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A Comparative Study of Outdoor Lighting System Performance

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We analyse in this work three outdoor lighting systems using three types of light sources, in order to determine their performance with respect to outdoor lighting restrictions. The study in this work contributes to gaining insights on how to increase the outdoor lighting systems' energy efficiency. We analyse two LED source types and one sodium fumes light source type, which illuminates various sections on a street in Reşiţa, Romania. Upon analysing and processing the data, we establish the performances of each of the three lighting sources, whether they respect the imposed standards, and which one is the best lighting source to choose. This work shows the necessity of field measurements regarding the lighting system efficiency before the acquirement of a specific system type.

Keywords: *lighting system, efficiency, LED, illumination, luminance*

1. Introduction

One of the European Union requirements from its member states is the increased energetic efficiency. Thus, the Applicant's General Guide to the Regional Operational Programme 2014-2020 [1] introduces the 3rd priority axis – supporting the transition to a low carbon emission economy. This axis has the specific objective "The energetic efficiency increase for residential and public buildings, and of the public lighting systems, especially of those systems that record high energy consumptions." Investments are to be made to changing fluorescent and glowing lighting systems with high energetic efficiency systems and long life time.

Several towns in Romania have implemented a system that uses high energetic efficiency lighting systems and with a long life time, using LEDs, some of them powered by renewable power sources (solar panels) [2].

Starting from this request and trend, Reşiţa city hall installed on two sections of the same street, two types of LED outdoor lighting systems.

To determine the lighting systems efficiency, compared to the currently installed systems based on sodium fumes, we measured the illumination level and the luminance on the three street sections.

2. Technical Characteristics of the Lighting Systems

High pressure sodium fumes lighting bulbs type Eurostreet ET 25 G HPS 150 W, produced by GE Lighting in two variants, tubular and elliptic, have the following features [3]:

- Number of sources – 1;
- Protection factor – IP 65;
- Total output – 171 W;
- Source nominal power – 150W;
- Nominal voltage – 230 V;
- Nominal current – 0.83 A;
- Colour temperature - 2000ºK;
- Nominal flux – 17500 lm, and 14500 lm, respectively.

Fig. 1 presents the light distribution polar curve for this lighting source type.

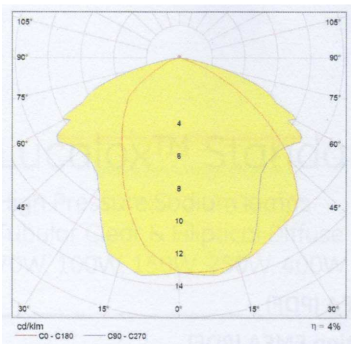

Figure 1. Polar curve of light distribution for high pressure sodium fumes lighting sources

Schréder TECEO LED 2 type lamps [4] have the following features:

- Number of LEDs – 88;
- Protection factor – IP 66;
- Source nominal power – 94W;
- Nominal voltage – 120-277 V;
- Nominal current – 0.35 A;
- Colour temperature - 4250ºK;
- Nominal flux – 12500 lm.

Figure 2 presents the light distribution polar curve for this type of light source.

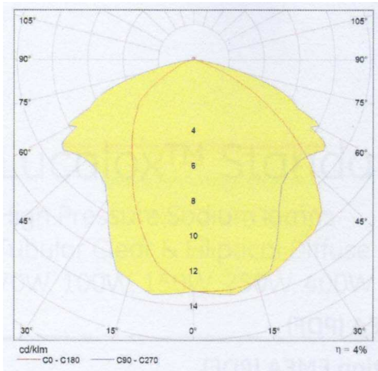

Figure 2. Polar curve of light distribution for Schréder TECEO LED 2 type lamps.

ZGSM Tech – Series-H, LD135H type LED lamps [5] have the following features:

- Number of LEDs – 88;
- Protection factor – IP 66;
- Source nominal power – 135W;
- Nominal voltage – 100-240 V;
- Nominal current – 0.69 A;
- Colour temperature – 3000-5000ºK;
- Nominal flux – 14850 lm.

Figure 3 presents the light distribution polar curve for this type of light source.

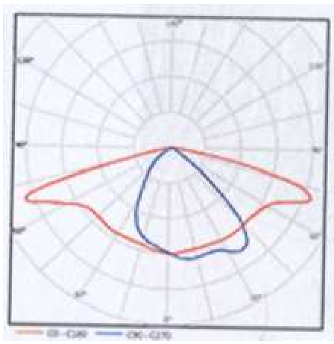

Figure 3. Polar curve of light distribution for ZGSM Tech – Series-H, LD135H type LED lamps.

A direct analysis of the light distribution polar curves we observe that the best light source is the ZGSM Tech – Series-H, LD135H type.

3. Required Constraints for Outdoor Lighting Systems

The STAS SR EN 13201-1:2003 and STAS SR EN 13201-2:2003 standards [6-8] list the requirements that an outdoor lighting system for public streets must fulfil, depending on:

- The driving speed (higher than 60 km/h, between 30 and 60 km/h, between 5 km/h and 30 km/h, and lower than 5 km/h);
- Type of traffic participants (vehicles, cyclists, pedestrians);
- Cleanliness degree of the traffic line measured by the maintenance plan coefficient which can take values between 0.5 and 0.8;
- The layout of the traffic lanes (foot walks, street lane, cycle paths, parking lanes, green areas, emergency lanes);
- Crossway densities (higher or lower than 3);
- Number of vehicles per 24 hours that use the traffic line (less than 4,000, between 4,000 and 7,000, between 7,000 and 15,000, between 15,000 and 25,000, between 25,000 and 40,000, and more than 40,000);
- Special requirements regarding the delinquency risk, the necessity to recognise persons, etc.

6 classes (ME1 to ME6) are established depending on these criteria. For each of these classes the standards establish minimal values for the average luminance, $\overline{L}$, for the average illumination, $\overline{E}$, for the general illumination uniformity, $U_0(E)$, for the general luminance uniformity, $U_0(L)$, for the longitudinal luminance uniformity, $U_l(L)$, for the threshold index, TI, and for the neighbouring area ratio, SR.

The average illumination, $\overline{E}$, and the average luminance, $\overline{L}$, are computed as averages of the respective values measured over the analysed area [9,10].

The general illumination uniformity, $U_0(E)$, and the general luminance uniformity, $U_0(L)$, are computed, respectively, depending on the average and minimal values of the illumination and luminance with the following relations:

$$U_0(E) = \frac{E_{\min}}{\overline{E}}, \tag{1}$$

$$U_0(L) = \frac{L_{\min}}{\overline{L}}, \tag{2}$$

The longitudinal luminance uniformity, $U_1(L)$, is computed by:

$$U_1(L) = \frac{L_{\min 1}}{L_{\max 1}}, \tag{3}$$

where L_{min1} and L_{max1} are the minimal, respectively, the maximal luminance measured on the lane axis along the traffic direction.

Beside these conditions a special care must be payed to:

- The electrical energy consumption (it should be as low as possible);

- The layout of the light posts and the orientation of the lighting devices such that they ensure the best light coefficients and the best visual comfort [11,12];
- The perturbations that are introduced in the system by the lighting devices, such that the energy consumption is not negatively influenced [13,14].

4. Case Study

The study aimed to find the illumination and brightness levels on the Republicii Boulevard in Reșița, Romania, on which three types of light sources are installed.

The technical characteristics of the analysed area, shown in Fig. 4, are:

- A green area, with flowers;
- Roadway paved with a light grey asphalt;
- Parking lane, with the same texture as the roadway;
- Foot walk paved with grey asphalt.

The technical characteristics of the light posts on which the lighting devices are mounted are:

- Distance between two consecutive posts – 32 m;
- Post's height – 12 m;
- Crutch length – 1.5 m;
- Tilt angle – 15 º.

We analysed three different spaces, with the same surface and light posts characteristics.

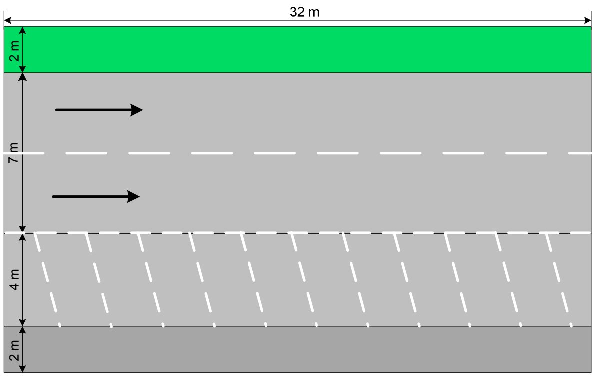

Figure 4. Detail of the analysed area.

The surface we analysed falls into the ME3 illumination class. According to the STAS SR EN 13201-2:2003 and SR 13433 standards, for this lighting systems class the following must be fulfilled:

- The average illumination on the observed surface must be at least E = 20 lx;
- The average luminance on the observed surface must be at least L = 1 cd/m^2;
- The general luminance uniformity must be at least $U_0(L)$ = 0.4 cd/m^2;
- The longitudinal luminance uniformity must be at least $U_1(L)$ = 0.5 cd/m^2;
- The threshold index must be at most TI = 15%;
- The neighbouring area ration must be at least SR = 0.5.

To determine the lighting system quality indices on the analysed surface, we made measurements at each point indicated in Fig. 5, as follows:

- 9 illumination and luminance level measurements on the posts' axis (light posts are installed on the green area);
- 9 illumination and luminance level measurements on the carriageway axis separating the two traffic lanes;
- 18 illumination and luminance level measurements on each of the two traffic lanes;
- 9 illumination and luminance level measurements on the foot walk axis.

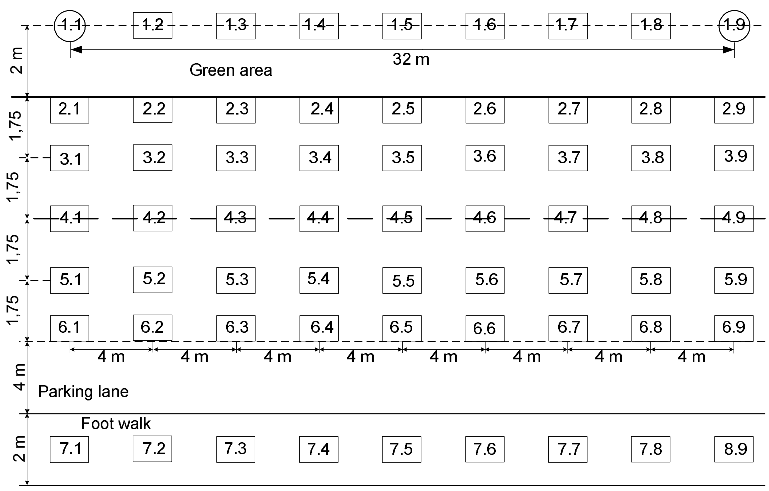

Figure 5. Measurement points for illumination and luminance levels.

The illumination and luminance values for the area where Schréder type lamps are used are shown in Tables 1 and 2.

According to our measurements, shown in Table 1 we found:

- The average illumination on the carriageway is E_{med} = 24.2 lx;
- The ration Emin/Emax = 0.4;
- The general illumination uniformity $U_0(E)$ = 0.57.

The source's luminance value was 2975 cd/m^2.

Table 1

R/C	1	2	3	4	5	6	7	8	9
1	28.6	31.5	24.6	20.5	18.1	21.2	24.6	32.2	27.8
2	31.1	32.2	25.3	20.8	18.8	21.7	25.1	33.9	31.8
3	32.4	32.9	25.8	21.5	19.3	22.3	26.4	32.3	33.4
4	34.2	33.6	26.5	22.2	20.7	23.2	28.2	33.2	34.5
5	25.5	23.4	196	18.2	15.5	16.8	19.3	21.7	27.2
6	20.2	19.8	17.5	14.7	13.9	15.3	16.8	19.8	20.4
7	8.1	7.,7	6.5	5.6	4.6	4.9	5.2	6.3	6.9

Table 2

R/C	1	2	3	4	5	6	7	8	9
1	-	-	-	-	-	-	-	-	-
2	1.72	1.67	1.26	1.13	0.94	1.08	1.41	1.55	1.67
3	1.41	1.37	1.06	0.92	0.77	0.93	1.13	1.34	1.31
4	1.24	1.15	0.95	0.85	0.72	0.84	0.96	1.12	1.19
5	1.12	0.92	0.73	0.68	0.64	0.58	0.69	0.87	0.89
6	1.02	0.83	0.67	0.54	0.48	0.58	0.56	0.66	0.82
7	-	-	-	-	-	-	-	-	-

According to our measurements, shown in Table 2, we have:
- The average luminance on the carriageway is L_{med} = 1 cd/m^2;
- The general luminance uniformity is $U_0(L)$ = 0.48;
- The longitudinal uniform luminance is $U_1(L)$ = 0.58.

The illumination and luminance level values for the street sector where GE Lighting, Eurostreet ET type lamps are installed, are shown in Tables 3 and 4.

Table 3

R/C	1	2	3	4	5	6	7	8	9
1	21.5	21	15.1	11.6	9	10.1	14.7	21.9	22.5
2	23.4	22.9	15.8	12	9.3	10.5	15.2	22.6	24.4
3	25.9	25.6	16.8	12.2	9.5	11.3	16.8	23	26.7
4	27.6	27.4	18.1	12.4	9.8	11.9	17.2	24.4	27.5
5	25	22.2	14.2	11.5	8.8	9.2	11.8	19.6	21.6
6	21	20.3	13.8	11.3	8.5	7.9	10.6	15.7	20
7	12	10.4	8.2	9.3	7.8	8.6	8	9.3	11

According to our measurements, shown in Table 3, we have that:
- The average carriageway illumination is E_{med} = 17.18 lx;
- Emin/Emax = 0.31;
- The general illumination uniformity is $U_0(E)$ = 0.49.

The light source's luminance was 6,964 cd/m^2.

According to our measurements, see Table 4, we have that:
- The average carriageway luminance is L_{med} = 0.91 cd/m^2;
- The general luminance uniformity $U_0(L)$ = 0.48;
- The longitudinal luminance uniformity is $U_1(L)$ = 0.37.

Table 4

R/C	1	2	3	4	5	6	7	8	9
1	-	-	-	-	-	-	-	-	-
2	1.75	1.5	0.89	0.65	0.53	0.8	1.05	1.78	2.02
3	1.41	1.19	0.8	0.6	0.51	0.57	0.84	1.51	1.66
4	1.17	1.08	0.73	0.52	0.49	0.52	0.71	1.21	1.31
5	0.94	0.88	0.64	0.48	0.46	0,.47	0.64	1.13	1.23
6	0.88	0.81	0.55	0.46	0.44	0.45	0.62	1.05	1.17
7	-	-	-	-	-	-	-	-	-

The illumination and luminance levels values on the street sector where type H-Series – Street Lights – Lighting tip ZGSM.LD 135 H lamps are installed are shown in Tables 5 and 6.

Table 5

R/C	1	2	3	4	5	6	7	8	9
1	26.8	24.8	20.1	15.9	14.9	16,3	19.2	22.5	23.6
2	27.5	25.3	22.5	16.5	15	17.2	21.3	25.6	26.1
3	28.3	27.5	25.1	17.3	16.5	17.8	22.3	26.7	28.9
4	31.4	28.1	27.3	18.6	17.2	18,5	22.6	27.8	30.7
5	24.4	22.6	19	16.4	13.7	14.8	17	19.7	22.2
6	23.8	22.1	18.4	15.3	11.1	13.9	15.6	18.1	18.6
7	20	18.7	15.5	12.8	10.9	11.1	12.2	14	14.6

According to the measurements we made, shown in Table 5, we have:

- Average carriageway illumination E_{med} = 21.25 lx;
- Emin/Emax = 0.35;
- General illumination uniformity $U_0(E)$ = 0.52.

The source's luminance was 9,000 cd/m^2.

Table 6

R/C	1	2	3	4	5	6	7	8	9
1	-	-	-	-	-	-	-	-	-
2	1.91	1.73	1.32	1.07	0.95	1.09	1.32	1,61	1.39
3	1.63	1.49	1.14	0.9	0.83	0.93	1.12	1.3	1.27
4	1.34	1.23	1.06	0.84	0.68	0.74	0.85	1.1	1.02
5	1.25	1.12	0.9	0.71	0.65	0.68	0.82	0.91	0.99
6	1.14	1.08	0.78	0.64	0.57	0.59	0.74	0.83	0.89
7	-	-	-	-	-	-	-	-	-

Following the measurements presented in Table 6 we have:

- Average carriageway luminance L_{med} = 1.05 cd/m^2;
- General luminance uniformity $U_0(L)$ = 0.54;
- Longitudinal luminance uniformity $U_1(L)$ = 0.51.

We note that this light source has a much higher brightness than all other light sources we analysed. This brightness is visually disturbing for traffic participants.

5. Conclusion

The analysis we presented here was done in order to have a basis to choose the optimal outdoor lighting system for traffic streets in the city of Reșița Romania. The criteria by which we choose the optimal lighting system are fulfilling the quality coefficients given by EU and national standards, which ensure the visual comfort of traffic participants. Table 7 presents a summary of our observations.

Table 7

Coefficient	Schréder type lighting systems	GE Lighting type lighting systems	Lighting ZGSM.LD 135 H type lighting systems
Source brightness	2975 cd/m^2	6964 cd/m^2	9000 cd/m^2
$\overline{E}$	24.2 lx	17.18 lx	21.25 lx
E_{min}/E_{max}	0.4	0.31	0.35
$U_0(E)$	0.57	0.49	0.52
$\overline{L}$	1 cd/m^2	0.91 cd/m^2	1.05 cd/m^2
$U_0(L)$	0.48	0.48	0.54
$U_1(L)$	0.58	0.37	0.51
P	94 W	171 W	135 W

From these results we conclude that:

- The GE Lighting and Eurostreet ET light sources types do not ensure an minimum of 20 lx average illumination;
- The average minimum levels of the luminance level, of the traffic lane axis luminance uniformity and on the entire surface is fulfilled by all three light sources analysed;
- The best illuminance uniformity is shown by the Schréder type light sources;
- Using a Schréder type lighting system reduces the installed capacity with 45.03% compared to the GE Lighting, Eurostreet ET light source type;
- Type H-Series – Street Lights – Lighting type ZGSM.LD 135 H lights have the highest brightness, provoking the most visual discomfort to the traffic participants.

We conclude, therefore, that, out of the three analysed light sources, the most efficient light source that offers the best visual comfort as well as a significant decrease in electrical energy consumption is the Schréder type light source.

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