Publication VI

Anne-Mari Ylinen, Grega Bizjak, Marjukka Puolakka, and Liisa Halonen. 2011. Road lighting practices and energy-efficiency – Slovenia and Finland. Ingineria Iluminatului - Lighting Engineering, volume 13, number 1, pages 29-44.

ROAD LIGHTING PRACTICES AND ENERGY-EFFICIENCY – SLOVENIA AND FINLAND

Anne-Mari YLINEN[1], Grega BIZJAK[2], Marjukka PUOLAKKA[1], Liisa HALONEN[1]
[1]Aalto University, School of Science and Technology, Finland
[2]University of Ljubljana Faculty of Electrical Engineering, Slovenia

Abstract. *Road lighting practices vary from one country to another. In this study road lighting regulations and laws, used technology and energy efficiency, and experiences of efficient technology in Slovenia and Finland is studied. Despite the differences between both countries, the state of the road lighting and the adopted practices are quite similar. Road lighting regulations are based on European standard EN 13201 in both countries. Slovenia has also adopted a Decree on Limit Values due to Light Pollution of Environment. In both countries the old installations with high pressure mercury lamps are still in use to great extent. For new installations mainly high pressure sodium lamps are used and in both countries first test installations of LED luminaires are in operation. Both Slovenia and Finland need to replace the high pressure mercury lamps in next years due to the ban on this lighting source by Ecodesign Directive. As a consequence, approximately 30% of the electrical energy used for road lighting will be saved. The estimated energy saving potential of 30% can also be used for whole European Union and modernization of road lighting would reduce the use of electrical energy in European Union by 10,500 GWh yearly which means also 4.7 Mt less of CO_2 emissions each year.*

Keywords: road lighting, energy consumption, energy saving

1 Introduction

The purpose of road lighting is to make people, vehicles and objects on the road visible without causing discomfort to the driver. Around 30% of the all the road accidents occur during the dark hours. Further, the accident risk is around 1.5 … 3 times greater during the night than during the day time. However, the traffic during the dark hours is around 30% of the daily traffic. Generally, road lighting reduces the accidents by approximately 30% [1].

On the other hand, road lighting is also a large consumer of electrical energy. According to available data around 1.3% of the total produced electrical energy is used for road lighting in European Union (EU) [2]. To reduce the energy use in lighting, the European Parliament and the European Commission adopted different Directives and Commission Regulations in this field.

But the question is, can these documents really bring energy savings connected with road lighting in all EU member countries in spite of their different practice on this field and very different climatic conditions. To answer to this question and to find out how large the energy savings in the road lighting could be, we compared the road lighting practice in two different EU countries: Finland and Slovenia. Finland represents the extreme conditions for the road lighting with two distinctive seasons: light and dark, and large number of days when roads are wet or snowy. Slovenia is somehow close to the European average with different climatic regions from Mediterranean to continental and Alpine. The countries have also rather different history which might be reflected in the road lighting installations as their live-span is 30 years and more.

According to the Slovenian regulations for road planning [3], [4] the road lighting needs to be installed on roads in settlements (urban areas), on brunches and crossroads of major roads outside the settlements, on bus stops, on pedestrian crossings and on sidewalks near them, on gas stations, rest areas and parking lots. The main purpose of the lighting is to assure traffic safety for the road users as well as to decrease the crime rate in residential areas.

The total length of roads in Slovenia is 38,500 km, of which 4,800 km are state owned and the rest belongs to municipalities. The length of the illuminated roads is not known but it is estimated that there are approximately 200,000 road lighting luminaires installed in Slovenia. The road lighting outside the settlements is in competence of State (Slovenian Road Agency) and for the one in the urban areas the Municipalities needs to take care of. That includes also the financing of maintenance and energy costs. After the independence of Slovenia in 1991, a large number of new and rather small municipalities were established. As their budget is not very high and there are a lot of problems they need to take care of, the road lighting was mostly put behind. The installations in city municipalities are newer but in many rural municipalities very old installations with high pressure mercury lamps are not only still in use, but also represent the majority. Consequently, the average energy use for road lighting in Slovenia is rather high. According to data collected in 2008 [5], the annual electrical energy for lighting the roads is 165.2 GWh or more than 84 kWh per capita. Taking into account that average CO_2 emission for production of electrical energy in Slovenia is 530 g CO_2/kWh [6], the contribution of road lighting to the green house emissions is 87,600 tons of CO_2.

According to Finnish law [7] the Finnish Transport Agency is responsible for giving the technical guidelines of roadways. The Finnish Transport Agency is a government agency operating under the jurisdiction of the Ministry of Transport and Communications and it is responsible for the maintenance and development of the transport system overseen by the government. The Finnish Transport Agency is mainly responsible for road lighting installations on highways, main roads, regional roads and connecting roads when lighting is needed for road safety or other lighting issues of the area. The road lighting can also be installed in cooperation with the municipality or the municipality can install lighting at its own cost. The installation of road lighting is based on cost-effective transportation economics [8]. Lighting is installed to high traffic flow roads where the benefit-cost ratio is at least two. In addition road lighting is always installed to tunnels, ferry berths, movable bridges and border stations [8].

In Finland, there are over 78.000 km of roads maintained by the Finnish Transport Agency of which 16% are illuminated. There are also around 26,.000 km municipality maintained roads and approximately 18 000 km of pedestrian and bicycle ways. In addition there are several hundred thousand kilometers of private and forest roads. The estimated amount of outdoor luminaires in Finland is 1.29 million, of which 50% are high pressure mercury luminaires and 45% high pressure sodium luminaires [9]. The rest are metal halide, low pressure sodium, fluorescent lamp or induction lamp luminaires.

The annual electricity consumption in Finland was 80.8 TWh in 2009 [10]. The estimated annual electricity consumption in outdoor lighting in Finland is 800 GWh [9], which is around 1% of the total electricity consumption. The average CO_2 emission for electricity production in Finland is 200 g CO_2/kWh [11]. Thus, the calculated average green house gas emissions for outdoor lighting is 160,000 t CO_2/a.

2 Road Lighting Design – Recommendations, Laws and Practices

Road lighting design, practices and recommendations vary in detail from one country to another. Road lighting design, calculations and measurements in Europe are based on technical report EN 13201:1 [12] and the standards EN 13201:2-4 [13], [14], [15] prepared by the European Committee for Standardization (CEN). The recommendations of the standard EN 13201:2-4 have been interpreted in different manners in different countries. Hence, some differences exist among road lighting recommendations between Slovenia and Finland.

2.1 Recommendations, Laws and Practices in Slovenia

The planning of road lighting is mostly done by the electrical engineers and based on the Recommendations for road lighting published by Slovenian Road Agency and Lighting Engineering Society of Slovenia [16]. The recommendations are based on European standard EN 13201, CIE documents concerning road lighting and some modern standards for road lighting from other countries. The use of recommendations as well as the use of adopted EU standard SIST (Slovenian Institute for Standardization) EN 13201:2-4 is not mandatory. The lighting classes listed in recommendations [16] are very similar to the ones in CIE 115:2010 [17] or EN 13201 [13]. The main classes are M for roads mainly used for motorized traffic, P for pedestrian areas and C for conflict areas. From 6 basic M classes (Table I) two (M3 and M4) are additionally divided into M3a, M3b, M3c and M4a, M4b but the changes are only in longitudinal uniformity U_l.

In the annex C of the recommendations also MEW classes (from 1 to 5) are listed for which the requests include the minimal values for U_0 for wet surface. These classes are listed only informatively and remarked as used only in climatic areas where roads are wet most of the time. They are not intended for use in Slovenia.

Table 1 Requests for M lighting classes from Slovenian recommendations.

CLASS	LUMINANCE OF THE ROAD SURFACE OF THE CARRIAGEWAY			DISABILITY GLARE	LIGHTING OF SURROUNDINGS
	L_m cd/m^2, min	U_0 min	U_l min	TI % max	SR min
M1	2.0	0.4	0.7	10	0.5
M2	1.5	0.4	0.7	10	0.5
M3a	1.0	0.4	0.7	15	0.5
M3b	1.0	0.4	0.6	15	0.5
M3c	1.0	0.4	0.5	15	0.5
M4a	0.75	0.4	0.6	15	0.5
M4b	0.75	0.4	0.5	15	0.5
M5	0.5	0.35	0.4	15	0.5
M6	0.3	0.35	0.4	15	-

According to the measurements [18], [19] most of recent projects are in line with EN 13201 which is not the case with older installations. Where high pressure mercury lamps (HPM) are still in use, the values of luminances or illuminances are mostly too low although the uniformity is good. Measurements show luminance below 0.5 cd/m^2 on roads of classes M4 or even M3. On the other hand, where old luminaires with HPM lamps were replaced by new ones with high pressure sodium (HPS) lamps, the values of luminances or illuminances are mostly too high. They can reach more than two times the recommended value. Measurements show up to 1.9 cd/m^2 on roads of M3 and M4 classes.

In year 2007, the Government of Slovenia adopted also a Decree on Limit Values due to Light Pollution of Environment [20]. The aim of the decree is to protect the living premises from the light trespassing, to reduce the energy used for outdoor lighting and also to limit the influence of the outdoor lighting installations on environment protecting so the nocturnal animals and dark sky. In the field of public street lighting, the decree regulates maximum allowed electrical energy consumption per capita and per year. The allowed per capita amount of energy consumption for street lighting managed by municipalities is yearly 44.5 kWh and additional 5.5 kWh are allowed for lighting of state roads and motorways. Besides that, only the properly mounted luminaires with ULOR (Upward Light Output Ratio) equal zero are allowed. The exceptions are luminaires used in areas protected as cultural monuments (e.g. old city centres), where ULOR<5% is allowed if power of the lamp is less than 20 W and if the illuminance on the ground is less than 2 lx. Also, luminaires which are part of the protected cultural monuments (e.g. old bridges) are allowed if the power of the lamp is less than 20 W. The decree demands that the energy consumption needs to be adapted and all inappropriate luminaires need to be replaced by the end of 2016.

2.2 Recommendations, Laws and Practices in Finland

Road lighting design guidelines and photometric requirements are given in Finnish Road Administration publication Tievalaistuksen suunnittelu [21]. The publication gives photometric requirements to traffic roads of motorized vehicles for medium to high driving speeds as well as for non-motorized ways. Also, recommendations for other road areas such as residential roads, roundabouts, road intersections of some complexity, pedestrian streets and cycle ways, other road areas lying separately or along the carriageway, and etc areas are given. Furthermore, the publication gives guidelines for selection of lighting classes appropriate for the case and layout design of the lighting fixtures for different types or road ways and conflict areas.

Finnish road lighting classes and photometric requirements are based on the European standard EN 13201:2-4 [13]-[15]. The AL lighting classes (Table II) are intended for motorized traffic roads of medium to high speed (at least 50 km/h). The road lighting design is done using standard reflection table R2 for dry roads and W3 for wet surfaces. However, if the road lighting design is made using only dry road surface reflection, ME1, ME2, ME3a, ME4a and ME5 of EN 13201:2 must be used.

The AL classes are similar to MEW series in EN 13201:2 with few additions. Class MEW4 is split into two classes AL4a and AL4b, where the former has average luminance requirement of 1.0 cd/m^2. The longitudinal uniformity requirements for classes MEW4 and MEW5 are given a value of 0.4 and the overall uniformity in MEW5 is raised from 0.35 to 0.4.

Finnish AE lighting classes that are intended for drivers of motorized vehicles and other road users on conflict areas such as intersections and roundabouts, correspond to CE-series in EN 13201:2. Also A-, ES-, and EV- series in EN 13201:2 are used as they are. The K-class corresponds to S-series in EN 13201:2 with the exception that class S7 is not used.

According to Finnish road lighting recommendations the average road surface luminance varies between 0.5 cd/m^2 - 2 cd/m^2.

Table 2 Finnish AL lighting classes for the motorized vehicles on traffic roads.

CLASS	LUMINANCE OF THE ROAD SURFACE OF THE CARRIAGEWAY FOR THE DRY AND WET ROAD SURFACE CONDITION				DISABILITY GLARE	LIGHTING OF SURROUNDIN GS
	Dry condition			Wet condition		
	L_m cd/m^2, min	U_0 min	U_l min	U_0 min	TI % max	SR min
AL1	2.0	0.4	0.6	0.15	10	0.5
AL2	1.5	0.4	0.6	0.15	10	0.5
AL3	1.0	0.4	0.6	0.15	15	0.5
AL4a	1.0	0.4	0.4	0.15	15	0.5
AL4b	0.75	0.4	0.4	0.15	15	0.5
AL5	0.5	0.4	0.4	0.15	15	0.5

The measurements made in the Aalto University Lighting Unit [22]-[24] indicate that average road surface luminance levels for dry road surfaces vary from approximately 0.2 cd/m^2 for poorly illuminated residential streets outside the urban area to around 3 cd/m^2 for better illuminated highways.

Different weather conditions affect the average road surface luminance significantly. For wet road surfaces the luminance levels could be over ten times higher and for snowy conditions up to five times higher compared to dry road surfaces.

3 Road Lighting Technology and Energy Figures

Outdoor lighting consumes a lot of energy and many of the major highways and residential streets are illuminated. The road lighting luminaires are long lasting and therefore many luminaires use old, outdated and inefficient technology. Also, different practices are used to select the luminaires.

3.1 Road lighting Technology and Energy Figures in Slovenia

As part of the former Yugoslavia, Slovenia had well developed lighting industry. The main producer of the road luminaires was Elektrokovina (later bought by Siteco). The most popular luminaire for road lighting was model CD and for the pedestrian areas mostly models UD and UE were used. CD luminaires were originally equipped with one high pressure mercury (HPM) lamp of 250 W or 400 W. There are still a lot of these luminaires along Slovenian roads but most of the ones, placed along state roads, were later refurbished with high pressure sodium (HPS) lamps with 150 W or 250 W. UD and UE models were originally equipped with two 125 W HPM lamps and just few of them were later refurbished with 70 W HPS lamps. More recent road lighting luminaire from the same company is model CX which comes in two sizes and is mostly used with HPS lamps. Most of the road lighting installations built in the last 15 years are made using these luminaires. In the years before the decree was adopted, also luminaires with compact fluorescent lamps (CFL) like Altra from Schréder or Axial from Philips became very popular for pedestrian areas.

Although the linear fluorescent lamps were never used for outdoor lighting in Slovenia the compact ones like Osram Dulux became very popular for pedestrian areas in last 15 years. They provide low cost high efficient solution with white light and good colour rendering. The lighting planners and municipalities are aware of the problems connected with the low surrounding temperatures, especially with the efficiency drop, but the winters in Slovenia are not as hard as in Finland. As this lamps are used only for street and pedestrian area lighting and not for road lighting this problem is not so critical. Anyhow in last years more and more low power metal halide (MH) lamps are used instead.

In some cities the municipalities renewed the road lighting during past years so modern and economic luminaires are currently in use. The light sources are mostly HST lamps for roads and CFL lamps for residential and pedestrian areas.

In such city-municipalities the average energy consumption per capita is usually around the limit of 44.5 kWh/capita set in the decree.

But in many (rural) municipalities rather old luminaires are still in use. Some are even older than 40 years. Although some of these old luminaires are equipped with HPS lamps, in most of them HPM lamps are still in use. For lighting of major roads mostly luminaires with HPM or HPS lamps with high electrical power of 400 W or 250 W are used. For lighting of streets in residential areas smaller luminaires are used and are mostly equipped with one or two HPM lamps with electrical power of 125 W.

In all older luminaires as well as in many new ones with HPS lamps electromagnetic ballasts are used. Electronic ballasts are mostly used with CFL lamps and where dimming is planed.

To show the differences, some data for two municipalities are listed in the Table IV below. Ljubljana is a capital of Slovenia and Medvode is a small town with rather large rural background.

Both cities are trying to reduce the energy consumption in last years by replacing the old luminaires with new ones. On roads the luminaires with HPS lamps are used but for pedestrian areas a white light is preferred so metal halide (MH) lamps or compact fluorescent (CFL) lamps are used. As can be seen from the data in Ljubljana, very few HPM lamps are still in use. In Medvode, the process of replacement is slower although in last two years 185 new lamps (36 W CFL lamps) were installed instead of older, mostly HPM lamps reducing so the electrical power of street lighting by 33.5 kW.

Table 3 Lamp numbers, energy consumption and greenhouse gas emissions of Ljubljana and Medvode in Slovenia.

	Ljubljana	Medvode
number of residents	276,091	15,068
number of lamps	33,237	1,280
number of HPM lamps	1,074 (3%)	234 (18%)
number of HPS lamps	15,407 (46%)	778 (61%)
number of MH lamps	2,537 (8%)	6 (0%)
number of CFL lamps	14,219 (43%)	262 (21%)
installed electrical power of road lighting, kW	3,824	320
annual burning hours of lamps	4,000	4,000
annual energy consumption of road lighting, GWh	15.3	1.3
annual emission of CO_2, t	8,114	677.6
electricity price, €/kWh	0.108	0.113

3.2 Road lighting Technology and Energy Figures in Finland

In Finland, the Finnish Transport Agency owns the lighting on highways and main roads. On regional roads and connecting roads the Finnish Transport Agency owns the lighting if it considers the lighting necessary. Otherwise the municipalities own the lighting. [8]

In Finland, the luminaires on roads maintained by Finnish Transport Agency could be over 30 years old. Over 20 years old street lighting luminaires are checked and the renovation needs are estimated [8]. The older luminaires were provided by several different manufactures for example

Idman (later bought by Philips), Siemens, Philips, Asea Skandia, Orno and Fresta [25]. The light distribution and the maintainability performance of luminaires must be type approved by the Finnish Transport Agency [26]. Thus, the new luminaires are provided by for example Philips, Siteco and Schréder [27]. Municipalities are not required to use the type approved luminaires for the installations they make at own cost, although, mostly they follow the instructions given by the Finnish Transport Agency. For example in Espoo [28] around 50% of the road and pedestrian way lighting luminaires are manufactured before 1990. Half of the luminaires are produced by Idman and the other half with equal shares by Siteco and Elektroskandia. The newer luminaires are produced by Philips (40%), Siteco (40%) and Schréder (20%). The new park luminaires are induction lamp luminaires (99%) provided by Luis Poulsen. There are also many luminaires as old as 60 years in suburban areas in Espoo.

In Finland, the estimated amount of high pressure mercury (HPM) luminaires is 51% of all the outdoor luminaires. The most common wattage is 125 W. High pressure sodium (HPS) lamp luminaires are used 45% of all the outdoor lighting and the most common wattages are 70 W and 150 W. The rest consist of low pressure sodium, metal halide (MH), induction and florescent lamp luminaires. [9]

The used ballasts are mainly magnetic in Finland. The electronic ballast are used in LED luminaires and in induction lamp luminaires.

Table 5 show the differences for two municipalities in Finland. Espoo is the second biggest town in Finland located in the south coast next to capital city Helsinki and Kerava is located around 30 km north of Helsinki.

For energy saving reasons the use of outdoor lighting has been reduced in Espoo and Kerava. Turning off every other luminaire has been used in both cities despite the fact that luminance uniformities are not satisfied. Espoo has also turned off all the luminaires in the summer time.

Table 4 Lamp numbers, energy consumption and greenhouse gas emissions of Espoo and Kerava in Finland

	Espoo	Kerava
number of residents	244,330	33,785
number of lamps	48,200	7,673
number of HPM lamps	10,000 (20.7%)	4,900 (63.9%)
number of HPS lamps	15,407 (66.4%)	2,500 (32.6%)
number of MH lamps	200 (0.4%)	247 (3.2%)
number of other lamps	6,000 (12.4%)	26 (0.3%)
installed electrical power of road lighting, kW	7,000	975
annual burning hours of lamps	3,900	4,000
annual energy consumption of road lighting, GWh	27.3	3.9
annual emission of CO_2, t	5,460	779
electricity price, €/kWh	0.061	0.045

Most of the few complaints from residents considered broken lamps when there were longer lightless sections rather than switching off every other or all the luminaires. Also centralized power reduction has been used in some areas in Espoo. Dimming and switching off every other luminaire is done between 10 pm and 6 am, when the traffic is low. The uniformity requirements are an issue especially during the winter time, when the day is short and dark nights are long. Dimming would be better solution to reduce the power consumption and still satisfy the uniformity requirements.

4 Experiences of Efficient Technology

The Ecodesign Directive will phase out inefficient high pressure mercury lamps used in road lighting by the end of 2015. Energy efficient lighting technologies that could reduce energy consumption already exists and efficient solutions in Slovenia and Finland are already in use.

4.1 Experiences of Efficient Technology in Slovenia

In Slovenia already years ago, in many luminaires high pressure mercury (HPM) lamps were replaced with high pressure sodium (HPS) lamps together with ballasts along major (State) roads. Although the achieved energy savings were considerable the main reason for the replacement was to achieve better lighting conditions. After the energy prices become higher, some municipalities found out that with the investment in road lighting considerable savings in energy (and money) can be achieved. The typical example is city Celje, where with replacement of all 4080 luminaires the energy consumption was reduced from 3706.7 MWh down to 1801.7 MWh [29]. Other possibilities were also considered and used by some municipalities like:

- replacement of HPM lamps with hybrid HPS lamps where replacement of ballast is not needed;
- replacement of residential area luminaires with HPM lamps with luminaires using CFL lamps.

After the adoption of the Decree on Limit Values due to Light Pollution of Environment the municipalities are forced to replace the old luminaires with new ones as the old ones do not comply with the requirements of the decree anymore. For the road lighting, practically only luminaires with HPS lamps are used and for the street lighting in residential areas luminaires with CFL lamps, but also with metal halide (MH) lamps are used. In last year also some luminaires with LEDs were installed, mostly for testing purposes.

In most cases the municipalities just replace the old luminaires with new ones on the same poles. As indicated in examples from Ljubljana and Medvode, HPS and CFL lamps are mostly used. Beside this option some municipalities also try to reduce the energy consumption with measures like:

- reduction of voltage and so also the reduction of energy used;
- use of two-step regulation ballasts to reduce the luminance and power consumption in night time;
- switching off the lighting in night time.

One possibility is also introduction of control systems. This option was considered in last year in some of Slovenian city municipalities and at least in Ljubljana some test installations are already in operation. But we can expect that regulation of luminous flux (dimming) will not be widely used in Slovenia. Due to Decree municipalities need to change practically all the luminaires in next years and due to lack of funds the luminaires are changed on one to one basis. With new luminaires old installations are still in use and in most cases they do not enable use of control systems or even a step reduction of luminous flux in a night time.

As most of the saving measures bring also better lighting conditions, they are well accepted by the citizens. There were some complaints about yellowish light and poor colour rendering after replacement of HPM with HPS lamps. That is why for the residential areas now mostly the CFL and MH lamps are used. There were no complaints of using luminous flux reduction in night hours as practically nobody noticed that. On the other hand, there were rather large complaints on switching off the lighting in night hours so this measure, although it brings large energy savings, will probably not be widely used in Slovenia.

4.2 Experiences of Efficient Technology in Finland

In Finland, on roads maintained by Finnish Transport Agency the need for replacing the high pressure mercury luminaires (41,100 lamps) has been made but no systematic replacement has been made. The high pressure mercury luminaires are so old that the entire illumination will be replaced by more efficient one. Thus, high pressure sodium lamp luminaires compose 79% of the roads maintained by Finnish Transport Agency.

Espoo has made a deal with Ministry of Employment and the Economy to reduce 9% energy usage by 2011. Most of the saving is achieved in buildings by reducing heat losses and using control systems. In road lighting more efficient light sources has been used. Since 1993, only high pressure sodium lamp luminaires have been installed and induction lamp luminaires have been installed since 1999. The replacement of high pressure mercury lamp luminaires in road lighting has been made to old poles by changing only the luminaire. The lamp power has been chosen according to pole spacing. For example 250 W HPM lamp luminaire has been replaced with 100 W HPS lamp luminaire. In park areas, the replacement has been made using induction lamps (55 W, 84 W).

In Espoo, 20% energy savings are also achieved by turning of every other luminaire between 10 pm and 6 am. In Espoo, there are approximately 150 control centers for turning off every other luminaire. Turing off every other luminaire is done year around in control center areas and it has been in use since 1982. There are also approximately 600 autotransformer control centers for dimming the illumination. The autotransformer control centers have been in use since 1995. Autotransformers reduce energy usage 30% - 40%. Also the operating life of lamps increases and luminous flux depreciation has decelerated due to under voltage operation.

Espoo does not have a detailed schedule for replacing the remaining 10,000 high pressure mercury lamps. Around 90% of these lamps are replaced by high pressure sodium lamps. Most of these remaining high pressure mercury lamp luminaires are in areas where the city is improving other public utility services. Thus, high pressure mercury lamps are replaced at the same time.

In Espoo, there are few experimental LED luminaire installations. The installations consist of only a few LED luminaires from different manufactures. The installations have been made by replacing the luminaire into old poles. The power reduction is not significant. However, the luminance level on the road surface has increased. [28]

As an example in Espoo an experimental LED street lighting installation was made where 16 high pressure sodium lamp luminaires were changed to four different types of LED luminaires. The measured power consumption and luminous intensity distribution curves of the LED luminaires and the original HPS lamp luminaire were measured at the laboratory. The LED luminaires were changed to existing poles (average pole spacing 27 m). Table 6 shows the result of the power consumption of each LED luminaire and the reduction in power consumption compared to the original HPS lamp installation. If the pole spacings were optimized, the reduction in power consumption compared to the optimized HPS lamp installation would vary between 28% - 68%. It should be noted, that the optimization was performed using DIALux software with the measured luminous intensity distribution curves. Also, the original HPS lamp luminaire was around 15 years old, whereas the LED luminaires were new. Increasing the luminaire spacing of LED luminaire D from 27 m to the optimized pole spacing 41 m would decrease the power consumption by 49%.

Kerava has some ideas about reducing the power consumption and the CO_2 gas emissions, but so far no official plans have been made. Also, Kerava does not have any other plans than replacing the high pressure mercury luminaires to more energy efficient ones.

Kerava has started replacing the inefficient high pressure mercury lamp luminaires. The luminaires have been replaced by HPS luminaires; 250 W HPM lamps to 150 W HPS lamps and 150 W HPM lamps to 70 W HPS lamps. The replacement is scheduled to be completed by 2016.

Kerava has some experiences of LED outdoor lighting. Fifteen LED luminaires were tried in street lighting in 2007, but unfortunately they broke in a thunderstorm the following summer. Some LED installations have been made to parks this year, and LEDs have been installed to a small residential road.

In Kerava, LED technology is seen an interesting solution to outdoor lighting in the future. At the moment the lack of experiences and suitable solutions in the market restrict their wider use. In the future LEDs are also seen as a solution to save energy. Today they use the same amount or even more energy than present efficient technology. [30]

High pressure sodium lamps are preferred mainly for cost reasons to replace HPM lamps in outdoor lighting. The price the high pressure sodium lamp is lower than metal halide lamp, the lifetime of HPS lamp is longer than MH lamps and also the dimming properties favor HPS lamps. Thus, the maintenance costs are lower for HPS lamp luminaires.

Both Espoo and Kerava have not made any user surveys of road lighting.

Generally, people are satisfied with the lighting and the light color of high pressure sodium lamps. In fact, Espoo received positive feedback when the cold color high pressure mercury lamps were changed to high pressure sodium lamps. The complaints usually concern broken lamps in general, or in the case where every other lamp is turned off. Turning off all luminaires was complained by few users who mainly drove during the night time.

Table 6 LED luminaire power consumption and reduction in power consumption [%] compared to the original HPS lamp installation in the case street in Espoo. Reduction in power consumption if the pole spacings were optimized.

LUMINAIRE	MEASURED POWER CONSUMPTION W	REDUCTION IN POWER CONSUMPTION %	REDUCTION IN POWER CONSUMPTION, OPTIMIZED POLE SPACING %
LED A	108	24.5	44.2
LED B	133	7.0	28.1
LED C	140	2.1	48.0
LED D	110	23.1	68.1

5 View of Possibilities to Save Energy

In Slovenia, already before the adoption of the Decree on Limit Values due to Light Pollution of Environment, some municipalities realized that with the investments in the modernization of road lighting the cost for the electrical energy can be significantly reduced. And with the adoption of the decree, the municipalities are practically forced to modernize the road lighting and so to reduce the energy consumption. As the main obstacle in many municipalities is the lack of investment funds they are trying to finance the investments through the achieved savings.

The amount of electrical energy, which municipality can save bringing the road lighting in accordance with the requirements of the decree is dependent of the state of the lighting and saving measures already taken by municipality before the decree was accepted. The practice shows that the energy consumption can be reduced by 10% to 50%. Taking into account the present energy consumption for road lighting in Slovenian municipalities, we calculate that around 58.6 GWh or 35.4% yearly can be saved which represents 31,058 t of CO_2 less each year.

In Finland, there are possibilities to save energy by replacing inefficient light sources to more efficient ones. Changing the 110 W high pressure mercury lamps to 70 W high pressure sodium lamps saves energy 36%. By changing the HPM in Espoo the energy savings are 1.6 GWh and the reduction in green house gas emissions is 312 t CO_2/a (5.7%). There is a significant energy saving potential (estimated up to 70%) with the LED lighting [31] together with intelligent control systems in the future [32]. Replacing the HPM, HPS and MH lamps with LED luminaires that would use 50% less energy would bring 31% savings in the total outdoor lighting energy consumption in Espoo. The green house gas emission would reduce be reduced by to 1700 t CO_2/a.

In Kerava, 64% of the lamps are high pressure mercury lamps. Replacing these lamps to high pressure sodium lamps brings at least 35% energy savings. The green house gas emission would reduce by 274 t CO_2/a (35%). Replacing all the luminaires with LED luminaires that would use 50% less energy would bring 50% savings in the total outdoor lighting energy consumption in Kerava. The green house gas emission would be reduced by 390 t CO_2/a.

6 Conclusions

From the results of the comparison one can see that despite of the differences between both countries, the state of the road lighting and the used practice are quite similar. In both countries the old installations with high pressure mercury lamps are still in use to great extend. For new installations mainly high pressure sodium lamps are used and in both countries first test installations of LED luminaires are in operation. We have also noticed that municipalities in Finland as well as in Slovenia are considering the replacement of the old luminaires with new more efficient ones in the next years. The reason is the same; in both countries municipalities will have to replace them due to the ban on high pressure mercury lamps in EU. Additionally in Slovenia municipalities need to replace them also because of the mentioned decree. But the results will be the same, with the replacement of luminaires with high pressure mercury lamps in Finland and with the replacement of luminaires that do not meet the requirements of the Decree in Slovenia, approximately 30% of the electrical energy used for road lighting would be saved.

We believe that the obtained results can also, to some extent, be use for the whole European Union. For recent road lighting installations up to date technology is used in all countries which means luminaires with high pressure sodium lamps but also some testing LED installations as well as testing installations of lighting control systems. The same can be stated also for state of the old installations. All over the EU still a large number of old luminaires with high pressure mercury lamps are in use. And due to the ban on this light source, it will need to be replaced in the next years. That means that the estimated energy saving potential of 30% can also be used for whole EU. Modernization of road lighting would thus reduce the use of electrical energy in EU by 10.500 GWh yearly which means also 4.7 Mt less of CO_2 emissions each year.

Acknowledgements

This work is part of the current research project “EkoValo” carried by Aalto University Lighting Unit. The research project is funded by Finnish Funding Agency for Technology and Innovation, Sitra, Ministry of Employment and the Economy, and several Finnish electric companies and municipalities. The authors also acknowledge the city of Espoo, Kerava, Ljubljana and Medvode for providing information to this work.

References

[1] International Comission on Illumination, 1992, Road Lighting as an Accident Countermeasure, Vienna, Austria.

[2] P. Van Tichelen et al, 2007, Final Report Lot 9: Public street lighting, Vito, p. 344.

[3] Government of the Republic of Slovenia, 2008, Law on road safety, Official Gazette of Republic of Slovenia, Vol. 56/2008, Ljubljana.

[4] Ministry of Transport, 2005, Book of rules for road design, Official Gazette of Republic of Slovenia, Vol. 91/2005, Ljubljana.

[5] G. Bizjak, M.B. Kobav, 2008, Assesment of potential energy savings in interior and exterior lighting. Faculty of Electrical Engineering, University of Ljubljana, Ljubljana, p. 63.

[6] Ministry of the Economy, 2010, Rules on the methods for deteremination of energy savings at final customers, Official Gazette of Republic of Slovenia, Vol. 04/2010, Ljubljana.

[7] Finlex, 2005, Maantielaki 503/2005, June 23. [Cited: November 10, 2010], http://www.finlex.fi/fi/laki/ajantasa/2005/20050503.

[8] Tiehallinto, 2006, Tievalaistuksen toimintalinjat, Edita Prima Oy.

[9] V. Sippola, 2010, Eco-design-direktiivin täytäntöönpanotoimenpiteiden vuoksi poistuvien lamppujen korvaaminen ulkovalaistuksessa, Master’s Thesis, Department of Electronics/Lighting Unit, Aalto University.

[10] Statistics Finland, 2010, Supplies and total consumption of electricity.

[11] Motiva Oy, 2004, Yksittäisen kohteen CO2-päästöjen laskentaohjeistus sekä käytettävät CO2-päästökertoimet, p. 15.

[12] European Committee for Standardization, 2003, EN 13201:1 - Road lighting. Part 1: Selection of lighting classes, Technical report, p. 30.

[13] European Committee for Standardization, 2003, EN 13201:2 - Road lighting. Part 2: Performance requirements, p. 16.

[14] European Committee for Standardization, 2003, EN 13201:3 - Road lighting. Part 3: Calculation of performance, p. 41.

[15] European Committee for Standardization, 2003, EN 13201:3 - Road lighting. Part 4: Methods of measuring lighting performance, p. 14.

[16] Lighting Engineering Society of Slovenia, 2000, Recommendations for Road Lighting PR5-2, Ljubljana.

[17] International Comission on Illumination, 2010, Lighting of Roads for Motor and Pedestrian Traffic, p. 45.

[18] G. Bizjak, M.B. Kobav, 2004, Study on the potential savings of electrical energy for street lighting in municipality Hrastnik. Faculty of Electrical Engineering, University of Ljubljana, Ljubljana.

[19] G. Bizjak, M.B. Kobav, 2009, Potential savings of electrical energy for street lighting in municipality Medvode. Ljubljana: University of Ljubljana, Faculty of Electrical Engineering.

[20] Government of the Republic of Slovenia, 2007, Decree about limiting values of light polution of environment. Official Gazette of Republic of

Slovenia, Vols. 81/2007, 109/2007, 62/2010. Ljubljana.

[21] Tiehallinto, 2006, Tievalaistuksen suunnittelu, Edita Prima Oy.

[22] M. Eloholma, J. Ketomäki, L. Halonen, 2001, Road lighting - Luminance and visibility measurements, Report 29, Lighting Laboratory, Helsinki University of Techonology, Espoo, p. 43.

[23] A. Ekrias, M. Eloholma, L. Halonen, 2007, Analysis of road lighting quantity and quality in varying weather conditions, The Journal of the Illuminating Engineering Society of North America, Vol. 4, pp. 89-98.

[24] A.F. Castillo, 2007, Intelligent management of road lighting control systems using fuzzy controllers, M.Sc.thesis, Lighting Laboratory, Helsinki University of Technology, Espoo.

[25] P. Hautala, 2010, Senior Adviser, Sito Oy, Interview, November 12.

[26] Tiehallinto, 2007, Tienrakennustöiden yleiset laatuvaatimukset ja työselitykset.

[27] Liikennevirasto, 2010, Tievalaistus/ sähkötiedote nro 7C Maanteillä käytettävät valaisimet.

[28] P. Sillanpää, 2010, Electrical Engineer, The City of Espoo, Interview, November 10.

[29] Z. Alt, 2007, Experiences in design and maintenance od road lighting in municipality Celje, Road lighting and light pollution, Velenje.

[30] A. Mäkirinta, 2011, Infrastructure Sercices Manager, The city of Kerava, Interview, November 2.

[31] U.S. Department of Energy. 2010, Solid-State Lighting Research and Development Multi-Year Program Plan.

[32] L. Guo, 2008, Intelligent road lighting control systems - experiences, measurements, and lighting control strategies, Doctoral Dissertation, Department of Electronics/Lighting Unit, Helsinki University of Technology.

Authors' information

Anne-Mari YLINEN
PhD Student
*
ph: +358 50 3160985
e-mail aane.ylinen@aalto.fi

Anne-Mari Ylinen got her Master degree from Department of Electrical and Communication Engineering, Helsinki University of Technology, Finland in 2007. She is a PhD student at the Lighting Unit and her interest areas of research include road lighting, road pavements, mesopic vision, and energy efficient lighting.

Grega BIZJAK
Associated Professor,
Dr.Sc. (Tech.)
University of Ljubljana
Faculty of Electrical Engineering
Tržaška ulica 25
SI-1000 Ljubljana
ph: +386 (01) 47 68 446
grega.bizjak@fe.uni-lj.si

Grega Bizjak received his doctorate in electrical power engineering in 1997 from University of Ljubljana, Faculty of Electrical Engineering. Currently he is an Associated Professor and Head of Laboratory of Lighting and Photometry at University of Ljubljana. He is active in the field of lighting and photometry as well as in the field of electrical power engineering. His main research interests in lighting are energy efficient indoor and outdoor lighting, use of daylight, LEDs in lighting applications and photometry. Prof. Bizjak in president of Slovenian National Committee of CIE, representative of Slovenia in CIE Division 2 and member of IEEE.

Marjukka PUOLAKKA
Dr.Sc. (Tech.)
*
ph: +358 50 3269549
marjukka.puolakka@aalto.fi

Marjukka Puolakka earned her doctorate in illuminating engineering in 2005 from Helsinki University of Technology, Finland. Senior Research Scientist in the Lighting Unit of Aalto University in Finland. Leader of the research team 'Outdoor Lighting and Visual Effects of Light'. Her interest areas include outdoor lighting, visibility at low light levels, mesopic photometry and LEDs in outdoor lighting.

Liisa HALONEN
Professor, Dr.Sc. (Tech.)
*Aalto University, School of Science and Technology
P.O.B. 13340
00076 Aalto, Finland
ph: +358 500 423232
e-mail: liisa.halonen@aalto.fi

Liisa Halonen earned her doctorate in illuminating engineering in 1993 from Helsinki University of Technology, Finland. She is the head of the Lighting Unit in Aalto University, School of Science and Technology, Finland. She has managed numerous national and international research projects. She is responsible for the Master- and Post-graduate education in illuminating engineering at Aalto University. Professor Halonen is the Operating Agent of Annex 45 Energy Efficient Electric Lighting for Buildings. She is the Finnish representative of CIE Div 3 and is working in several CIE technical committees.

Received 25 May 2011
Revised 23 June 2011