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

Hrvoje Glavaš, Damir Blažević, Milan Ivanović

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: CO₂ emission, energy efficiency, light sources, public lighting

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].

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).

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>
<thead>
<tr>
<th>LSG</th>
<th>N° Settl.</th>
<th>N° Inhabit. × 10^3</th>
<th>N° street lamps</th>
<th>Power / kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ci</td>
<td>7+60</td>
<td>207392</td>
<td>3664</td>
<td>20900</td>
</tr>
<tr>
<td>Mu</td>
<td>196</td>
<td>123114</td>
<td>4600</td>
<td>5600</td>
</tr>
<tr>
<td>OBC</td>
<td>263</td>
<td>330506</td>
<td>8264</td>
<td>25690</td>
</tr>
</tbody>
</table>

Source: a [6]; b [7]; c ÷ e [8]; b [9] [10]

Table 2 The PL infrastructure in towns of OBC – 2008

<table>
<thead>
<tr>
<th>City</th>
<th>N° settl.</th>
<th>N° Inhabit. × 10^3</th>
<th>Street length / km</th>
<th>Square / m²</th>
<th>N° PL spots</th>
<th>PL Power / kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Manastir</td>
<td>4</td>
<td>11</td>
<td>43</td>
<td>10</td>
<td>971</td>
<td>206</td>
</tr>
<tr>
<td>Belišće</td>
<td>9</td>
<td>12</td>
<td>28</td>
<td>5</td>
<td>1109</td>
<td>157</td>
</tr>
<tr>
<td>D. Miholjac</td>
<td>7</td>
<td>10</td>
<td>30</td>
<td>7</td>
<td>1556</td>
<td>158</td>
</tr>
<tr>
<td>Đakovo</td>
<td>9</td>
<td>30</td>
<td>61</td>
<td>15</td>
<td>3600</td>
<td>422</td>
</tr>
<tr>
<td>Našice</td>
<td>19</td>
<td>17</td>
<td>28</td>
<td>12</td>
<td>1826</td>
<td>342</td>
</tr>
<tr>
<td>Osijek</td>
<td>11</td>
<td>114</td>
<td>392</td>
<td>31</td>
<td>13190</td>
<td>2399</td>
</tr>
<tr>
<td>Valpovo</td>
<td>8</td>
<td>12</td>
<td>32</td>
<td>9</td>
<td>1502</td>
<td>230</td>
</tr>
<tr>
<td>OŠEZ</td>
<td>67</td>
<td>207</td>
<td>614</td>
<td>89</td>
<td>23754</td>
<td>3914</td>
</tr>
</tbody>
</table>

Source: a, c, d [6]; b [7]; c, 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.

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 (m²) of city squares and local roads in 2008, i.e. on light per 973 m². 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 m². The average for towns of OBC is one light on 489 m².

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).

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 %.

**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

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

**Table 3** Settlements without PL in OBC – 2010

<table>
<thead>
<tr>
<th>LSG</th>
<th>Nº settl.</th>
<th>Nº settl. without PL</th>
<th>Nº settl. with low PL</th>
<th>Nº street. with low PL</th>
<th>Street length / km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>67</td>
<td>0</td>
<td>30</td>
<td>125</td>
<td>48,5</td>
</tr>
<tr>
<td>Mu</td>
<td>196</td>
<td>6</td>
<td>40</td>
<td>152</td>
<td>51,5</td>
</tr>
<tr>
<td>OBC</td>
<td>263</td>
<td>6</td>
<td>70</td>
<td>277</td>
<td>100,4</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>City</th>
<th>N° settl. without PL</th>
<th>N° settl. with poor PL</th>
<th>N° street. without PL</th>
<th>N° street. with poor PL</th>
<th>Street length without PL</th>
<th>Street length with poor PL</th>
<th>Street length low PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>5</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Be</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>7</td>
<td>1</td>
<td>11</td>
<td>7,3</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Da</td>
<td>9</td>
<td>3</td>
<td>20</td>
<td>5,6</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>19</td>
<td>14</td>
<td>18</td>
<td>11,1</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Os</td>
<td>11</td>
<td>9</td>
<td>73</td>
<td>22,9</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Va</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>1,9</td>
<td>10</td>
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<td></td>
</tr>
<tr>
<td>OBC</td>
<td>67</td>
<td>30</td>
<td>125</td>
<td>48,7</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>LSG</th>
<th>2000</th>
<th>2005</th>
<th>2007</th>
<th>2009</th>
<th>2010</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ci</td>
<td>12139</td>
<td>13836</td>
<td>14747</td>
<td>16077</td>
<td>16527</td>
<td>3,1</td>
</tr>
<tr>
<td>Mu</td>
<td>3354</td>
<td>6093</td>
<td>6784</td>
<td>7853</td>
<td>7576</td>
<td>8,5</td>
</tr>
<tr>
<td>CR</td>
<td>643</td>
<td>826</td>
<td>918</td>
<td>1043</td>
<td>1053</td>
<td>5,1</td>
</tr>
<tr>
<td>OBC</td>
<td>16136</td>
<td>20755</td>
<td>22449</td>
<td>24973</td>
<td>25156</td>
<td>4,5</td>
</tr>
</tbody>
</table>

Source: [9, 10]

Important annual development indicators of PL include: (a) electricity consumption for PL per capita, (b) electricity consumption for PL per m² 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/m² and (c) 5,3 %. Data for towns are presented in Fig. 8 and 9.
Electricity consumption for PL in towns situated in OBC and other towns in Croatia has been carried out. 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 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 made. This consumption increases from 643 MWh in the year 2000 to 1053 MWh in the year 2010 as shown in Tab. 5.

### 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: Strživojna (index 990), Šodolovci (696) and Kneževi Vinograd (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 Vinograd (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 Vilaheo (63,2 kW·h/inhabitant) and Petrijevec (36,5 kW·h/inhabitant); micro region of Dakovo, Levanska Varoš (85,6 kW·h/inhabitant) and Viškovec (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.
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) solutions in lighting engineering, and especially in sector, it is necessary to know contemporary technical problems of energy efficiency in the public lighting sector, the following can be concluded:

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, 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

554 Technical Gazette 19, 3(2012), 549-556
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].

Calculations concerning carbon dioxide emission (CO₂) were performed according to the Regulation on Energy Audits of Buildings [24]; the emission factor per energy unit (kg of CO₂/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 CO₂ 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).

- 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).
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].

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