A survey on solutions to increase energy efficiency in public lighting system of Romania

Ionut Ciobanu
Faculty of Power Engineering
University Politehnica of Bucharest
Bucharest, Romania
ionutciobanu81@gmail.com

Radu Dumitru Pentiuc
Faculty of Electrical Engineering and Computer Science
University "Stefan cel Mare" Suceava
Suceava, Romania
radup@eed.usv.ro

***Abstract*—Energy efficiency is one of the priority European Union under the Europe 2020 Strategy. A key area in energy efficiency to be acted upon is street lighting. Public lighting consumption in Romania represents about 1% of total electricity consumption. The choice between the redesign of public lighting systems or use solutions of retrofit for the replacement of lamps or luminaires can be made following a flowchart analysis but also taking into account the investments budget.**

Keywords—street lighting; energy efficiency; LED; retrofit; new systems

I. INTRODUCTION

Energy efficiency is one of the priority European Union under the Europe 2020 Strategy. In the energy field, it includes three main complementary objectives of energy and climate by 2020: to reduce emissions of greenhouse gas emissions by 20% compared to 1990, to generate 20% of primary energy from renewable energy sources and to increase energy efficiency by 20%.

A key area in energy efficiency to be acted upon is street lighting. Energy efficiency in this area involve in addition to significantly reducing the consumption of electricity and additional benefits associated with eliminating environmentally harmful technologies, reduce maintenance costs and achieve a much better overall control environment for street lighting.

Street lighting is an important public service provided by public authorities at a local level. Quality lighting is essential for road safety, personal safety and urban ambience. Street lighting provides visibility for motorists, cyclists and pedestrians, thus reducing the number of road accidents. Public lighting also indirectly facilitates crime prevention through increased sense of personal safety and security of public and private adjacent properties. Street lighting can also boost the attractiveness of cities and communities as commercial and cultural centers, by highlighting local landmarks or accentuating atmosphere during major public events.

However, many street lighting systems are technically outdated, and therefore, highly inefficient. This leads to large amounts of electricity used and high levels of maintenance.

Total final consumption of a country is divided by the International Energy Agency (IEA) in four sectors:

- residential.
- services.
- transport (both passenger and freight).
- industry.

The services sector covers "trade and public services" and in international recommendations on energy statistics it is referred to as the tertiary sector.

This sector covers a large number of economic activities that can be private, public or a combination of both [1, 2].

Public lighting is an important component services sector.

II. ENERGY EFFICIENCY INDICATORS FOR PUBLIC LIGHTING IN ROMANIA

Indicator - is something that gives an indication and could be any of the various statistical values that provide an indication.

An indicator used for public lighting can be an absolute value (the total energy consumption of public lighting), or a report (public lighting energy consumption compared to the number of inhabitants).

Indicators can be expressed in units of energy (total consumption of the lighting system), report (kWh per fixture) or percentage (x% of energy consumption in public lighting based on the total energy consumption of a locality).

In public lighting we can identify a number of energy efficiency indicators, of which the most important are:

- the total annual electricity consumption of the public lighting system in a country (L1).
- the total annual electricity consumption of the public lighting system based on final electricity consumption of a country (L2).
- the total annual electricity consumption of the public lighting system reported the number of inhabitants of the country (L3).

In Romania for the past three years the energy efficiency indicators for the public lighting system are as shown in Table 1:

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TABLE I. INDICATORS OF ENERGY EFFICIENT PUBLIC LIGHTING SYSTEMS IN ROMANIA FOR THE YEARS 2012, 2013, 2014

Year	Indicator L1	Indicator L2	Indicator L3	Final consumption of electricity of Romania	The population of Romania on January of the year
2012	669 GWh	1.28%	31.38 kWh/capita/year	52,211 GWh	21,316,420
2013	584 GWh	1.44%	29.17 kWh/capita/year	40,627 GWh	20,020,074
2014	461 GWh	1.10%	23.12 kWh/capita/year	41,909 GWh	19,942,642

Analyzing the table above we notice a decrease in the indicator L1 of 31.1% between 2012 - 2014 that leads to the conclusion that the energy efficiency of public lighting system in Romania is on a positive slope [3, 4].

The total annual cost estimate of the electrical energy consumed by public lighting system for the years 2012, 2013, 2014 is shown in the chart below with the assumptions:

The number of operating hours in a year for public lighting system is 4,000 hours, of which: hours between 22.00 - 07.00 – 2,400 hours (t1); hours outside the range of 22.00 - 07.00 – 1,600 hours (t2).

Average price of electricity for low voltage level is: 0.5622 lei/kWh for 2,400 hours in the range 22.00 - 07.00 (p1) and 0.1832 lei/kWh for 1,600 hours outside the range 22.00 - 07.00 (p2).

Cost of the total annual electricity consumed by public lighting system:

$$P = t1 \cdot p1 + t2 \cdot p2 \quad (1)$$

TABLE II. ESTIMATED COST OF ELECTRICITY RELATED PUBLIC LIGHTING SYSTEM IN ROMANIA FOR THE YEARS 2012, 2013, 2014

Year	The total annual electricity consumption of the public lighting system (indicator L1)	The total annual electricity consumption of the public lighting system in the hours 22.00-7.00	The total annual electricity consumption of the public lighting system outside the hours 22.00-7.00	The total annual cost of electricity consumed by public lighting system
2012	669 GWh	401.4 GWh	267.6 GWh	274,691,400.00 Lei
2013	584 GWh	350.4 GWh	233.6 GWh	239,790,400.00 Lei
2014	461 GWh	276.6 GWh	184.4 GWh	189,286,600.00 Lei

From the analysis of consumption data for four localities in Romania with a population between 53,308 and 293,567 inhabitants results the following data presented in the table below:

The average power installed on the luminaire ranges from a maximum of 199,98 W/luminaire at 133,32 W/luminaire with an estimated average 150 W/luminaire, which implies the need for investments in modernization retrofitting in these systems of public lighting.

For Romania, finding effective solutions to achieve economic lighting, comfortably acceptable in terms of quantity and quality is more important than reducing the electricity consumption for lighting systems.

Reporting the total annual electricity consumption of the public lighting system in Romania for 2012 at an average power of 150 W/luminaire, we get the result of 1.115 million luminaires related to the lighting system in Romania.

III. DESIGNING ENERGY EFFICIENT PUBLIC LIGHTING SYSTEMS

The designing and planning process is an important step in the implementation of any project of street lighting. It is very important to understand the recommendations of the standard street lighting and assess the area where the new lighting system is to be installed in order to take decisions on the types of lighting technologies to be used.

Implementing an efficient street lighting project depends largely on analysis of local needs, existing infrastructure and available technology and also clear understanding of the potential cost and energy savings to be achieved through overall design [5].

Flow chart analysis of steps needed in designing an energy efficient public lighting system can be applied both to new lighting projects and improving existing systems:

1.1. Streets category

European standard CEN/TR 13201 includes four independent parts that need to be fulfilled to correctly dimension the adopted lighting system: Part 1 Selection of lighting classes; Part 2: Requirements for performance; Part 3: Calculation of the street lighting system performance; Part 4: Methods of measuring the performance of the lighting system [6].

Choosing the appropriate classes of lighting depends on the following general criteria: the speed of the primary user (in km/h); the type of the primary user; other admitted types of users; types of users excluded; intersections, slowing devices); amounts of traffic (vehicular traffic density, cyclists and pedestrian traffic, risk of aggression); environmental influences (lighting level of ambient, atmospheric conditions); risk areas yes/no; main weather conditions dry/wet.

1.2. Quality street lighting recommendations

Quality factors of the public lighting system depend on performance criteria.

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TABLE III. COMPARISON BETWEEN THE NUMBER OF LUMINAIRES, AVERAGE POWER INSTALLED AND THE NUMBER OF INHABITANTS IN FOUR LOCALITIES IN ROMANIA

Locality	Number of inhabitants	Year	Annual consumption of electricity for the public lighting system	Number of street lighting fixtures	Installed power per luminaire	Public lighting consumption relative to the number of inhabitants in a year
A	136,480	2010	7,480 MWh	12,386 pieces	150.98 W/luminaire	54.81 kWh/capita/year
B	53,308	2012	2,539 MWh	3,174 pieces	199.98 W/luminaire	47.63 kWh/capita/year
C	147,245	-	5,424 MWh	7,852 pieces	172.70 W/luminaire	36.84 kWh/capita/year
D	293,567	2012	9,905 MWh	18,573 pieces	133.32 W/luminaire	33.74 kWh/capita/year

Choosing classes of lighting depends on the following performance criteria: Lmed - average luminance (cd/m2), which represents a minimum value required; U0min - general uniformity (%) = Lmin/Lmed; longitudinal uniformity U1min (%) = Lmin/Lmax; maximum physiology blindness Ti (%); adjoining area ratio SR (minimum amounts required) [6].

European standard CEN/TR 13201 - Part 2: Requirements concerning the performance shows 6 classes the lighting ME1, ME2, ME3 (a, b, c), ME4 (a, b), ME5, ME6 which presents criteria of performance:

Class	Luminance of the road surface of the carriageway for the dry road surface condition			Disability glare	Lighting of surroundings
	$\bar{L}$ in cd/m² [minimum maintained]	U_o [minimum]	U_l [minimum]	TI in %[a] [maximum]	SR[2b] [minimum]
ME1	2,0	0,4	0,7	10	0,5
ME2	1,5	0,4	0,7	10	0,5
ME3a	1,0	0,4	0,7	15	0,5
ME3b	1,0	0,4	0,6	15	0,5
ME3c	1,0	0,4	0,5	15	0,5
ME4a	0,75	0,4	0,6	15	0,5
ME4b	0,75	0,4	0,5	15	0,5
ME5	0,5	0,35	0,4	15	0,5
ME6	0,3	0,35	0,4	15	no requirement

Fig. 1. The lighting classes according to european standard CEN / TR 13201 - Part 2.

1.3 Retrofit solutions or new lighting system

1.3.1 Redesigning lighting system

When available financial resources allow lighting system redesign it can be reached to reduce electricity consumption without compromising visual comfort. Creating a modern lighting system may result in significant cuts in consumption of electricity by reducing the level of luminance (light) with decreasing traffic and is a solution that should be considered from the design phase so as to ensure acceptable conditions for a low traffic.

Modern lighting systems allow the integration of a telemanagement system that provides individual control of each street lamps. Light is thus provided where and when necessary, as each luminaire can be started, stopped the light intensity can be adjusted manually or according to preset programs.

The system allows real-time collection and analysis of information about lighting network status, while turning it into a smart city infrastructure. Management tools provided by the software offer a real-time map system, signals any change in the network, alerts about possible energy losses and offers advanced optimization procedures.

Communication between lamps and cabinet installed systems is done by two technologies: via power lines (Power Line Communication) or WiFi. For communications between the flashpoints of the public lighting system and application software any internet connection available locally can be used.

1.3.2. Retrofit solutions

Where limited financial resources do not allow redesigning the entire system of public lighting retrofit projects are an effective way to increase energy efficiency by maintaining the current quality of light.

The use of new and high luminous efficiency sources, notably through the introduction of LED technology instead of high pressure mercury or sodium vapor is becoming increasingly used.

For the most part, lamp posts in Romania were placed on poles with common use for bloth home networks and public lighting. These poles are located at a distance of 35-40 m between them and sometimes are more recessed from the street curb.

In this case changing lamps or luminaires do not always lead to compliance with the performance criteria corresponding to the classes of lighting which include that street. (luminance average Lmed (cd/m2), uniformity general U0min (%) = Lmin/Lmed, uniformity longitudinal U1min (%) = Lmin/Lmax, maximum physiology blindness Ti (%), compared to the above SR).

2. List of new technologies and solutions used

After determining the quality requirements for the identified type of street lighting and validating the chosen solution for achieving energy efficiency through retrofit solutions or new lighting system redesigned, it is necessary to establish the lighting technology to be used. Selecting appropriate lamps and luminaires will have a substantial effect on improving overall system efficiency, while reducing costs and energy consumption. As such, selecting two lighting technologies and using appropriate tools and software

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available to simulate design options and optimal quality solutions is an important step in the design of the lighting system.

Choosing classes of lighting depends on the following specific parameters: area (splitting directions, the density of

Most existing street lighting installations use one of these types of lamps: high-intensity discharge (HID), high pressure sodium (HPS), metal halide (MH) and mercury vapor lamps (MV).

HPS lamps are some of the solutions used in street lighting, due to the high efficiency and long life lamps. MH lamps often provide efficiency values equivalent to those of HPS, but have a lower life expectancy.

MV lamps have an outdated technology, but are still found in street lighting applications.

Choosing a technology for lighting lamps takes into account both the initial cost of investment and the life cycle costs of operation, maintenance, and replacement.

η luminous efficiency of a light source is the ratio of luminous flux Φ emitted by the source and power consumption of mains P by the light source.

$$\eta = \frac{\Phi}{P} = \frac{\int_{380nm}^{760nm} \phi_\lambda \cdot d\lambda}{\int_0^\infty p_\lambda \cdot d\lambda} \quad (2)$$

Luminous efficiency is an economic indicator of a light source.

For an ideal transformation of the power absorbed by a source that emits monochromatic light with a wavelength of 555.5 nm results a luminous efficacy η= 683 lm/W. In reality, the current artificial light sources have a much lower luminous efficiency [7-10]. In the table below are some examples.

Luminous efficiency of light sources has evolved over the years from the initial Edison lamp to the LED technology, as follows:

TABLE IV. LUMINOUS EFFICIENCY FOR VARIOUS LIGHT SOURCES

Light source	**Luminous efficiency lm/W**
Initial Edison lamp	1.4
The filament lamp	10 ··· 40
Halogen lamp	20 ··· 45
The fluorescent lamp	35 ··· 104
Lamp mercury vapor high pressure	37 ··· 63
Lamp high pressure sodium	54 ··· 153
Metal halide lamp	80 ··· 125
White LED	100··· 165

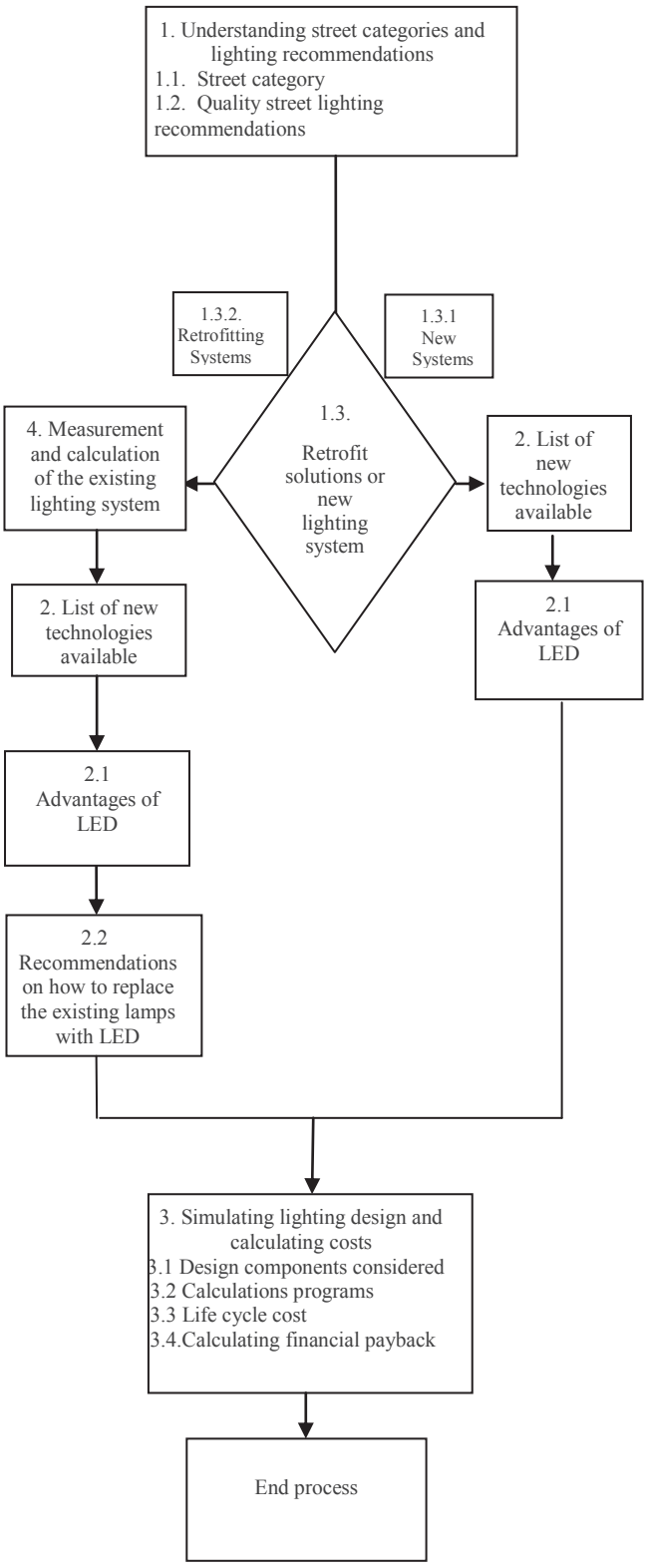


Fig. 2. Flowchart of steps required analysis system design energy efficient public lighting.

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2.1 Advantages of LED

On average luminaires with LEDs have the longest lifespan and tend to offer the highest efficiency, however, HPS lamps also offer relatively long lifetimes and good general efficiency system. As a result, both HPS and LED technologies have the potential to increase the energy efficiency of street lighting leading to reduced costs and energy consumption.

Dimming the LED

In order to reduce electricity consumption related to the lighting on some streets an optimization of the lighting system can be achieved by reducing light intensity (dimming) during the night, in low traffic hours in the figure.

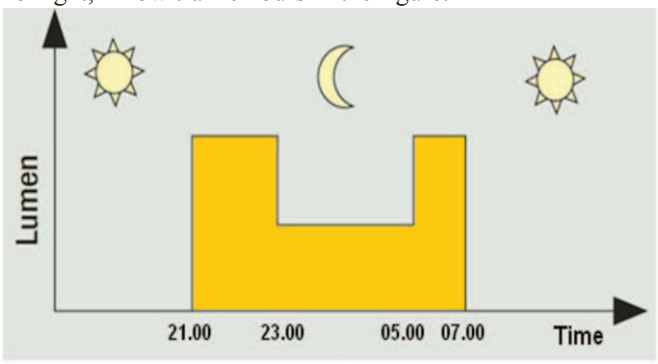


Fig. 3. Identified periods at night to reduce light intensity of the luminaire.

Basically in this period you can go to a class or two classes below illumination (from ME3a to ME4a and then ME5), but still respecting the lighting standards related to the new classes in which it was framed.

Reducing lighting to reduce overall consumption of electricity without the realization of traffic measurements beforehand leads to much higher costs due to additional accidents.

Through this optimization the amount of electricity used by the luminaire can be reduced by over 30% and thus reducing system cost and public lighting.

2.2 Recommendations on how to replace the existing lamps with LED

A rapid assessment, in case you choose retrofit solution to replace the existing fluorescent, mercury, sodium lamps or LED is presented below:

Existing Lighting Technology	Typical Wattage (W)	Average Efficacy (lm/W)	Estimated Downward Luminaire Light Output (lm) [1]	Recommended HPS Lamp Wattage [2]	Recommended LED Luminaire Wattage [3]
Fluorescent	40	80	2,080	35	30
Fluorescent	80	80	4,160	70	50
Mercury Vapor	50	45	1,463	35	30
Mercury Vapor	80	45	2,340	35	30
Mercury Vapor	125	45	3,656	70	45
Mercury Vapor	250	45	7,313	100	90
Mercury Vapor	400	45	11,700	150	140

Fig. 4. Powers recommended to change existing lighting lamps with sodium lamps or LED

Notes:

1. Estimated based on luminaire efficiency of 65%.
2. Estimated lamp based on contraceptive efficacy of 100 lm/W and luminaire efficiency of 70%; Shall the total wattage HPS luminaire consider losses power in control gear.
3. Estimated based on LED contraceptive efficacy of 100 lm/W and luminaire efficiency of 90%; Power losses already included in LED driver.

3. Simulating lighting design and calculating costs

3.1. Design components considered

Obtaining a desired lighting quality is largely dependent on the selected fixtures. However, their placement and configuration along the street, is of major importance for the layout, lighting and public safety [7].

List of key parameters to be taken into account by the designer to meet the lighting quality recommendations are:

- mounting height: the higher the mounting height the more light/power will be needed power to achieve a certain enlightenment, but there will be a better uniformity.
- layout: lighting poles can be placed unilaterally, bilaterally or bilateral alternating face-to-face, or axial.
- spacing: a greater distance between luminaires leads to lower lighting levels and uniformity decreases, however, the closeness leads to higher costs and it is not always practical.
- lamp type: these guidelines recommend the use of long-life and high efficiency HPS lamps or new light-emitting diodes (LED).
- fitting: the luminaire chosen must be suitable for the type of the chosen street and power.

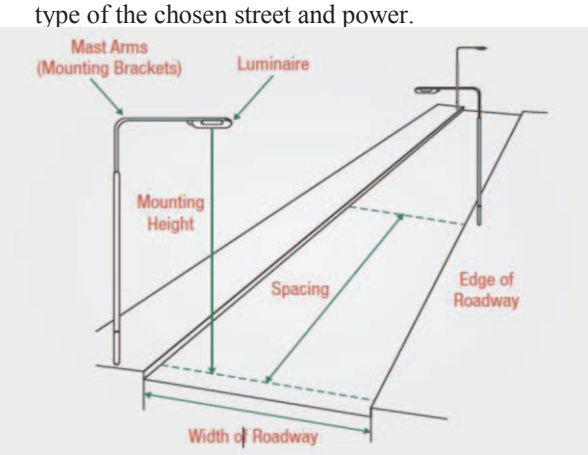


Fig. 5. Key parameters for street lighting technical projects.

3.2. Calculation Programs

To achieve the quick lighting calculations it is used a specialized software such as Dialux – a database that contains the main manufacturers of lighting fixtures. This is a free and complete software and is developed by DAL GmbH for professional light planning and is accessible to all manufacturers of lighting systems for calculating interior and exterior lighting [11].

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Following the identification of the lighting class as per previous requirements (general criteria, specific parameters, performance criteria), type of luminaire, the color temperature of it and how to locate the luminaire (height of installation, angle of the device, distance from the curb of the street) lighting technical calculations can be made.

Photometric results calculated using Dialux program based on input data will show that in the table below:

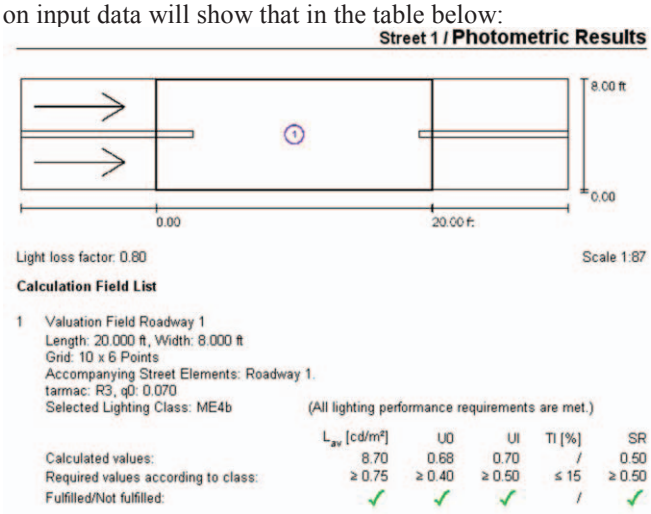


Fig. 6. The lighting results using Dialux.

3.3. Life cycle cost

Life cycle cost is a calculation that provides information on the total cost of a lighting system throughout its life (from purchase to replace).

The two main functions of the life cycle cost are to compare different lighting technologies (or other energy products) and to determine the effectiveness of the proper system selection cost.

A system that requires a smaller initial investment may use more energy (higher operating costs), requiring frequent cleaning luminaire (higher maintenance costs) and have a shorter lifespan (requires replacement). On the other hand, a system that requires a higher initial investment can cost much less over its life.

$$LCC = Cb + Cm + Ce + Cr - S \tag{3}$$

where:

- LCC is life cycle cost.
- Cb is cost to buy.
- Cm is cost to maintain it (if required for maintenance).
- Ce is cost of energy to run for his life.
- Cr is replacement costs.
- S is savings of energy.

The figure below shows a comparison between the frequency of replacement of HID and LED lamps. The operation of 50,000 hours of LED lamps will replace HID lamps 6 times:

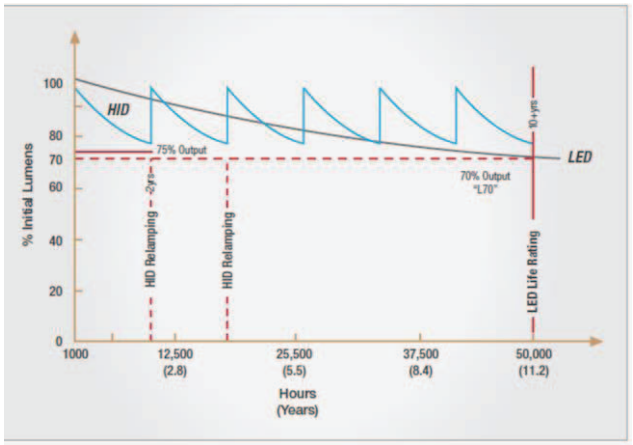


Fig. 7. Comparison of HID lamps and LED.

3.4. Calculating financial payback

Preliminary analysis of the amortization period can be achieved using the formula below:

$$Pf = Co / E\&M \tag{4}$$

where:

- Pf is payback in years.
- Co is the initial cost to retrofit or new system.
- E&M is annual energy savings and maintenance costs.

IV. CONCLUSION

Consumption of public lighting system in Romania represents about 1% of the total consumption of electricity.

The average power per fixture installed in the localities analyzed varies from a maximum of 199.98 W/luminaire to 133.32 W/luminaire with an estimated average 150W/ luminaire.

With reference to the total annual electricity consumption of the public lighting system in Romania for the year 2012 at an average power of 150 W/luminaire, we get the result of 1.115 million luminaires related lighting public lighting system in Romania.

For the increasing of the energy efficiency of public lighting system in Romania there are proposed two choices: the solution of redesigning the public lighting systems or the use of solutions for retrofit to replace lamps or luminaires and LED technology use.

By choosing any of the options outlined above and using LED lighting technology the power installed on the luminaire will decrease by up to 35% and thus the power consumption will be reduced accordingly.

In addition to reducing consumption by introducing LED technology on certain streets an optimization of the lighting system by reducing light intensity (dimming) can be achieved.

During the night, in low traffic hours the amount of electricity used by the luminaire can be reduced by over 30%.

Introducing LED technology together with dimming on certain streets can lead to a decrease in total public lighting consumption by over 40% a year from current levels.

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