7 and Table 8. Analysing the tables one can see that there are important differences between the results for each standard. When one of the conditions is facial recognition, results are difficult to obtain, which in some cases can mean a considerable reduction of distance between poles.

Based on the data from Table 7, Table 8 and Fig. 5 one can understand that the required power increases with the level of illumination and is much higher if facial recognition is one of the design requirements. The interesting fact is that when there is no need for facial recognition (Fig. 5 *b*, *c*) the differences are very small, although the width of the street is much larger for Road 1 arrangement compared to Road 2. When conditions of vertical or hemicylindrical illuminance need to be met for facial recognition purpose, the angle of the bracket arm needs to be bigger for the lighting fixture from the other side to light the footpath.

Table 7
Specific Power Calculated for Road 1

Standard	Light Class	Power of the lamp	Distance between poles	Linear specific power [W/km]	Unitary specific power [W/m²/lx]	Eavg [lx]	Emin [lx]	Evmin [lx]	Emin.sc [lx]	Eavg/ Emin
NP062	*P1*	*2x76W*	*23*	*6609*	*0.049*	*26.86*	*15.75*	*-*	*5.12*	*-*
	P2	*2x60W*	*30*	*4000*	*0.054*	*14.93*	*4.03*	*-*	*2.02*	*-*
	P3	*2x35W*	*27*	*2593*	*0.048*	*10.82*	*4.96*	*-*	*1.40*	*-*
	P4	*2x18W*	*24*	*1500*	*0.044*	*6.81*	*3.76*	*-*	*1.03*	*-*
	P5	*2x10W*	*21*	*952*	*0.042*	*4.49*	*3.07*	*-*	*0.76*	*-*
	P6	*2x10W*	*23*	*870*	*0.084*	*2.18*	*0.93*	*-*	*0.5*	*-*
**** EN 13201-2:2015*	*P1*	*2x68W*	*46*	*2957*	*0.037*	*16.12*	*5.03*	*-*	*-*	*-*
	P2	*2x52W*	*48*	*2167*	*0.037*	*11.78*	*3.19*	*-*	*-*	*-*
	P3	*2x35W*	*50*	*1400*	*0.037*	*7.58*	*1.6*	*-*	*-*	*-*
	P4	*2x27W*	*54*	*1000*	*0.038*	*5.24*	*1.01*	*-*	*-*	*-*
	P5	*2x10W*	*31*	*645*	*0.043*	*3.01*	*1.59*	*-*	*-*	*-*
	P6	*2x10W*	*46*	*435*	*0.042*	*2.05*	*0.61*	*-*	*-*	*-*
**** EN 13201-2:2015 with facial recognition*	*P1*	*2x76W*	*25*	*6080*	*0.056*	*21.82*	*11.51*	*4.65*	*4.02*	*-*
	P2	*2x60W*	*27*	*4444*	*0.068*	*13.06*	*7.67*	*3.09*	*2.15*	*-*
	P3	*2x43W*	*26*	*3308*	*0.074*	*8.98*	*6.07*	*2.9*	*1.91*	*-*
	P4	*2x27W*	*26*	*2077*	*0.077*	*5.36*	*3.48*	*2.58*	*1.72*	*-*
	P5	*2x18W*	*26*	*1385*	*0.068*	*4.05*	*2.48*	*1.00*	*0.68*	*-*
	P6	*2x10W*	*26*	*769*	*0.054*	*2.85*	*1.55*	*0.61*	*0.42*	*-*
Denmark	*E1*	*2x35W*	*47*	*1489*	*0.06*	*5*	*0.45*	*-*	*-*	*-*
	E2	*2x18W*	*47*	*766*	*0.061*	*2.5*	*0.4*	*-*	*-*	*-*
	E3	*2x10W*	*59*	*339*	*0.068*	*1*	*0.26*	*-*	*-*	*-*
RP08	*High*	*2x76W*	*32*	*4750*	*0.04*	*23.9*	*-*	*5.2*	*-*	*1.8*
	Medium	*2x52W*	*29*	*3586*	*0.043*	*16.5*	*-*	*2.0*	*-*	*2.4*
	Low Pedestrian Residential Low	*2x10W*	*24*	*833*	*0.056*	*3.0*	*-*	*0.8*	*-*	*1.6*
	Low pedestrian Residential Medium	*2x18W*	*29*	*1241*	*0.039*	*6.3*	*-*	*1.1*	*-*	*2.3*
	Low Pedestrian Rural	*2x10W*	*28*	*714*	*0.068*	*2.1*	*-*	*0.6*	*-*	*3.1*

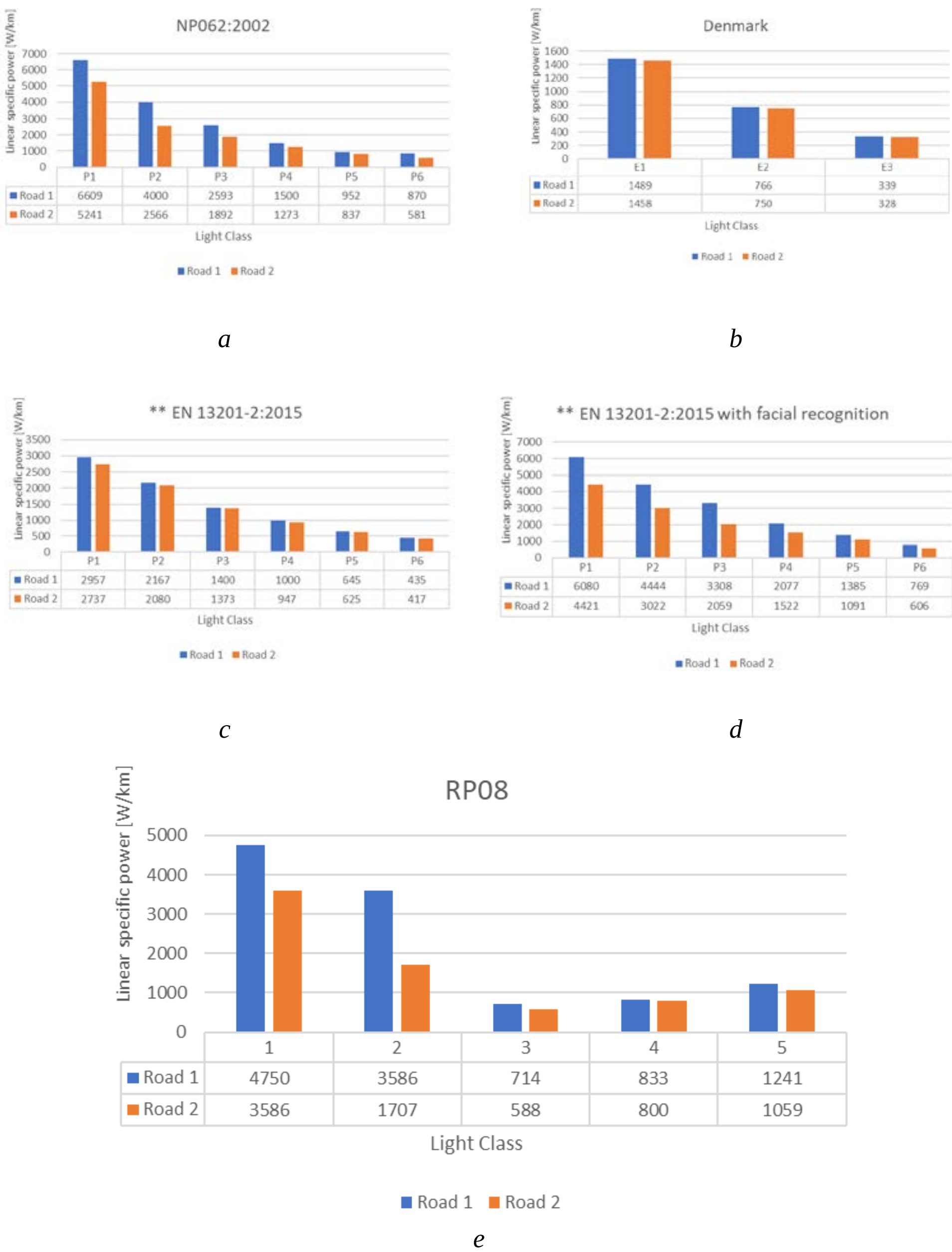

Fig. 5 – Comparison of specific linear power.

Table 8
Specific Power Calculated for Road 2

Standard	Light Class	Power of the lamp	Distance between poles	Linear specific power [W/km]	Unitary specific power [W/m²/lx]	Eavg [lx]	Emin [lx]	Evmin [lx]	Emin.sc [lx]	Eavg/ Emin
NP062	*P1*	*2x76W*	*29*	*5241*	*0.049*	*21.02*	*14.19*	*-*	*5.02*	*-*
	P2	*2x68W*	*53*	*2566*	*0.051*	*10.03*	*5.11*	*-*	*2.58*	*-*
	P3	*2x35W*	*37*	*1892*	*0.048*	*7.91*	*5.02*	*-*	*1.77*	*-*
	P4	*2x35W*	*55*	*1273*	*0.051*	*5.02*	*2.5*	*-*	*1.43*	*-*
	P5	*2x18W*	*43*	*837*	*0.052*	*3.24*	*1.99*	*-*	*0.75*	*-*
	P6	*2x18W*	*62*	*581*	*0.052*	*2.24*	*1.04*	*-*	*0.5*	*-*
**** EN 13201-2:2015*	*P1*	*2x52W*	*38*	*2737*	*0.036*	*15.19*	*6.65*	*-*	*-*	*-*
	P2	*2x52W*	*50*	*2080*	*0.036*	*11.56*	*3.09*	*-*	*-*	*-*
	P3	*2x35W*	*51*	*1373*	*0.036*	*7.6*	*1.76*	*-*	*-*	*-*
	P4	*2x18W*	*38*	*947*	*0.035*	*5.36*	*2.23*	*-*	*-*	*-*
	P5	*2x10W*	*32*	*625*	*0.04*	*3.13*	*1.6*	*-*	*-*	*-*
	P6	*2x10W*	*48*	*417*	*0.037*	*2.27*	*0.68*	*-*	*-*	*-*
**** EN 13201-2:2015 with facial recognition*	*P1*	*2x84W*	*38*	*4421*	*0.058*	*15.12*	*9.26*	*5.4*	*5.27*	*-*
	P2	*2x68W*	*45*	*3022*	*0.054*	*11.18*	*6.47*	*3.14*	*2.61*	*-*
	P3	*2x35W*	*34*	*2059*	*0.052*	*7.85*	*4.34*	*2.53*	*2.23*	*-*
	P4	*2x35W*	*46*	*1522*	*0.053*	*5.74*	*3.27*	*1.51*	*1.28*	*-*
	P5	*2x18W*	*33*	*1091*	*0.063*	*3.48*	*2.15*	*1.09*	*1.05*	*-*
	P6	*2x10W*	*33*	*606*	*0.059*	*2.06*	*1.18*	*0.60*	*0.52*	*-*
Denmark	*E1*	*2x35W*	*48*	*1458*	*0.055*	*5.26*	*0.44*	*-*	*-*	*-*
	E2	*2x18W*	*48*	*750*	*0.059*	*2.53*	*0.46*	*-*	*-*	*-*
	E3	*2x10W*	*61*	*328*	*0.066*	*1.0*	*0.28*	*-*	*-*	*-*
RP08	*High*	*2x52W*	*29*	*3586*	*0.056*	*12.9*	*-*	*5.1*	*-*	*1.5*
	Medium	*2x35W*	*41*	*1707*	*0.05*	*6.8*	*-*	*2.1*	*-*	*1.5*
	Low Pedestrian Residential Low	*2x18W*	*45*	*800*	*0.053*	*3.0*	*-*	*0.8*	*-*	*1.6*
	Low pedestrian Residential Medium	*2x18W*	*34*	*1059*	*0.052*	*4.1*	*-*	*1.0*	*-*	*1.5*
	Low Pedestrian Rural	*2x10W*	*34*	*588*	*0.059*	*2.0*	*-*	*0.6*	*-*	*1.7*

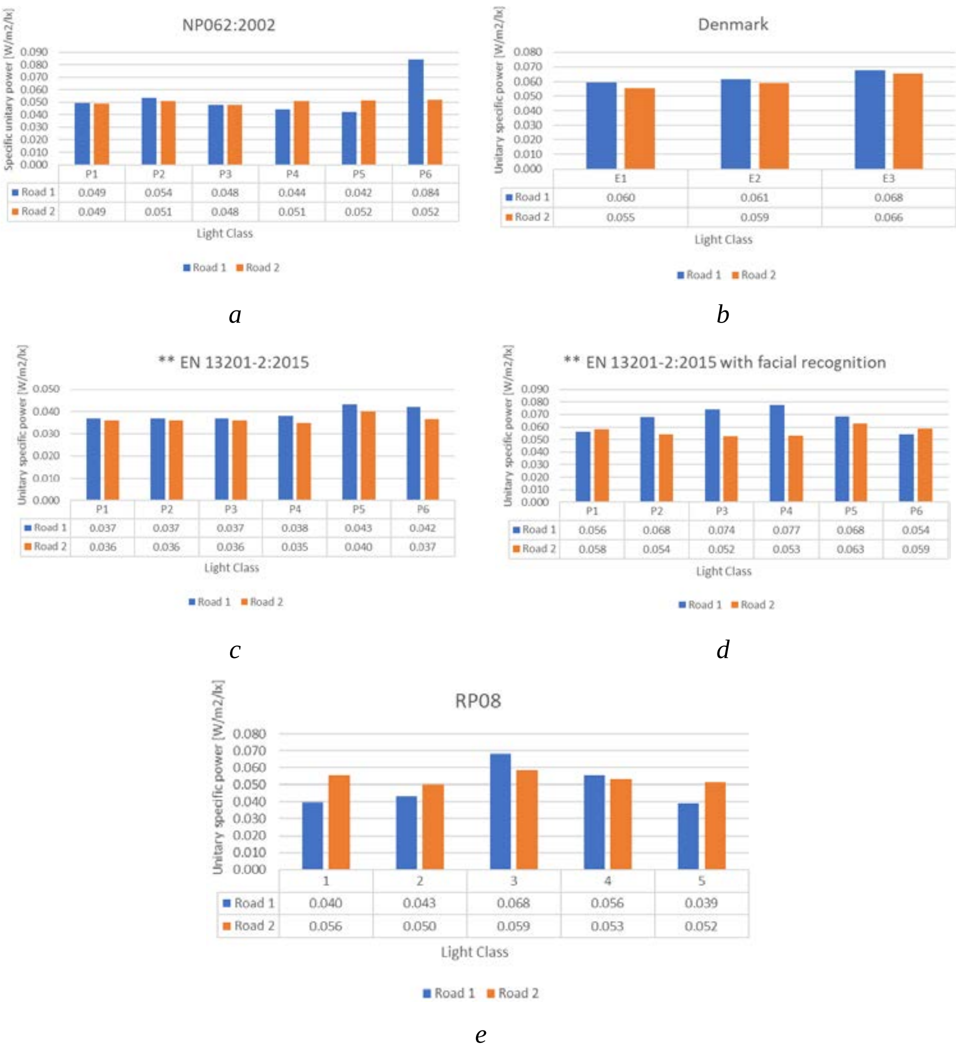

Fig. 6 – Comparison of specific unitary power.

Looking at Fig. 6 one can see that the unitary specific power [W/m^2/lx], is, in some cases, smaller for the road with more traffic lanes. This fact indicates a problem in establishing the efficiency of the street lighting system when $E_{v,min}$ $_x$and $E_{sc,min}$ needs to be taken into account. Although the standards tell that the efficiency is compared to E_{avg}, in reality, when $E_{v,min}$ or $E_{sc,min}$ need to be met it is possible that for the same road, an installation with a smaller power to satisfy all conditions and to be considered less efficient, which from the user's point of view can be confusing. Based on this study the author recommends the utilization of a new parameter of energy efficiency in parallel with the one recommended by the standards. This parameter will reflect the linear power density [W/km] and will be calculated with the formula:

$$\eta = \frac{P \times 1000}{d} \text{ [W/km]} \quad (1)$$

where: *P* – Sum of the power of the lamps from each side of the road; *d* – Distance between poles.

This formula can be used only if the arrangement on both side is symmetric, otherwise the formula will be:

$$\eta = \frac{P_1 \times 1000}{d_1} + \frac{P_2 \times 1000}{d_2} + \ldots\ldots\ldots + \frac{P_n \times 1000}{d_n} \text{ [W/km]} \quad (2)$$

where: *Pi* – Power of the lamp from each arrangement of the road; d_i – Distance between poles from each arrangement of the road.

4. Conclusions

Based on this paper we can conclude that this method of finding the best solution for straight road calculation is much faster than other ways of doing the calculations. The study-case demonstrates that the most restrictive standard is the Romanian, which, although it has the biggest lighting level requirement, E_{avg} for each lighting class, it also has the $E_{avg,sc}$ value not optional, which increases the power of the light needed a lot in most of the cases. It is clear that the Denmark standard is much less restrictive in regards to footpath lighting requirement, most probably, because of the very low conflict rate in the country.

Although the standard relate to unitary power density [W/m^2/lx] as the energy efficiency unit of the lighting system, this value sometimes is not very relevant because it can't give a clear reflection of the efficiency of the system. This paper recommends the utilization of an extra parameter, linear power density, to establish the efficiency of the system, measured in [W/km], which would give a clear understanding of what is the power consumption for a section of a road.

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METODE AUTOMATE DE ALEGERE A SOLUȚIEI OPTIME ÎN ILUMINATUL STRADAL

(Rezumat)

Această lucrare prezintă o metodă automată de calcul pentru iluminatul stradal utilizând asistentul programului DIALux 4.13. Lucrarea analizează o metodă prin care se realizează un număr foarte mare de calcule într-un timp foarte redus. În vederea realizării acestor calcule s-au considerat o serie de parametri variabili: curbe de distribuție a intensității luminoase, distanța dintre stâlpi, lungime și unghi de înclinare consolă. Pentru realizarea calculelor s-au luat în considerare și o serie de parametri ficși: distanța de la stâlp la șosea, aranjament. Pentru a evidenția utilitatea și viteza cu care se realizează calculele s-a realizat un studiu de caz prin care se compară valorile recomandate pentru proiectarea sistemelor de iluminat stradal pietonal (trotuare) din diverse țări. Standardele pentru care s-a realizat studiul sunt: standardul românesc NP062, standardul european EN 13201-2 cel american RP08 și cel din Danemarca.

Prima concluzie în urma studiului realizat este că timpul în care se poate găsi soluția optimă, este foarte redus, durând aproximativ 5 minute realizarea unei soluții în care au fost realizate aproximativ 5000 de combinări pe baza parametrilor evidențiați mai sus. Alt lucru constatat este că programul are totuși niște limitări generate de numărul de curbe de distribuție importate. S-a constatat că la un număr mai mare de curbe de distribuție (aproximativ 100) programul nu mai reușește să calculeze, acesta blocându-se.

A doua concluzie importantă este că cel mai restrictiv standard din punct de vedere al zonelor pietonale este NP062, acesta având și cel mai mare consum energetic necesar pentru îndeplinirea valorilor recomandate. Valoarea puterii unitare ($W/m^2/lx$), este aproape tot timpul mai mare decât în cazul celorlalte standarde, lucru care confirmă faptul că normativul este vechi și nu ține cont de noile cerințe de eficiență energetică

care ar trebui să reprezinte unul din principalele criterii atunci când proiectăm orice instalație consumatoare de energie.

Deși standardul face referire la densitatea de putere unitară [W/m^2/lx] ca și unitate de măsurare a eficienței sistemului de iluminat, uneori această valoare nu este foarte relevantă. Această lucrare recomandă utilizarea unui nou parametru, suplimentar, densitatea specifică liniară, pentru a stabili eficiența sistemului, măsurată în [W/km], ceea ce ar oferi o imagine clară a consumului de energie pentru o secțiune de drum.