Improved Public Lighting at the University of São Paulo - Brazil

JOSÉ CARLOS MARTINEZ MELERO[1], EMERSON ROBERTO SANTOS[2], ELVO CALIXTO BURINI JUNIOR[1], HÉDIO TATIZAWA[1]

[1]Institute of Energy and Environment, University of São Paulo
Avenida Professor Luciano Gualberto, 1289, Butantã, São Paulo-SP, BRAZIL
[2]Electrotechnical, Technical School,
Rua Clélia, 2064, Lapa, São Paulo-SP, BRAZIL

Abstract: The University of São Paulo (USP) transitioned the roadway lighting technology at the University called Armando de Salles Oliveira (USP-CUASO campus) from High-Pressure Sodium Vapor Lamps (HPSVL) and Metal Halide Lamps (MHL) to the Solid-State Lighting (SSL). So, this paper presents and discusses the outcomes of the lighting installations and the depreciation of light output from luminaires installed at the Institute of Energy and Environment (IEE) at USP using field data collected over two years (2018–2023). The analysis incorporates aspects related to corrective maintenance, predominantly performed last year, necessitated by the end of the useful life of components such as electronic drivers (66%), 50 W LEDi modules (17%) and others (17%). The failure rate of the sampled luminaires in the IEE area increased from 10% to 28% between August 2021 and January 2023.

Key-Words: Public Lighting, Solid-State Lighting (SSL), LEDi, light output depreciation, lifetime, corrective maintenance.

Received: June 22, 2022. Revised: October 11, 2023. Accepted: November 14, 2023. Published: December 31, 2023.

1. Introduction

Road lighting using Solid-State Lighting (SSL) LEDi technology was installed at the Cidade Universitária Armando de Salles Oliveira (CUASO) campus of the University of São Paulo (USP) in São Paulo (city), Brazil. This process involved the replacement of High-Pressure Sodium Vapor Lamp (HPSVL) and Metal Halide Lamp (MHL) lighting systems to the LEDi (inorganic light emitting diode) technology as a new system that was implemented in September, 2013. The project aimed for a minimum luminous efficiency of 85 lm/W. The initial illuminance value established in the 2012 project exceeded the minimum requirements outlined in the local standard. Additionally, the uniformity index surpassed the specifications set by the current Brazilian technical standard [1]. Records obtained for the parking area in the region known as Polytechnic School based on data sampled in 2014, indicated an average illuminance value of 67 lux and a uniformity index of 0.448 (Emin/Average) [2].

In accordance with the Brazilian technical standard, the specified minimum requirements are 20 lux for the average illuminance and 0.3 for the uniformity index [1]. In 2016, 47 lux was presented for the average and 0.11 for uniformity [2]. In the lighting project at CUASO, there was no specified illuminance limit depreciation for maintenance or replacement of luminaires with devices featuring higher luminous efficiency.

Projections from the DOE (USA) indicated the possibility of a rapid evolution in light production efficiency for SSL technology [3].

Even before the implementation of SSL technology, CUASO had raised concerns about the durability of the new SSL system for lighting, specifically regarding the lifetime of LEDi luminaires.

Regardless of the light source type used, the luminous depreciation will occur over a time of use, however, sampling from the survey by a mesh of illuminances between poles or contiguous light points is a task, that requires support staff (both day and night) that consume consuming a lot of time and, it is a process not very efficient. In the literature, the operation method of the LEDi technology is indicated ("when applicable") as one of the two main concerns related to failures (USA, 2014) in addition to the gradual reduction of the light output (luminous or lumen depreciation) [4]. The IEC has established two metric parameters for the service life of SSL (LEDi-based) luminaires.

Both are related to "gradual" and "abrupt" light output (luminous flux) degradations suggesting the application of standard set for quantities reported by the market, such as: "average lifetime" and the associated "abrupt failure value" [5].

This article discusses lighting records of CUASO obtained in locus and the company report responsible for implementing and maintaining the LEDi technology over more than 09 (nine) years (from November, 2013 to January, 2023) [2]. The CUASO public lighting system showed a high failure rate in the Institute of Energy and Environment (IEE-USP) area after the pandemic period (SARS-COV 2). This situation required that maintenance actions be intensified, and such services were developed throughout 2022 with the team and after the acquisition of the electronic drivers [6].

2. Methodology

2.1 Selecting events and dates

After 34,700 hours of operation (August, 2021), the public lighting system of CUASO using SSL (with LEDi) had a high failure rate of about 10%, according to sampling carried out in the IEE area [7]. This indicated the need for corrective interventions to restore the ordinary conditions of the SSL lighting. The fact that activities at CUASO were suspended and re-established after the pandemic period (SARS-COV 2) required intensified maintenance actions. These services have been developing with the acquisition of electronic drivers and their teams.

Currently (January, 2023), it is estimated that the operation of the equipment is close to 41,000 hours since the initial energization (September 25, 2013).

The Campus Administration of USP - CUASO (PUSP-C) records indicate that more than 1,200 light fixtures were repaired throughout 2022.

A publication of 2014 was presented paired records on the Correlated Color Temperature (T_{cp}), when it was obtained by direct measurement and calculation using the same instrument (manufactured by Minolta, model XY-1), which was used to carry out the field sampling of this work.

Those results were parameterized for different light sources, such as: (HPS, 03 (three) SBFL, MH and 02 (two) LEDi). Both values (reading and calculation) are presented including records (Table 1, n. order 6) for T_{cp} carried out on November 11, 2013, mainly for 11 (eleven) luminaires of CUASO [8]. The calculation methodology used the chromaticity coordinates to determine the T_{cp} based on the algorithm* proposed by Robertson, A. R. in 1968 [9].

In an audit, the objective was to evaluate the lighting systems comparatively of CUASO. Three types of light sources were iinstalled at CUASO in the year 2013 (HPS, MH and LEDi). Parameters assessed from measurement (reading) and calculation) are: Correlated Color Temperature (T_{cp}); average illuminance (E_m); mean luminance (L_m) and luminance coefficient (q);, (ratio of luminance to illuminance per point) mean and associated bilateral confidence intervals (ICB).

The average illuminance of typical equipment at CUASO (manufactured by Peterco, HPS of 250 W with housing for auxiliary equipment and borosilicate glass diffuser) was evaluated according to conditions established in the test field (IEE/USP) [10].

A report of 2019 was considered, containing records for illuminance obtained by direct measurement and calculations (average and uniformity) for different years: 2014, 2016, and 2019, but it was not indicated, which type of lux meter was used [2]. In this same article, only the maximum values of the lane (vehicle) recorded for each of the 07 (seven) grids of sampled points are considered (it is believed that the measurements were carried out at the pavement level as observed in 2016 [11]). The definition of illuminance maximum points is attributed to the high probability of their occurrence in the position known as Nadir, which has the luminaire at the Zenith position, this procedure is possible to compare samples taken in the IEE-USP area in 2018 and 2023, which are presented in this work [12].

The averages have traceability when obtained from the meshes defined in the measurement report; the Brazilian technical standard considers 2 (two) transverse lines normally with higher values [1, 2].

This characteristic can distort the mean raising its value improperly and for this reason, it was not considered in this article.

Note: *In the updated CIE terminology (17-258 - correlated color temperature) there is one note that tells us, “there is a limitation on the range of valid coordinates and an indication that the T_{cp} can be calculated from a simple search procedure of minimum value in the determination of the Planck temperature (black body), which provides the smallest difference between the input chromaticity and the Planck locus recommended by methodology [8]. Also, this signals that some of the values contained in tables of the cited reference are not updated and the second abbreviation used as "CCT".

2.2 Parameters considered that infer the luminous depreciation

The parameters considered in this article are road plane illuminance (vehicular and pedestrian), the T_{cp} (read and calculated from the chromaticity coordinates, x, y, using software), and the "distance"

(Duv) between the considered point and the Planck locus [13].

To determine the average that was later used to estimate depreciation between the different periods (years), the data obtained in the IEE area during 2018 and 2023 and the position called as Nadir, were stratified by illuminance ranges ≤ 20 lux; between 20 and 30 lux; between 30 and 40 lux; between 40 and 50 lux; between 50 and 60 lux; ≥ 60 lux and < 70 lux; and ≥ 70 lux.

The range containing the highest frequency (primary mode) was used, due to the distribution of records obtained, which are presented. The two-sided confidence interval with level of 95% was calculated and used to quantify the dispersion of the record concerning the average.

3. Results

Currently, data collected (see Table 4, [6]) for different types of luminaires indicates that there are already products on the Brazilian market with: nominal luminous efficiency in the range from 135 to 170 lm/W; two nominal T_{cp}; eight for 4000 K and three for 5000 K; nominal electrical power in the interval from 47 W to 197 W and relative price in USD$/klm from 4.36 to 12.88.

Based on a list of 680 repaired items in USP lighting at CUASO (PUSP-C) from March to October of 2022 (after 07 months), it was verified that the highest need for replacement was for electronic drivers, which represented 67% of replaced items and together with the replacement of LEDi modules accounted for more than 86% of the items already replaced. The smallest fraction of failure occurred for the surge suppressor item (2.65 %), then for the item called as telegestor (telemanager) (3.98%) and Y-cable (7.24%) [6].

3.1 Events and dates

3.1.1 T_{cp} from SSL in 2013

The values presented in Table 1 refer to measurements carried out at CUASO in 2013 using different types of light sources; the lines numbered from 1 to 6 correspond to the average value and line 7 to a single reading/calculation [8].

Table 1 shows the correlated color temperature (T_{cp}) values obtained by directly reading the instrument used [8].

Table 1. Average value determined for 06 (six) types of artificial electric light sources and single reading data (in line, number 7). Source: samples measured at CUASO, USP [8].

		T_{CP} (k.K)	
Order number	Light source type	Reading	Calculated
1	HPSVL	1.89	2.20
2	SBFL (g)	2.70	2.70
3	SBFL (o)	2.68	2.68
4	SBFL (g)	2.63	2.64
5	MHL	3.60	4.80
6	LEDi (c)	3.52	4.23
7	LEDi (g)	(3.62)	(4.51)

In table 1, the HPS and MH installations for road lighting on a pole with a curvilinear shape present at CUASO (Av. Prof. Almeida Prado) were measured on November 07, 2013, and after, when it installed using SSL (LEDi) luminaries on metal poles at CUASO (Av. Prof. Luciano Gualberto road for pedestrians and vehicles) and SBFL - Single Base Fluorescent Lamp (or compact), whose samplings measurements were carried out at laboratory [8]. In addition, the T_{cp} obtained by direct reading on the instrument used (Table 1) presents values calculated using the methodology of Robertson, A. R. and the chromaticity coordinates obtained by direct reading using the same instrument [9].

3.1.2 Maximum illuminance, CUASO, USP

Table 2 presents the maximum illuminance for 07 (seven) grids, where measurements were carried out at CUASO. The data were obtained from the report delivered to PUSP-C indicating that the samplings occurred in 2014, 2016 and 2019 [2].

Table 2. Maximum illuminance is measured between two poles at different points on the road or area grid of CUASO [2].

Measurement location and time of occurrence[b]	Maximum Illuminance (lux) Year		
Identification	2014	2016	2019
Av. Luciano Gualberto[a]	92	77	73
Av. Almeida Prado	90	77	80
Av. Lineu Prestes	97	82	76
Rua do Lago (street)	76	70	64
Rua do Matão (street)	96	62	63
Estacionamento FEA (parking)	106	80	65
Estacionamento POLI (parking)	108	86	83

Note: [b] Maximum values extracted from each mesh/grid of the report considered [2].

3.1.3 Measurements carried out in 2013

The result of the sampling carried out in the test field (IEE/USP) with poles separated by 35 meters, the calculated illuminance (mean value and confidence interval) was 8.2 ± 0.8 lux. The other mentioned values were sampled on November 7, 2013, in the direction of 45° concerning the normal direction and origin on the surface of the pavement. Table 3 shows the results [10].

Table 3. Road lighting technologies at CUASO used in 2013: average illuminance, average luminance, asphalt luminance coefficient, correlated color temperature reading, and correlated color temperature calculated [10].

Measurement parameter	MHL [c]	HPSVL [c]	LEDi
Average illuminance (lux)	13±1	43±12	58±12
Average luminance (cd/m^2)	0.57±0.05	1.3±0.2	2.8±0.5
Asphalt luminance coefficient (mcd.lm^{-1})	45±5	34±6	50±6
$T_{cp\ (reading)}$ (K)	3600±36	1893	3510
$T_{cp\ (calculated)}$ (K)	4793±43	2220	4235

Note: [c] Nominal electrical power of 250 W for each luminaire [10].

3.1.4 Audit carried out in 2016 and 2018

In 2016, follow-up and measurements were carried out, whose results when in the field showed an acceptable reading difference between instruments and points confronted (location: Avenue Luciano Gualberto) [11]. In Figure 1, 45 illuminance results were plotted (IEE, in 2018) according to the luminaire identification (at the Zenith position).

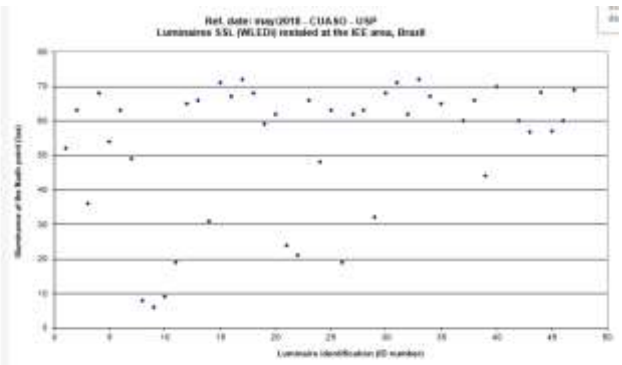

Fig. 1: Luminaire (at Zenith position): illuminance at the Nadir point *vs.* CUASO SSL luminaires ID identification number (May 2018).

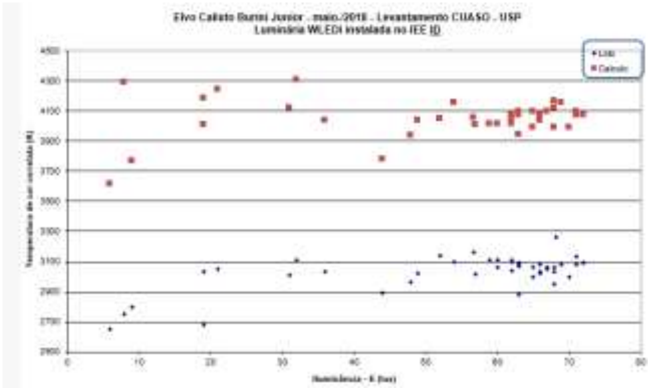

Fig. 2: Correlated color temperature obtained with an instrument and calculated *vs.* CUASO SSL luminaires Nadir illuminance (May 2018).

The illuminance sampling was carried out for Av. Luciano Gualberto, between 22h34 min. and 22h46 min. on September 8, 2016. This road is for vehicles and pedestrians and is located close to the IEE. Measurements for 6 (six) transverse lines, 1 (one) longitudinal line (pedestrian route), and 10 longitudinal lines (vehicle route) were obtained. For the 59 measurements in the vehicle, the average and ICB of 99% and 44 ± 6 lux were obtained; the standard deviation of 18 lux; ranging from 14 lux to 82 lux; mode of 49 lux, and for minimum illuminance ratio by the average with the value of 0.32 lux.

For the pedestrian pathway, 6 (six) measurements were obtained and the average and ICB 99% of 51 ± 10 lux was collected; a standard deviation of 10 lux ranging from 39 lux to 67 lux; and for the minimum illuminance ratio by the average, the value of 0.77 lux. Based on the results of a report accessed from a similar location in 2016, for the 45 records in the vehicle, an average of 41.8 lux was obtained ranging from 13 lux to 77 lux, and for the minimum illuminance ratio by the average the value of 0.31 lux [14]. It is mentioned that 15 lux (minimum illuminance) and 0.20 lux (uniformity) are expected for the class (V3) considered for the road [1]. For the pedestrian pathway reported in 2016, 05 (five) measurements were collected and an average of 45.6 lux was obtained ranging from 36 lux to 56 lux; for the minimum illuminance ratio by the average value of 0.79 lux[14]. Mention is also related to 5 lux (minimum illuminance) and ≥ 0.20 (uniformity) expected for the class (P3) considered for the route [1]. The body of the report also mentions 20 lux (minimum illuminance) and ≥ 0.30 (uniformity) predicted for class (P1) as reference values for the vehicle parking area [1, 14].

3.1.5 Audit carried out in 2018 at IEE

When stratified values of sampled illuminance are considered (in 2018) for the condition ≥ 50 lux, the sample containing 31 results presented the range from 52 lux to 72 lux, standard deviation of 5 lux, a mean of 64 ± 2 lux, which corresponds to a dispersion of 3%. In the condition > 60 lux, the sample containing 23 results presented the range from 62 lux to 72 lux and standard deviation of 3.2 lux and a mean of 66.4 ± 1.3 lux, which corresponds to a dispersion of 2 %.

The T_{cp} records calculated values (in 2018) and a sample containing 40 results showed the range from 3615 K to 4309 K, standard deviation of 126 K, average of 4055 ± 39 K, which corresponds to a dispersion of 1 %; and D_{uv} records, calculated values (in 2018), a sample containing 40 results showed the range from 2.20 to 3.92 (x 10^{-3}) lux, standard deviation of 0.32 lux, average of 2.75 ± 0.10 (x 10^{-3}) lux, which corresponds to a dispersion of 3.6 %.

3.1.6 Nadir illuminance, T_{cp}, D_{uv} (IEE, 2023)

Sampling was carried out on January 9, 2023, in the IEE-USP area at CUASO. On this date, 11 luminaires without lighting (off) were identified, 01 (one) luminaire with very low intensity and 01 (one) with intermittent failure resulting in a relative number of failures (abnormal condition) of 28%.

Even a pedestrian luminaire has two modules instead of one and a luminaire is mounted above a roof, both were not considered dark spots. When sampled illuminance values are considered (in 2023) stratified by removing the value 113 lux (luminaire with two 50 W modules, pedestrian route) and condition > 40 lux, the sample containing 21 results presented a range from 44.2 lux to 68 lux, standard deviation of 7 lux mean of 57 ± 3 lux, which corresponds to a dispersion of 5%.

The T_{cp} records calculated values (in 2023) and a sample containing 32 results showed a range from 2256 K to 4130 K, a standard deviation of 324 K, average of 3975 ± 112 K, which corresponds to a dispersion of 3% and D_{uv} records, calculated values (in 2023), a sample containing 32 results showed a range from 2.50 to 3.40 (x 10^{-3}) lux, a standard deviation of 0.24 lux, average of 3.05 ± 0.08 (x 10^{-3}) lux, which corresponds to a dispersion of 3%.

The ambient temperature and external relative humidity were sampled at each measurement point with an instrument manufactured by Minipa, model MT-241 for a sample containing 30 results. It presented a range from 20.9°C to 23.1°C, average of 21.8 ± 0.2°C, which corresponds to the dispersion of 0.93% and for the external relative humidity to the range from 61% to 72%, an average of 67 ± 1 %, which corresponds to a dispersion of 1.5 %.

3.1.7 Light output depreciation

The reduction of the light output for lamps in the IEE-USP area sampled in 2018 and 2023, can be used to estimate the depreciation that was calculated by the ratio of 57 lux/66.4 lux, which represents 86% that presented a reduction in light output of 14% identified when the Nadir point was used as a reference and the extraction procedure explained based on the modes. This reduction occurred over 4.6 years. It is possible to estimate an average rate of 3% per year for the period considered. This value makes it possible to formulate a hypothesis for the installation, which in September, 2023 completed 10 years since the initial energization. It may present a reduction of 30% in the light output that will be at the level called L_{70}.

Other locations, such as avenues, may show a more significant decrease in depreciation, due to the emission of particulates by bus exhaust, for example. The removal of LEDi modules from luminaires with two or more modules was observed some in the IEE area. This fact was also observed with direct impact on the records of light output at the Nadir point. The idealized methodology (Nadir measurement) was used because it is simpler than the IESNA methodology [15]. The decision to remove LEDi modules from the luminaires was based on restoring the maximum possible light output.

Figure 3 shows the data of maximum illuminance values obtained from the accessed report for 2014, 2016, and 2019 with 07 (seven) meshes of CUASO roads and parking lots and average illuminance from Nadir for the IEE area in 2018 and 2023, including linear regression and equation [2].

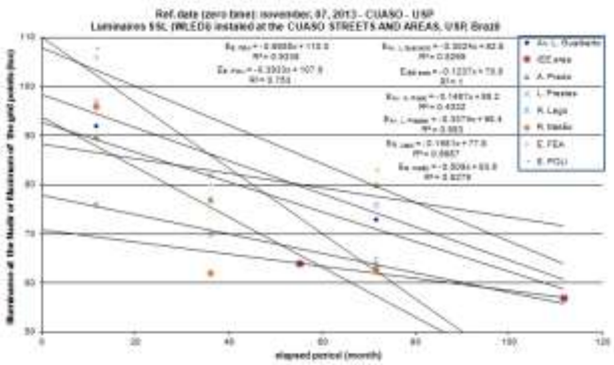

Fig. 3: Data of maximum illuminance values for 2014, 2016, and 2019 with 07 (seven) meshes in CUASO roads and parking lots) and average illuminance of Nadir for the IEE area in 2018 and 2023 included regression and equation [2].

For each set of 03 (three) points maximum, an adjustment was made using linear regression and the equations and the value of the quality parameter R^2 are presented [2]. It should be noted that the occurrence of non-conforming records between the final and previous values (second and third) indicates an anomaly occurring between each data acquisition in the field. Usually, a reduction of the light output is expected; however, in some cases, there was an increase (see Fig. 3, Rua do Matão (street), for example). In Figure 4, the points where the poles and light fixtures are installed in the area of the IEE - USP, CUASO are presented and identified [16].

Fig 4: Map of the IEE-USP, CUASO, area with the position of the poles, where the light fixtures with identification are installed ID [16].

In Fig. 5, IEE-USP area changes are indicated as proposed in the path of ducts (and light points, circuits: 002 and 003), due to pedestrian routes not foreseen in the project (ref. file: <USP- EL-IMP-R04-21.pdf>, dated May 20, 2013) [17].

Fig. 5: Map, in the plan of the IEE-USP area (in CUASO), an electrical circuit with a suggestion for changing the path of ducts (and light points, circuits: 002 and 003), due to unforeseen pedestrian routes [17].

Some light points planned and implemented, as shown in Fig. 5 were not included in Fig. 4, designed to identify the current situation (in 2016) during the inspection performed.

4. Discussion and conclusion

A hypothesis for the installation, which in September, 2023 completed 10 years since its initial energization is the definition of the date, which it will present a 30% reduction in light output and that will have reached the end of service life called L_{70}.

Other places, such as avenues, may present a more significant reduction in light depreciation, due to the emission of particulates by bus exhaust, for example.

The removal of LEDi modules from luminaires with 02 (two) or more modules was observed, some in the IEE area. This fact was observed by measurement, as it affected the records made of light output at the Nadir point. This corrective maintenance measure may cause a reduction in illuminance values below the established minimum requirement.

The idealized methodology (measurement at Nadir point) was used in the IEE area because it is simplified concerning the IESNA methodology [15].

It proved to be valuable and capable of indicating light depreciation and the hypothesis of a temporal rate.

The reference T_{cp} is considered as a parameter, the average is calculated and presented (in Tab. 1, line 6 of 4230 K) for the sample obtained in 2013 and the average values for 2018 (4055 K) and average in 2023 (3975 K), there presented a reduction of - 4% (in 2018) and reduction of -6% (in 2023) according to samples used.

For the D_{uv} parameter, taken as reference, the average calculated for 2018 (2.75×10^{-3}) and the average in 2023 (3.05×10^{-3}) presented absolute increase of 0.30×10^{-3} and a relative 11% according to the samples used.

It was verified that the need to replace electronic drivers represented 67% of the items replaced and that, together with the LEDi module, they corresponded to more than 86% of the items already replaced [6].

Data collected for different types of luminaires indicated that there are products in the Brazilian market with nominal luminous efficiency in the range from 135 to 170 lm/W with a relative price range of USD$/klm from 4.36 to 12.88 [6]. These data, among others, should be considered in an evaluation of the best maintenance of components, as has been carried out (in 2022) by the CUASO.

Administration or the complete replacement of the luminaires and in a procedure called "in the group".

Considering the mean value of illuminance (of 13 lux) and nominal power (of 250 W), the accessed MHL light point (Table 3) proved to be uncompetitive concerning the HPSVL (of 250 W, manufactured by Peterco, with 8.2 lux) having agreed to deactivate both lamps.

Without the application of any correction, due to different spectral emissions of the sources, the SSL system (LEDi) showed significantly, higher illuminance and luminance (2.8 cd/m^2) compared to the HPS system (1.3 cd/m^2). The luminance coefficient indicates the possibility of good performance for the system with SSL technology and suggests the possibility of reducing the light output.

In the comparison of the systems (Table 3) with a correlation between luminance and illuminance, luminance coefficient showed a higher value (50 mcd/lm) for LED technology of CUASO concerning MHL and HPS and the condition established for comparative analysis between technologies. In a previous work and methodology (in 2002 and luminance meter manufactured by LMT, model L 1009), luminance coefficients of 96 mcd/lm were obtained for a system carried in France and 77 mcd/lm carried out in São Paulo, Brazil, for the HPSVL technology [18]. In the present analysis, note that the ability of the pavement to return incident light is considered. When lighting is analyzed based on the concept of illuminance, the focus is exclusively on equipment. It is imperative to include the floor and the user as part of the lighting system. Both for the capacity to produce light per electrical power of the installation (HPSVL in France with 150 W and in Brazil with 250 W, nominal) and for average luminance produced under nominal conditions, the results are similar and above 3 cd/m^2.

Based on a period of about 4 (four) and a half years, an average rate of 3% per year for light depreciation was estimated in a region that does not have vehicle traffic whose particulate emissions can be significant. This value made it possible to formulate a hypothesis for the installation, in general, that in September 2023 (10 years from the initial energization) could present a reduction in light output of 30% or reach the typical end-of-life level called L_{70}. The present result aligns with the depreciation rate for the accumulation of dirt of 3% per year, as fixed by literature [19]. This suggests the incorporation of cleaning practices as a maintenance procedure by PUSP-C in CUASO.

The use of LED luminaires in public lighting is a reality and its expansion requires case studies that can reveal the useful life of this equipment since this information is fundamental for the financial models adopted. This article aims to contribute to these studies, providing data that can be compared.

Acknowledgements

To Eng. Leonardo Brian Favato, Campus Administration of USP - PUSP-C, for spreadsheets and information on maintenance at CUASO, and City Hall of Santo André, São Paulo state, for budget information to the acquisition of SSL luminaires (LEDi) in the Brazilian market.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the present research at all stages, from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.