STREET LIGHTING APPRECIATED BY PEDESTRIANS: A FIELD STUDY

Romnée, A.[1], Bodart, M.[1]
[1] Architecture & Climat, Université catholique de Louvain, Louvain-la-Neuve, BELGIQUE
ambroise.romnee@uclouvain.be

Abstract

Street lighting standards are based on quantitative measurements of various parameters such as luminance, illuminance, glare and lateral light distribution. At the moment, we know that subjective criteria are also important for pedestrians in order to achieve high quality street lighting.

A field study was conducted under LED light and HPS light in order to identify the indicators of a high quality street lighting designed for pedestrians. The survey compares these indicators to the characteristics, enumerated by the participants, for each LED light or HPS light. Finally, the survey measures the feeling of safety, the visual comfort and the perception of lighting atmosphere for pedestrians.

This paper shows that the near visibility, the feeling of safety, the brightness, the illumination uniformity and a non-glare light are cited as the more important indicators of high quality street lighting for pedestrians.
Moreover the paper also shows that the characteristics of LED light, appreciated by pedestrians, are well correlated to the indicators of a high quality street lighting.
Finally this research shows that pedestrians always prefer LED light to HPS light whatever the concept of feeling of safety, the concept of visual comfort or the perceived luminous atmosphere is concerned.

Keywords: Field study; LED street lighting; pedestrians; indicators

1 Introduction

Street lighting standards recommend to provide sufficient amount of light to ensure to cover the street safely with a good visual comfort and an appreciated luminous atmosphere.
Several studies have shown that other criteria, essential for the user and especially for pedestrians, should also be considered in order to achieve high quality street lighting.
The aim of this paper is to reveal these criteria and to discover how the light spectrum may influence their perception.
Several studies have already been carried out to investigate the appreciation of light by pedestrians, under different conditions. Jaatinen (Jaatinen, 2010) found that LED lighting is too bright and causes glare but it is not always considered as a negative feature. He also found that pedestrian walking in streets illuminated by LED luminaires feel safer than in streets illuminated by MH luminaires. Rea and al. (Rea, Bullough, Akashi, 2009) said that at identical lighting level, a street lit by white lamp appears brighter and safer than a street lit by HPS sources. Boyce and Bruno (Boyce, Bruno, 1999) discovered that the higher the photopic illuminance, the more positive the perceptions and the stronger the preference, regardless of lamp spectrum. Knight (Knight, 2010) found that, as same light level, spaces illuminated by white sources are perceived brighter, safer and more comfortable than spaces illuminated by orange sources.
The results of these studies suggest a significant positive effect of LED sources to the appreciation of street lighting.
To go further than these studies, a field study was conducted in two adjacent streets in order to study the pedestrian appreciation of public lighting under LED sources and HPS sources.
The survey firstly aimed to identify which are the indicators of a high quality street lighting designed for pedestrians.
It also aimed to compare these indicators with the positive aspects, enumerated by the participants, of each LED light or HPS light.
The survey finally aimed to measure the feeling of safety, the visual comfort and the perception of lighting atmosphere for pedestrians.

2 Method

2.1 Overview

The experiment took place in a pilot site developed for the GEPPADI project (Romnée et al., 2013).

Forty one subjects experienced two similar streets, each illuminated by different light source installed in the same type of luminaire. The first street, called “reference street”, was illuminated by HPS sources and the second street, called “test street”, was lit by LED sources.
For both streets, each subject was first immersed in the light by walking in the street and then driven to the test location. At each test location, the subject was asked to answer a questionnaire (identical in both streets) about its appreciation of the light.
Through this questionnaire, subjects were asked to give their opinions or their feeling of safety and of visual comfort and their perception of the lighting atmosphere. They were also asked to points out which are, to their opinion, the indicators of a high quality street lighting. They were finally asked to characterize both light sources, according to these indicators.

The subjects, 21 men and 20 women, were grouped by 5. The experiment was conducted during 4 nights in March 2013 with 2 groups per night. In order to investigate the influence of the order of exposition (from LED street to HPS street and vice versa), one group started the survey from LED street and the other group started simultaneously from HPS street.
41 % of subjects were under 30 years. 37 % of subjects were between 30 and 60 years. 22 % of subjects were older than 60 years. The average year of participants was 42.

2.2 Independent and dependent variables

Performing an inquiry request to compare two types of variables: independent and dependent variables. An independent variable is a hypothetical factor affecting the activity studied. A dependent variable that depends on the action of the independent variable is intended to undergo the action of this factor (De Singly, 1992). The independent variables are the elements of the analysis so that the dependent variables are the means used to perform the analysis.

Two independent variables were used in the survey: lamp type (LED or HPS) and profile of participants (the age, the order of exposition).
Twelve dependent variables fell into three concepts were measured during the experiment. These concepts are the feeling of safety, the feeling of visual comfort and the perception of lighting atmosphere. These concepts are abstracts objects of synthetic and intuitive knowledge. In order to be studied, they have to be measured by some dependent variables or indicators (De Singly, 1992). One dependent variable or indicator can measure different concepts.

Table 1 (next page) summarises the relationship between the variables, on base on the following research papers; (Boyce, Bruno,1999; Akashi, Rea, 2001; Raynham, Saksvikronning, 2003; Bacelar,2005; Fotios, Cheal, 2007; Deleuil, 2009; Rea, Bullough, Akashi, 2009; Alferdinck et al, 2010; Jaatinen, 2010; Knight, 2010; Ylinen, Paluolakka, Halonen, 2010; Viikari et al, 2011).

Table 1 - independent and dependent variables

INDEPENDENT VARIABLES	DEPENDENT VARIABLES: CONCEPTS	DEPENDENT VARIABLES: INDICATORS (non-exhaustive)
- **Lamp type** (LED or HPS) - **Profile of participants** (age, gender, order of exposition)	- **Feeling of visual comfort**	- Distance vision / Perspective - Color rendering / Identification of color - Amount of light - Glare - Readability of path / Contrast - Color of light - Vision surroundings - Uniformity of light
	- **Feeling of safety**	- People appearence - Color rendering / Identification of color - Walking alone at night - Socialization - Glare - Readability of path / Contrast - Distance vision / Perspective - Amount of light - Uniformity of light - Identification of people
	- **Perception of luminous atmosphere**	- Uniformity of light - Color rendering / Identification of color - Amount of light - Color of light

2.3 Construction of the questionnaire

In both streets subjects were asked a series of identical questions that addressed the three concepts explained above (see Table 1).
As the investigation pursued different objectives, the questionnaires presented 3 types of questions (see a sample in Figure 1): firstly, subjects were asked to mark their level of agreement with a proposal on a scale of 6 steps; secondly; they were asked to take position between two opposite characteristics of light on a scale of 6 steps and thirdly, they were asked to give their own opinion about what is a high quality street lighting and about some characteristics of each light source.

Each question referred to an indicator (see Table 1) of the studied concept. An indicator could be measured by many questions in order to compare responses. A concept was covered by many questions.

1 - I can see clearly other people in the street.

not agree at all ☐ ☐ ☐ ☐ ☐ ☐ *strongly agree*

2 - I think the light is evenly distributed all along the sidewalk on wich I walk.

not agree at all ☐ ☐ ☐ ☐ ☐ ☐ *strongly agree*

3 - The sidewalk on wich I walk appears dark.

not agree at all ☐ ☐ ☐ ☐ ☐ ☐ *strongly agree*

I think the color of the light is ...

13 - *cold (bluish)* ☐ ☐ ☐ ☐ ☐ ☐ *warm*

14 - *unpleasant* ☐ ☐ ☐ ☐ ☐ ☐ *pleasant*

15 - *stressful* ☐ ☐ ☐ ☐ ☐ ☐ *relaxing*

According to you, what are the qualities of a good public lighting (3 or 4 words)

Figure 1 - sample of the questionnaire

2.4 Quantitative analysis of a qualitative appreciation

For each question, the subjects were asked to give their opinion on a scale of 6 steps. So each question was given a score between 1 and 6.
By convention, the score 6 corresponded to the highest score and was related to the answer: "Strongly agree" to the first type of question or to the most positive expression in the second type of question. Conversely, a score of 1, related to a "not agree at all" answer, corresponded to the lowest score.

As each question received a score, we were able to evaluate the appreciation of each indicator. The score of an indicator was the average scores for each question assessing the indicator.
A score was assessed for each indicator, which allowed then to evaluate a score for each concept. Based on the literature (Martin, 2005: Deleuil, 2009) we constructed an index of appreciation in order to evaluate the three concepts (the feeling of safety, the feeling of visual comfort and the perception of luminous atmosphere).

We then calculated the satisfaction index I_a which indicates a level of positive or negative satisfaction, ranging from +100 to -100, for the studied dependent variables (or concept). This satisfaction index I_a is based on the average scores for each indicators assessing the concept (see Table 1).

$$I_a = 200 * \sum_{x=1}^{N} \frac{i_x}{N * 6} - 100 \qquad (1)$$

Where

I_a is the satisfaction index of the studied concept
i_x is the score of an indicator assessing the studied concept
N is the number of indicator assessing the studied concept

It is then possible to make a graph (Figure 2, left) whose abscissa is the index of appreciation of the concept studied for the street lit with HPS sources and whose ordinate is the satisfaction index of the concept studied for the street lit with LED sources. Each dot represents a subject.

A graph is then created for each dependent variable and consists in four quadrants whose signification is explained in Figure 2 (right). Moreover, the graph inform about:

1. People who have a very little marked or very low opinion on the analysed concept (subjects for whom $I_a \leq |50|$).
2. People who always prefer LED lighting compared to HPS lighting (subjects located above the 45°-line ($I_a > 45°$)).
3. People who appreciate the LED lighting and depreciate the HPS lighting (subjects located in Q4).

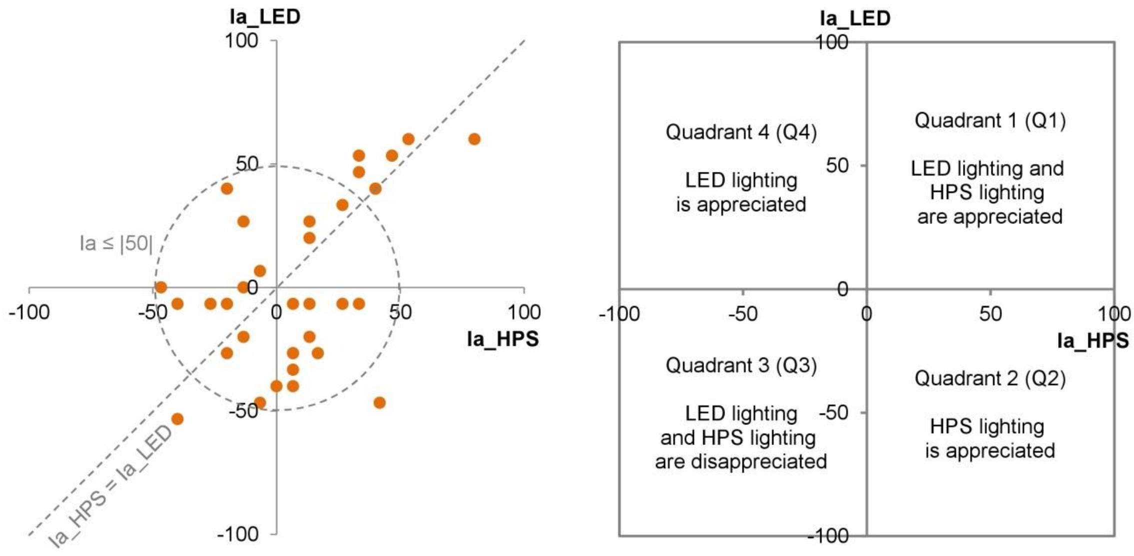

Figure 2 - method of analysis

3 Results

3.1 Indicators of a street lighting of high quality

Data collected with the open question (What are the qualities of a good public lighting?), in each street, were analysed regrouping the opinion of subjects on each topic. These topics are the indicators of a high quality street lighting designed for pedestrians.
We have counted the frequency of citation of each indicator in order to identify which are dominating for pedestrians.

Seventeen indicators of street lighting have been cited by pedestrians for characterising a street lighting of high quality. 15 of these 17 indicators had been used to measure the different dependent variables of the survey.
The two additional indicators relate to the ecological, economic aspect and to the feature to be adapted to the function.

Five indicators are cited by 60 % of the participants (Figure3). They are thus considered as the dominant.
For pedestrians street lighting of high quality is thus a lighting allowing to see closely, providing a feeling of safety, with an enough amount of light, uniform and not glaring.

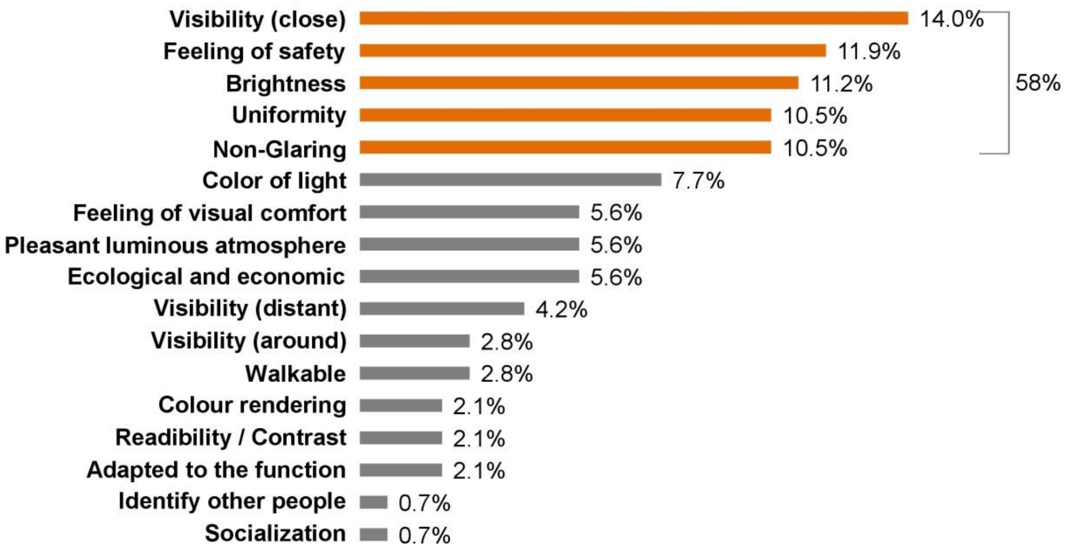

Figure 3 - indicators of a high quality street lighting designed for pedestrians

3.2 Comparison between the indicators of a street lighting of high quality and the encountered light characteristics

In each street, we asked the subjects to indicate some characteristics of the public lighting. These characteristics were then considered as the indicators of a street lighting of high quality, as mentioned above (Figure 3).
According to pedestrians, LED sources are soothing for a late afternoon, modern, nice but dazzling when one stares and a little cold. HPS sources are shabby, dingy, old fashion, sad, scenery of a sufficient place for the sweet horror movie but satisfactory for the season.

Among these characteristics, we have counted the frequency of mentioned qualities that we compared to the frequency of mentioned indicators of quality.
In this way, we can measure the difference of percentage between the frequency of mentioned qualities of LED lighting or HPS lighting and the frequency of citation of the general qualities expected of a public lighting designed for pedestrians (Figure 4).

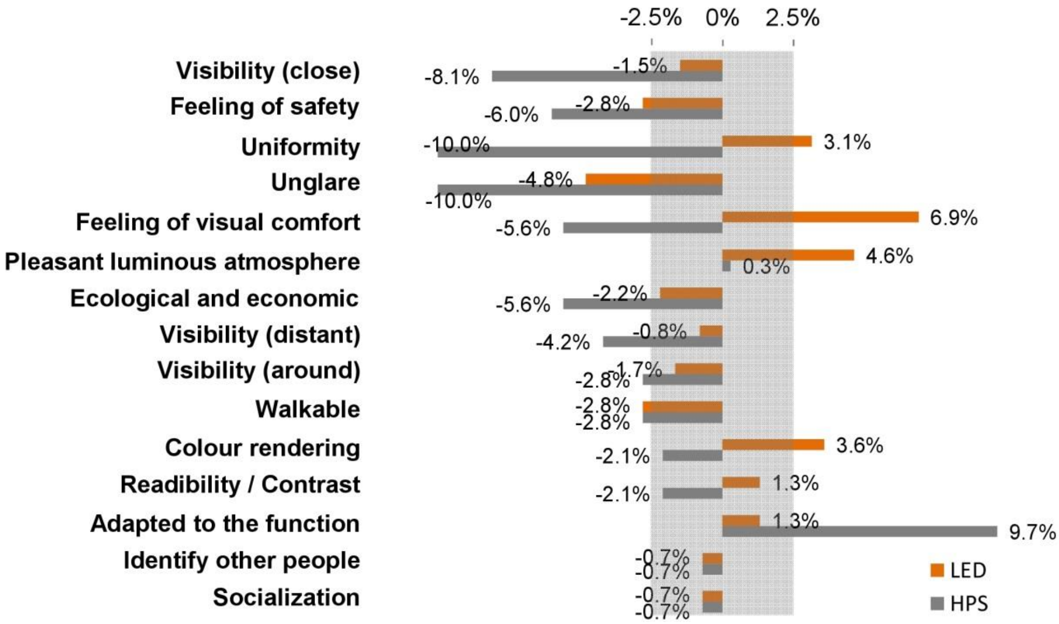

Figure 4 - comparison between a high quality street lighting and LED lighting or HPS lighting

According to Figure 4, 50 % of the characteristics cited as qualities for LED lighting are also indicators for street lighting of high quality, designed for pedestrians (IC 95 - ± 2.5 % around 0 %). Moreover the average difference between the qualities of LED lighting and a street lighting of high quality is 2 % compared to the average difference of 7 % for HPS lighting.
The need for lighting to be adapted to its function for pedestrian street is the only indicator cited more often for warm sources than for LED sources. Moreover this indicator is the only characteristic of warm sources to be recognised by pedestrians as positive. All other indicators are negative for the warm sources.
Some indicators are recognized by pedestrians as positive for LED lighting and negative for HPS lighting. The feeling of visual comfort is more appreciated under cold sources than under warm sources. The colour rendering and the readability/contrast of the pavement are cited as advantage for LED lighting and as disadvantage for HPS lighting. The uniformity appears more relevant under LED lighting than under HPS lighting.

3.3 Analysis of dependent and independent variables

The answers to questions were translated to a score between 1/6 and 6/6 as explained above. For each subjects, for each light sources, we calculated the satisfaction index of the concept studied (see Table 1 and Equation 1). Results are presented in Figure 5 to 8.

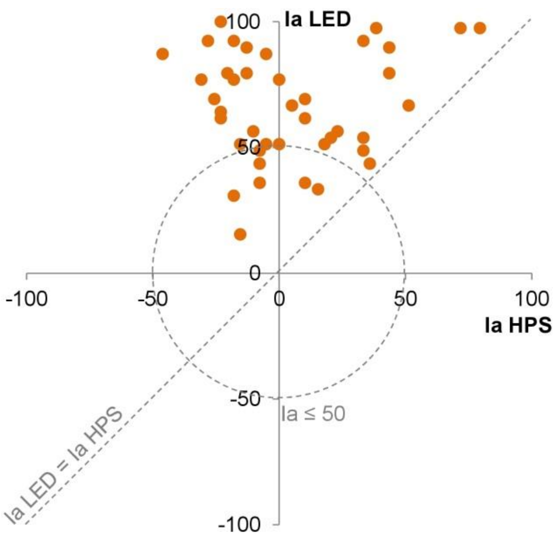

Figure 5 - global appreciation of light

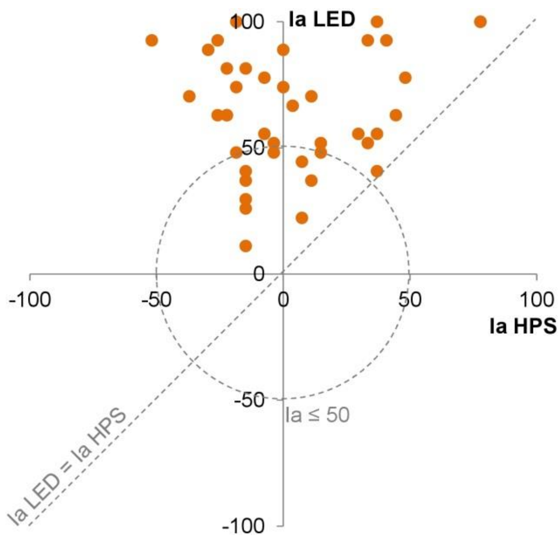

Figure 6 - global feeling of safety

Figure 5:
1. $I_a \leq |50|$: 22 %
2. $I_a > 45°$: 100 %
3. Q4 : 51 %

Figure 6:
1. $I_a \leq |50|$: 29 %
2. $I_a > 45°$: 100 %
3. Q4 : 51 %

The global appreciation of light (consideration of all questions in the questionnaire, regardless of the notion) and the global feeling of safety depend on the type of light source: in both dependent variables 100 % of people prefer LED lighting to HPS lighting ($I_a > 45°$) for 100% of the subjects.
Moreover, half of people feel safe and enjoys LED lighting while do not feel safe and do not enjoy HPS lighting (analysis of Q4).
Finally, more than 70 % of subjects have a significant opinion for each dependent variable (analysis of $I_a \leq |50|$). This confirms that the type of light source influences the appreciation of light and the feeling of safety.

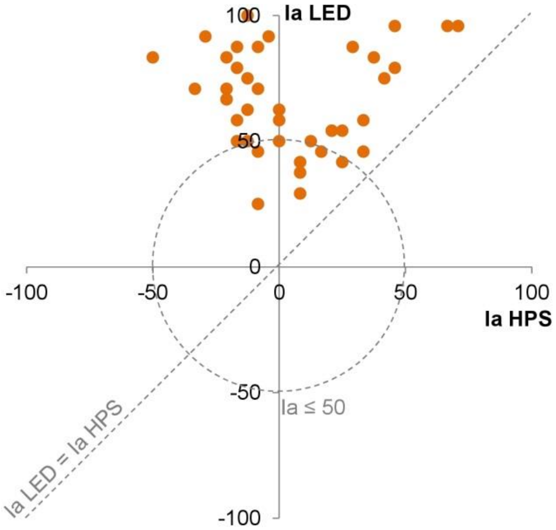

Figure 7 - global feeling of visual comfort

1. $I_a \leq |50|$: 19 %
2. $I_a > 45°$: 100 %
3. Q4 : 49 %

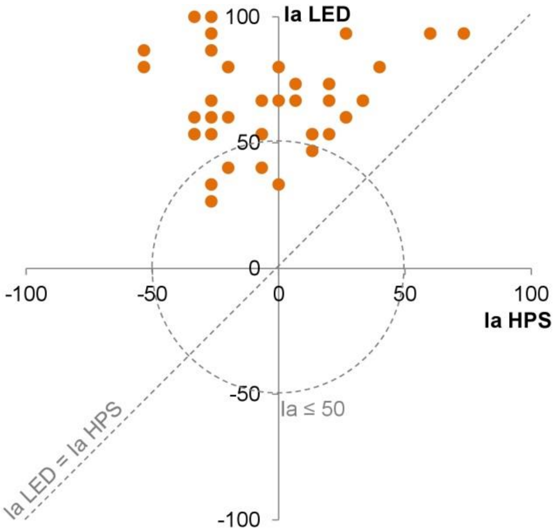

Figure 8 - global perception of luminous atmosphere

1. $I_a \leq |50|$: 15 %
2. $I_a > 45°$: 100 %
3. Q4 : 54 %

The global feeling of visual comfort and the perception of luminous atmosphere depend on the type of light source: in both dependent variables 100 % of people prefer LED lighting to HPS lighting (analysis of $I_a > 45°$).
Moreover, half of people feels visually comfortable and enjoys the luminous atmosphere of LED lighting while they do not feel visually comfortable and do not perceive a good luminous atmosphere under HPS lighting (analysis of Q4).
Finally, more than 80 % of subjects have a significant opinion for each dependent variable (analysis of $I_a \leq |50|$). This confirms that the type of light source influences the visual comfort and the perception of luminous atmosphere.

Table 2 provides a cross analysis between the dependent variables and the independent variables.
We don't specifically analyse the criteria $I_a > 45°$ because we have seen above that whatever the subject and whatever the concept analysed, 100 % of the subjects prefer LED lighting.

Table 2 - analysis of dependent and independent variables

		Appreciation		Safety		Comfort		Atmosphere	
		Ia ≤ |50|	Q4	Ia ≤ |50|	Q4	Ia ≤ |50|	Q4	Ia ≤ |50|	Q4
Direction	**LED -> HPS**	14%	52%	19%	48%	19%	57%	14%	52%
	HPS -> LED	30%	50%	40%	55%	20%	40%	15%	55%
Gender	**Male**	28%	52%	38%	52%	28%	48%	19%	57%
	Female	15%	50%	20%	50%	10%	50%	10%	50%
Age	**< 30 years**	37%	37%	37%	31%	44%	44%	19%	50%
	30 - 60	19%	62%	31%	69%	25%	69%	12%	62%
	≥ 60 years	11%	78%	11%	78%	11%	67%	11%	78%

The order of lamp exposition affects all notions except the perception of luminous atmosphere: seeing first the white light sources LED increase the appreciation of each concept ($I_a \leq |50|$ under HPS sources is two times higher than $I_a \leq |50|$ under LED sources while Q4 is relatively equal).

The gender affects all notions: women are more categorical in favour of LED sources ($I_a \leq |50|$ for male is two times higher than $I_a \leq |50|$ for female while Q4 is relatively equal). Women, on average, rated more severely HPS sources.
We perceive the two same effects of age on the four notions: firstly, the older you are, the more you appreciate the LED sources and the more you depreciate HPS sources (Q4 becomes higher as we get older), secondly, the older you are, the more categorical you become categorical in our appreciation of notions in favour of LED sources ($I_a \leq |50|$ becomes lower as we get older).

4 Discussion

The main result of the survey is that the type source influences the feeling of safety, the feeling of visual comfort and the perception of luminous atmosphere. For pedestrians, LED lighting is always preferred to HPS lighting. This agrees with the findings of previous studies assessing that white sources are more appreciated than yellow ones (Morante, 2008) (Deleuil, 2009) (Knight, 2010).
The profile of the subject (gender and age) affects the feeling of safety, the feeling of visual comfort and the perception of luminous atmosphere.
Women are more assertive in their appreciation. This observation confirms a previous study of Deleuil (Deleuil, 2009).
The older you are, the safer you feel, the more visually comfortable you feel. Older people appreciate also more the luminous atmosphere of LED lighting. These results should be confirmed by other studies using the same number of participants per age category. However, the results should be confirmed by another study increasing the number of subjects.

Moreover, in agreement with other studies (Mosser, 2003) (Deleuil, 2009) the characteristics of a quality public lighting should consider quantitative variables and qualitative variables.
Street lighting standards should integrate, in addition to the brightness, the uniformity or the glare, some requirements about the feeling of safety or the close visibility. These five requirements are cited by the population as indicators of a street lighting of a high quality, designed for pedestrians.
This study confirms that it is essential to integrate environmental and economic considerations in current standardisation in order to obtain public lighting of high quality.

Funding

The GEPPADI project (Sustainable and Intelligent Public Lighting Management in Business Parks), funded by the Walloon Region, is organised in partnership with companies of ARTHOS Technics et Ets. E. Ronveaux SA, SPI, the economic development agency for the province of Liège, the Electronics, Microsystems, Measurements and Instrumentation unit (EMMI) at the University of Liège and the Architecture & Climate laboratory of the Catholic University of Louvain.

References

ALFERDINCK, J., HOGERVORST, M., VAN EIJK, A., KUSMIERCZYK, J., 2010, Mesopic vision and public lighting - A literature review and a face recognition experiment. TNO - Ministery of Infrastructure and Environment (I&M).

AKASHI, Y., REA, M., 2001, The effect of oncoming headlight glare on peripheral detection under a mesopic light level. In, 2001. Herbert Utz Verlag, 9.

BACELAR, A., 2005, The Influence of Dimming in Road Lighting on the Visibility of Drivers. *Journal of Light & Visual Environment*, 29, 44-49.

BOYCE, P., BRUNO, L., 1999, An evaluation of high pressure sodium and metal halide light sources for parking lot lighting. *Journal of the Illuminating Engineering Society*, 28, 16-32.

DELEUIL, J.-M. (2009). EVALUM: De l'évaluation de différentes sources lumineuses par les usagers. In. Deleuil J.-M. (éd.) (2009) *Eclairer la ville autrement : Innovations et expérimentations en éclairage public*.Lausanne : Presses Polytechniques et Universitaires Romandes. pp. 36-52

DE SINGLY, F., (1992), *L'enquête et ses méthodes: le questionnaire*, 2nd édition, Paris : Armand Colin éd.

FOTIOS, S., CHEAL, C., 2007, Lighting for subsidiary streets: investigation of lamps of different SPD. Part 2—Brightness. *Lighting Research and Technology,* 39**,** 233.

JAATINEN, S, 2010, The use of LEDs in pedestrian ways, parking areas and parks – A user study. Thesis: Master of Science. Espoo : Aalto University

KNIGHT, C. 2010. Field surveys of the effect of lamp spectrum on the perception of safety and comfort at night. Lighting Research and Technology, 42, 313.

MARTIN, O., (2005), *L'enquête et ses méthodes: l'analyse de données quantitatives*, 2nd édition, Paris : Armand Colin éd.

MOSSER, S., (2003), *Eclairage urbain; enjeux et instruments d'actions*, Thèse de doctorat : Urbanisme, Paris : Université Paris 8 – Vincennes-Saint-Denis

REA, M., BULLOUGH, J., AKASHI, Y. 2009. Several views of metal halide and high-pressure sodium lighting for outdoor applications. *Lighting Research and Technology*, 41, 297.

RAYNHAM, P., SAKSVIKRONNING T., 2003, White light and facial recognition. *The Lighting Journal*, 68, 29-33.

ROMNÉE, A., LEJEUNE, G., BODART, M. *A new real time intelligent management model for street lighting*. CIE Centenary Conference : Towards a New Century of Light (Paris, du 15/04/2013 au 16/04/2013). In: *Proceedings of CIE Centenary Conference : Towards a New Century of Light*, 2013.

VIIKARI, M., PUOLAKKA, M., HALONEN, L. & RANTAKALLIO, A. 2012. Road lighting in change: User advice for designers. *Lighting Research and Technology,* 44**,** 171-185.

YLINEN A., PUOLAKKA M., HALONEN L., *Impact of mesopic design on outdoor lighting energy efficiency*. In: CIE 2010 Lighting Quality and Energy Efficiency, 2010 Vienne.