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Recommendations for energy efficient and visually acceptable street lighting

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ABSTRACT

While designing new street lighting installations or dealing with reconstructions of the existing ones, lighting designers usually do not take into consideration all of the available means for energy savings and optimal performance. This paper offers a set of the most important recommendations regarding the relevant influencing factors for energy savings in street lighting, the majority of which represent the results and conclusions of original research. Recommendations which result from user needs and regard visual quality are also briefly presented. Taking all of these recommendations into account provides improvement of appearance and sense of security, as well as energy and cost savings.

1. Introduction

Public (predominantly street) lighting participates with 2.3% in global electricity consumption [1]. Since possibilities for energy savings in street lighting are numerous and since some of them enable reductions in electricity consumption of even more than 50%, energy-efficient programs in this field are very welcome.

Street lighting is often considered taking into account only one or few specific “drivers”. The role of the designer is to help the municipal officers include other important drivers into the overall project goal in order to achieve an optimal lighting solution, which will reduce municipal electricity and operating costs, meet traffic and pedestrian safety requirements, increase sense of security, minimize glare, limit light trespass and light pollution, support economic development, improve aesthetics,… [2].

At present, towns throughout the world are engaged in street lighting reconstructions. They are carried out as:

- the changeover to more efficient luminaires at the end of the economic life of the existing ones, and
- the changeover to more efficient luminaires before the end of the economic life of the existing ones, intended either to reduce electricity consumption, greenhouse gas emissions and costs, or to create attractive street lighting which municipalities consider to be the key component of their downtown revitalization plans [3].

The most common activities include the replacement of the existing luminaires equipped with high pressure mercury (HPM) lamps by modern luminaires with high pressure sodium (HPS) or metal-halide (MH) lamps, gaining considerable energy savings and sometimes increased sense of security. Also, the old luminaires with IP54 degree of protection (dust protected and protected against splashing water) and conventional HPS lamps are being replaced by modern luminaires with improved optics, better mechanical protection (usually IP65: dust-tight and protected against water jets) and HPS lamps of improved photometric and technical properties. Through such actions, sometimes with reason, but more often not, upgrades [3], attempting to reuse the existing poles, pole locations and luminaire mounting locations, are applied.

Very often, taking into consideration only the photometric requests, energy savings, maintenance period and the cost of installation, HPS lamps, characterized by poor colour rendering, are inappropriately applied (in parks, squares, promenades, shopping areas, etc.), creating an unpleasant ambience.

With energy savings as the goal, dimming systems are sometimes applied (in the form of step-dimming ballasts or centralized control systems), frequently without adequate information regarding their installation and application.

Due to the fact that designers most often do not exploit all of the available possibilities for energy savings, this paper is intended to sum up as many relevant influencing factors as possible, and to offer recommendations intended for both energy savings and optimal performance of street lighting.

The following two sections contain a concise statement for each of the recommendations, which is followed by detailed explanations and/or precise directions.

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Note that scientific papers dealing with street lighting strategy plans are extremely rare [3,4], while the situation with indoor lighting is quite different (see, for example, references [5–12]). Fortunately, there are available reports on street lighting strategy published by authorities of cities like New York, Sydney, Melbourne, Salzburg,... [2,13–19].

2. Recommendations relevant for energy savings

2.1. Prior to reconstruction of street lighting a choice between an upgrade and redesign should be made (redesigns are not constrained by existing equipment and equipment locations [3])

Reconstruction of street lighting requires adequate design. However, sometimes upgrades are not based on lighting design (which should be made using licensed software), but on the experience gained from previous reconstructions (for example, luminaires with HPM lamps of 400 W are replaced by luminaires with HPS lamps of 150 W, which are usually considered equivalent). If in such cases lighting levels existing prior to reconstruction were higher than necessary, electricity consumption will remain excessive. A distinctive example is represented by a recent demo installation on Dimitrija Tucovica street in Belgrade, where the existing luminaires (IP54) with conventional HPS 400 W lamps were replaced by new luminaires with improved optics, IP66 degree of protection (dust-tight and protected against heavy seas) and HPS 250 W lamps with improved photometric and technical characteristics. The maintained luminance levels (those existing at the end of the maintenance period) before and after the reconstruction amounted to 4.79 cd/m^2 and 4.42 cd/m^2, respectively. The photometric calculations showed that HPS lamps of only 100 W could be used, producing the maintained luminance level of 1.52 cd/m^2, which is practically equal to the requested 1.5 cd/m^2 (according to reference [20], this street belongs to the ME2 lighting class, for which the minimum average road surface luminance equals $L_{av} = 1.5$ cd/m^2, the minimum overall and longitudinal uniformity ratios are $U_o = 0.4$ and $U_l = 0.7$, and the maximum threshold increment is TI = 10%).

Based on the lighting design, an economic comparison of the upgrade and redesign solutions can be done, by the application of the generally accepted cost-discount method [4], which takes into account not only initial (investment), but also electricity and maintenance costs within the exploitation period (20–30 years).

2.2. Special attention should be given to the determination of the street lighting class

The procedure presented in the valid CEN document [20] is recommended, because it precisely leads the designer to the determination of the street lighting class, taking into account numerous influencing factors (typical speed of the main user, other allowed users, excluded users, separation of carriageways, types of junctions, interchange spacing, intersection density, traffic flow of vehicles, cyclists and pedestrians, difficulty of navigational task, parked vehicles, facial recognition, crime risk, complexity of visual field, ambient luminance, etc.). The majority of the procedure steps are based on objective criteria, and not on subjective evaluation. On the contrary, the determination of the street lighting class according to the relevant CIE document [21] is based on a few influencing parameters only, which are evaluated subjectively. For example, high speed roads and dual carriageway roads are classified into the following two street lighting classes: M1 ($L_{av} = 2$ cd/m^2) and M2 ($L_{av} = 1.5$ cd/m^2). In order to choose between M1 and M2, all the designer has to do is to decide if traffic control and separation of different types of road users (taken as a single parameter!) is poor (M1) or good (M2). In addition, the guide aimed to differentiate "poor" from "good" is not precise.

Since all of the photometric requests and, consequently, lamp power and pole spacing depend on the street lighting class, considerable energy savings could be achieved by its adequate determination.

2.3. Measurements for determining the road surface reflection properties are recommended

The reflection properties of the road surface, which considerably influence its luminance level, can be defined with sufficient accuracy by using only two easily-measured parameters:

- S1, which indicates the degree of specularity of the road surface, and
- Q_0, which indicates the level of the total reflectivity (or lightness) of the road surface (see, for example, reference [22]).

Using the commonly used R classification system, each dry road surface belongs to one of four standard classes (RI-RIV), the classification being made only according to the value of the S1 factor. Each of the standard classes is described by a corresponding reduced luminance coefficient table (also called a reflection table, or r-table) and the normalized Q_0 coefficient, on which the luminance calculations are frequently based. Since the measured value of Q_0 usually deviates from its normalized value, and since the luminance level is linearly proportional to Q_0, the photometric calculations should be performed using the actual (measured) value of Q_0 (whenever the calculations are based on the normalized value of the Q_0 coefficient lower than its actual value, electricity consumption is higher than necessary).

An additional possibility for energy savings is offered by the Schréder Group GIE which developed a mobile (portable) reflectometer. This device, the accuracy of which has been validated on numerous actual road surfaces, enables on-site measurements of road surface reflection properties. Easy to use, it provides the possibility for quick measurement of road surface reflection properties at all relevant points of the surface. The developed software calculates not only the value of Q_0, but also the elements of the corresponding r-table, which more accurately describe the reflection properties than the Q_0 coefficient and r-table attached to the selected standard class of the R system. The use of this data enables accurate calculations and therefore prevents excessive electricity consumption.

Using computer-aided design, the optics of a luminaire can be designed to maximize light reaching the road surface [19]. However, the luminance level and uniformities considerably depend on the road surface reflection properties. Bearing this in mind, the designers of the Schréder Group GIE constructed a luminaire (Furyo) with two available reflectors, one of which is suitable for concrete roadways, characterized by diffuse reflection ($\approx$RI), while the other is suitable for asphalt roadways, characterized by semi-diffuse reflection ($\approx$RIII).

2.4. If HPS lamps are applied, they should be with improved photometric and technical characteristics

HPS lamps with improved photometric and technical properties, introduced a few years ago, have the following advantages compared with conventional lamps of this type:

- higher efficacy (up to 150 lm/W),
- higher resistance to shocks and vibrations, and