Influence of intelligent control systems on parameters of public lighting

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1. Introduction

This article will describe the possibilities of the management and control systems of road lighting, the influence of intelligent control systems on light parameters of road lightning as well as the overall influence of the management and control system on the values of light intensity and uniformity and traffic safety in particular lighting classes.

Public lighting system is an electric device that is subject to all safety regulations and recommendations related to the operation of electrical equipment. Also, each lighting system must satisfy the minimum standards set by the value of luminance, glare and lighting uniformity according to the classification and the importance of communications. The basic objective of the management and control of public lighting system to ensure trouble-free operation of public lighting system while achieving energy savings in particular the operation of the system in the dimming mode at certain intervals during the night. The density of traffic at night which varies in certain cases can also change the class of road lighting and thereby allows us to intervene and change the parameters of the lighting system. By adjusting luminous flux of the lamps at different time periods, we can save the cost of public lighting system

In Europe, within the framework of Intelligent Energy Program and e-street project, “Intelligent Road Lighting” systems are being installed and energy efficiency in road lighting applications is becoming important. With the Telemanagement systems for road lighting, luminous flux of the lamps can be adjusted to different levels based on the traffic, weather and other parameters. A Telemanagement system consists of an “outdoor luminaire controller” which controls the dimming equipment in the luminaire, a “local control unit” in the supply panel and a “central management system”. With the use of the Telemanagement system, luminance flux of the lamps in road lighting installations are reduced and energy saving amounts of 30% in Norway, 45% in Finland, 24% in England, 37% in Sweden are declared. In USA, Streetlight Intelligence (STI) Lumen IQ device is used in a similar system to Europe and energy savings up to 40% is declared. In China, a central dimming system is used and 30% of energy savings declared [5].

As we can see nowadays, there are several management and control systems of public lighting that promises energy savings of up to 30% to 45%. The question is whether the dimming of lamps to such an extent satisfies the minimum value of intensity and uniformity of light intensity and under what conditions. The aim is to determine under what conditions it is possible to dim street lighting and to what level so the dimming mode meets the standard set value by CIE standards, and still is economical.

2. Standard requirements

European standard EN 13201-1 provides guidance on the selection of lighting classes and related aspects. Instructions can be used for fixed lighting equipment to provide users of public roads good visibility during darkness, road safety, traffic intensity, and should contribute to a feeling of security [1]. Standard specifies the class of light in another part of EN 13201-2 and provides instructions for their use, plus includes a system for defining the area of public transport as the parameters that are relevant to the lighting.[2]

This standard specifies requirements for lighting, which depend on the geometric arrangement of the relevant section, on the traffic and time restricted circumstances. It is the responsibility of road authorities for the relevant sections and thus assess the relevant parameters. Unless otherwise stated, the parameters are valid only during night. Parameter values can vary at different times during the night and evening different seasons, and may therefore be modified during these periods [1]. Significant changes in parameter values can be used at different times of the night, particularly with respect to the ambient brightness and intensity of traffic. From Table 1 we can notice that during the night one of the parameters that can vary and thus influence the change of lighting class of communication is the intensity of road traffic.

Use of the tables in Annex A to EN 13201-1 may therefore show different classes of lighting appropriate to the different times. It may therefore be necessary to use more detailed analysis of the intensity of traffic during the night, than the one that is provided by the average daily intensity (ADT). That means, in the terms of changes of road traffic at night we can modify the operation parameters of the lighting system in the dimming mode so that they are adhered to standard value of the intensity and uniformity of road lighting in the relevant lighting class. Therefore, it would be necessary in the design of management and control of public lighting system to define beside of the class of lighting for 100% operation and class of light which has been proposed for the dimming mode.

Parameters		Possibilities
Spatial Arrangement	Directionally distributed communication	Yes No
	Types of intersection	Interchange Intersection
	The distance between intersections, The distance between bridges	>3 km <3 km
	Density of junctions	< 3 junction/km > 3 junction/km
	Conflict area	No Yes
	Constructions measures to calm traffic	No Yes
Impact of traffic	**Average daily traffic**	**Less than 7 000** **Between 7 000 and 15 000** **Between 15 000 and 25 000** **More than 25 000**
	Intensity of Cycling traffic	Normal High
	The intensity of pedestrian	Normal High
	Difficulty of navigational task	Normal High
	Parked vehicles	No Yes
	Recognition of surface	Unnecessary Necessary
	Crime Risk	Normal High
Effects of environment and external influences	Complexity of Field of Vision	Normal High
	Brightness of Surroundings	Rural Environment City Environment Inner-City Environment
	Main Weather Type	Dry Wet

Table 1, The parameter list of possible choices or values

Currently the market offers us several management and control systems of public lighting founded mostly on the system of changing the input voltage, step change of wattage of frequency of light sources. All of these management systems promise high energy savings with the possibility of reducing the luminous flux of lamps up to 80% [4][6]. But if the following conditions are satisfied by standards established values of the illumination is questionable. So we tried to simulate those conditions to find out what standards do they satisfy and then tried to find out under what circumstances is possible to dim road lights and on what level will this dimming insure energy saving and satisfy European standards

3. Simulation of today's regulation and control systems and its influence on lighting classes

Firstly we listed all classes of lighting at full intensity of traffic and the appropriate classes of lighting during the night at a reduced intensity of traffic (Table 2) as described in Annex A in EN 13201-1. As for other parameters, we consider that they remain unchanged.

Lighting classes at full intensity of traffic	ME1	ME2	ME3a	ME3b	ME3c	ME4a	ME4b	ME5	ME6
Lighting classes at reduced intensity of traffic	ME3b	ME3b ME4a	ME4a ME5	ME4a ME5	ME4b	ME5	ME5	ME5 ME6	ME6

Table 2, Reduction of lighting classes dependent on intensity of traffic

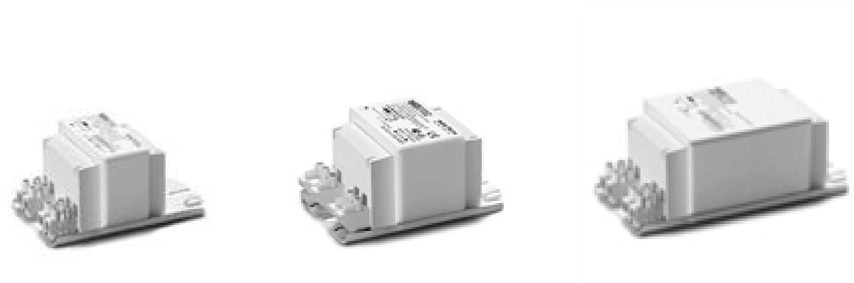
From the table 2 we can see that in some cases dependent on intensity of the traffic flow lighting class can be changed by 3 levels. In these cases we planned with extreme changes in traffic intensity during night but also according to prescribed values given by standards. In other words, if we want to save energy by reducing luminance flux of the lamps, the maximum we can get is to this lighting class if we want to satisfy standard values.

Class	**Luminance of the road surface of the carriageway for the dry road surface condition**			**Disability glare**	**Lighting of surroundings**
	$\overline{L}$ in cd/m^2 [minimum maintained]	**U_o [minimum]**	**U_l [minimum]**	**TI in % [a] [maximum]**	**SR[b] [minimum]**
ME1	2,0	0,40	0,70	10	0,50
ME2	1,5	0,40	0,70	10	0,50
ME3a	1,0	0,40	0,70	15	0,50
ME3b			0,60		
ME3c			0,50		
ME4a	0,75	0,40	0,60	15	0,50
ME4b			0,50		
ME5	0,50	0,35	0,40	15	0,50
ME6	0,30	0,35	0,40	15	-

[a] An increase of 5 percentage points in TI can be permitted where low luminance light sources are used.
[b] This criterion may be applied only where there are no traffic areas with their own requirements adjacent to the carriageway.

Table 3, ME-series of lighting classes [2]

For simulation of controlling and regulation of public lighting we used method of dimming by switching power output on ballast. There were used three types of ballast, the one that reduce power from 150W to 100W, the one that reduce power from 100W to 70W and the one that reduce power from 70W to 50W (Figure 1).



a) b) c)

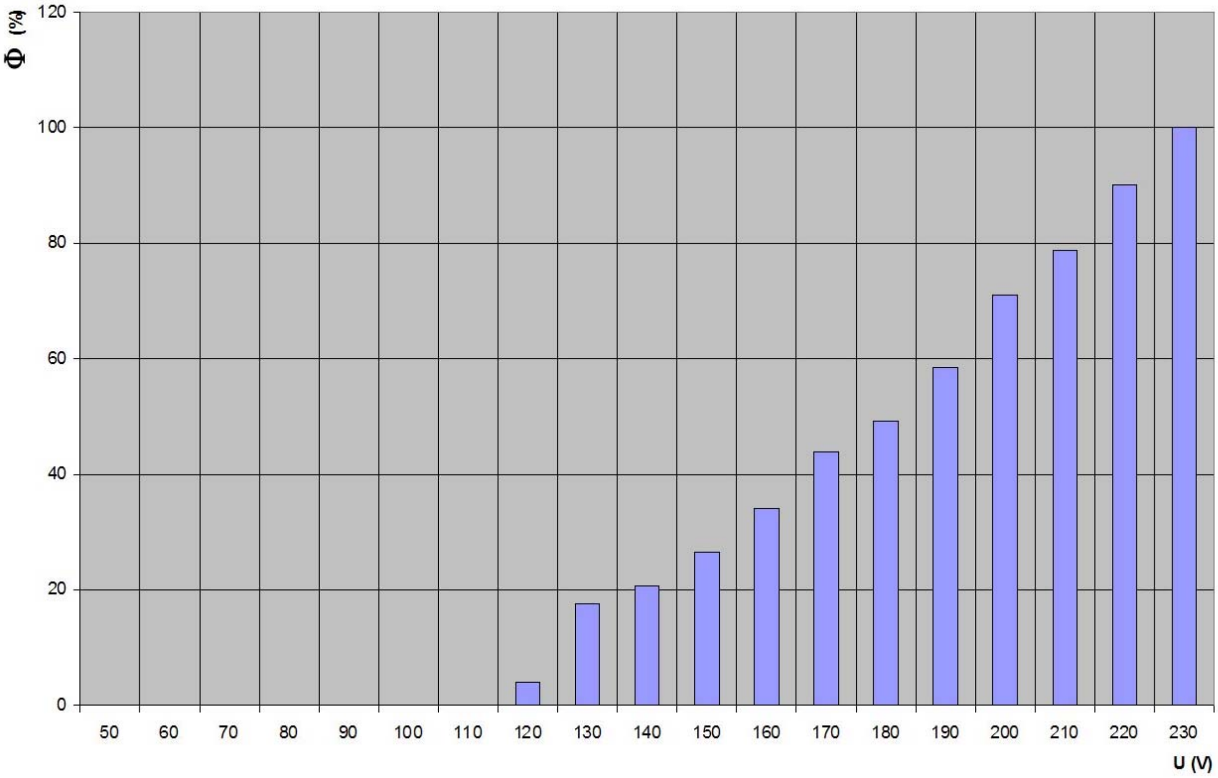
Figure 1, Used Ballasts for High pressure sodium lamps with power reduction: a) 70W/50W, b) 100W/70W, c) 150W/100W

This method of controlling and regulation by switching power output is used in most applications of intelligent controlling of public lighting. Today most of the used ballasts are electronic ballasts which reduce power output by changing frequency or similar but in final result is the same. Output power is reduced down to 40% and that means that luminous flux of lamp is reduced down to even 80% in some cases.

As for light sources we used high pressure sodium lamps SON-T (NAV-T) SUPER 4Y with power of 150W, 100W and 70W (Figure 2). Those light sources because of their excellent parameters like efficiency up to 140 lm/W and long life time up to 28 000h are mostly used in road lighting. Also high pressure sodium lamps easily can be dimmed by reducing wattage or voltage although this reducing is not directly proportional to the change of luminous flux so we have to keep this in mind. Dependence of luminous flux on voltage is shown in Graph 1.

Figure 2, High pressure sodium lamps used for testing 150W, 100W and 70W

As for the testing we used spherical integrator to measure decrease of intensity of high pressure sodium lamps when the power is reduced. For each lamp, we wait about 15-20 minutes to stabilize and after switching the power output also for about 15 – 20 minutes for stabilization. Readings are listed in Table 4.



Graph 1, Dimming of high pressure sodium lamps by reducing of voltage

High pressure sodium 150W			Decrease of power
Power output	150W	100W	33%
Luminous flux [%]	100%	31,7%	-
High pressure sodium 100W			**Decrease of power**
Power output	100W	70W	30%
Luminous flux [%]	100%	54,7%	-
High pressure sodium 70W			**Decrease of power**
Power output	70W	50W	28,5%
Luminous flux [%]	100%	43,3%	-

Table 4, Dependence of luminous flux on reducing wattage

From Table 4 we can see that the reduction of luminous flux at 150W high pressure sodium lamps with switching power output from 150W to 100W fell to 31.7% of the total value. This means that if we use ballast like this one that changes power output from 150W to 100W we will lose for about 68% of luminous flux. In reality this enormous change of luminous flux may represent catastrophic change of light intensity on a road.

To find out how will this power reducing ballast affect the intensity and safety in street lighting we made simulation and calculated the change of average road surface luminance. For simulation we use simple road with width 7m for each lighting class with one side lighting installation (Figure 3) and IP65 cover luminaries with proper light distribution curve and light source for each lighting class (Figure 4).

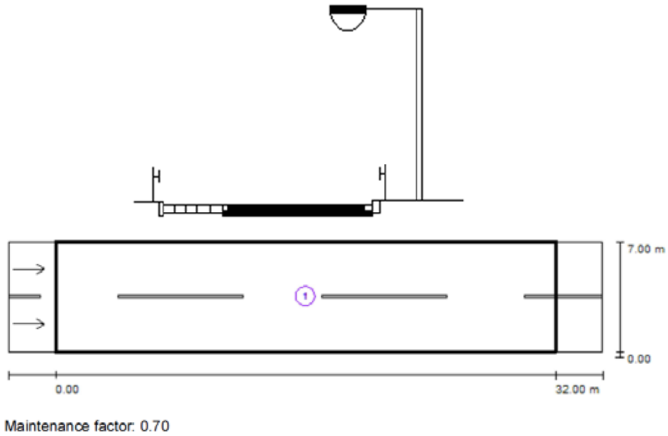


Figure 3, Scheme of the sample road

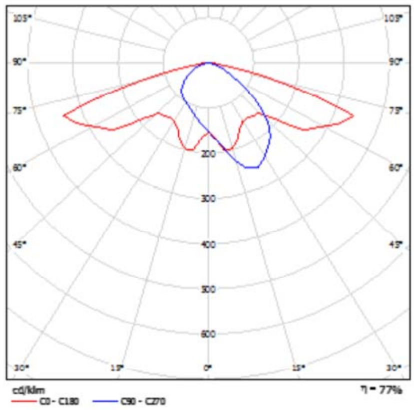


Figure 4, Light distribution curve of luminaire

As for the pole distance, mounting high and boom angle were used most effective cases in terms of quality, functionality and of course esthetics. For each lighting class we measured average road surface luminance under full intensity and under dimmed intensity to find out how will this affect change of lighting class. Readings are listed in Table 5.

Class 1	L_1 [cd.m^{-2}] (power output 1)	Used HPS	Φ [%] (after power switching)	L_2 [cd.m^{-2}] (power output 2)	Class 2
ME1	2,0	SON-T 150W	31,7%	0,63	**ME5**
ME2	1,5	SON-T 150W	31,7%	0,48	**ME6**
ME3a	1,0	SON-T 150W	31,7%	0,32	**ME6**
ME3b	1,0	SON-T 150W	31,7%	0,32	**ME6**
ME3c	1,0	SON-T 150W	31,7%	0,32	**ME6**
ME4a	0,75	SON-T 100W	54,7%	0,41	**ME6**
ME4b	0,75	SON-T 100W	54,7%	0,41	**ME6**
ME5	0,5	SON-T 70W	43,3%	0,21	**-**
ME6	0,3	SON-T 70W	43,3%	0,13	**-**

Table 5, Measure of average road surface luminance in full power and reduced power

As we can see from Table 5, as a result of reducing power is rapidly decreasing of road surface luminance. According to these calculations highest lighting classes M1 and M2 in reduced power mode will change to M5 and M6 lighting class. And for the lowest lighting classes M5 and M6 in reduced power mode will correspond to a maximum of “S” lighting classes or similar. So we can conclude that using this way of control and regulation of public lighting, although we can achieve energy savings up to 30% but we cannot keep down the value of light intensity according to EN 13201-2.

Since the design of public lighting systems in practice is dimensioned to be most economical, therefore to achieve the lowest standards required, the use of such control and regulation system foe saving the energy, street lighting in reduced power mode does not meet the standards in any circumstances. To achieve the required values in reduced power mode is necessary to over dimension lighting system from 25% up to 60%. This will increase power consumption and overall costs so the whole system would not be economical at all.

4. How to save energy and also fulfill the standards

Energy savings and also fulfillment of the required values and standards is possible only with continuous variation of luminous flux by changing for example voltage with possibility of specific regulation for each lighting class.

For the purpose of quantifying the maximum possible energy savings with regulation and control of public lighting, we performed simulations in a computer program DIALux for each lighting class. Regulation was performed by reducing the supply voltage of high pressure sodium lamps to a value in the dimming mode, when the resulting luminous fluxes have fulfilled the standard value of corresponding lighting class.

The choice of the lighting classes in dimming mode we have performed from the Table 2. From defined values of luminance of the road surface which we must achieve in the appropriate lighting class in dimming mode, we determined the percentage of luminous flux and from the Graph 1 we determine under what voltage this luminous flux will be achieved. Using this voltage and known current we calculated the power P2 [W] with which we quantify the energy saving for each class separately. The results are shown in Table 6.

Class 1	L_1 [cd.m^{-2}]	P_1 [W]	Φ [%]	P_2 [W]	L_2 [cd.m^{-2}]	**Class 2**	Energy savings
ME1	2,0	150W	50%	117W	1,0	**ME3b**	22%
ME2	1,5	150W	67%	129W	1,0	**ME3b**	14%
ME2	1,5	150W	50%	117W	0,75	**ME4a**	22%
ME3a	1,0	150W	75%	135W	0,75	**ME4a**	10%
ME3b	1,0	150W	50%	117W	0,5	**ME5**	22%
ME3c	1,0	150W	75%	135W	0,75	**ME4b**	10%
ME4a	0,75	100W	67%	86W	0,5	**ME5**	14%
ME4b	0,75	100W	67%	86W	0,5	**ME5**	14%
ME5	0,5	70W	60%	58W	0,3	**ME6**	17%
ME6	0,3	70W	100%	70W	0,3	**ME6**	0%

Table 6, Comparison of road surface luminance in normal mode and dimmed mode, quantifying the energy savings.

From the Table 6 we can conclude that the greatest savings we can obtain are under ME1 class and in special cases, under class ME2 and ME3 where the energy savings in these cases reaches up to 22%. The problem with these classes is that, in practice there are not so many of them. Road communications to which we can assign these lighting classes are not so represented, respectively are present in small quantities but also in those cases is dimming on these roads unsuitable and ultimately not desirable.

In reality, the biggest energy savings can be achieved by regulation and control of light in the lighting classes ME4, ME5 and ME6. These classes are represented in more than 90% of cases of street lighting especially in smaller towns and villages. As seen from the Table 6 within these classes we are currently limited especially in the class ME6 where according to the standards we have no possibility to control public lighting. This is due to large traffic densities which are defined in standards, where the smallest traffic density is 7000 vehicles during the day. In most cases this is too high number of vehicles, especially at night when the traffic density is around 100 vehicles or even less.

5. Conclusion

At the end of this research we identified influence of intelligent control systems on parameters of public lighting. As we have seen, the most of the intelligent control systems which use reducing power method and declare of 40% energy saving does not have to fulfill the standards and may have catastrophic influence on traffic safety. Because of these reasons it will be appropriate to include this in European standards and to determine the bottom limit of reducing light intensity by setting of appropriate lighting classes in dimming mode. Specify exactly what is dimming limit in each lighting class and under what conditions.

Another objective of this research was to determine the maximum reachable energy savings by dimming of street lighting. As the result of this research was found out that in reality in Slovak Republic, the biggest energy savings can be made under lighting classes ME4, ME5 and ME6 and currently under these classes we are limited with regulation and in some cases we have no possibilities of dimming at all. According to this result, it will be required to adjust European standards and define few lower lighting classes and more detailed classification of the traffic congestion especially in the lower levels of density. These changes should give as possibility to save energy and secure traffic safety in lower and most represented lighting classes.

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