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LIGHTING, QUALITY AND ARTIFICIAL INTELLIGENCE

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Abstract

Data collected during investigations with lighting equipment using Solid State Lighting - SSL (WLEDi) technology are presented and considered. One focus is on the quality parameters of artificial lighting. Research on road lighting was carried out at the University City Armando de Salles Oliveira (CUASO), Campus of the University of São Paulo - USP and for internal lighting from an experiment at the Institute of Energy and Environment for more than 2,600 hours. The long-term experiment uses different brands of Edison-type WLEDi lamps (E-27) is running under regulated energy, continuously, and ambient temperature. The results obtained show the depreciation of the light output and correlated colour temperature, just as it was obtained for the CUASO road lighting system that has already completed more than 20 kh in service. The results are expected to increase local knowledge about the depreciation of light production by the SSL technology used by Brazilian consumers.

Keywords: Chromaticity coordinate, Colorimetry, Correlated colour temperature, Light output depreciation, LED, Luminous efficacy, Measurement, Photometry, Solid State Lighting (SSL), White Inorganic LED (WLEDi).

1 Introduction

The University of São Paulo - USP, in the year 2013 (September), started the energization of the new "white light" points from the WLEDi (Inorganic White Lighting Emitting Diode) technology for road illumination on the USP campus: CUASO. As of November of 2013 the light output of the installation started to be sampled in order to accumulate records to estimate the light depreciation rate of the SSL system. A high rate implies in anticipation of maintenance and can reduce the lifetime of the facility. The number of light points at CUASO has increased. The minimum luminous efficiency prescribed for luminaire acquisition was 85 ℓm/W. Three models of luminaires have been received, and the nominal electrical power of each luminaire also sets a threshold for light output or minimum luminous flux: (50 W), 4.7 kℓm; (100 W), 8.9 kℓm and (200 W), 16.6 kℓm. Currently, a process is under way to establish concessionaires for the administrative management of the public lighting (IP) network in the city of São Paulo and in the current project, there is a prescription for "total" luminous efficiency of no less value at 120 ℓm/W; the correlated colour temperature of the light emitted by the luminaires is set at (4000 ± 300) K; the depreciation of the light output up to 30%, the useful life (L_{70}) must be at least 50,000 hours, the average daily usage period of 12 hours, the reference ambient temperature (40 ± 1)°C are referenced. The four main parameters related to the quality of artificial lighting that in Brazil are migrating to SSL technology, both outdoors and inside buildings, but not in order of importance, are indicated as: the depreciation of the light output (during normal service), the correlated colour temperature (T_{cp}), the luminous efficiency and the life expectancy. Glare[*] that causes discomfort, disability (SCHREUDER, D.A., 1998; CIE 117, 1995; CIE 190, 2010); Flicker (IEEE Std 1789, 2015; CIE TN 006, 2016), Colour rendering index - CRI (CRAWFORD, B.H., 1959; SCHANDA, J., 2002; OHNO, Y., 2005; SCHANDA, J., 2007; POUSSET, N. et al., 2009); Total harmonic distortion - THD (IEEE Std 519, 2014) are also very important parameters, and only for operational reasons will not be extensively considered in the present article. After the commercialization of incandescent light bulbs was banned, for the Brazilian's consumer at the

[*] CIE e-ILV: "17-492 glare", http://eilv.cie.co.at/term/492; CIE e-ILV: "17-330 disability glare", http://eilv.cie.co.at/term/330; CIE e-ILV: "17-333 discomfort glare". http://eilv.cie.co.at/term/333.

residential sector, which has an Edison type receptacle (E-27 code), currently has two light sources options: the single base fluorescent bulb (compact) and the WLEDi lamp, whose investment value is already attractive. The stability of the colour of the light emitted by the SSL technology devices is as important as the luminous efficacy and the light output depreciation that can be used to define the lifespan. The spectral shift of the light emitted can be used to anticipate SSL device failure. In order to carry out analyses in this sense it is necessary to have reliable data on coordinates of chromaticity to calculate the correlated colour temperature (T_{cp}) and the distance (D_{uv}) of the colour chromaticity from the device considered in relation to the Planck locus.

The present paper is inserted in a scenario of technological transition, basically, from the artificial light source based on the electric discharge in gases to the electric light from solid state lighting (SSL). In outdoor lighting, the exchange occurs from the technology of the high-pressure sodium lamp (yellowish light) to SSL. At the residential sector, indoor lighting is from the dominant single base fluorescent lamp technology to SSL. The diffusion of SSL technology, in the residential sector, the replacement of Edison-type lamps (E-27) had reported a very high failure rate. To collaborate with human resources training in the field of lighting engineering an experiment with WLEDi E-27 lamps is being carried out and an equipment (sphere integrator photometer) is been used to sample the light output. Instrument portability is due to the reduced constructive geometry to assist both in it transport to the test site and due the aspects of source thermal stabilization.

The submitted project proposal† presented to the Research Office at University of Sao Paulo (USP) did not have been contemplated with financial resources (CANUTO, S.R.A. 2019) and for this reason the intended work on Artificial Intelligence (AI) did not advance according to our interest and as previously predicted. The reduction in electrical energy consumption by using WLEDi illumination in a projected the exhibition area (museum at IEE/USP) may use in the future (AI) technique. An intelligent network can automatically change patterns and lighting intensity by combining needs, minimizing negative impacts and providing alternatives.

The two main objectives of the present article are identified and considered below.

1.1 SSL Outdoor Lighting Installation Research Objective (USP-CUASO campus)

The aim of conducting research on the road lighting at the University of São Paulo, CUASO campus is to collect data from the lighting system to estimate light output depreciation, as contributions to the maintenance and to the process of replacing WLEDi lighting equipment in CUASO (Brazil). To consider results from an exploratory study carried out with focus on quality evaluation and characteristics such as correlated colour temperature (T_{cp}) of the light source, D_{uv} distance, and luminous efficiency of the luminaire based SSL (WLEDi) technology. An image of the CUASO-USP road lighting installation obtained in the year 2013 is presented (see Figure 1).

Figure 1 – CUASO/USP, Avenue Prof. Luciano Gualberto, Sept., 2013

† "Digital Lighting Control Using Artificial Intelligence".

1.2 Lifespan Experiment (SSL, E-27) Objectives

The focus is on obtaining reliable parameter data to be used to identify premature failure on SSL devices. Extraction of experimental data from SSL lamps with Edison base type, acquired at the Brazilian consumer market. This part of the work is also dedicated to training and human resource training.

2 Methodology

To access the illuminance and chromaticity coordinates from SSL products, particularly, at field site it was used a tristimulus colorimeter‡, Minolta, Chroma meter, xy-1. The chromaticity coordinates were used as input in software based on Robertson methodology (ROBERTSON, A.R., 1968) to calculate T_{cp}, also D_{uv}. In the present article both methodologies were used (the second: Software ColorCalculator, 2019).

2.1 Road lighting research at the University of Sao Paulo, campus CUASO

To access the illuminance and luminance from SSL system, at field site, it was used the LMT pocket photometer and the Minolta, LS-110. Samplings were carried out, over time to collect data from the lighting system of CUASO WLEDi. The T_{cp} were obtained at laboratory and the illuminance values were used to calculated depreciation rate for the CUASO over a period of 15,000 hours.

2.2 Long-term SSL lamp with Edison (E-27) base type experiment

An integrating photometer was assembled and put into service to sample relative light output from WLEDi lamps with Edison (E-27) base type during a long-term durability test that is been conducted. Equipment previously developed and used as a reflectometer for road surface reflectance estimation on site (BURINI JUNIOR, E. C., 2002) was modified and used as an integrating photometer at the lifespan room site. The integrating photometer consists of a hollow sphere part with an internal diameter of approximately 0.4 m (see Figure 2, the black sphere), the lamp housing (the white cylinder, diameter of approximately 0.18 m) to be coupled at the "main port" of the integrating photometer.

Figure 2 – The integrating photometer (at bottom: sphere in black colour) with the housing designed (cylinder in white colour) mounted on top, after February, 2019

‡ Note: To use direct instrument reading values for T_{cp}, calibration factor need to be applied.

The 2π sphere geometry recommendation (IESNA, 2008) was adopted for the existing equipment modification. For the reconditioning of the internal special white paint (based on Barium Sulphate), eight coats was applied. Attention was required during the period of curing between layers and due to the appearance of black spots, possibly, fungi that appear overnight on the sphere inner surface. It was removed using sand paper before the next coat was applied. At the principal integrating photometer port housing was designed and implemented, provided with Edison base type to accommodate a light bulb with E-27 base. All pieces received paint in the interior wall elaborated at IEE and based on Barium Sulphate.

The lamps under test as the reference element used were installed inside the integrating photometer, energized. The lux meter head was installed at the second port for light reading. The determination of the light output is done by calculation and it is relative to the reference used. Six lamps were used for reference porpoises: two incandescent lamps; three WLEDi lamps, 12 W (6500 K) and one WLEDi lamp 9 W (5000 K). In the present article results are presented based on the reference lamp identified by R1 (# 9), 12 W. It is very important to reduce the period for lamp under test steady state condition, after the momentary shutdown of each lamp.

In the period of December, 2018 and February, 2019 the light output was sampled with a luminance meter positioned at the axis of each bulb. In order to be able to sample the electrical characteristics each lamp need to be switched off momentarily to be transferred to the measurement circuit. The Figure 2 shows part of the E-27 samples installed (base up position, about 10 inch separation between lamps), energized (regulated electric power line: 225 Vac) on a continuous basis and at the test site.

Figure 3 – WLEDi lamps installed (base up position, E-27, 225 Vac) running at the test site

3 Results

A compendium of data collected in Brazil from WLEDi equipment of two lighting sector is considered. The parameters illuminance, luminance sampled from surveys conducted; T_{cp} and light output depreciation results from calculations are presented. An intelligent network will combine consumers' needs, minimize negative impacts and will change lighting intensity automatically to reduce de electricity consumption by WLEDi illumination. This part of the article was organized, mainly, in exterior and interior lighting.

3.1 Road lighting research at the University of Sao Paulo, campus CUASO

The University of São Paulo (USP) has altered the road lighting of the University City Armando de Salles Oliveira (CUASO) to white light from solid state technology (SSL: WLEDi) since September, 2013. The project was considered done in July, 2014. Since the beginning lighting system has been regularly monitored to access same change parameters temporal change, basically, T_{cp} and depreciation of the light output. The faults observed in the CUASO road lighting system differ from the observed faults in equipment in the city of São Paulo (BURINI JUNIOR, E.C., 2017). The luminous efficiency of no less value at 150 ℓm/W, probabilly, wiil be the new reference to the next lighting equipment exchange at CUASO-USP.

3.1.1 Results from SSL source colour for road lighting

Figure 4 shows CIE 1931 (x, y) space and the Planckian locus with chromaticity coordinates data from WLEDi equipment (the points circumscribed by the dashed line were sampled from luminaires currently installed at CUASO-USP (BURINI JUNIOR, E. C. et al., 2015) and were obtained at laboratory conditions.

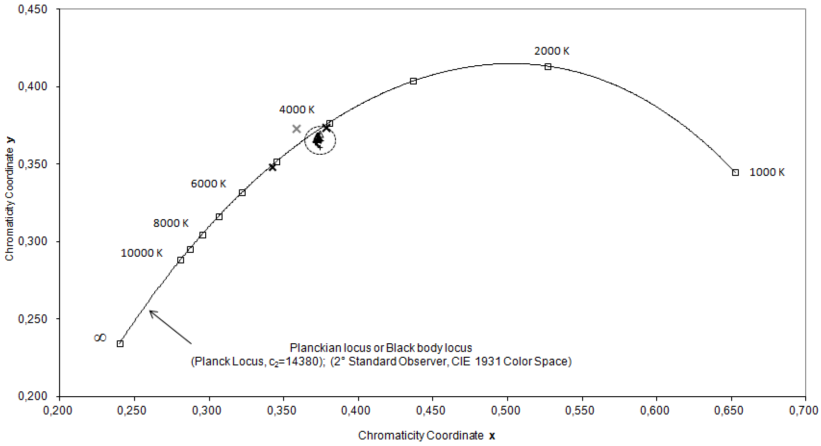

Figure 4 – The CIE 1931 (x, y) space diagram with chromaticity coordinates sampled from WLEDi equipment (the points circumscribed by the dashed line were sampled from luminaires currently installed at CUASO-USP and the three cross-type notations indicate other WLEDi equipment (BURINI JUNIOR, E. C. et al. 2015a)

The chromaticity coordinates plotted on Cartesian plane, near and below the Planck's locus data were obtained from luminaire of the CUASO/USP and the (notation: "x") indicate other WLEDi road lighting equipment. The distance between the chromaticity coordinate points of the radiation emitted by light source, in relation to the Planck locus (see Fig. 4), can alter the colour perception. This distance is not usually considered in Brazil when two light sources are selected or compared; only the T_{cp} values are considered.

3.1.2 Road lighting illuminance at CUASO-USP

In relation to the data sampled in the Avenue Prof. Luciano Gualberto, CUASO-USP, in parallel lines, longitudinal to the roadway, between three contiguous fixtures, the illuminances collected at floor level were treated, statistically; the results are presented in Figure 5.

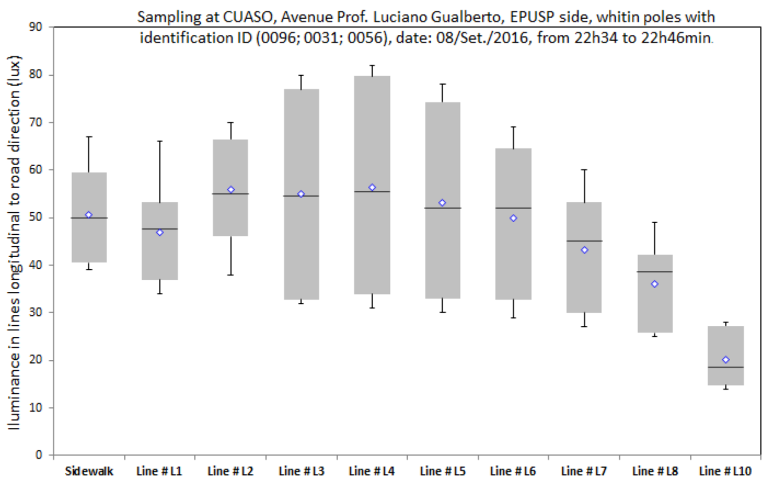

Figure 5 - Illuminance data sampled in parallel lines, at CUASO-USP, Avenue Prof. Luciano Gualberto, after statistic treated (BURINI JUNIOR, E. C. et al. 2016)

The data at CUASO, Avenue Prof. Luciano Gualberto, and date: 08/Sept./2016, was made from six measuring points at each longitudinal line to the road direction (66 total of measuring points). Similar procedure done for illuminance data presented for Avenue Prof. Luciano Gualberto were sampled for seven others sites and roads at CUASO during the same night.

3.1.3 System characteristics and light depreciation from data collected at CUASO-USP

The Table 1 presents some results from data collected during field research at CUASO during a period of 15 kh.

Table 1 – ILLUMINANCE, LUMINANCE AND CORRELATED COLOR TEMPERATURE, MEAN VALUES, OF SAMPLES OBTAINED AT CUASO-USP (BURINI JUNIOR, E.C., 2015a).

Period (x 1000 h)	date (dd/m./year)	IEE side (road)	EPUSP side (road)	EPUSP side (sidewalk)	$T_{cp\ calcuted}$ (K)
at Avenue Prof. Luciano Gualberto/CUASO-USP					
(MVM) **0**	07/Nov./2013 (*)	{(13 ± 1) lx e (0,57 ± 0,05) cd.m^{-2} }		---	(4793 ± 43)
(WLEDi) **0**	07/Nov./2013	---	{(2,8 ± 0,5) cd.m^{-2} e (67 ± 14) lx}		(4235 ± 21)
10	18/Mar./2016	(**45,9 ± 1,5**) lx	---	---	(3989 ± 26)
10	18/Mar./2016		{(2,4 ± 0,3) cd.m^{-2} e (**65,9 ± 7,6**) lx }	---	(4017 ± 70)
(n=10) 15	26/Mai./2017	(**44,2 ± 1,9**) lx	---	---	(3989 ± 16)
(n=10) 15	26/Mai./2017	---	(**62,8 ± 10,2**) lx	---	(4027 ± 50)
at Avenue Prof. Almeida Prado/CUASO-USP					
(VSAP) **0**	07/Nov./2013 (*)	{(43 ± 12) lx e (1,3 ± 0,2) cd.m^{-2} }		---	(2220 ± 13)
(n=11) 15	26/Mai./2017	(62,1 ± 9,5) lx	---	---	(4058 ± 27)
at square of PUSP-C and others					
(n=3) 15	26/Mai./2017	---	---	[116,5 ± 1,6 lx]	(3296 ± 37)
(n=27) 15	26/Mai./2017 (***)	---	---	{58,3 ± 1,5} lx	(4079 ± 47)

Notes: - (*) (BURINI JUNIOR, E. C. et al., 2015a); - (**) Sample that had the lamp at the zenith position and the photometer at the nadir position (CUASO, at the "foot of each pole") corrected value from instrument calibration; and - (***) large sample.

The parameters assed from CUASO lighting system were illuminance, luminance and correlated colour temperature. The illuminance data collected during field surveys (see Table 1) was used to estimate the depreciation of the light output of equipment's sampled and that were installed at both sides of the Avenue Luciano Gualberto, CUASO-USP. The calculus results are presented at Table 2.

Table 2 – WLEDi EQUIPMENT DEPRECIATION AND RATE AT BOTH SIDES OF ONE CUASO AVENUE AND PERIOD OF 15 kh (BURINI JUNIOR, E.C., 2017a)

Avenue Luciano Gulberto, side EPUSP (0 a 15) kh	6,3 %
Avenue Luciano Gulberto, side EPUSP (10 a 15) kh	4,7 %
Avenue Luciano Gulberto, side IEE/USP (10 a 15) kh	3,7 %
RATE: estimated current range of (0,84 ± 0,10) % .kh^{-1}	

3.2 Long-term SSL lamp with Edison (E-27) base type experiment

The experimental data were asses to verify possibly early failure occurrence, T_{cp} position and light output depreciation of lamps from different brands sold at Brazilian consumers market. Preliminary results from a long-term experiment about depreciation of light output are considered. The durability test has already exceeded 2600 hours and only one lamp failure at (1407 ± 69) hours.

During the long-term experiment the light output, the electrical characteristics of each (E-27) SSL lamp and the local ambient temperature have been systematically sampled. Different lamps have been used as standard (reference) and are energized exclusively during the sampling process of light output that intended to occur approximately every 168 hours. The references WLEDi lamps were seasoned during 100 hours. A second methodology was used to sample the light output, replacing the method by the luminance meter. This happened from the availability of an integrating photometer (sphere). In both methodologies the lamp needs to be switched off momentarily when it is withdrawn from the test rack and transferred to the measurement circuit. By the use of the integrating photometer (sphere) and to restore the thermal stabilization condition, since the mass of each lamp is reduced, a period of 5 minutes was adopted to read the instrument (lux meter) used. For the operating cycle the WLEDi lamps were operated continuously (ENERGY STAR, 2015).

3.2.1 Initial chromaticity coordinates results from WLEDi E-27 lamps

Before starting of the long term experiment and for each representative brand, the samples were energized and the chromaticity coordinates were obtained with equipment Minolta, model CS-200 at the lamp axis of symmetry direction. The chromaticity coordinates were plotted on the Cartesian plane and are presented by Figure 6.

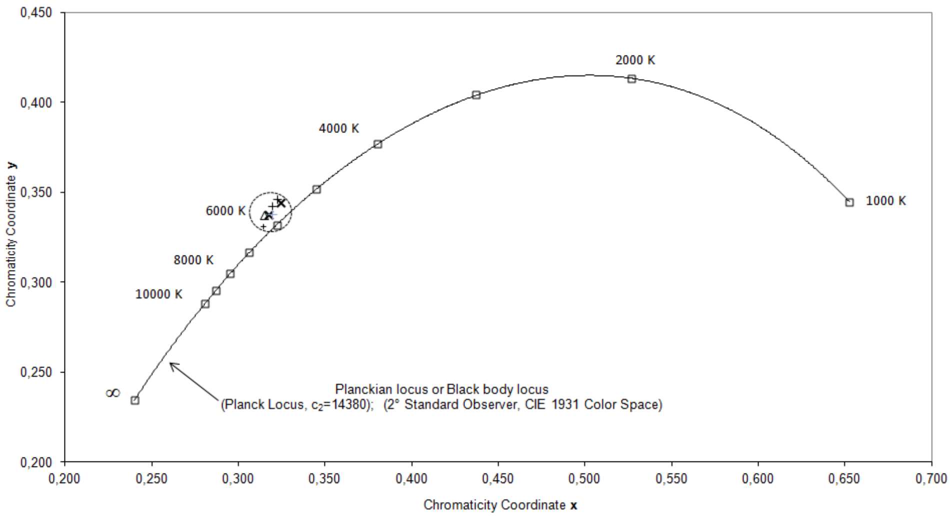

Figure 6 – The CIE 1931 (x, y) space diagram with chromaticity coordinates from WLEDi lamps, (base E-27 type) used in for the long term experiment and sampled initially after thermal stabilization of 60 minutes (BURINI JUNIOR, E. C. et al. 2019a)

The chromaticity coordinates were sampled at regular periods of time, from 10 to 10 minutes and the data presented at Figure 6 are after 60 minutes for thermal stabilization. A dashed circle was drawn around the chromaticity coordinate points sampled and indicates a relative position above the Planck Locus and around 6000 K.

3.2.1.1 Relative light output data for Edison base WLEDi lamps (up until 815 h)

The initial period of the long term experiment was conducted under average temperatures with a decreasing profile and range of (32.9 to 29.5) °C and the light output was sampled by the use of a luminance meter (with tube) positioned in the direction of the axis of symmetry and juxtaposed to the diffuser of each lamp. The values of the ambient temperature were elevated until the middle of February, when fluctuations with variable amplitude occurred. The lowest temperature value was recorded on March 22, 2019, at 22.6°C.

The position of the luminance meter head can change a little from the axis of symmetry direction, and in same case (lamps without Lambertian behaviour) it can change the reading making difference.

The relative light output was calculated considering as the reference lamp code R1, # 9, 12 W for six different brands and eight samples of WLEDi lamps, with base E-27 are shown in Figure 7.

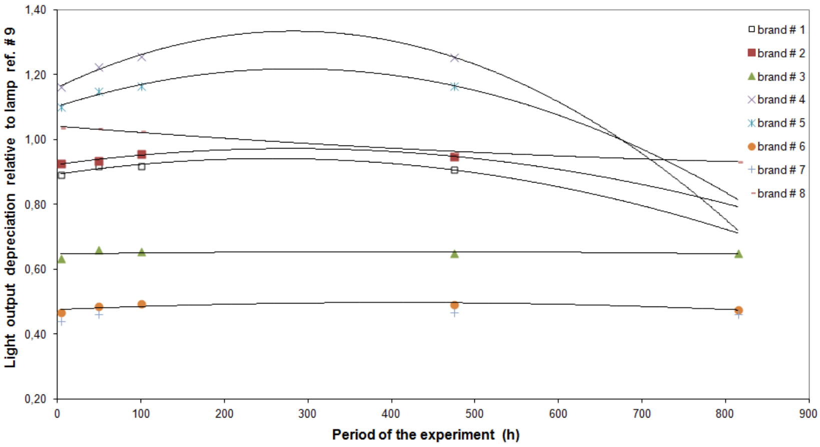

Figure 7 – The light output results from six different WLEDi lamp brand and eight samples (base E-27 type) during the first 815 h of the long term experiment

The samplings whose results are presented according to Figure 7 were performed for the first 815 h and for lamp brand # 2 it has data correction to previous result presented (BURINI JUNIOR, E. C. et al., 2019). The variations were extrapolated using curve (second order type) adjustment. It is from the initial methodology used (the integrating photometer had not been completed), the luminance meter. From Figure 7 it is possible to identify three distinct behaviours for the temporal variation of the light output. The sampled light output results from lamps # (1, 2, 4 and 5) showed an increase in luminous flux up to about 300 test hours, when they went through a maximum value probably and then start reduction (depreciation). The sampled light output results from lamps # (3, 6 and 7) showed very little temporal (up to 815 h) variation of the luminous flux. The sampled light output result from lamp # 8 presented continuous temporal reduction of the luminous flux and the failure recorded occurred with the # 8 lamp (see the section 3.2.1.2).

3.2.1.2 Relative light output data for Edison base WLEDi lamps (up until 2.5 kh)

After over 2600 test hours elapsed only one lamp was considered to have failed after (1407±69) hours. After 815 h, considering as the reference lamp code R1, # 9, 12 W, the integrating photometer for the sample procedure, all the results from the six different brands and eight samples of WLEDi lamps, with base E-27 are shown in Figure 8.

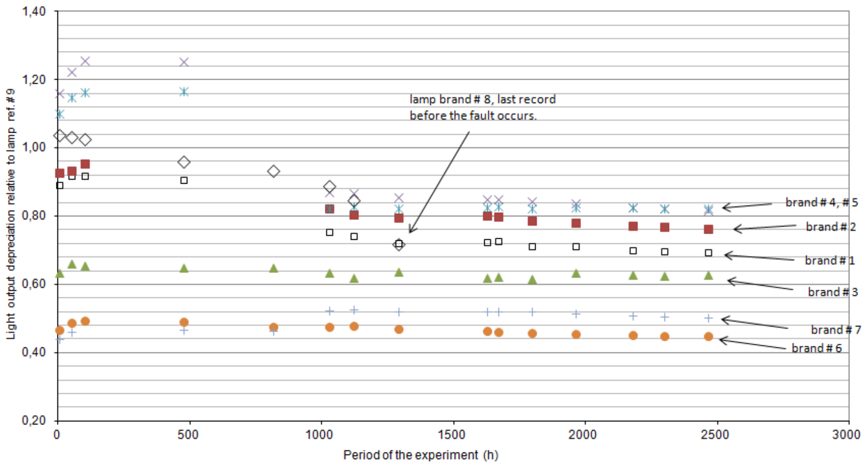

Figure 8 – The light output results of six different WLEDi lamp brand (base E-27 type) used in for the long term experiment and sampled after thermal stabilization of 5 minutes

Figure 8 presents all the results for the sampled light output, in particular after 815 hours of test when the methodology was changed and introduced the integrating photometer and a period of five minutes has been considered for the thermal stabilization before reading the light output. Sampling results for lamp # 8 are also indicated, particularly, those before the failure has occurred. They show occurrence of significant light output depreciation for sample # 8. For the other samples up to the moment (2.6 kh test), no signal indicating the possibility of failure of any other sample was revealed.

4 Conclusions

The main objective of this article was to present results of investigations conducted from lighting equipment using SSL (WLEDi) technology. One focus was on the quality of artificial lighting in both exterior and interior building. Data were collected at the CUASO, Campus of the University of São Paulo, for road lighting and interior lighting at the Institute of Energy and Environment in a long term experiment.

The experiments is been carried out from lamps from SSL technology (WLEDi) with Edison (E-27) base, purchased from consumer’s market and for the outdoor equipment installed at CUASO road lighting, lighting system parameters, like illuminance, luminance, T_{cp} and light depreciation were presented and considered.

An integrating photometer was assembled and used as auxiliary equipment for sampling light output from WLEDi lamps, E-27 base type during a long-term experiment that is still running. This photometer showed higher quality results, in relation to the data obtain with the luminance meter methodology used initially.

Records from experiments performed, presented and considered can expand the local knowledge about lighting equipment parameters and light output depreciation from Solid State Lighting technology. Results from a long-term experiment with six different brands and eight types of lamps with Edison base (E-27), after more than 2,600 hours of test, showed that only one sample, at (1407 ± 69) hours, presented failure. A survey result from the road lighting of the University Sao Paulo, at the City Armando de Salles Oliveira (CUASO) that has already completed more than five years (20 kh) running showed light output depreciation that do not come from the environment.

Acknowledgment - To CAPES and Electric Machinery Room Lab, at IEE.

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