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QUALITY AND ENERGY EFFICIENCY OF PUBLIC LIGHTING IN THE AREA OF THE OSIJEK-BARANJA COUNTY

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Original scientific paper

This article preliminary points to the importance of public lighting (PL), environmental unintended effects, as well as organisational questions concerning PL. PL infrastructure and electricity consumption in the area of the Osijek-Baranja County, as well as comparison of electricity consumption for PL with the towns in Croatia are analyzed in detail. The article particularly points to contemporary electrical engineering solutions of PL construction, light sources and PL control systems. Furthermore, it analyzes energy efficiency of PL in the Osijek-Baranja County.

Keywords: *CO_2 emission, energy efficiency, light sources, public lighting*

Kvaliteta i energetska učinkovitost javne rasvjete na području Osječko-baranjske županije

Izvorni znanstveni članak

U radu se uvodno ukazuje na važnost javne rasvjete (JR), ekološki neželjene posljedice te organizacijska pitanja javne rasvjete. Detaljno se analizira infrastruktura JR i potrošnja el. energije za JR na području Osječko baranjske županije te usporedba potrošnje el. energije za JR s gradovima u RH. Posebno se ukazuje na suvremena elektrotehnička rješenja izgradnje JR, izvora svjetlosti i sustava za regulaciju JR te utvrđuje razina energetske učinkovitosti JR na području Osječko-baranjske županije.

Ključne riječi: *emisije CO_2,, energetska učinkovitost, izvori svjetla, javna rasvjeta*

1 Quality and energy efficiency of public lighting in the area of the Osijek-Baranja County

Public lighting (PL) has been neglected in scientific research in the last two decades in Croatia. Only with the adoption of the Act on effective energy use in final consumption [1], according to which each county in the Republic of Croatia is obliged to make a programme and plan of energy efficiency in final energy consumption, public lighting has again become a research topic of interest.

1. 1 Public lighting - an important sector of electricity consumption

Public lighting is an important sector of electricity consumption in every country. The first argument of importance is the safety component according to which PL provides visual conditions for normal traffic flow and communication of people in public operating areas, as well as the effects PL provides regarding psychological and physical safety of people and property. The second group of important characteristics involves the effects of PL in the aesthetic environment of life in settlements (squares, park and monument illumination) and in this context relevant effect on the attractiveness of tourism supply of urban localities.

The conducted correlation analysis based on data for gross domestic product (GDP) per capita and consumed electricity for PL per capita for European countries has shown low correlation coefficients (under 0,5) which means that there is no interdependence between the achieved GDP per capita and electricity consumption per capita for PL as opposed to very strong correlation of GDP and electricity consumption in industry and households [2].

The fundamental starting point in the analyses of energy efficiency in the Osijek-Baranja County (OBC) and consequently PL, must take account of war aggression against Croatia and wartime destructions which led to heavy human losses, large number of wounded, displaced and refugees, large material destructions in industry, municipal infrastructure and residential buildings, and subsequently to broken social relations and low level of social cohesion in eastern Croatia. All these factors had unfavourable influence on the economic activity, public utility and living standard of the population including the field of public lighting. After peaceful reintegration of the UNTAES area East into the Croatian constitutional and legal system (1998), the rebuilding process of damaged infrastructure facilities and the electric-power system began [3].

1.2 Quality and unintended effects of public lighting

PL quality can be objectively evaluated based on measurements of illumination of public spaces in settlements and roads by using special measurement equipment. As far as the authors are informed, such measurements do not form a basis of comparison of PL quality in international proportions (neither for a particular country nor towns) due to its high price. But, an evaluation of PL quality can be carried out by measuring the energy consumption for PL with an insight into the number and structure of lights and area of settlements and roads. Thus, a better insight into the situation relative to PL within an area, e.g. settlements, towns, a region or entire countries, can be achieved. In addition to benefits of public lighting use, there are some unintended effects on human environment and nature. In urban areas PL influences the processes in nature, e.g. the 'day - night' cycle which has influence on plant and animal life nearby the lighted areas. Moreover, it adversely affects biodiversity, ecosystems, as well as human health. This is specially manifested if PL is not properly designed and/or managed. In addition to consequences, like light pollution, we need to mention undesirable (and unnecessary) shedding of light on the sky and disruptive road lighting.

No ecological lighting equipment includes all lights where the light source (e.g. a bulb) is not appropriately directed at the area that needs to be lit which, as a result, leads to uncontrolled light emission into the environment and sky causing light pollution (Fig. 1).

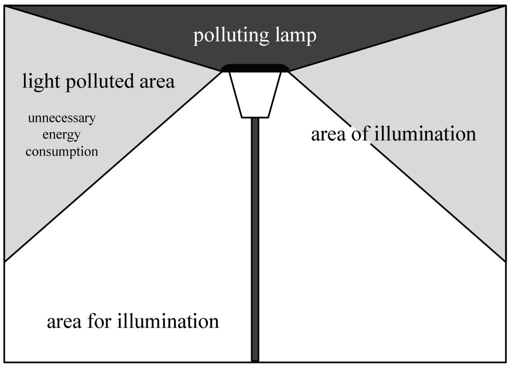

Figure 1 An inappropriate street lamp

1.3 Organisational questions of public lighting

In terms of organisation PL is part of municipal infrastructure of every inhabited area whose construction and keeping is regulated by the Utility Services Act [4] and which is under the authority of the local self-government (LSG) of towns and municipalities. During previous decades PL changed several times its organisational affiliation between the electric-power industry and local self-government [5]. So, in 1998 "Elektroslavonija" Osijek granted authorization for PL to 53 towns and municipalities in the Slavonian region.

Lighting of motorways, state roads and corresponding tunnels and bridges is considered as public lighting, but is under authority of Croatian Motorways (CM) and Croatian Roads (CR) which build instalments, maintain and bear the electricity costs.

2 Infrastructure of public lighting in OBC

Infrastructure of public lighting includes: a) lamp posts and power cables, b) lighting equipment, c) light sources and d) management system. Development and complexity of the local PL system depends on territorial spread and configuration of settlements, density and development of residential and business buildings, number of inhabitants, road length and surface of squares and economic development of LSG. Tabs. 1 and 2 present basic elements of the PL system in OBC (Fig. 2).

Out of a total of 264 settlements in OBC, 7 LSG units have the status of a city (Ci), which territorially and administratively also include 60 suburban settlements and villages, and 197 settlements administratively organized into 35 municipalities (Mu). According to the 2011 Census, the area of OBC has 193696 inhabitants in towns and 111203 in villages. Number of 23754 lights (70 %) is installed in cities, while the municipality area has 10200 (30 %) lights. The total power of lights increased from 3677 to 6054 kW in the period from 2000 to 2010. Out of the total power of 6054 kW in the county, 69,4 % has been installed in towns and 30,6 % in the municipality area.

Table 1 The infrastructure of PL in OBC in 2008

LSG	N° Settl.	N° Inhabit.	N° street lamps			Power / kW
			Classic	Modern	Total	
	a	b	c	d	e	f
Ci	7+60	207392	3664	20090	23754	4203
Mu	196	123114	4600	5600	10200	1851
OBC	263	330506	8264	25690	33954	6054
Source: a [6]; b [7]; c ÷ e [8]; b [9] [10]						

Figure 2 The Area of Osijek-Baranja County [6]

Table 2 The PL infrastructure in towns of OBC – 2008

City	N° settl.	N° Inhabit. $\times 10^3$	Street length / km	Squares $\times 10^3$ / m^2	N° PL spots	PL Power / kW
	a	b	c	d	e	f
B. Manastir	4	11	43	10	971	206
Belišće	9	12	28	5	1109	157
D. Miholjac	7	10	30	7	1556	158
Đakovo	9	30	61	15	3600	422
Našice	19	17	28	12	1826	342
Osijek	11	114	392	31	13190	2399
Valpovo	8	12	32	9	1502	230
OBŽ	67	207	614	89	23754	3914
Source: a, c, d [6]; b [7]; e, f [8]						

A special indicator of the situation regarding PL in an area is the number of settlements, as well as the number of streets in those settlements which do not have PL installed. The data for OBC, towns and municipalities are shown in Tabs. 3 ÷ 5.

Out of 67 urban settlements (which have PL), 30 settlements have not got public lighting installed in 125 streets in the overall length of 48,9 km. Out of 161 settlements in municipalities, 6 settlements are without PL, 40 settlements have not a completed public lighting system in 152 streets in the overall length of 51,5 km. It follows that in the area of OBC there are 6 settlements completely without PL and 70 settlements have not got public lighting installed in 277 streets which makes an overall length of 100,4 km.

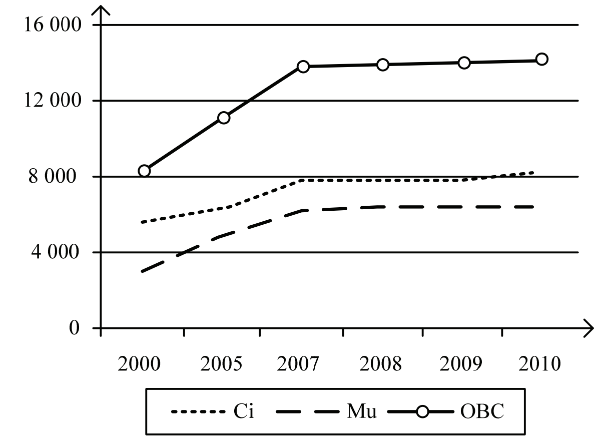

Figure 3 Number of street lamps in OBC [9]

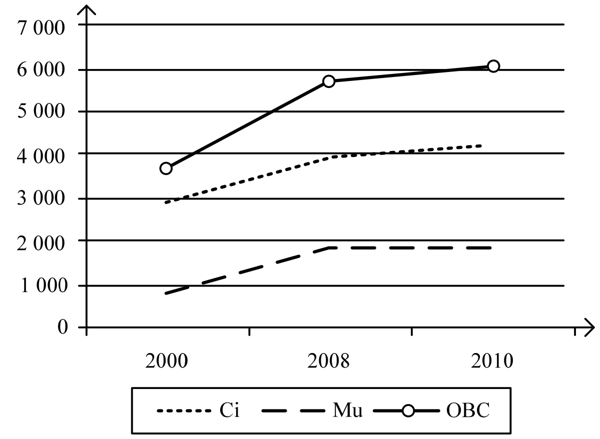

Figure 4 The power of PL in OBC [9]

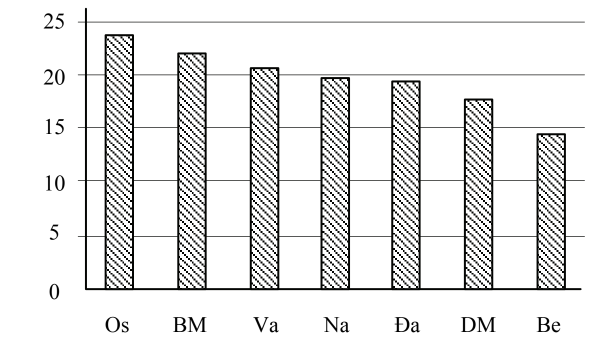

Figure 5 Power for PL per capita in towns of OBC (W) in 2010

Calculations from previous tables show that out of 330 506 inhabitants living in OBC around 4000 inhabitants (1 %) live in settlements and 22 500 inhabitants (7 %) live in streets without PL and around 60 000 inhabitants live in streets with poor public lighting (Fig. 7). Tabs. 4 and 5 represent a brief review of settlements and streets without public lighting for towns and municipalities in OBC.

According to data from 2008 shown in Tab. 2, the PL system of the towns of Beli Manastir and Đakovo accounts for 100 % of modern lights (gas discharge lamps), and the following are: Našice (95 %), Osijek (89 %) Belišće (80 %), Valpovo (45 %) and Donji Miholjac (27 %). The average of modern lighting in towns in OBC is 85 %.

The total of electricity power of PL in towns shows an increase from 2892 kW to 4203 kW for the period 2000 ÷ 2010. The total power of lights in the year 2010 is the highest in the city of Osijek (2555 kW); the following are: Đakovo, Našice, Valpovo, Donji Miholjac, Beli Manastir and Belišće.

Osijek has the highest power (23,7 W) for PL per capita in 2010. The following are: Beli Manastir (21,1 W), Valpovo (20,9 W), Našice (19,8 W), Đakovo (19,5 W), Donji Miholjac (18,8 W), Belišće (14,4 W); Fig. 5

Data show that Beli Manastir has the lowest number of lights per square meter (m^2) of city squares and local roads in 2008, i.e. on light per 973 m^2. It is followed by Osijek (595), Valpovo (434), Donji Miholjac (346), Belišće (299) and Đakovo (263). The most favorable ratio is displayed in Našice with one light on 194 m^2. The average for towns of OBC is one light on 489 m^2.

Donji Miholjac has the most favourable ratio of inhabitants per light in 2008, i.e. 6,6 inhabitants per light. The following towns are: Valpovo, Đakovo, Osijek, Našice, Belišće and Beli Manastir. The average for towns of OBC is 8,7 inhabitants per light (Fig. 6)

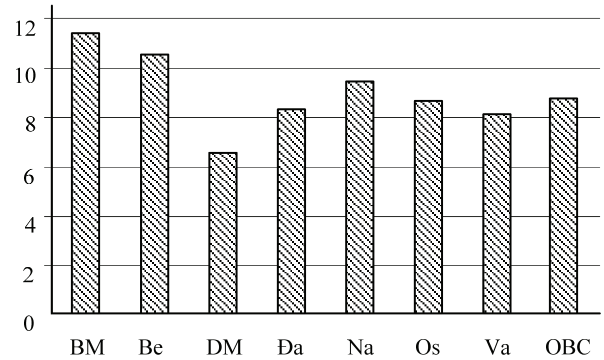

Figure 6 Number of inhabitants per light in the towns of OBC - 2008

Table 3 Settlements without PL in OBC – 2010

LSG	N° settl.	N° settl. without PL	N° settl. with low PL	N° street. with low PL	Street length / km without PL	Street length / km low PL
Ci	67	0	30	125	48,5	100
Mu	196	6	40	152	51,5	100
OBC	263	6	70	277	100,4	200
Source: [11]						

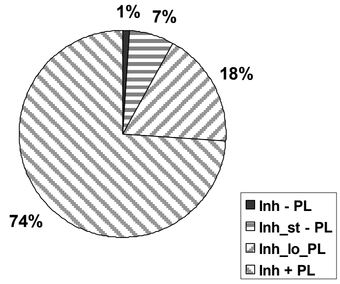

Figure 7 Availability of PL to population of OBC in 2010

There are big differences among particular municipalities concerning electricity infrastructure expressed through power of lighting per capita. This gap ranges from 27 W (municipality Šodolovci) to 8,7 W per capita (municipality Popovac).

Table 4 Streets without PL in the cities of OBC - 2010

City	N° settl.	N° settl. with poor PL	N° street. with poor PL	Street length	
				without PL	low PL
	a	b	c	d	e
BM	4	0	0	0	5
Be	9	0	0	0	5
DM	7	1	11	7,3	20
Đa	9	3	20	5,6	10
Na	19	14	18	11,1	10
Os	11	9	73	22,9	40
Va	8	3	3	1,9	10
OBC	67	30	125	48,7	100
Source: [11]					

3 Electricity consumption for PL in OBC

Tables 6 and 7 represent electricity consumption for public lighting in OBC from 2000 to 2010. The total consumption of electricity for PL increases at an annual rate of 4,5 %, i.e. from 16,1 to 25,5 GW·h, which makes a growth rate of 69 % (index 169) in the last 11 years. A larger increase in consumption is reached in municipalities (index 229) than in towns (index 145), because the reconstruction of local PL systems after the Homeland war was more intense in rural areas.

3.1. Consumption in the towns

Osijek (9958 MWh) had the highest electricity consumption of PL compared to other towns in the year 2010 whereas Belišće had the lowest (547 MWh) (Fig. 7). During the observed period (2000 ÷ 2010) a major increase was achieved in Beli Manastir (index 250), while Osijek had the smallest growth index (index 117). The growth index for cities in OBC in this period is 136.

Table 5 Electricity consumption for PL in OBC / MWh

LSG	2000	2005	2007	2009	2010	SR
Ci	12139	13836	14747	16077	16527	3,1
Mu	3354	6093	6784	7853	7576	8,5
CR	643	826	918	1043	1053	5,1
OBC	16136	20755	22449	24973	25156	4,5
Source: [9, 10]						

Important annual development indicators of PL include: (a) electricity consumption for PL per capita, (b) electricity consumption for PL per m^2 of public traffic area, and (c) ratio of electricity consumption for PL and households. The average in OBC is for (a) 83,0 kW·h/inhabitant, (b) 186 kW·h/m^2 and (c) 5,3 %. Data for towns are presented in Fig. 8 and 9.

Table 6 Number and length of streets without PL in municipalities of OBC - 2010

Municipality	N° settl.	N° settl. without PL	N° settl. with poor PL	Street length	
				without PL	low PL
	a	b	c	d	e
Antunovac	2	0	2	2	0,6
Bilje	8	0	8	44	5,4
Bizovac	8	2	0	4	1,0
Čeminac	5	1	2	6	1,3
Čepin	5	1	3	13	10,1
Darda	4	0	3	7	1,4
Drenje	12	1	2	13	3,0
Jagodnjak	4	0	4	28	21,1
Kn.Vinog	9	0	4	4	1,8
L. Var	11	1	1	1	0,9
Podgorač	9	0	6	22	1,7
Sat. Đak.	2	0	2	3	1,2
Strizivojna	2	0	1	2	1,7
Trnava	6	0	1	2	1,5
Viškovci	3	0	1	1	0,5
Total	90	6	40	152	51,46
Source: [11]					

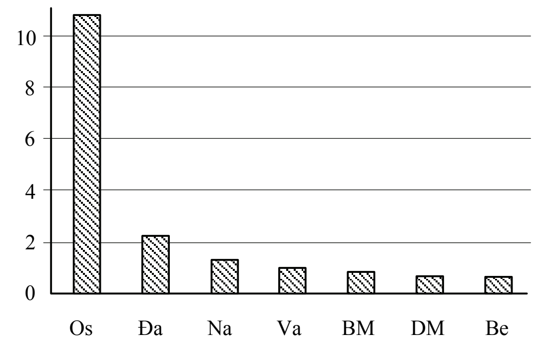

Figure 8 Electricity consumption for PL in the cities of OBC in 2010 (in GW·h)

Table 7 Electricity consumption for PL in the towns of OBC / MW·h

	2000	2005	2007	2010	2000=100
BM	372	676	784	931	250
Be	384	514	685	654	142
DM	443	482	608	706	159
Đa	1052	1481	1645	2273	210
Na	911	1213	1393	1347	146
Os	8531	8869	8971	10725	117
Va	445	601	761	1007	188
Total	12139	13836	14747	17644	136
Source: [9]					

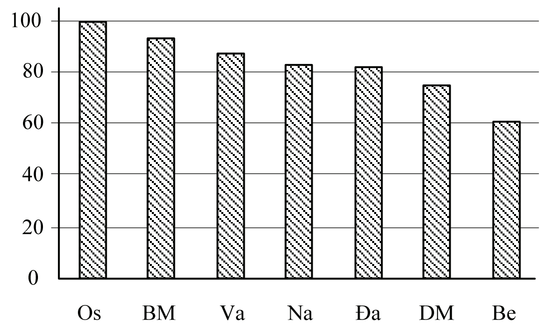

Figure 9 Annual electricity consumption for PL per capita in the towns of OBC for the year 2008 (in kW·h/inhabitant)

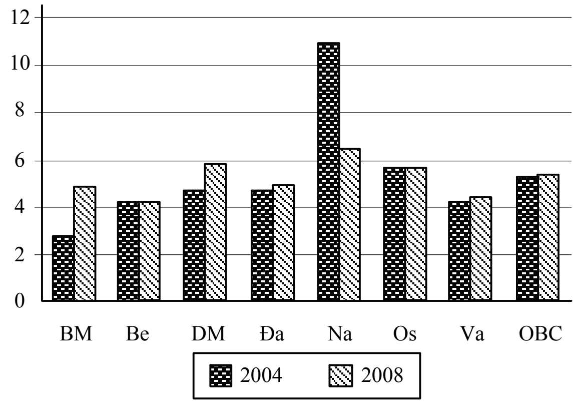

Figure 10 Share of electricity consumption for PL in household electricity consumption of the towns in OBC in 2004 and 2008 (in %).

3.2. Consumption in municipalities

The highest electricity consumption for PL among municipalities in 2010 was observed in the municipality of Čepin (840 MW·h), and the lowest (60 MW·h) in Podravska Moslavina. During the period of 2000 ÷ 2010 a major increase was achieved in the following municipalities: Strizivojna (index 990), Šodolovci (696) and Kneževi Vinogradi (566), while a decrease was noticed in municipalities of Ernestinovo and Magadenovac with index 96 as shown in Fig. 11. Annual electricity consumption for PL per capita in municipalities amounts to 61,5 kW·h/inhabitant. Furthermore, data show that there is a significant gap among particular municipalities based on micro regions (distribution areas) which ranges from 50,1 kW·h per capita within the distribution area of "Elektroslavonija" Donji Miholjac and Valpovo to 77,9 kW·h per capita within the distribution area "Elektroslavonija" Osijek. Also, the consumption gap per capita is even higher within particular distribution areas. In the micro region of B. Manastir, the municipality of Kneževi Vinogradi (97,2 kW·h/inhabitant) has the highest consumption rate per capita, while the municipality of Popovac has the lowest rate (31,5 kW·h/ inhabitant). The following micro regions and their corresponding municipalities show the following statistics: micro region of D. Miholjac_and Valpovo, municipality Viljevo (63,2 kW·h/inhabitant) and Petrijevci (36,5 kW·h/inhabitant); micro region of Đakovo, Levanjska Varoš (85,6 kW·h/inhabitant) and Viškovci (39,1 kW·h/inhabitant); micro region of Našice, Podgorač (67,6 kW·h/inhabitant) and Donja Motičina (35,6 kW·h/inhabitant) and micro region of Osijek, Šodolovci (97,4 kW·h/inhabitant) and Vladislavci (61,9 kW·h/inhabitant).

3.3 Consumption under authority of Croatian Roads

Croatian Roads (CR) performs planning activities regarding development of public roads, building and maintenance of state roads except for motorways. CR use and maintain over 150 traffic signals with several hundred lights on intersections of state roads and bridges, which go through the area of OBC. Based on bills for electricity issued to the Croatian Roads by Croatian Electrical Power Distribution Company (HEP ODS d.o.o.), estimation on the electricity consumption for traffic light and PL under the authority of the Croatian Roads in OBC has been made. This consumption increases from 643 MWh in the year 2000 to 1053 MWh in the year 2010 as shown in Tab. 5.

3.4 Comparison of electricity consumption for PL

The state statistics do not record the sector of electricity consumption separately as it did 20 years ago. Since 2004 the Croatian Bureau of Statistics has been quadrennially issuing a review on energy consumption for PL in towns. Based on these data a comparison between 7 towns situated in OBC and other towns in Croatia has been carried out. Regarding the power of PL per capita, Donji Miholjac ranks 4th and is followed by Đakovo (12), Valpovo (18), Belišće (26), Našice (28), Osijek (36) and B. Manastir (49). According to the electricity consumption for PL per capita Beli Manastir ranks 15th and is followed by Našice (29), Valpovo (32), Donji Miholjac (36), Osijek (42), Đakovo (44) and Belišće (57). Rebuilding of electric power infrastructure and installation of public lighting in the area of OBC led to an increase of the share of electricity consumption from 5,38 percent in 2005 to 5,64 % in 2009. (Fig. 12) for PL in whole Croatia.

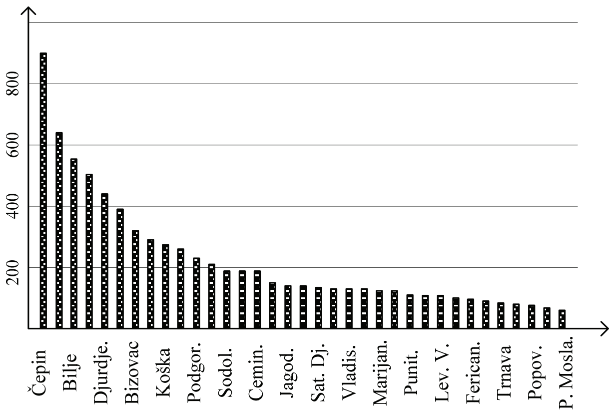

Figure 11 Electricity consumption for PL in municipalities (2010) (in MW·h)

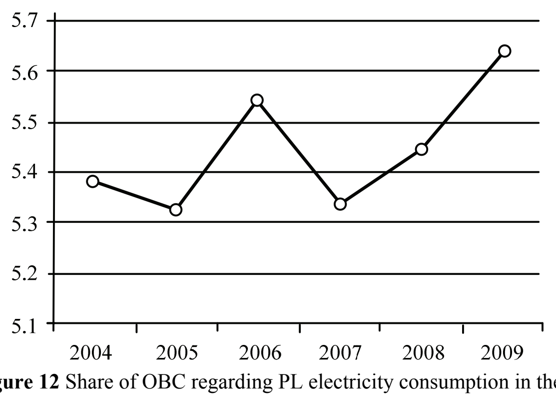

Figure 12 Share of OBC regarding PL electricity consumption in the Republic of Croatia (in %)

Due to the fact that international energy related publications have not been analyzing PL as a separate sector of energy consumption since 1980, but have incorporated it into "other broad consumption" [2, 12, 13, 14] , only few publications estimate the number of lamps in EU countries which, however, are not applicable to this paper.

4 Public lighting and energy efficiency

Level of information on contemporary technical solutions represents the first step in the organization of every human activity in the present civilization, as well as a starting point for developing organizational models and reaching economic decisions. In order to understand problems of energy efficiency in the public lighting sector, it is necessary to know contemporary technical solutions in lighting engineering, and especially in technologies regarding: a) lamps, b) light sources, c) regulations and d) PL system maintenance [15, 16, 17, 18, 19, 20].

a) After the 1980`s three significant steps were made in lamp technology thus creating an important shift in quality: (1) luminous efficiency of lamps was increased from 70 % to around 85 % by optimizing forms and material of reflectors; (2) reduce decrease of light efficiency from 25 % to 7 % during life time, and (3) optimization of lamp optics on the type of light source, as well as on the road profile. All of these improvements have contributed to both energy efficiency of 5 ÷10 % and better environmental protection from light pollution by controlling light emission in areas which do not necessarily need to be lit up. Consequently, the total possible effect on energy efficiency using modern lighting technology reaches up to 30 %. Furthermore, there are additional benefits relative to the quality and durability of lamps, as well as aesthetic effects.

b) The technology of light sources has also made significant progress in three basic directions: (1) efficiency and maintenance increase, as well as the bulb life, (2) increase of light quality (spectrum quality) and (3) bulb life extension. The development focused on two technologies in parallel: high-pressure technology (high pressure gas discharged sodium and metal halogen sources) and low pressure technology (compact fluorescent bulbs). Efficiency of top grade road light sources is increased by 15 %. Due to quality luminous flux maintenance, the efficiency at the end of working life grows by the next 10 % compared to the previous generation of high pressure bulbs. Total energy savings on light sources including the time behaviour of source rates more than 20 % thus ensuring longer working life of bulbs (a 4-year change cycle) and a more quality light spectrum [3].

c) Introduction of lighting control systems means adjustment of PL as required by the local time and area. It is a fact that different parts of town require different levels of illumination during night. Even a simple model with a two-step control (the so called "night regime") can contribute to energy savings of up to 20 %. Additional savings can be achieved by using electronic control. During the lighting dimming regime, another aspect of energy saving can be achieved, i.e. instead of the fixed 40 % it is possible to carry out better power control of up to 20 % of rated capacity, as well as the progressive continuous control instead of jump control during night. It can be concluded that the regime control system can be built into the PL system, thus enabling the control of PL power during night, as well as the luminous flux, which prolongs the lifespan of the light source and saves energy. Savings which can be achieved by reconstruction of the existing PL systems, e.g. replacement of lamps, can reach up to 30 % and up to 50 % by replacement of lamps and installation of PL control systems.

d) The key element of PL energy efficiency is the maintenance of the local PL system which traditionally refers to: (1) periodical cleaning of lighting equipment and (2) emergency replacement of faulty working light sources. The modern approach to maintenance is more complex and is based on new needs of the local community, on emerging technologies and wider spectrum of activities. That spectrum of activities includes: 1) maintenance of the functionality of the local PL system (continuous control and intervention), 2) preventive intervention (control and cleaning of lights), 3) maintenance of quality and reliability of the PL systems (measurements and correction of power factors) and 4) control of the local PL system based on the needs of the local community. Computerization of maintenance processes, as well as application of automation open new possibilities for optimal fulfilment of PL maintenance.

Benefits of emerging technologies are: 1) better recording and control of all elements of the local PL system, 2) enhanced efficiency of maintenance employees, 3) savings in material costs, 4) better planning and preparation of usual maintenance activities, and 5) possibility to regulate the operation mode (technical control of PL) thus saving energy. Computerization integrates all working processes concerning PL maintenance. Moreover, all operating events are registered in real-time and can lead to better decision making for optimal focusing on the maintenance process and control of the local PL system resulting in reduced maintenance costs, increased general safety of people, property and traffic, as well as in more stable and satisfactory revenue of the maintenance company.

4.1 Energy efficiency of public lighting in OBC

Based on the research of the local PL systems in the area of OBC, the following can be concluded:

- 22 % of light source can be classified as classic, and 78 % as modern light sources. At this point it should be stressed that the Croatian statistics still relies on an obsolete definition of "modern light source" which includes mercury containing bulbs, mercury-iodine bulbs and sodium bulbs; therefore these data should not be relied on [3]. Namely, according to the EU directive high-pressure mercury light sources should be phased out for environmental reasons and are not considered modern any longer [21].
- 40 % of lighting equipment is technologically outdated, and 30 % is over 20 years old. On the basis of such a structure of lighting equipment in OBC, it can be estimated that some ware between 30 % and

45 % of electricity is used more than necessary due to current insufficient quality of public lighting.

- 12 % of the local PL system can adjust light output based on local requirements, which means that additional installation of such systems would save around 15 % of electricity.
- Except in Osijek (2007) [22] measurements of active power in local PL systems for the purpose of compensating reactive power have not been performed yet. According to this information, it can be estimated that energy costs are higher by 5 % than needed.
- All towns and municipalities in OBC have a contract-based maintenance service; however, this research does not consider the quality of such maintenance service. Based on previous insight into the practice, personnel and equipment of maintenance companies, it can be concluded that a traditional concept of PL maintenance is applied.

4.2 Environmental performance of local PL systems

There are no data regarding environmentally friendly arranged illuminating posts in the local PL systems of OBC. A rough estimation can be done based on the fact that 30 % of illuminating posts in the area of OBC are more than 30 years old, and that during the last ten years around 15 000 new illuminating posts were installed. However, the question arises whether environmental standards were respected during installation. Therefore, it is not possible to estimate the influence of PL on the local natural environment [23].

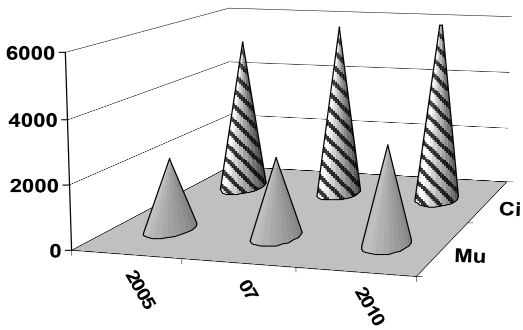

Figure 13 CO_2 emission of PL in OBC (tons)

Calculations concerning carbon dioxide emission (CO_2) were performed according to the Regulation on Energy Audits of Buildings [24]; the emission factor per energy unit (kg of CO_2/kW·h) amounts to 0,376. Results obtained by the application of this factor to the energy consumption of PL in OBC for the period of 2000 ÷ 2010 show an increase of CO_2 emissions from 5665 (in 2000) to 9585 tons (in 2010) (Fig.13).

5 Concluding considerations

Public lighting in the area of OBC was in an unfavourable position. Apart from the mentioned (national) issues, the situation was also difficult due to the following: (1) wartime destructions which struck the public lighting infrastructure, (2) post-war rebuilding which had other priorities, (3) economic crisis resulting in insufficient investment in PL, (4) insufficient knowledge of the local self-government about its own PL resources (there is no registry on public lighting), (5) funding of PL from the utility service fee which does not function well, (6) environmental component of public lighting which is neither sufficiently understandable to the wider public nor to experts.

This research has analyzed the basic technical elements of PL infrastructure, its operation and quality, as well as energy efficiency of PL in the area of OBC.

Infrastructure development of public lighting in OBC

This research has pointed to basic elements of PL in the area of OBC during the period from 2000 to 2010 (Fig. 14).

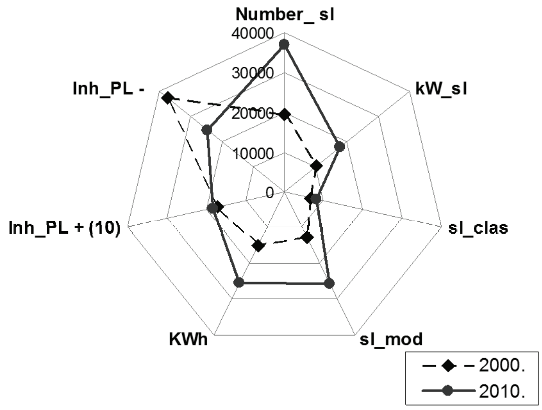

Figure 14 Basic elements of PL system in OBC in 2000 ÷ 2010

- increased number of illumination posts (from 19 500 to 37 000),
- increased power of PL lights (from 3677 kW to 6054 kW),
- improved structure of PL lamps; higher number and faster increase of (a) modern lamps from 12 675 on 25 690 in relation to (b) classic lamps from 6825 to 8264,
- reduced number of inhabitants in settlements without PL (from 37 500 to 24 500 inhabitants).
- increased number of inhabitants in settlements that have PL (from 169 890 to 182 890).

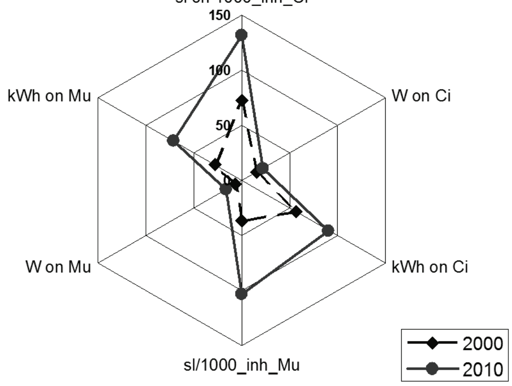

Figure 15 Quality of public lighting in OBC 2000 and 2010

Quality of public lighting

This research has pointed to basic elements of the quality of public lighting in municipalities and towns in OBC and their development in the period from 2000 to 2010 (Fig. 15):

- increased number of lighting equipment per 1000 inhabitants in towns (from 72 to 123) and municipalities (37 to 93),
- increased power of PL lighting equipment per capita in towns (from 10,8 to 18,5 W) and municipalities (from 5,5 to 13,9 W),
- increased energy consumption for PL per capita in towns (from 56 to 85 kW·h) and municipalities (from 27 to 64 kW·h).

Other questions regarding efficiency of local PL systems

During this research and in communication with the authors of this paper, more professionals from different institutions and companies engaged in PL emphasized the problem of "neglect of public lighting" in the area of OBC (but also in the whole Croatia) pointing to numerous examples and unsolved problems: (1) absence of updated registers on lighting equipment, as well as its management, (2) insufficient number of PL maintenance services, (3) absence of prescribed standards and procedures on PL maintenance, (4) lack of concern regarding environmental aspects in local PL systems in OBC, (5) absence of annual statistical reports on PL for all levels of the local self-government, (6) lack of presence of the subject in public service broadcasting, (7) insufficient awareness of the importance of PL, (8) lack of professional education on PL, (9) insufficient number of developmental projects in the PL sector, etc.

An important power engineering (and administrative) problem which results in an unfavourable situation in the PL sector is the question of (il)legal connection of digital billboards on the local PL systems. This poses a series of questions out of which we only point to the following one (because of the technical structure of this study) that concerns (unreported) engagement of electric power and power factor (cos φ) [25].

6 References

[1] Zakon o učinkovitom korištenju energije u neposrednoj potrošnji (The Act on to effective use of energy in final consumption), National Gazette, 152/08

[2] Ivanović, M. Komparativna analiza potrošnje električne energije za javnu rasvjetu u Evropi (Comparative analysis of electricity consumption for public lighting in the Europe) "Energija", Zagreb, 36, 2(1987), str. 127-132.

[3] Ivanović, M. Znanost i regionalna energetika (Science and Regional Energetsics), ISBN 953-6032-502-3 Elektrotehnički fakultet Osijek, 2006.

[4] Zakon o komunalnom gospodarstvu (The Utility Services Act), National Gazette, 26/03; 49/11

[5] Glasilo saveza gradova i općina RH; (Bulletin of Union cuties and municipalities of Croatia) 15.3.2001. ISSN 1331-209X

[6] Županija u brojkama 2005. 2006.; 2007.; 2008.(OBC in numbers) Osječko-baranjska županija, Osijek

[7] DSZ, Popis stanovništva 2001. (Census of Population) Zagreb, 2001.

[8] DSZ, Javna rasvjeta i isporučena električna energija u 2008. g. (Public lighting and supplied electricity in 2008) Priopćenje – br. 6; 1.10.2009.

[9] HEP ODS Elektroslavonija Osijek, pogonska izvješća 2000. ÷ 2010. (Operating reports).

[10] HEP ODS Zagreb, Annual reports 2004. ÷ 2009.

[11] Agency for Development OBC, 2011.

[12] Energy Statistics Database United Nations Statistics Division; http://www.nationmaster.com/

[13] Energy Yearly statistics 2005, Eurostat, ISBN 978-92-79-06483-8, Luxembourg: 2007.

[14] Eurostat; http://epp.eurostat.ec.europa.eu/portal/, 2011.

[15] Tichelen, P.V.; Geerken, T.; Jansen, B. et al. Preparatory Studies for Eco-design Requirements of EuPs, Final Report - Lot 9: Public street lighting, VITO, 2007.

[16] Wilken Dale et al, European Road Lighting Technologies; The American Association of State Highway and Transportation Officials, September 2001 (www.international.fhwa.dot.gov)

[17] Light's Labour's Lost - Policies for Energy-efficient Lighting, OECD, Paris, 2006.

[18] An Initial View on Methodologies for Emission Baselines, Energy Efficiency Case Study, OECD & International Energy Agency, Paris, 2001.

[19] Barić, T.; Glavaš, H.; Jozsa, L. Capacitive Influence of High Voltage Overhead Transmission. // Energija, 56, 2(2007), pp. 232-249.

[20] Blažević, D.; Ivanović, M.; Glavaš, H. Održavanje javne rasvjete na području OBŽ (Public Lighting Maintenance on the OBC Area) 21. Znanstveno-stručni skup organizacija i tehnologija održavanja - OTO 2012; Županja, April, 19-20, 2012. Proceedings, pp. 41-50

[21] Directive 2005/32/EC Eco-Design Reguirements for Energy-Using Products (www.eup-ecodesign.com/)

[22] Nikoloski, S. i suradnici. Mjerenje i analiza vršne snage postojeće javne rasvjete u Osijeku (Measurement and analyses of peak power of existing public lighting in the Osijek), Elektrotehnički fakultet Osijek, 2008.

[23] Kljajin, M.; Opalić, M.; Hnatko, E.; Stojkov, M. Importance of Design for Recycling Electronic and Electrical Equipment. // Proceedings of the I International Conference "Ecology of urban areas" 2011, Zrenjanin, Hunting Manor, 30th September 2011.

[24] Pravilnik o energetskim pregledima građevina (Regulation on Energy Audits of Buildings), National Gazette, 5/11.

[25] Stojkov, M.; Trupinić, K.; Poleto, D. Reduction of power and voltage losses in low voltage networks by reactive power compensating. The 18th International Conference on Electricity Distribution, CIRED, Turin, Italia, 6-9 June 2005., Session No 5 - Power Distribution System Development.

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