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Public Lighting in Portugal: Standardization and Results

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Abstract:

Outdoor public lighting (PI) is a major concern on design and manage cities. PI standardization has been of interest not only at national level but also at the European Commission. In the present work a brief review is made on standardization and legislation on PI. There are PI international regulations applied in different countries in the absence of a national standardization. The installation of public lighting requires compliance with EN 13201, which determines the type and intensity of illumination on the road depending on its use (rural or urban). The present paper is a milestone on the standardization and results in Portugal.

Keywords:

Road and Pedestrian Street Lighting, Standardization, Luminance, Energy Efficiency

1. Introduction

The level of road lighting is directly related to safety at night [1,2]. The PI reduces the collision rate between 5 % and 58 % [3]; the average for collision reduction is 30 % [4]. But, PI management is not only a road safety measure; it can also be a problem due to energy consumption [4]. The US Federal Highway Administration (1990) developed a study in the United States; they found that nighttime accident rates were five times higher than daytime accident rates: approximately 50 % of fatalities occurred at night [2]. In summary, it has been proven that PI reduces the rate of accidents at night.

The amount of light influences the choice between going on foot or vehicle [5] in relation to security / crime, that is, people are less "frightened" at night because of PI. In addition, the PI facilitates the proper detection of obstacles as a precautionary measure for tripping hazards (it is considered an obstacle when it is not perceived in time to avoid collision) or road collisions [6,7]. Researchers consider tripping hazards: uneven pavement, a slab or raised terrace lid, a hole in the pavement, construction work, "abandoned" or poorly "parked" bikes, poorly parked cars, street furniture, etc.

There are three methods for evaluating road illumination systems: illuminance, luminance and the shortest distance for target visibility [2]. The illuminance method is

mainly used for field evaluation of road lighting systems because it is easy to obtain the data, especially because portable light meters are used. There is an achromatic contrast threshold for discrimination of a quasi-static target. It is the ability to identified correctly obstacles at night under the minimum amount of light [8]. There are studies and standards that define the minimum level appropriate lighting for pedestrians [7]. However, drivers have different needs from pedestrians to see obstacles and other hazards [7]. Each municipality needs to consider the lighting levels recommended in European standards [9]. European standards, in turn, can be transposed into the legislation of each country.

Other relevant aspect of PI is cost. Energy efficiency is one of the seventeen sustainable development objectives proposed for 2030 by United Nations. "The management of the PI cities systems has an impact on municipality's budgets. Therefore, optimization has become relevant" [10]. Luminaires maintenance is one of the issues for efficient energy consumption (i.e. the stand where lamps are mounted, when neglected can lead to a significant waste of energy) [10]. According to [10], replacing the PI system with the best technological alternative allows both a very significant reduction of energy consumption and CO_2 emissions reduction. These reductions mean both economic and environmental benefits to municipality and society. However, modernization of PI systems demands considerable investments.

On the other hand, continuous evolution is foreseen and municipalities increasing awareness is expected. Currently, PI project contemplates three factors: a) sustainability to reduce environmental impact of energy consumption, investing in the use of renewable sources, and awareness of consumption efficiency; b) rationality, that is the increasing of social-environmental awareness in order to encourage active participation; and c) efficiency to reduce losses occurring in energy distribution networks. An efficient PI requires an intelligent system that allows the identification of faults and the control of light levels, which can increase in the hours of greater use and decrease in the hours of less use [11]. According to [10], it is recommended monitoring of: LED technology evolution, luminaire performance, and control and supervision technologies such as tele-management associated with flow regulators and motion sensors.

It is well known that LED-based luminaries perform better than retro reflective devices. They perform not only traditional road lighting functions. They can be seen at a greater distance and with a wider range of viewing angles. Besides, they are low energy consumption [12]. According to researchers on curvature roads, LED are visible 300 m away by drivers, which helps to reduce collision risk. But LED technology, as any other one, requires the statement of selection criteria because of safety and energy efficiency issues.

It was verified that PI designers in Portugal use international and European standards to advise and idealize the projects in order to contribute to: lighting quality during night time, safety and energy efficiency.

2. Materials and Methods

In view of the diversity of PI regulations, the objective was the compilation of illuminance and luminance normative thresholds in different circulation areas as a way to contribute to safety and energy efficiency.

An PI literature review was carried out on the most applied international and European standards, namely on road and pedestrian traffic, and its transposition into Portuguese legislation. For the Portuguese study case the requirements of road and pedestrian lighting of national legislation were validated by comparison with the Reference Document for Energy Efficiency in Public Lighting

3. Review

PI is required for lighting and security [13]. A public lighting standard is required to ensure proper installation and provides a basis for public procurement. In 1927, the British Standard (BS) identified eight lighting classes defined by the minimum mounting height and the maximum space / height ratio [14]. The level of illuminance was also defined for each of the eight classes, ranging from 0.1 lux to 21.5 lux. According to [9], [14] and the British Standard may be considered the first milestone in the technical progress of street lighting. Waldram suggested a second milestone that was the field study in 1928, in Sheffield, UK, that studied 52 experimental facilities. Since then, the types of lighting have been changing. As an example, BS in 1992 recommended three types of lighting for secondary roads with horizontal illuminances of 3.5 lux, 6.0 lux and 10 lux [9]. These minimum rates were not intended to be considered as mandatory but as a classification of the amount of light required. Many early standards served to describe the characteristics of the lighting system rather than performance metrics such as lighting or luminance. It happened partially because there were only a limited range of lamp types available. BS 1974 recommended distance spacing between poles according to road width. This remained the main approach to lighting design until late 1980s [9]. Since then, the use of computers for lighting projects has become a commonplace.

Outdoor lighting influences considerably the consumption of electricity. It demands the selection of lighting type. Therefore, the International Commission on Illumination (CIE) developed PI procedures for streets and roads with motor or mixed traffic. Several modifications of the CIE process of 115-2010 were implemented. The modifications were related to traffic composition and ambient light, as well as the inclusion of a value related to the complexity of the visual field. Also it was discussed the need for further investigation on the selection of lower lighting classes during late night hours.

3.1. International Commission on Illumination

The International Commission on Illumination (CIE) is the leading international organization in lighting, founded in 1913 and recognized by the International Organization for Standardization (ISO). This organization comprises 38 countries (24 Europeans). Portugal is not represented in CIE [9]. All members have a national body to coordinate lighting-related activities. Examples: Spanish Lighting Committee (CEI), French Lighting Association (AFE), German Lighting Cooperative (FGL), Institution of Lighting Engineers (ILE) in England, Hellenic Illumination Committee (HIC) in Greece. The CIE develops procedures for category and quality of PI. CIE describes two main objectives of road lighting: (1) to enable all users, including drivers of motor vehicles, motorcycles, bicycles and animals to be seen; and (2) to allow pedestrians to see the dangers, to orient themselves, to recognize other pedestrians giving them a sense of safety [9]. Another factor to consider is the luminance levels of road surfaces that are generally very dynamic and depend on weather conditions [15]. Since the publication of CIE 115 (1995), energy consumption and environmental

aspects became relevant, and a better performance of lamps and lighting were considered. On the other hand, the introduction of electronic control equipment made it possible adjustable lighting for roads. A structure was developed to select the appropriate lighting type based on the luminance or illumination concept, taking into account parameters relevant to visual field [9]. It was also applied, for example, time-dependent variables such as traffic conditions, volume and time, so that the model offers the possibility of using adaptive lighting systems. Guidelines and standards for road lighting are provided: i.e. it is provided recommendations for the appropriate level of luminance or brightness and color. Regarding the PI issue of roads and streets, some examples of standards are mentioned: the CIE 115:2010, BS 5489-1: 2013, European standards (EN) 13201-1:2014, EN13201-2:2015, and Illuminating Engineering Society of North America (IESNA) founded in 1906 / American National Standard for Roadway Lighting (ANSI) IESNA / ANSIRP-8:2014. These procedures were written and analyzed by committees of a wide range of stakeholders: manufacturers, designers, installers, politicians and researchers. In addition, they carry out empirical research to provide recommendations according to current needs. The discussion focuses on road lighting that affects pedestrians and drivers. The categorization used by the CIE distinguishing the two sets of lighting recommendations established by the European standard EN 13201: M-classes and P-classes. M-class is intended for drivers and vehicles routes. P-class is intended for pedestrians and cyclists, also for drivers at low speeds (40 km / h) [9].

3.2. The normalization EN 13201

Normalization regulates indirect light flow to the minimum required by safety standards to avoid unnecessary waste of energy (over lighting), while ensuring adequate safety and energy savings. Therefore, it is evident the importance of measuring the effective degree of luminance in a section of the road and comparing it with the minimum required by law [16].

Santos [17] analyzes the European standard EN 13201 developed by the European Commission of Normalization (CEN). It is divided into four parts: a) EN 13201-1 establishes the methodology for selecting the class of lighting according to each outdoor type area; b) EN13201-2 defines the photometric values for each lighting class; c) EN13201-3 defines the network-based calculation method for each area and how to measure its photometric parameters; and d) EN13201-4 recommends methods for measuring lighting performance in already installed systems.

Each type of circulation path is associated with more than one illumination type. A lighting type is defined taking into account a set of photometric requirements that indicate the user's visibility needs upon the type of roads and areas [18]. In Portugal, there are three categories of roads under the PI point of view: fast (R), mixed (M) and slow (L). They address types of traffic, speed and EN 13201-2 lighting type published in 2003 [18]. The lighting type requirement is consequence of the categories of road ´ user and road area. That is, the lighting type should fulfill the visual needs of road 'users, and considers environmental aspects of road lighting [19]. Local lighting should provide adequate pedestrian traffic lighting [19].

4. Results and Discussion

4.1. Management Tools and Portuguese Regulations

The lack of Portuguese PI national legislation contributed to the adoption of international standards [20]. According to [20], a non-binding proposal elaborated by the European Federation of Agencies and Regions for Energy and the Environment (FEDARENAE) in partnership with the Portuguese Center of Lightening (CPI), and the Portuguese Engineers Association was submitted to the Secretary of State for Energy and Innovation of the Ministry of Economics, Innovation and Development of Portugal (SEEI / MEID).

PI installation complies with EN 13201, which determines the type and intensity of street lighting depending on rural or urban use. Decree 454/2011 [21] of Portuguese National legislation provides some standardization rules for municipalities and concessionaires, mainly referred to responsibility and cost sharing.

Portuguese contracts for distribution licenses of low-voltage electricity, such as PI, are linked to Decree no. 344-B / 82 [22], of September 1, modified by Decree no. 341/90 of October 30 [23], Decrees no. 182/95 [24] and 184/95 [25], both of July 27. Regulation (administrative mandate called Portaria) No. 90-A / 92 of February 10 [26] and Regulation 454/2001 of May 5 [21] establish the clauses of the contract license for distribution of low-voltage electricity. According to Águas [27], in Regulation no. 454/2011 [21], article 30-2, when a City Council decides to implement a new PI networks, it is the concessionaire responsibility the installation of municipality current type lighting, distribution network, installation labor, connection and disassembly. Considering also the same Regulation, it is established that if the City Council decides to choose light poles, lighting fixtures or lamps of a different type, it will be the concessionary's responsibility to bear the cost exceeding. According to Águas [27], it makes extremely difficult the decision making regarding new models for new projects. According to Águeda, the municipality is obligated to provide the resources for projects to remodel or change existing supports or lamps. "The costs for facilities maintenance also limit the freedom of equipment choice. In fact, only when the equipment is of standard type and the concessionary fully assures the maintenance costs of the lighting fixtures and their supports…" [27]. Therefore, the option for non-standard equipment implies that a City Council supports all these costs [21, article 31-4].

Regulation no. 454/2011 [21], Annex III defines the types of current light sources to be used in a municipality. The overall illuminance and uniformities recommended for rural areas, aerial and underground networks are shown in Table 1. The urban centers are those that require more illumination compared to the peripheries (Table 1 / Table 6). The same Regulation also refers to some recommendations regarding lamps safety perception. Safety is higher when the amount of lamp light is larger and the lamp is brighter (measured in W) [1]. The classification and methodology for determining the indicators can be found in EN 13201-2: 2015, which are referred to in the Reference Document for Energy Efficiency in Public Lighting [28].

Illuminances in the range of 0 to 10 lux, small increasing in illumination produces large increasing in safety citizen perception [1]. For illuminance above 50 lx, the increasing of illuminance makes no difference to perceived safety. According to Boyce et al. [1] it is required around 30 lux for outdoor lighting to be seen as an example of good lighting and safe for pedestrians that walk alone at night. Fotios, Uttley & Hara [7] studied the recommended illuminance effect for residential streets in the UK. It ranged from 2 lux to 15 lux. These results are close to the values established by Regulation No. 454/2011: minimum of 5 lux (aerial network) and a

maximum of 25 lux (streets). Rombauts, Vandewyngaerde & Maggetto (1989) [29] confirm the maximum recommended value 25 lux because values above 25 lux do not increase the recognition of "objects" as in the case of illuminance in residential streets.

Table 1. *Illuminance and uniformities recommended for rural areas: aerial and underground network [21, annex III].*

Sites	Underground network	Aerial network
Downtown, streets layout, main streets	15 lux	10 lux
Suburbs	10 lux	5 lux
Global uniformity (minimum average)	0,35	0,35

Table 2. *Lights for rural areas [21, annex III].*

Rural areas	Lights
Streets layout	VSAP 70 W e 100 W
Garden	VM 80 W e 125 W

Table 3. *Urban areas [21, annex III].*

Urban Areas	Recommended global illuminance and uniformity
Streets layout and main streets	25 lux
Suburbs	20 lux
Global uniformity (minimum average)	0,4

Table 4. *Lights for urban areas [21, annex III].*

Urban areas	Lights
Streets layout	VSAP 70 W, 100 W e 250 W
Garden	VM 80 W e 125 W

Table 5. *Old city center [21, annex III].*

Urban areas	Recommended global illuminance and uniformity
Downtown	20 lux
Surrounding area	15 lux
Global uniformity (minimum average)	0,35

Table 6. *Lights for old city centers.*

Old city centers	Lights
Streets layout	VSAP 70 W, 100 W, 150 W e 250 W
Garden	VM 80 W e 125 W

Outdoor luminaires and specifications recommended by degree of protection are described in Table 7 and 9.

Table 7. *Luminaries [21, annex III].*

Types/Sites
Vehicular traffic routes
Low pollution areas

Table 8 .*Luminaries [21, annex III].*

Enclosed luminaries (with diffuser), minimum protection degrees	Types
Accessory compartment	PI 43; IK08
Optimal fixture	PI 54; IK08

Table 9. *Luminaries [21, annex III].*

2. High polluted area	Types
Accessories compartment	
Enclosed luminaries (with diffuser), minimum protection degrees	
a) Accessories compartment	PI43; IK08
b) Optic compartment	PI65; IK08

High polluted areas are: sea coast areas, industrial complexes and urban areas with intense automobile traffic. Areas of low pollution are describen in Table 10.

Table 10. *Low polluted areas [21, annex III].*

Gardens	Spherical (or ball) luminaires with PI54 minimum protection range; IK10, diameter 450 mm, light reflecting equipment (reflector).
Old City Centers	Non-standard material. In the case of current types of materials defined in the standard, the cost is paid by the company Energias de Portugal (EDP).

"Arms and light poles" [21] is used to:

(a) Aerial networks: galvanized iron pipe arms, according to the Directorate-General for Energy design.

(b) Undergrown network: hot dip galvanized poles, useful height 8 m, 10 m and 12 m, octagonal section with identical, single, double or triple arms, with compartments of 0,75 m or 1,25 m; metal columns, hot-dip galvanized, 4 m high, octagonal cross-section.

(c) Old city centers: non-standarized. In the case of current types of materials defined in the standard, the cost is paid by EDP.

Regulation no. 148/84 of March 15 [30] establishes a concession agreement for low voltage electricity distribution. This is celebrated between a municipality and EDP. However, Regulation [26] modified some of the contract clauses. Subsequently, due to changes in the law, and due to technological innovations, another model of contract was published in Regulation [21,27]. The contract specifies that the low voltage network comprises the voltage transformation substations, the low voltage lines, the branches, the public space lighting installations, and equipment and accessories. Public space lighting networks are generally owned by the City Councils and, by license contract, the network is generally managed and maintained by EDP [27]. The Energy Efficiency Fund (FEE) is a financial instrument defined in Decree Law no. 50/2010 [20], which finances programs and measures foreseen the implementation of the National Plan for Energy Efficiency (PNAEE). The FEE activity is in line with "Portugal 2020" economic, social and territorial development policy [32]. FEE contributes to achieve the targets set for a reduction in energy consumption of 25 % by 2020, Council Resolution of Ministers no. 20/2013, 10 April 2013 [33]. The progress and efforts made by EU Members to achieve the targets by 2020 have enabled the establishment of new targets for 2030 (late 2014) to reduce energy consumption by at least 27 % [34].

4.2. Review

Outdoor PI contributes to streets and roads safety. A lighting management system tailored to the needs of users can also be financially efficient. PI savings are of public interest because it is associated to sound financial management in face of excessive municipal spending. In order to optimize PI projects, it is mandatory to take in

account local characteristics and comply with applicable international and local legislation.

The diverse types of lighting in roads and pedestrian routes must be adjusted. It depends on the amount of light required during the night time. Safe driving during the night depends on the amount of light on the roads and streets. Legislation is an indispensable tool for management of this public good, which contributes to citizen's safety as stated in the international, European and national regulations. However, further research is required to study the needs of lightening of large diversity of sites. The designers and managers require "guiding" tools for municipal PI management systems.

In order to contribute to sustainable development goals, investment in LED technology is required to reduce energy costs and even reduce the amount of CO_2.

It should be noted that national legislation lacks of information compared with international and European standards. Therefore, designers are obliged to take international instruments as guide to meet minimum quality standards, such as the design of luminaires

5. Conclusion

The level of road lighting is an important factor for night safety. The legislation has focused on the safety of all road users: drivers and traffic routes, pedestrians and cyclists. International standardization such as the CIE, EN, IESNA / ANSIRP have contributed to PI quality and efficiency. They have contributed to the national regulation regarding the types of public lighting; they take in account the luminance according to each site characteristics.

The parameters and the respective indicators for public lighting are minimum values and can be increased according to the Reference Document for Energy Efficiency in Public Lighting.

However, the dossier is not closed; there are still a number of possible improvements to implement.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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