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Impact of public lighting on pedestrians' perception of safety and well-being

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ABSTRACT

A survey was conducted of 275 pedestrians in a nocturnal urban environment in the city of Granada (Spain). The objective was to evaluate user perceptions of the impact of different kinds of public lighting on perceived safety from criminal actions and on general well-being (avoidance of stress, glare, headaches, etc.). As part of the study, average illuminance was also measured in each street to detect potential correlations between survey data, illumination levels, and color of light. The results of this study indicate that well illuminated streets (that is, where lighting is uniform) with higher illuminance levels, tend to make people feel safer and better. This marked preference for more light is now less of a drawback because modern LED lighting permits higher levels of illuminance with low electricity consumption. It was also found that, besides the lower economic and environmental impact of High Pressure Sodium (HPS) lighting, stemming from the significant reduction in light pollution, the results generally indicated a better performance of this kind of lighting. However, despite the fact that white light could lead to higher levels of light pollution, it seemed to make people feel safer. These facts should be seriously considered by lighting engineers, urban planners, and city administrators when making difficult decisions about the design of lighting installations.

1. Introduction

The main objective of public lighting is to ensure the safety of people, property, and goods. However, the different ways of implementing lighting installations and their economic, environmental, and social costs have led researchers and engineers to question the accuracy of crucial parameters such as light intensity and color as indicators of the performance of lighting installations.

The economic and environmental impact of light intensity is evident since installations with higher illuminance levels (luminous flux per unit of surface on the ground as required by regulations (International Commission on Illumination, 2010) need more powerful light sources, which, of course, consume more electricity. Consequently, lighting installations with a lower average illuminance are more economical, efficient, and environmentally friendly than those with a higher average illuminance.

In addition to the economic impact stemming from higher electricity consumption, the environmental impact from higher levels of greenhouse gas emissions (as well as other emissions) is an important factor to be considered. In the city of Granada (Spain), administrative records show that the annual electricity consumption from public lighting is 23.3 GW h and that the installed power per inhabitant is 24 W. These figures evidently justify a reduction in electricity consumption by public lighting as long as this does not negatively affect the safety and comfort of city residents.

Nonetheless, this is an extremely complex problem that brings to the foreground the controversy regarding illuminance levels and safety (Peña-García, 2008). No consensus has been reached on this issue, and thus there is still a great deal of uncertainty regarding the most effective solution. It seems clear that increased street lighting reduces fear of vulnerability to criminal action in city residents, regardless of age or gender (Tien et al., 1977). This was also reflected in the sample population of pedestrians (Painter, 2009) who responded to our survey. However, other researchers, who conducted similar studies, found that in spite of the fact that their respondents felt safer, there was no statistically significant evidence that street lighting impacted the level of crime (Tien et al., 1977).

Although the controversy about light intensity levels still persists (Peña-García, 2008), it should be underlined that there is a

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great difference between ‘more light’ and ‘better light’. In this sense, the results obtained by certain researchers indicate that ‘better light’ enhances safety (Painter and Farrington, 1997, 1999). Alternate ways of achieving cheaper and more environmentally friendly public lighting, such as the optimization of the geometrical parameters of the installation for maximum efficacy and uniformity (Gómez-Lorente et al., 2013; Rabaza et al., 2013), are also the current focus of active research. This reflects the importance of public lighting installations with a high-performance capacity in the daily life of urban communities.

The second parameter analyzed in this research study is the color of the light emitted by public lighting installations. This color has a significant impact on financial and environmental costs. Moreover, it also affects the well-being of city residents. This is directly related to the physical phenomenon of light scattering by the molecules and particles in the atmosphere. The light scattering model used depends on the size of the particles (Iqbal, 1983). In the case of air molecules and particles smaller than the wavelength of light, the Rayleigh theory applies (Strutt, 1899). However, if the size of the scattering particles is larger (e.g. aerosols) and independent of light wavelength, then the Mie scattering theory applies (Mie, 1908).

Of the two light scattering models, Rayleigh scattering, which is approximately 18 times more intense for blue light than for red light, is more relevant for public lighting (Iqbal, 1983). Rayleigh scattering is responsible for the blueness of the sky in the daytime and the redness of the sunset. Despite being the cause of such beautiful atmospheric phenomena, Rayleigh scattering also produces light pollution because the scattered light does not illuminate the streets, but rather goes out in all other directions with the subsequent waste of energy and disturbance for astronomical observations.

Given that the white light of public lighting emitted from Metal Halide (MH) or LED lamps has a higher content of blue light (which is more intensively scattered) than the amber or yellow light (also known as yellow-sodium light), emitted from High Pressure Sodium (HPS) lamps, the choice of light color is extremely important from an environmental point of view. In fact, this choice also has an economic impact because the corrective measures required to mitigate the consequences of light pollution are costly.

In addition, there is an important controversy about whether yellow light is more beneficial than white light. More specifically, mainstream research states that yellow-sodium (Y-S) light (i.e. light emitted by HPS light sources) enhances visual performance (de Boer, 1967) whereas other studies claim that white light (metal-halide or LED light sources) permits facial recognition in pedestrian areas, increases well-being, and even activates commerce and nightlife because of its excellent chromatic reproduction (Raynham and Saksvikrønning, 2003).

Evidently, the color of light affects visual performance. Moreover, different colors can be more suitable for certain light installations than for others, depending on their purpose. Therefore, decision-making concerning financial and environmental costs must take the use of light installations into account. In this regard, yellow-sodium light is more popular because it produces lower levels of light pollution. This scenario predominates in countries whose regulations (Ministry of Industry, 2008) specifically state that in certain cases, the spectrum of public light sources must exclude short wavelengths (present in white light), which, as previously mentioned, are more intensively scattered. However, lighting installations for commercial or aesthetically sensitive areas (e.g. monuments, gardens, public parks, etc.) usually emit white light because of its better chromatic reproduction.

In summary, both, intensity and color of light are extremely important in public lighting installations in terms of financial savings, environmental impact, safety perception, and the well-being of city residents. However, the optimization of light parameters is very complex given the wide range of elements that must be considered. Initially it would seem that optimal public lighting should have low illuminance levels and use yellow-sodium light because of its lower economic and environmental impact. Nevertheless, in certain cases, there are also very convincing reasons to consider and opt for the slightly higher (though not abusive) illuminance levels produced by white light (Raynham and Saksvikrønning, 2003).

The main objective of this work was to study the impact of public lighting on pedestrians' well-being and perceived safety by focusing on the following two basic aspects of the light emitted: (i) average illuminance on the ground; (ii) color of the light. To achieve this goal, a macro-survey was conducted in the street while the lighting was working. The results of this research as well as the survey itself, envisaged by as a data collection tool, are extremely interesting for lighting designers, urban planners, and especially city administrators as a way to enhance the safety and well-being of citizens without increasing the very high energy consumption of public lighting or even better, by decreasing it.

2. Materials and method

An *in situ* five-point scaled survey with 11 questions was administered to 275 randomly chosen pedestrians who were approached as they were walking along five streets (55 surveys per street) in the city of Granada. The objective of this questionnaire was to ascertain the relationship between respondent preferences and perceptions and measured illuminance and uniformity levels. An English version of the survey is included in Appendix A.

The five-point scale incorporates the "agreement alternatives", that are the most popular being used for a wide variety of psychosocial variables. For this kind of questionnaires, one of the valuation criteria questionnaires must be the internal consistence (American Educational Research Association, 2014).

Two trained female survey takers collected data for a period of ten days (two weeks from Monday to Friday), in the month of February. They began working after sunset at approximately 19:30, after the public lighting was turned on and its light sources stabilized. Each day they finished collecting data at about 21:00, before the number of pedestrians on the street started to decrease.

Regarding the choice of the streets, it was decided to avoid economically depressed areas as well as areas in the neighborhood of police stations because social aspects could lead to biased conclusions. All the streets under consideration were similar in terms of pedestrians and cars flow, especially during the hours when the surveys were carried out. In addition, the selected streets belonged to residential areas in the center of the city with no specially intense commercial activity due to the potential influence of the lighting from shop windows etc.

Table 1 lists the streets in Granada where the survey was administered. In what follows, the streets will be referred to by their abbreviation in Table 1.

These streets and their nocturnal lighting are shown in Figs. 1a–1e.

As part of our research study, the illuminance levels (luminous flux on each square meter of road surface) were also measured with a fully cosine corrected luxmeter. From these measurements, the average illuminance, E_{av}, was calculated with the standard nine-point calibration procedure (Grieneisen et al., 2006), which is the most widely used method in street lighting measurements. The average illuminance is the parameter that characterizes the quantity of light provided by a lighting installation in an urban environment (CIE, 2010). In addition to this parameter, the illuminance uniformity, U_0, defined as the ratio between the minimum illuminance level measured and the average illuminance on a given