Light & Engineering
Vol. 25, No. 4, pp. 115-122, 2017

Svetotekhnika
No. 5, 2017, pp. 62–68

EFFECTS OF LED LIGHTING ON THE LUMINANCE COEFFICIENT[1]

Pablo R. Ixtaina and Braian D. Bannert

Laboratorio de Acústica y Luminotecnia Comisión de Investigaciones Científicas LAL–$5IC Gonnet, Argentina
pixtaina@yahoo.com

ABSTRACT

The application of luminance technique in road lighting requires the knowledge of the reflection properties of the road surface. The effect of LEDs radiation spectra on these reflection properties is analyzed in the present paper. On this topic, CIE publication No 30–2 notices that road surfaces are not completely spectrally unselective, nevertheless, the effects on reflection of luminous sources spectra used on the road are usually disregarded. A spectral study on samples of Argentinean draining road surfaces is shown in this paper. Size standardized samples were measured under the standard observation angle, for three different light incidence angles. A focused spectrometer was used as detector. A standard high pressure sodium lamp (HPS) and a cool street LED luminaire were used as light sources. A specially built diffuse surface was used as reference in order to compare the spectral differences in reflection.

As a result, colour selectivity was found. The spectral samples selectivity produced a photopic absorption about 5 to 10 percent greater in HPS lamps spectra than LED sources.

Keywords: LED, road lighting, road reflection, spectra

I. INTRODUCTION

In road lighting, the visual perception of the driver is conditioned by the luminance distribution on the surface of the lit road. In this model, known as Luminance Technique, reflection properties of the road surface are characterized by the luminance coefficient "*q*", proportionality factor, for each road point, between its illuminance and the luminance reflected in the observation direction. The integer of luminance coefficient "q" on a solid angle that underlies a road element is called average luminance coefficient *Qo*, useful factor for evaluating the degree of "lightness" of the road surface.

The surface *Qo* impacts directly on the energetic efficiency of the installation. A "lighter" surface

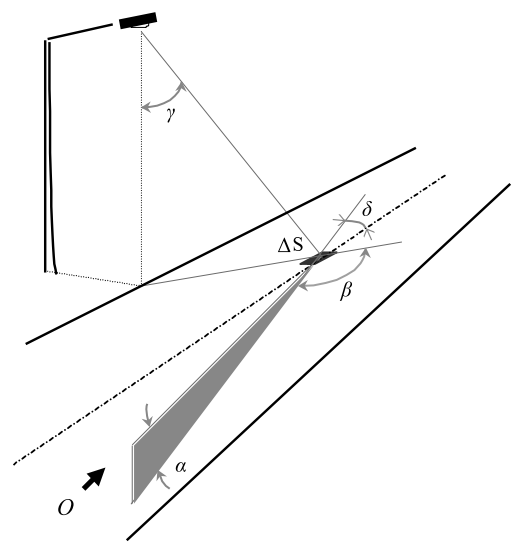

Fig.1. Basic geometry for the vision analysis in roads

[1] On basis of report at the European Lighting Conference LUX EUROPA 2017, September 18–20, 2017, Ljubljana Slovenia

will result in greater luminances in direction to the observer for a same distribution of illuminances. As *Qo* is a property mainly determined by the type of asphalt mixture or the kind of concrete, as well as the building methods used, its value can change regionally or by zones. This effect has already been observed for asphaltic concretes of a same area, with different compounds or application techniques [1]. It is then worth studying if this "degree of lightness" can change with the spectrum of light sources used in the lighting system. Particularly, and in the light of the current technological changes, our present work will focus on the possible effects of "spectral selectivity" that influence the reflection of white LEDs light.

1.1. Luminance coefficient

The luminance L of an elementary surface ΔS on the road (Fig. 1) is determined by equation (1):

$$L = \frac{I(C,\gamma)}{H^2} q(\alpha,\beta,\delta,\gamma) cos^3(\gamma), \tag{1}$$

where $I(C,\gamma)$ is the lighting intensity of the luminary in direction to the point where luminance is calculated, H the height of the luminary installation and q is the road luminance coefficient.

The luminance coefficient depends completely on the road surface: basic material, binder composition, application method final texture, time of use, etc. Far from being a constant, its value depends on the positions of the observer and on the lighting source with respect to the point under consideration. Studies showed that a valid simplification is to fix the observation angles: it has been standardized the driver's vision line parallel to the road axis ($\delta = 0^o$) and its elevation so that it has an impact on the vision point with a slope $\alpha = 1^o$. Thus, the standardized conditions for vision on road consider q dependent only on β and γ [2].

If E is the exact illuminance on the road, (1) can be rewritten as:

$$L = q(\beta;\gamma)E. \tag{2}$$

The luminance coefficient complies with the function of proportionality factor, for each road point, between illuminance and luminance. Thus, it is defined the average luminance coefficient Qo, which quantifies the degree of "lightness" of the road surface:

$$Q_0 = \frac{1}{\Omega_0} \int_{\Omega 0} q d. \tag{3}$$

In (3), Ωo represents the solid angle that underlies the element Δs in Fig. 1. As it was mentioned in the previous paragraphs, higher values of *Qo*, associated with "lighter" surfaces, will allow obtaining an increase of average luminance for the same system of lighting (thus, increasing the installation efficiency).

1.2. Coefficient *Qoo*

If there is an enough amount of simultaneous evaluations of accurate luminances and illuminances on several sections of a road surface, it is possible to use factor *Qoo*, relationship between average luminance and average illuminance as an empirical approximation of the road degree of lightness:

$$Q_{00} = \frac{Lm}{Em}. \tag{4}$$

Although there is no theoretical relationship between *Qo* and *Qoo* coefficients, the low dispersion obtained in the analysis of an important number or luminance and illuminance evaluations allows inferring a good performance of this coefficient as marker of the road lightness degree [1–3].

The study described in [1] verified significant differences in the "lightness" degree of surfaces in access and urban motorways of Buenos Aires

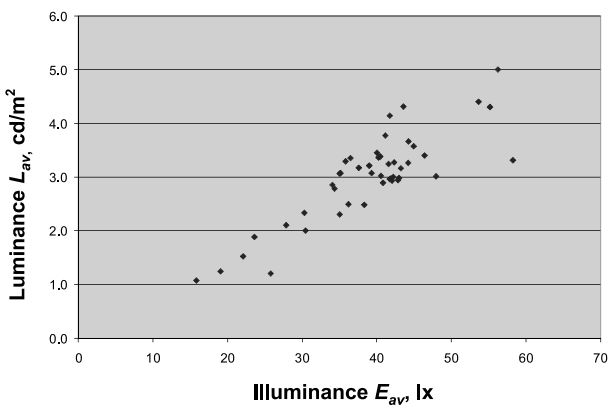

Fig. 2. Example of luminance-illuminance relationship, [1]

Table 1. Assessed LED Installations

Motorway	Measurements	*Qoo* (average) [cd/m^{2}lx]	Standard uncertainty [cd/m^{2}lx]
La Plata – Bs AS City. Section 1	8	0,0860	0,006
La Plata – Bs As City. Section 2	4	0,1080	0,010
Bs As City Urbans motorways	6	0,0828	0,005
Panamericana	2	0,0640	——

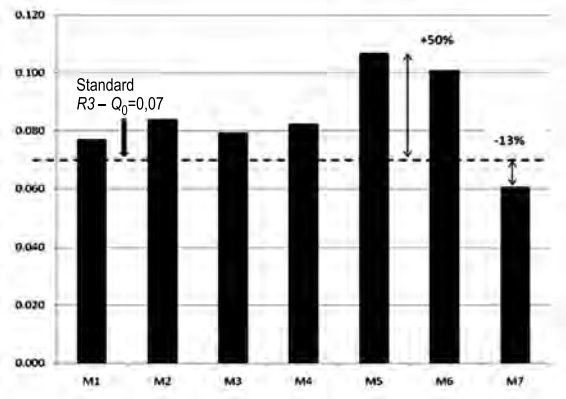

Fig.3. *Qoo* values, [1]

City (Argentina). Such work had as basis more than 300 simultaneous evaluations of luminance and illuminance, carried out in motorways close to Buenos Aires City for the time period 1998–2012. All measurements were carried out following the standardized procedures according to the Argentinean recommendations [4]. The studied installations used HPS vapor lamps and the following rules were met:

- The collected data were grouped by sections with the same kind of asphalt (composition and application technique);
- Time periods only without recoating or changes of surfaces were considered;
- Lighting installations were kept without changes for each assessed zone, except for cleaning, repairs and lamp changing.

Fig. 2 shows an example of luminance-illuminance relationship of an assessed zone. For the studied cases, a clear correlation *E-L* was observed, and this justified the definition and use of *Qoo*.

Comparing the different studied sections, it can be observed substantial differences in the lightness degree of their surfaces. Besides, the study shows a significant discrepancy between the *Qoos* of the actual surfaces and the *Qo* of the standard surface of CIE R3, used as almost exclusive reference of local designs. Fig. 3 summarizes the results obtained in the mentioned study. In this figure, M1, M2, etc. correspond to different sectors or motorways with homogeneous surfaces.

2. DEGREE OF LIGHTNESS UNDER LED LIGHTING

The aim of the present work is to verify if there is any change in the average luminance coefficient assignable to white LED light. In other words, it is intended to find some kind of spectral selectivity in the reflection from the surface.

2.1. Background.

Ekrias [5] studied the spectral reflection of eleven types of asphaltic compounds from Finland, combining samples of "natural" surfaces and with aggregates of colour pigments for clarifying them. His measurements were based on circular samples, of 100 mm in diameter, incidence angles *b*= 20º and elevation *g*=55º. The observation angle *a* was 35º, larger than standard CIE of 1º. Fig. 4 allows observing some samples used in such research. In the image, it can be observed an important size of stone, with a much smaller proportion of binding asphaltic compound than that of surfaces in use in our coun-

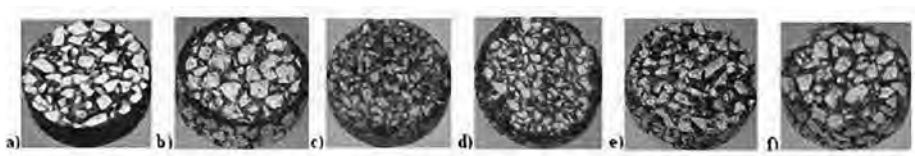

Fig. 4. Samples of surfaces used in [5]

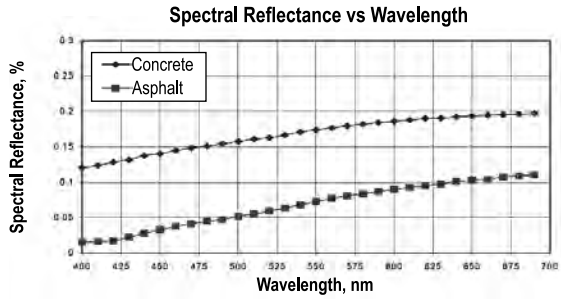

Fig. 5. Results of Adrian's spectral studies

try. Besides, some of the samples presented a reddish tone, possibly due to colouring aggregates.

The mentioned tone is shown in the spectra obtained by Ekrias, which evidence a slight increment in their reflectance towards the red zone of the spectrum.

Adrian's studies [6] show similar results. In this case, the studied samples were asphaltic concretes or concretes, without specifying the use of any type of colouring aggregate. Fig. 5, extracted from [6], shows a growth in the reflectance for growing wave lengths, similar to that found in [5].

American studies [7] show an increase in the reflectance towards the red, more evident on surfaces worn out due to several years of use (Fig. 6). It is noteworthy the coincidence among studies from distant places (USA – Europe), despite the high regional influence on the surface composition and the use or non-use of colouring aggregates.

2.2. *Qoo* with LED Lighting

Following the model of the experience described in [1], luminance and illuminance simultaneous measurements were analyzed in motorway installations with LED lighting, extracted from the database of the laboratory for the period 2013–2016.

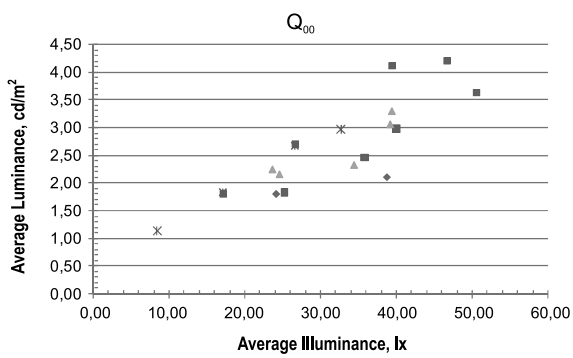

Fig.7. Luminance / illuminance relationship for the studied sections with LED

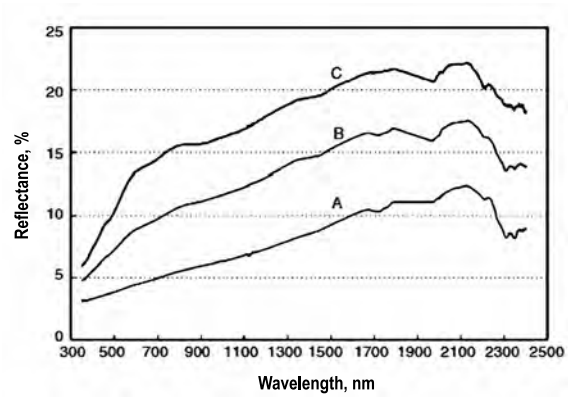

Fig.6. Herol's studies (USA). C surface with over ten years of use

The assessed cases were installations reconverted to LED (15 measurement areas) and tests of LED devices. The latter were based on measuring "witness" sections, formed by the replacement of at least 4 consecutive columns of luminaries in a motorway section. The assessment area was placed in the central reservation (5 cases). All considered tests had their correlation with HPS devices and were counted for the test [1]. Likewise, care was taken to include only those evaluation areas without extreme changes on the road surface. Table 1 summarizes the analyzed cases.

The standard uncertainty considering only that assignable to type A component, was evaluated following [8].

Although the considered cases were limited, the uncertainty was of the same order of magnitude as in the test [1] and that is why *Qoo* estimations for LED lighting can be considered representative for each type of surface. The last case is an excep-

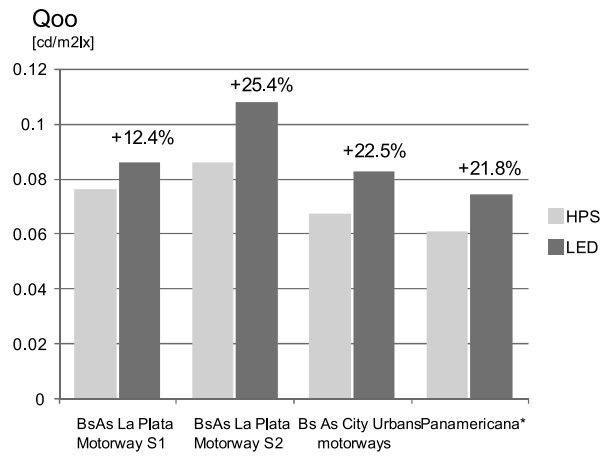

Fig.8. Comparison of *Qoo* obtained for installations with HPS lamps and LEDs

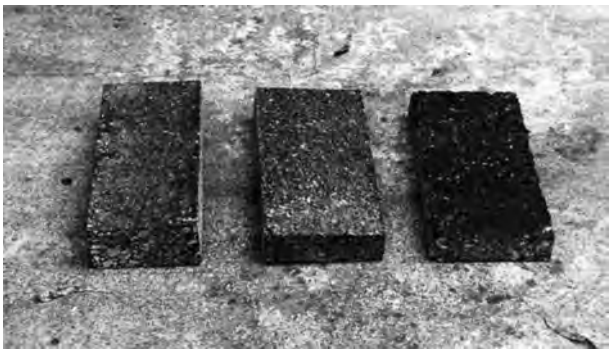

Fig. 9. Samples of draining surfaces, similar to the surfaces of the studied motorways

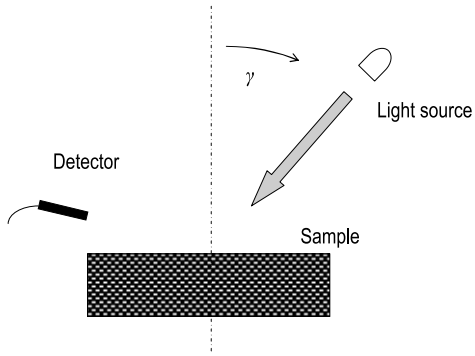

Fig.10. Diagram of measurement system

Fig.11. Aspects of the experience, detector

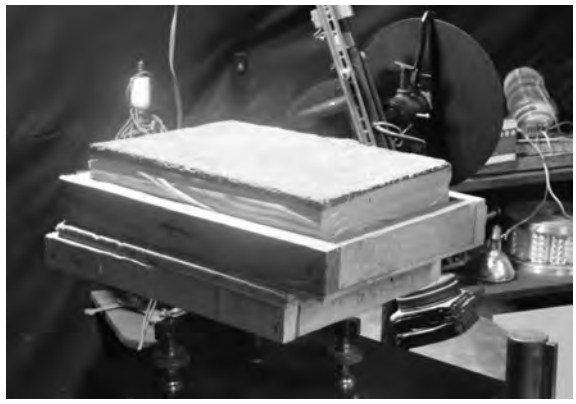

Fig. 12. Aspects of the experience, sample

tion with only two measurements, which are included just as an illustrative example.

2.3. Results

Fig. 7 shows the average luminance and average illuminance relationships for each studied sections.

In Fig. 8, the *Qoo* values obtained with traditional lighting (HPS lamps) and the new LED luminaires are compared for each zone.

The obtained results indicate an increase in the "lightness degree" of each road surface for the LED spectrum. In a first analysis, this result coincides with the background mentioned before. As the qualitative fact of source spectrum influence on the average reflection of surface is that reflection cannot be considered achromatic. However, the link between the *Qoo* increment for the LED spectrum with the "reddish" tone of the surfaces studied by Ekrias, Adrian and Herold is not clear. This trend combined with the blue prevailing spectrum of LED suggests an opposite result to that found in our study. Coherent with this last idea in [5], it is mentioned an improvement in *Qo* for surfaces lit with HPS lamp with respect to the same surface under white light (high pressure mercury).

On the other hand, we cannot affirm that European or American surfaces of the mentioned research can be comparable to those currently in use in Argentina, and which were studied here. Fig. 9 shows samples of such surfaces of the "draining" type. It can be observed a granulometry and different colours from those presented in Fig. 4. It is evident that the comparison between photos has only a relative descriptive value, but shows a higher density (at least superficial) of binder and smaller stone size for the local surfaces. Besides, the images do not show evidence of reddish tones.

3. SPECTRAL STUDY

3.1. Measurement diagram

Works were carried out on a sample similar to those shown in Fig. 9, of standardized dimensions for evaluation of samples [2], assembled on equipment for measuring r-table of LAL (Sample Reflectometer). The light source was placed in b=0º, and

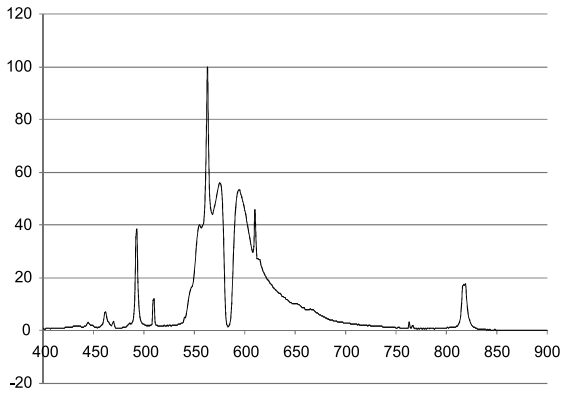

Fig. 13. Spectrum of used HPS lamp

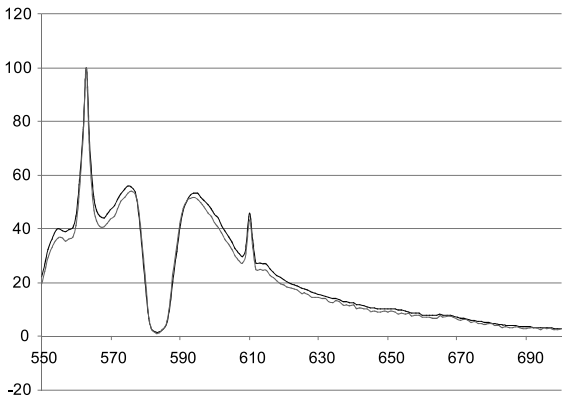

Fig. 15. Direct and reflected spectrum for HPS

three angles of vertical incidence: g = 0º, 15º and 30º were used.

The spectrum reflected by the sample was recorded with a spectrometer Avantes Starline, AvaSpec 2048 [9] with observation angle of standard CIE, a=1º.

Fig. 10 shows a diagram of the measurement system, in Figs. 11 and 12 are aspects of the experience.

Two light sources were compared. On one hand, HPS lamp, tubular clear bulb type, which spectrum is shown in Fig. 13.

A plate with Surface Mounted Devices (SMD) LED components, without refracting lens, chromatic features *x= 0.362, y= 0.366, CCT= 4500 K* was used as LED source. Its spectrum is shown in Fig. 14.

3.2. RESULTS

Comparison of direct and reflected spectra was carried out from re-scaling them to percentage values of their respective maximums. Overlapping of both curves should indicate (in the case of no coincidence) the zones with differences in spectral absorption. Fig. 15 compares spectra for HPS lamp

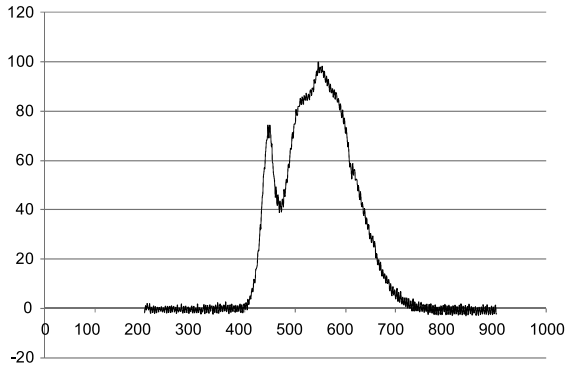

Fig.14. Spectrum of used LED source

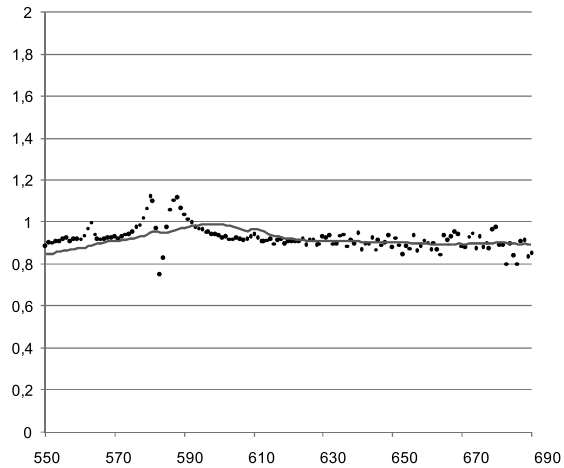

Fig. 16. Reflected/direct spectrum relationship and tendency line

with incidence g of 30º and it is representative of g 0º and 15º. It has been highlighted the spectrum region with greater differences being outstanding the region 560–580nm and 590–630 nm, which present a greater absorption than in the rest of the spectrum.

In the mentioned zones, the quotient of both curves (which should be centred in 1 due to re-scaling) is prone to locate near 0.9 what may indicate 10 % more of absorption in this part of the spectrum (Fig.16).

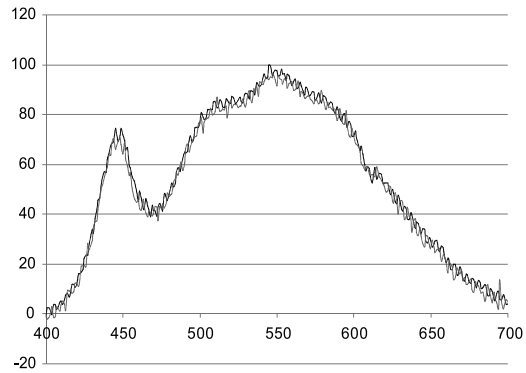

Fig.17. Direct and reflected spectrum for LED

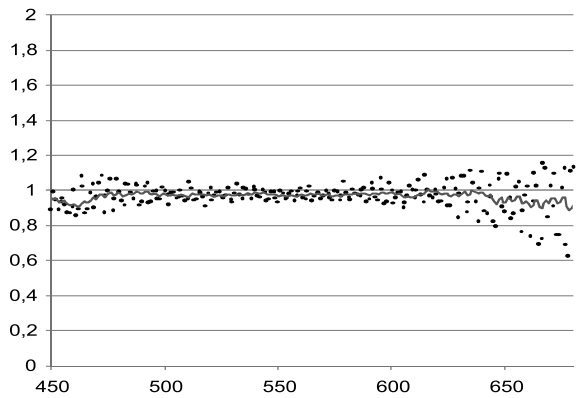

Fig.18. Reflected/direct spectrum relationship and tendency line

Fig. 17 shows overlapped direct and reflected spectra for LED source. Except for a little difference in region 450–500 nm and around 650 nm, both curves seem overlapped, showing slighter discrepancies than for the sodium case. Fig. 18, which presents the relationship reflected to direct spectrum, shows more thoroughly this phenomenon.

In the spectrum visible zone, Fig. 18 shows a trend line very close to 1.

For evaluating the "photopic" effect of these differences and being able to quantify with a unique number, representative of the average reflection in the visible zone (value only valid for the measuring conditions: a= 1°, b= 0° and d= 30°), factors F1 and F2, proportional to emission and photopic reflection, were calculated and defined as:

$$F1 = \int Gdir(\lambda)V(\lambda)d\lambda. \quad (6)$$

$$F2 = \int Gref(\lambda)V(\lambda)d\lambda. \quad (7)$$

In (6) and (7), $V(\lambda)$ is the standardized curve of the spectral sensitivity of the human eye and $G(\lambda)$ are the measured spectra, "*dir*" direct and "*ref*" reflected by the sample in the already mentioned conditions. Fig.19 shows, as example, $Gref(\lambda)$, $V(\lambda)$ and the product, for the sodium lamp case.

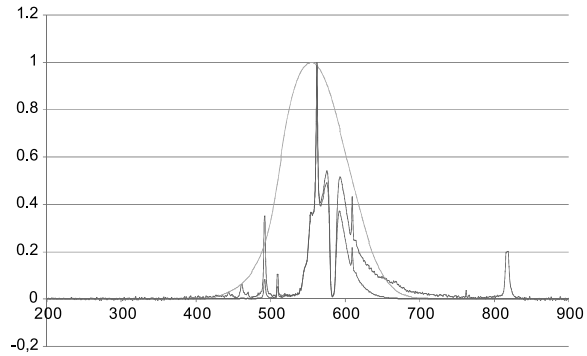

Fig. 19. HPS reflected spectrum and curve $V(\lambda)$

Table 2 summarizes the result of the performed calculation. It is observed a difference in favor of LED reflection ("gain") close to 4 % for the studied surface, for the observation and lighting conditions already mentioned.

4. CONCLUSIONS

The results found are in agreement with previous studies carried out in this laboratory and the research performed in Europe and USA regarding the existence of a soft dependence of the reflection on surfaces with the incident light spectrum. This implies a slight colouring towards reddish green that appears in all studies despite the different research techniques used and the type and composition of surfaces studied.

The study with actual surfaces, in use in the metropolitan area of Buenos Aires allowed correlating this "spectral selectivity" with an increment (gain) in the lightness degree when LEDs are used compared to the HPS lamp spectrum. The *Qoo* improvement found in motorways were of an order of 20 % average, whereas in the spectral study on a sample, the increment could be estimated around 4 %. It is worth mentioning here that in the last case the sample was a surface not necessarily similar to the

Table 2. Results of Photopic Comparison

Spectrum	$F = \int G(\lambda)V(\lambda)d\lambda$	Relative difference (F2-F1)/F1	LED to HPS reflected gain
Direct HPS lamp	25,00	–5,92 %	3,8 %
Reflected HPS lamp	23,52		
Direct LED	85,30	–2,12 %	
Reflected LED	83,49		

actual ones in use nowadays. However, the agreement, at least in the tendency, indicates a new advantage of LED technology and its link to energy efficiency.

ACKNOWLEDGEMENT

The authors are thankful to the CIC PBA, where Pablo Ixtaina is a member of the Scientific and Technological Researcher Career and Braian Bannert is professional member.

REFERENCES

1. Ixtaina, Pablo R; Vidal, Pedro A., *Road Surface Lightness and Energy Efficiency inroad Lighting,* 12th European Lighting Conference "LUX EUROPA 2013, Poland, 2013.

2. Publication CIE Nº 30–2 (TC-4.6), *C*alculation and measurement of luminance and illuminance in road lighting. Vienna, 1982.

3. Ixtaina P, Armas A, Bannert B, *Use Effects on the Reflection of Macro Textured Surfaces*. Journal of Applied Engineering Sciences ISSN: 2247–3769 / e-ISSN: 2284–7197, VOL(6), ISSUE1/2016, pp51–56, May 2016.

4. Instituto Argentino de Racionalización de Materiales, IRAM AADL J 2022–2, Alumbrado Público, Vías de Tránsito – Clasificación y Niveles de Iluminación. Buenos Aires, 1995 J.

5. Ekrias A, Ylinen A, Eloholma M, Halonen L, Effects of Pavement Lightness and Colour on Road Lighting Performance.CIE International Symposium on road surface photometric characteristics: Measurement Systems and Results, Italy, 2008.

6. Adrian W., Jobanputra R, Influence of Pavement Reflectance on Lighting for Parking Lots. Portland and Cement Association, PCA R&D Serial No 2458, 2005.

7. Herold, M. *R*emote Sensing of Impervious Surfaces, Ch. 12 – Spectral Characteristics of Asphalt Road Surfaces, Wageningen University, DOI: 10.1201/9781420043754, 2007.

8. International Organization for Standardization ISO, "Guide to the expression of uncertainty in measurements", Switzerland, 1993.

9. http://www.avantes.com/products/spectrometers/starline.

***Pablo R. Ixtaina*,**
Prof., Universidad Nacional de La Plata Electrical Engineer, Professor of Electrical Measurements and Lighting for degree and postgraduate careers at National and Technological La Plata Universities. Researcher of the Comisión de Investigaciones CIentíficas (Buenos Aires, Arg.), he has carried out postgraduate studies, improvement work and scientific visits at the National University of Tucumán, La Plata National University, Optical Research Center Ciop, LMT Laboratory (Berlin, Germany), Philips Lighting Application Center (Eindhoven, Holland). He is Director of the Laboratorio de Acústica y Luminotecnia, LAL, Buenos Aires Official Research Center in Light and Sound. He is member of the "Public Lighting" Commission of the Argentinean National Standards (IRAM). He has about 40 publications in Scientific and Technical Journals and Congress reports

Braian D. Bannert
is in staff of the Universidad Nacional de La Plata Engineer in Electronics. He belongs to Comisión de Investigaciones CIentíficas (Buenos Aires, Arg.) scientific staff. He currently participates in studies related to the area of lighting technology