IV ENGINEERING OF ENVIRONMENTAL ENERGY

ANALYSIS OF GHG REDUCTION POSSIBILITIES IN LATVIA BY IMPLEMENTING LED STREET LIGHTING TECHNOLOGIES

Ansis Avotins, Leonids Ribickis
Riga Technical University,
Institute of Industrial Electronics and Electrotechnics
ansis.avotins@rtu.lv

ABSTRACT

This manuscript deals with the EU policy in energy efficiency and CO2 emission reduction from the perspective of possible improvements in Latvia street lighting system. The paper also shows the results of examination of the existing situation, estimation of further street lighting development possibilities, and experimental measurements in real conditions.

Key words: street lighting, GHG emissions, solid-state lighting, energy efficiency

INTRODUCTION

Nowadays a demand for more energy efficient devices also in lighting industry is increasing, as there is a great potential for energy savings and CO2 emission reduction to contribute to the European Union (EU) Action Plan for energy efficiency, where the EU in 2008 adopted an integrated energy and climate change limitation policies to be implemented by 2020. With this policy it is intended to develop the sustainable and energy efficient economy of Europe with low carbon emissions, by implementing such events as greenhouse gas reduction by 20%, energy consumption reduction by 20% (or improving energy efficiency), 20% of the EU energy obtained from renewable sources. Street lighting systems have a high potential for improving the energy efficiency, which are identified as significant energy consumers, but they are needed for traffic and citizen safety and security.

Solid-state lighting still is a new technology for street lighting application and its main advantage is the ability to regulate light output in full range - from 0% to 100% with no photometric parameter changes, where conventional lighting with high intensity discharge (HID) lamps, could be regulated just from 50% to 100%, and can cause color shift and color rendering index (CRI), as well as significant drop of luminous efficiency (lm/W).

As a new technology LEDs still are in the development process, and the main obstacle for wider application of LED luminaries is the initial cost of LEDs, which tend to be much higher than HID sources. According to a DOE study, LED technology has been experiencing steady rates of improvement not only in efficiency (approximately 35% annually) but also in cost (approximately 20% annually). When looking at some economic aspects from the engineering - economic analysis done in (Azevedo et al., 2009), which indicates that white solid-state lighting already has a lower levelized annual cost (LAC) than incandescent bulbs, and will be lower than that of the most efficient fluorescent bulbs by the end of this decade.

To compare different illumination technologies with different lifetimes by economical means, a LAC should be compared rather than just the net present value.

$$LAC = I\frac{d}{(1-(1+d)^{-n})} + O\,\&\,M$$

where I is the initial capital investment in the lighting system, d is the discount rate, n is the number of the years of lifetime, and O&M is the expected annualized cost of operation and maintenance.

It indicates that countries with limited budget should be careful by planning investment in retrofitting the existing street lighting lanterns with high pressure sodium vapor (HPS) lamps to new solid-state lighting with light emitting diode (LED) technology, unless the retrofitting is technically and economically justified or subsidized with additional investments.

MATERIALS AND METHODS

Description of LED luminary

It is important to understand the main characteristics of LEDs in order to understand how to drive them properly. One of the LED characteristics is their colour, with very narrow band of wavelength, which determines the voltage drop across the LED, while it is operating. The current level determines the light output level, the higher the current, the higher the luminosity of a LED, and also the temperature. Due to production variations, the LED wavelength and thus also the voltage drop has variations, typically ±10 %

(Winder, 2008). As the temperature rises, the voltage drop reduces by ~2mV per degree. When operating LED at maximal parameters, small changes in voltage can make significant changes in the current value and possibly damage the LED, thus appropriate power supply must be used.

To obtain a correct value of CO2 emissions for street luminary, which is mainly obtained from the consumed electrical energy value, not only the light source efficacy (lm/W), but also the ballast and fixture efficiency (lm/W) should be taken into account, as they can significantly influence the total efficacy (lm/W). Also electromagnetic ballasts typically consume 10-15% more electrical energy than similar electronic ballasts.

Table 1

Efficacy of lighting devices and fixtures

Light source efficacy [lm/W]	Ballast efficiency [%]	Fixture efficiency [%]	Total efficacy [lm/W]
Incandescent 4 to 18 lm/W	100	40 - 90	2 -16 lm/W
Halogen 15 to 33 lm/W	100	40 - 90	6 - 30 lm/W
Fluorescent tubes 60 to 105 lm/W	65 - 95	40 - 90	16 - 90 lm/W
CFL 35 to 80 lm/W	65 - 95	40 - 90	9 - 68 lm/W
HID 14 to 140 lm/W	70 - 95	40 - 90	4 - 120 lm/W
White LED 60 to 188* lm/W	75 - 95	40 - 95	18 - 170 lm/W

*188 lm/W is a target for white LED at 2015 of US DOE

Table 1 shows a comparison of different light source luminaries, thus the total efficacy ranges differ from the light source efficacy (Azevedo et al., 2009).

Standards

Another important topic for public and street lighting luminaries is compliance with different local and EU standards, which help municipalities to avoid low quality products and ensure sustainable lighting. The compliance of LED luminaries to lighting class is very important for municipalities which manage the city lighting system. For LED luminaries there is no special standard of their performance, the parameters and norms defined in the existing standard EN 13201-2:2004, which includes recommendations from CEN and CIE, can be applied to choose an appropriate LED luminary.

These standards are recommendations, but some other standards or government rules can be mandatory for the municipalities in Latvia, like the road maintenance class. If, the road maintenance class defined by traffic intensity, is used for the choice of the lighting class, then combining it with EN 13201-2:2004 classes, Table 2 can be made.

Table 2

Lighting class vs road maintenance class in Latvia

Average traffic intensity (cars per day)	Municipality road **class**	Lighting class
above 5000	A	M1, M2, M3
from 1000 to 5000	A1	M1, M2, M3
from 500 to 1000	B	M1, M2, M3
from 100 to 500	C	M2, M3, M4, M5
below 100	D	M4, M5

Table 3

Lighting class, minimal luminance and recommended illuminance of road class

Lighting class	Minimal luminance, L_{min} (cd/m^2)	Minimal illuminance amount, E (lx)
M1	2,0	30
M2	1,5	20
M3	1,0	15
M4	0,75	10
M5	0,5	7,5

Most of the small municipalities are able to measure illuminance with a standard lux meter, and chose the appropriate values from Table 3.

Any LED driver circuit using the MOSFET switch connected to AC mains should meet the limited radiated, emitted and harmonic current emissions specified by the standard IEC/EN 61000-3-2. Within this standard the Class C corresponds to the lighting.

The conducted emission limits in the 150kHz to 30MHz frequency range are specified in the standard IEC/EN 61000-6-3 (covers 20MHz to 1GHz). The emission levels to meet the EN55022/CISPR22 Class B are 30dBμV/m in the frequency range 30MHz to 200MHz.

RESULTS AND DISCUSSION

Survey of lighting systems in Latvia

To obtain data about the existing situation in the lighting systems in Latvia, an intensive survey of 44 public lighting managing companies, agencies and Latvian municipalities was done by help of the Latvian Ministry of Environment.

The survey indicates that most lighting systems in Latvia have not been reconstructed since their installation date (some of them are more than 30 years old), most of the street lighting managing institutions (municipalities, agencies, private companies) in the survey admit that some part of their lighting system is in bad technical condition. Mostly it deals with old poles for luminaries, that have reached the end or are very close of their depreciation period, for materials like reinforced concrete, steel, wood, in average 35% of the system (see Fig.1.).

Also lots of cables are very old (see Fig.1.) and in bad condition, due to damaged isolations during road reconstructions and repairs.

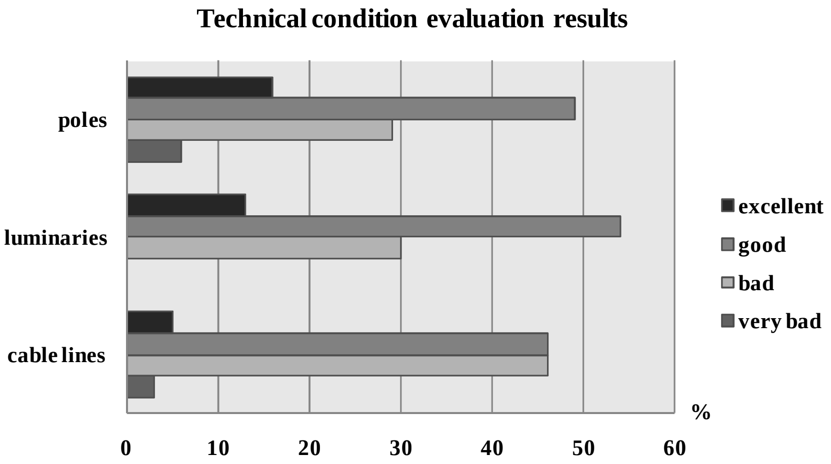

Figure 1. Overall technical condition of poles, luminaries and cable lines of lighting systems.

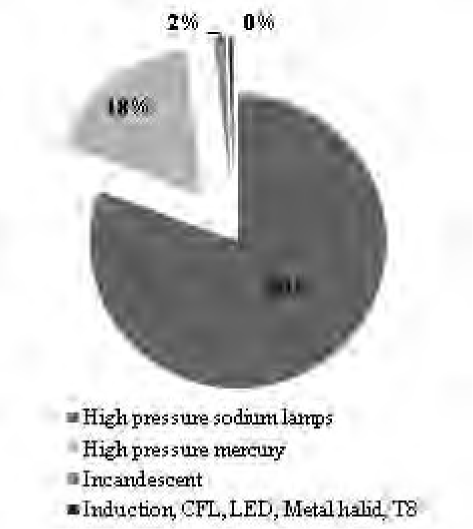

Figure 2. Total rated power versus light source used.

Implementation of power line communication for dimmable LED luminaries would be a challenge in this situation.

As the change of luminaries is the easiest way to reduce the energy consumption, most of the managing institutions of lighting systems, are in the process to change or already have changed old luminaries with mercury vapour lamps to luminaries with High Pressure Sodium (HPS) vapour lamps, thus admitting in the survey, 33% (see Fig.1.) of the luminaries to be in a bad technical condition in an average lighting system. The payoff of investment (change to HPS) will be reached in the next 2-4 years, depending on the system operating hours per year, giving the time and opportunity to develop intelligent power LED luminary. From the survey data the total rated power of luminaries installed at the lighting systems in Latvia is 12,148 MW, which is calculated from the indicated light source technology, capacity and number at the survey questionnaires. Fig.2. shows the percentage of the total rated power of the installed light source technologies. It is obvious that the HPS lamps dominate at street lighting systems, as it is still one of the most efficient light sources, but surprising is that there still are 18% of mercury vapour lamps and even incandescent lamp light sources, and that gives a great opportunity to change these 19% to LED technology luminaries, as the retrofitting investment payoff would be more cost-effective, than retrofitting HPS lamps with LEDs.

As it can be seen from Table 4, the total costs and energy consumption from 2008 to 2009 has decreased, despite the continuously growing electricity rates.

Table 4

Total power of lighting installations and costs

		Latvia Total	Riga	Other cities
Power of lighting installations		MW	MW	MW
Total power of light installations	2008	13,543	7,3	6,243
	2009	13,757	7,2	6,557
Consumption of electrical energy		MWh per year	MWh per year	MWh per year
Electrical energy consumed	2008	46 228	28 203	18 025
	2009	36 497	21 966	14 532
Costs		10^6 LVL per year	10^6 LVL per year	10^6 LVL per year
Consumed electrical energy	2008	2,706	1,410	1,055
	2009	2,136	1,286	0,851
Annual O&M *excluding* energy consumption	LVL	1,958	1,014	0,944
Annual O&M costs *including* energy consumption	LVL**	4,095	2,300	1,795

Table 5

Results of calculation of CO_2 savings

Retrofitting Scenario Description	Average rated power per lamp	lamp count	Electrical energy savings	CO2 savings per year (0,397)	Electrical energy savings per lifetime	CO2 savings per lifetime (0,397)
	W	pc.	MWh/year	t/year	MWh/life	t/life
Incandescent	133	1 196	0	0	0	0
LED w/o dimming	27	1 196	534	212	10 626	4 218
LED + dimming	27	1 196	590	234	11 734	4 658
HME	239	9 069	0	0	0	0
LED w/o dimming	70	9 069	6 478	2 572	128 915	51 179
LED + dimming	70	9 069	7 573	3 006	150 702	59 829
HPS	137	72 568	0	0	0	0
LED w/o dimming	70	72 568	20 363	8 084	405 216	160 871
LED + dimming	70	72 568	29 123	11 562	579 553	230 083
Total possible savings w/o dimming			27 375	10 868	544 756	216 268
Total possible savings with dimming			37 286	14 803	741 990	294 570

It was possible due to the implemented “light saving” measures, like turning off the lighting at night hours due to mechanical timer, turning off two phases, where both methods are not preferable as no light would be available, or changing to more effective lamps or luminaries, where the survey indicates that it was the best method for most of the managing institutions of the lighting systems.

Calculation of possible CO_2 savings

The Latvian lighting systems have present luminaries with incandescent lamps, high pressure mercury lamps (HME), high pressure sodium lamps with very wide range of rated power of lamps, so more than one retrofitting scenario is possible.

To calculate the potential CO_2 savings of retrofitting the existing light souces to LEDs, an average rated power per lamp light source type is calculated, and according to the survey data, totally 1196 incandescent lamps are installed with the average rated power 132,9W per lamp, and the total rated power 158,94kW, as these lamps are mainly installed in parks and decorative lighting, where the pole height is around 6m, an appropriate average LED lamp of 27W can be used to reach similar luminous output. Also 9069 HME lamps, with the average rated power of 239,44W per lamp, are available and the total rated power is 2171,5kW and an appropriate LED lamp would be 70W (average value).

The total number of HPS lamps is 72568, with the average rated power of 136,56W and the total rated power of 9909kW and an appropriate LED lamp would be 70W (average value). For calculations it is assumed, that the lighting system is working 11 hours daily, but when using dimming 4 hours have 100% of light output, 1 hour - 70% and 6 hours - 30% of light output.

According to the method for calculation of GHG emissions from the Latvian Ministry of Environment, 1MWh = 0.397 t CO_2 GHG emissions, when saving electrical energy.

On-site optical measurements of LED luminaries

Nowadays at the market lots of simple LED (without embedded dimming capability) luminaries are already available, but the technical data about the optical and electrical properties are mostly not full, or little technical info, as it is the result of aggressive marketing strategy. To compare production variations and specified optical parameters of several LED luminaries available on the market, on-site testing was done with the method, which can be repeated by every municipality with an ordinary luxmeter.

In order to evaluate the illumination level of the street more accurately, LED luminaries were placed in series, as shown in Fig.3, where HPS luminary is equipped with a 250 W high-pressure sodium vapor bulb. The selected layout allows switching off HPS luminaries, thus the illumination measurements are not affected by adjacent luminaries. The measurements are performed by Hagner "EC-1" luxmeter, (lx 0.1-200000 range, and accuracy +/- 3% (+/- digit).

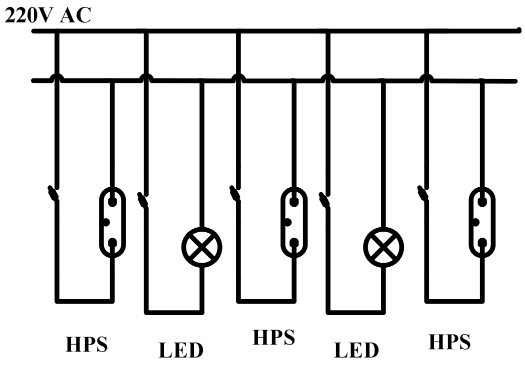

Figure 3. On-site luminary layout..

The experimental street lane is typical M3-M4 class, with the width of 12 m, pole height of 8-10 m. The distance between the poles typically is around 30-35m. Thus according to the measurement method described in the CIE standards, a measurement point of 2x2m intersection was selected, and accordingly the lux value measured. The obtained data are shown in Figure 4, where the darkest color represents the value close to 0 lux and lighter color – closer to 20 lux, an exception is LED 2, LED 7 and LED 8, where the central grey dots represent 40-50 lux. From the obtained graphs the optical properties can be evaluated and compared with HPS luminary. As it can be seen, LED 1, LED 3-5 does not meet the requirements to replace the HPS 150W luminary, but it shows better uniformity, thus it allows to place these luminaries in parks or places where the poles are less than 6 m high. LED 6-8 are supposed for different distances between the poles and lane widths, so to get better uniformity, a careful selection must be done.

Electrical parameter measurements of LED luminaries

Also electrical properties are mostly unclearly described in the LED luminary technical datasheet, not telling if the active power value includes the power supply consumption and losses. To evaluate the electrical properties of LED luminaries, LED1-8 was tested, where LED9 is floodlight, which optical performance is not comparable with HPS streetlamps.

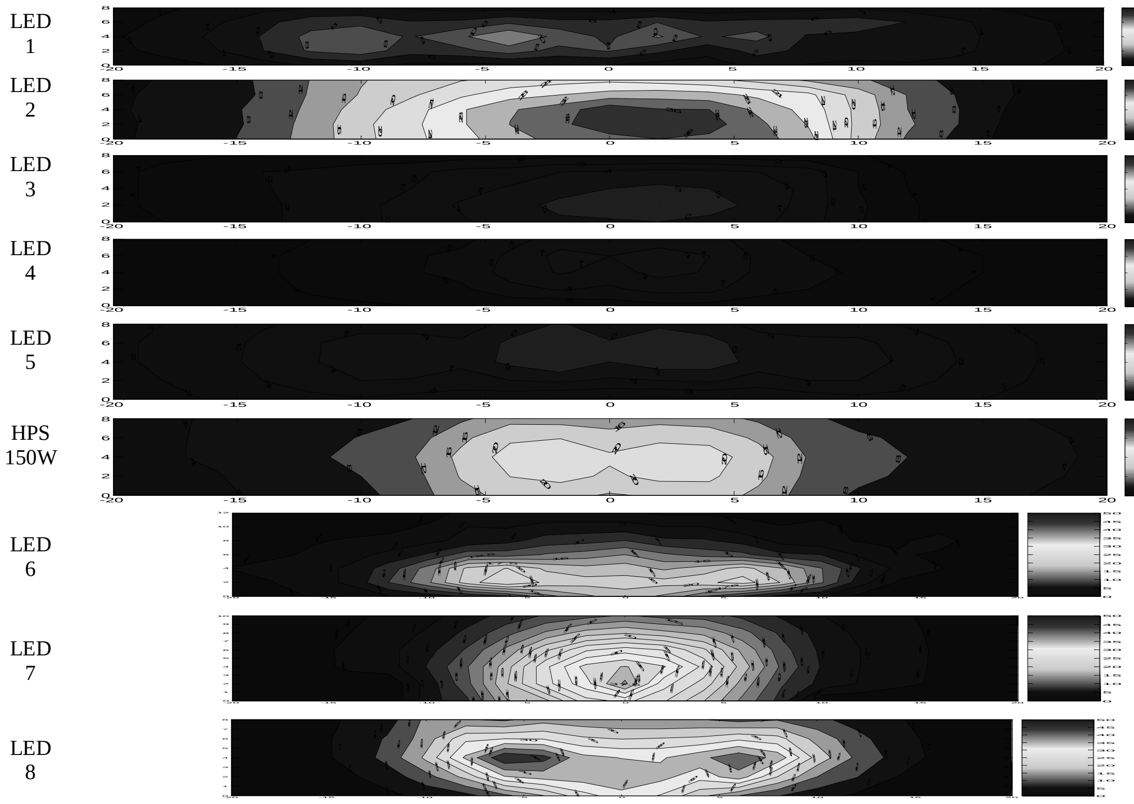

Figure 4. Comparison of different LED luminary photometrical performance at ~ 45 lux scale.

Table 6

Comparison of different LED luminary electrical parameters

Parameter Luminary	U [V]	I [mA]	P [W]	$\phi 1$	cos(ϕ1)	I1 [mA]	THDi [%]	S [VA]	Q [var]
LED1 50W	225	390	51	19	0.95	240	128	87.2	70.7
LED2 225W	224	1020	221	12	0.98	1010	16	228.4	57.6
LED3 35W	225	170	35	21	0.93	160	17	38.2	15.2
LED4 25W	225	110	25	-3	1.00	110	29	26	7
LED5 50W	228	210	47	14	0.97	210	26	50	17
LED6 140W	221	683	150	3.7	0.998	679	11.2	151.3	19.5
LED7 112W	222	564	124	0.75	0.999	561	10.9	125.3	13.7
LED8 84W	221	489	107	2.59	0.999	486	11.9	108.3	13.7
LED9 24W	216	114	24	11.3	0.98	112	15.3	24.6	6.1
HPS 400W	225	1730	369	-14	0.97	1670	28	395	141
HPS 150W	226	780	165	-18	0.95	770	20	176	63

$$Q = U_{rms} \times I_{rms} \times \sin(\varphi_1) \quad (1)$$

$$S^2 = P^2 + Q^2 \quad (2)$$

$$S = \frac{P\sqrt{1+\mathrm{THD}^2}}{\cos\varphi_1} \quad (3)$$

The TrueRMS or instantaneous current and voltage values were measured experimentally, and other electrical parameters were calculated in MATLAB using formulas 1-3, and as the supply voltage distortion is negligible, it was considered that the voltage waveform is sinusoidal. Thus the results are shown in Table 6.

CONCLUSIONS

The survey also shows that a simple HME luminary change can be economically justified also changing them directly to LED luminary, thus increasing the CO2 emission savings.

All of the tested LED luminaries have passed the electrical quality requirements for cos$f$, but one of them has efficiency problems with THD, reactive power, and two - compliance with the optical performance requirements for ME2-ME3 class streets. The measurement results show that LED luminaries can replace the existing HPS and HME, but due to the high price, it needs additional political or financial support.

REFERENCES

Azevedo Lima I., Morgan Granger M., Morgan F. (2009) The Transition to Solid-State Lighting. *Proceedings of the IEEE*, Vol. 97, No. 3, p. 481-510.

Winder S. (2008) *Power supplies for LED driving*. Elsevier.