Experimental Evaluation of the Photometric Performance of LED Luminaires for Public Lighting under Accelerated Aging

Evaluación Experimental del Desempeño Fotométrico de Luminarias LED para Alumbrado Público Bajo Envejecimiento Acelerado

A. R. Meneses[1] 0000-0002-7684-503X
C. H. Ventura[1] 0000-0002-6729-9209
M. Z. Fortes[1] 0000-0003-4040-8126
A. Pombo[1] 0009-0007-3311-1064
E. Lourenço[1] 0000-0002-9534-9509
R. Ayres[1] 0000-0001-6239-9705

[1] Fluminense Federal University, Niterói, Brazil
E-mail: anarmsb@id.uff.br, alanpombo@id.uff.br, carloshenriques@id.uff.br, eduardo_lourenco@id.uff.br, mzamboti@id.uff.br , rafaelayres@id.uff.br

Abstract

This work presents an experimental investigation of the effects of aging on the photometric performance of public luminaires equipped with LED technology. Four commercial models with powers of 40W, 80W, 150W, and 200W were evaluated, subjected to standardized tests under controlled laboratory conditions. The tests followed the IES LM-80-15 standards and INMETRO regulations, and included photometric analyses, goniometric tests, UV radiation tests, and In-Situ thermal measurements (ISTMT). The results reveal significant variations in luminous flux, energy efficiency, and light quality over six thousand hours of simulated operation. Optical degradation, especially of the lenses, showed a direct impact on the uniformity of light distribution. The study provides relevant technical support for the specification, acquisition, and maintenance of public luminaires, contributing to the increase of the lifespan and efficiency of the urban lighting system.

Index terms— Public lighting, LED, accelerated aging, photometric performance, laboratory tests, regulatory compliance.

Resumen

Este trabajo presenta una investigación experimental sobre los efectos del envejecimiento en el desempeño fotométrico de luminarias públicas equipadas con tecnología LED. Se evaluaron cuatro modelos comerciales con potencias de 40 W, 80 W, 150 W y 200 W, sometidos a ensayos estandarizados en condiciones controladas de laboratorio. Las pruebas se realizaron de acuerdo con las normas IES LM-80-15 y las regulaciones del INMETRO, e incluyeron análisis fotométricos, ensayos goniométricos, pruebas de radiación ultravioleta y mediciones térmicas *in situ* (ISTMT). Los resultados revelan variaciones significativas en el flujo luminoso, la eficiencia energética y la calidad de la luz más de seis mil horas de operación simulada. La degradación óptica, especialmente de las lentes, mostró un impacto directo en la uniformidad de la distribución luminosa. El estudio proporciona un soporte técnico relevante para la especificación, adquisición y mantenimiento de luminarias públicas, contribuyendo al aumento de la vida útil y la eficiencia del sistema de alumbrado urbano.

Palabras clave— Alumbrado público, LED, envejecimiento acelerado, desempeño fotométrico, ensayos de laboratorio, cumplimiento normativo.

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1. INTRODUCTION

The replacement of traditional public lighting systems with luminaires based on LED (Light Emitting Diode) technology represents a milestone in the advancement of public policies aimed at energy efficiency, sustainability, and urban safety. This technological transition has been widely encouraged by regulatory bodies and government programs, such as the National Electric Energy Conservation Program (PROCEL), due to the high luminous efficacy, longer lifespan, and lower environmental impact of LED solutions ([1], [2]). However, the long-term reliability of LED luminaires still raises technical concerns, especially regarding the stability of their photometric parameters in operating environments. The optical degradation of materials, aging of electronic components, and thermal variations directly affect the performance and regulatory compliance of these devices ([3][4],[6]).It is therefore essential to conduct experimental investigations that simulate real conditions of prolonged use, considering not only the initial tests but also the impact of extended operation cycles, ultraviolet radiation, temperature variations, and environmental exposure. Technical standards such as IES LM-80-15 and INMETRO Ordinance No. 25/2022 establish the criteria and methodologies for characterizing the maintenance of luminous flux, luminous efficacy, thermal stability, and chromatic characteristics of LED luminaires ([3], [5], [7]).Recent research (e.g., [4], [5]) demonstrates that, although LEDs exhibit slow and progressive degradation, optical elements such as polycarbonate or polypropylene lenses are highly susceptible to UV radiation and can to present yellowing, cracks or loss of transparency.

These effects compromise the photometry of the luminaire even when the emitting chip still maintains satisfactory performance. Thus, it becomes essential to evaluate the system as a whole — LED, driver, housing, heatsink, and optics — in an integrated manner and in accordance with the conditions of use. In this context, this article proposes a rigorous approach to evaluating the photometric performance of four models of LED luminaires used in public lighting in Brazil. The research was conducted at the Luminotechnics Laboratory of the Federal Fluminense University (LABLUX/UFF), accredited by INMETRO, through the performance of photometric tests, goniometric tests, UV aging, in situ thermal tests (ISTMT), and lifespan tests, according to the recommendations of applicable standards.

The study aims to quantify the impacts of accelerated aging on photometric parameters, validate compliance with legal requirements, and provide technical support for decision-making by municipalities, concessionaires, and manufacturers. The article is structured as follows: section 2 presents the theoretical and normative foundations that support the adopted methodology; section 3 defines the specific objectives of the investigation; section 4 describes the models of luminaires studied and the experimental protocol; section 5 details the tests performed; section 6 discusses the results obtained; and section 7 presents the conclusions and technical recommendations.

This study contributes to scientific literature by presenting laboratory-measured data obtained in accordance with applicable technical standards, emphasizing the relevance of evaluating key parameters throughout the service life of LED public lighting luminaires. The assessment of these parameters is essential for verifying performance stability, degradation behavior, and luminous quality, thereby supporting compliance evaluation, product qualification, and regulatory decision-making.

2. THEORETICAL FRAMEWORK AND LUMINOTECHNICAL FOUNDATIONS

2.1 Fundamentals of Photometry and Luminotechnics

The characterization of the performance of public lighting systems with LED technology requires the understanding and application of fundamental principles of photometry, a field of optics dedicated to measuring visible light in terms of its perception by the human eye. The basic photometric quantities used in this study include Luminous Flux (Φ), Luminous Intensity (I), llluminance (E), Luminance (L), Luminous Efficacy (η), Correlated Color Temperature (CCT or CCT), Color Rendering Index (CRI), Maintenance Factor (FM).

In addition to these classic concepts, the present study makes use of complementary metrics such as the BUG parameter (Backlight, Uplight, Glare), developed by the Illuminating Engineering Society of North America (IESNA), which classifies the distribution of luminous flux in zones for controlling light pollution.

2.2 Fundamental Technical Standards

The investigation is anchored on a solid normative basis, composed of regulations and technical procedures that ensure the comparability and reproducibility of results. The following applied standards stand out:

- IES LM-80-15 – Defines the procedures for measuring the maintenance of luminous flux of LEDs over time. [8]
- INMETRO Ordinance No. 25/2022 – Establishes criteria for performance evaluation and energy efficiency of public lighting fixtures. [9]
- ENERGY STAR TM-21-11 – Protocol for estimating the lifespan of LEDs based on LM-80 data. [10]
- IESNA LM-79-19 – Procedure for photometric and electrical measurement of LED-based lighting products. [11]
- ASTM G154-16 – Standard for accelerated UV exposure testing for plastics and polymeric materials. [12]
- CIE 13.3-1995 - Method of Measuring and Specifying Colour Rendering Properties of Light Sources [13].

These standards ensure that the tests conducted at LABLUX/UFF comply with national and international performance and safety requirements. They also underpin the criteria for mandatory certification of products in Brazil.

2.3 Degradation of Optical Components

Although LED chips exhibit good stability over the projected lifespan (50,000 hours or more), several studies indicate that the optical elements of luminaires — such as diffusers and collimating lenses made of polycarbonate or polypropylene — are sensitive to degradation induced by ultraviolet radiation and thermal variations ([5], [6]). Phenomena such as yellowing, loss of transparency, formation of microcracks, and modification of the refractive index result in significant losses of useful luminous flux, alteration of the emission spectrum, and distortion of the spatial distribution of light. Figure 1 illustrates the outcome of this process in lenses exposed for six thousand hours in a UV chamber.

Figure 1: Process in Lenses Exposed for Six Thousand Hours in a UV Chamber.

2.4 Importance of Systemic Evaluation

The photometric behavior of an LED luminaire cannot be evaluated in isolation from the emitting source. The interaction between the various elements — light source, driver, housing, heat sink, optical elements, and mounting system — determines the actual performance of the luminaire in the field ([4], [5]). Thus, tests such as absolute photometry, ISTMT (In Situ Temperature Measurement Test), and accelerated aging simulations are essential to extrapolate the LED behavior in the laboratory to real urban operating conditions. The use of the TM-21/LM-80 spreadsheet, as recommended by Energy Star [4], enables this projection based on reliable measurements.

3. STUDY OBJECTIVE

The increasing adoption of LED luminaires in public lighting requires systematic analyses that demonstrate their durability, photometric stability, and compliance with technical standards under real or simulated prolonged use conditions. Thus, the main objective of this study is: To evaluate the impact of accelerated aging on the photometric, chromatic, and energy performance of different models of LED luminaires used in public lighting, focusing on the degradation of optical components and the variation of normative parameters of technical compliance. Specifically, the work seeks to:

- Quantify the depreciation of luminous flux, luminous efficacy, and correlated color temperature (CCT) over six thousand hours of simulated operation.
- Verify the maintenance of luminous distribution through goniometric tests according to the BUG criteria of IESNA.
- Evaluate the effect of ultraviolet (UV) radiation on the optical behavior of polypropylene and polycarbonate lenses, with special attention to the color rendering index (CRI) and the R9 parameter.
- Conduct In Situ Test (ISTMT) for critical thermal analysis of the most exposed LED of the luminaire, correlating the measurements with the LM-80 data and estimating the projected lifespan (L70) through the ENERGY STAR model ([10]).
- Validate compliance with INMETRO Ordinance No. 25/2022 and other applicable standards regarding the minimum performance required for the marketing and certification of public LED luminaires in Brazil.

4. CASE STUDY

4.1 Luminaire Models

The following LED luminaire models were analyzed as shown in Table 1, with typical application in public lighting:

Table 1: LED Luminaire Models

Model	Power	Color Temp.	Degree of Protection	Optical Class.
GL 421	200W	5000K	IP66	Type II - Medium
Modular LED Aries	80W	4000K	IP66	Type II - Short
MG	150W	6500k	IP66	Type I - Short
Modular LED Aries	40W	5000K	IP66	Type II - Short

The selection of models was based on availability at the LABLUX/UFF laboratory and the representativeness of the national market. All models were provided by manufacturers with a consolidated presence in the public lighting segment.

4.2 Methodological Considerations

The luminaires used were made available exclusively for testing purposes, with mandatory return to the manufacturer at the end of the study, according to the granting protocol.

The 200W luminaire (GL 421) was the only one to have the LM-80 report of the LED, allowing the In Situ Test (ISTMT) to be conducted with an estimated lifespan based on TM- 21 extrapolation. The other luminaires were subjected to flux maintenance tests, according to the guidelines of [9].

All experimental tests were conducted on fully assembled luminaires, evaluated as integrated systems. The in-situ measurement was the only test performed at the LED level; however, it was carried out with the LED mounted within the luminaire assembly, ensuring that the electrical, thermal, and optical operating conditions were representative of actual luminaire operation.

All tests were conducted at the LABLUX laboratory, and the reported results present traceable measurement uncertainty values.

4.3 Equipment Used

The following instruments were used (Figure 2), all properly calibrated according to metrological requirements:

- Ulbricht Integrating Sphere – Measurement of total luminous flux.
- Everfine DPS Voltage Source – Control of voltage and supply frequency (220 VAC / 60 Hz).
- Everfine HAAS 2000 Spectroradiometer – Measurement of spectrum, CCT, and color rendering index.
- Yokogawa WT210 Wattmeter – Accurate measurement of active power and power factor.

Figure 2: Ulbricht Integrating Sphere and Goniophotometer

All tests were conducted in a controlled environment (25 ± 1 ºC and relative humidity < 65%).

4.4 Testing Schedule

The luminaires remained in continuous operation for six thousand hours, with data collection at regular intervals. Table 2 summarizes the adopted schedule:

Table 2: Summary of the schedule

Time Marker	Operating Time Actual	Date
Installation	0 h	06/11/2017
1st Measurement	1000 h	20/07/2023
2nd Measurement	2000 h	07/11/2023
3rd Measurement	3000 h	20/12/2023
Final Test	6000 h	(according to simulation)

5. TESTS CONDUCTED

This section details the experimental procedures applied in the evaluation of the performance of LED luminaires, according to technical standards and testing protocols adopted by the Lighting Laboratory of the Federal Fluminense University (LABLUX). The tests were conducted with the aim of measuring changes in the photometric and electrical parameters of the devices over six thousand hours of simulated operation.

5.1 Photometric Test

The photometric tests were conducted according to the parameters of IES LM-79-19 and INMETRO Ordinance No. 25/2022. Measurements were taken initially and after intervals of 1000h, 2000h, 3000h, and 6000h. The following parameters were recorded:

- Luminous Flux (lm).
- Luminous Efficiency (lm/W).
- Correlated Color Temperature (CCT).
- Color Rendering Index (CRI and R1 to R15).
- Electric Current (A), Voltage (V), Power (W), and Power Factor (PF).

5.2 Goniometric Test

The goniometric test was conducted using a type C goniophotometer, according to the IES LM-79-19 specification. The equipment allows measuring the spatial distribution of luminous intensity in spherical coordinates and generating photometric files (.IES). Variations of the BUG (Backlight, Uplight, Glare) system were evaluated over the initial 3000h of operation. The 80W and 150W luminaires showed variations in the glare index and in the flow distribution, changing from B2-U2-G2 to B3-U2-G2 and B3-U1-G1 respectively. The 200W luminaire showed stability in the BUG parameter, maintaining the classification B4-U2- G4.

5.3 Ultraviolet Test (UV)

The UV test was conducted in the OTS UV Test Machine chamber, illustrated in Figure 3, simulating continuous solar exposure with UV-B radiation (280–315 nm) and control of temperature and humidity.

Figure 3: Temperature Trend Line of the Studied Models

The polypropylene lenses remained in the chamber for 2016h, in cycles of 12h, with 8h exposed to 70 ºC and 0.49 W/m², and 4h with humidity at 100% at 50 ºC. Cloudiness, loss of transparency, and color change were observed in the lenses.

5.4 Life Test

The luminaires were kept in continuous operation for six thousand hours in a controlled environment as illustrated in Figure 4. This test, according to [3], allows verifying the maintenance of luminous flux and other characteristics over time. The measurements followed the same periodicity as the photometric tests.

Figure 4: Life Test

5.5 In Situ Thermal Test (ISTMT)

The ISTMT test was applied exclusively to the 200W GL 421 luminaire, which had an LM-80 report provided by the manufacturer. According to IES TM-21-11 and Energy Star [4], the LED temperature was measured using a type K thermocouple, installed at the point of highest thermal dissipation, as shown in Figure 5.

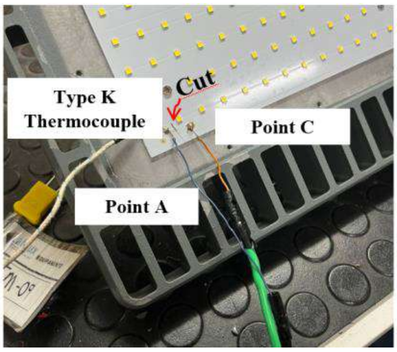

Figure 5: Connections in the Luminaire for the ISTMT Test

During the tests, the luminaire was positioned in the climate chamber at 45 ºC for 40 minutes as illustrated in Figure 6. The temperature and current data allowed for a comparison of performance with the limits of LM-80.

6. RESULTS AND DISCUSSION

The analysis of the results obtained over six thousand hours of testing demonstrated measurable variations in the photometric, spectral, and thermal performance of the evaluated luminaires. The results are presented below by evaluated parameters, emphasizing degradation behavior and compliance with applicable technical requirements.

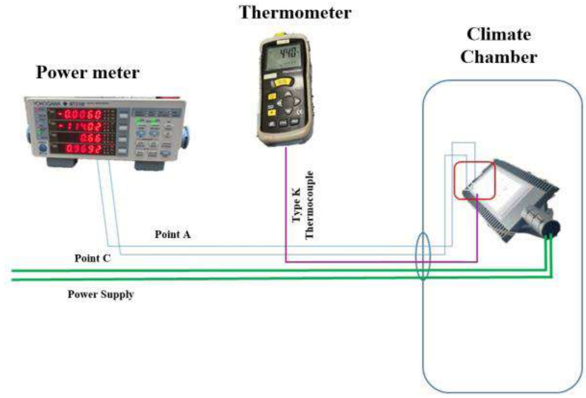

Figure 6: Schematic of the ISTMT Test

Table 3 presents a comparison of the photometric parameters measured before and after the aging tests, highlighting the depreciation of luminous flux, correlated color temperature (CCT), and luminous efficacy.

Table 3: Compares the Photometric Parameters

Power	40 W		80 W		150 W		200 W	
Maintenance	0.81		0.90		0.75		0.81	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Luminous Flux (lm)	6953.80	5640.60	11551.70	10363.79	16072.60	11977.20	38992.30	31493.88
Eficiencia Luminosa (lm/W)	172.55	140.98	143.28	129.06	116.88	86.00	195.73	159.74
CCT (K)	5033.88	4361.00	4118.04	3852.36	6822.36	5311.44	5063.04	4335.12
Ra	77.70	75.60	76.70	75.60	79.90	76.30	77.70	75.70
R1	75.00	71.00	74.00	72.00	77.00	71.00	74.00	71.00
R2	83.00	81.00	83.00	82.00	84.00	82.00	84.00	82.00
R3	88.00	89.00	89.00	90.00	87.00	90.00	89.00	90.00
R4	76.00	74.00	75.00	73.00	79.00	77.00	75.00	72.00
R5	75.00	71.00	73.00	71.00	79.00	72.00	74.00	71.00
R6	75.00	73.00	75.00	74.00	78.00	75.00	76.00	74.00
R7	87.00	87.00	84.00	84.00	87.00	87.00	86.00	86.00
R8	64.00	59.00	60.00	57.00	68.00	60.00	63.00	59.00
R9	-3.00	-12.00	-6.00	-9.00	1.00	-16.00	-6.00	-13.00
R10	57.00	54.00	58.00	57.00	60.00	56.00	59.00	57.00
R11	71.00	67.00	69.00	67.00	75.00	67.00	68.00	65.00
R12	56.00	50.00	56.00	53.00	64.00	54.00	55.00	50.00
R13	76.00	73.00	75.00	74.00	79.00	73.00	76.00	73.00
R14	93.00	93.00	93.00	94.00	92.00	94.00	94.00	94.00
R15	70.00	66.00	69.00	67.00	74.00	66.00	70.00	66.00
I (A)	0.20	0.20	0.38	0.37	0.65	0.66	0.92	0.91
U (V)	220.00	220.00	220.00	220.00	219.80	219.80	219.60	219.70
P (W)	40.30	40.01	80.62	80.30	137.50	139.30	199.20	197.10
PF	0.92	0.92	0.97	0.98	0.96	0.96	0.98	0.98

Goniometric testing identified changes in luminous intensity distribution and glare-related parameters for the 80 W and 150 W luminaires. The 80 W luminaire exhibited a change in BUG classification from B2–U2–G2 to B3–U2–G2, while the 150 W model changed from B3–U1–G1 to B3–U2–G2. The 200 W luminaire maintained its BUG classification throughout the test period, remaining at B4–U2–G4.

The ultraviolet (UV) exposure test revealed visible yellowing of the optical lenses after aging, as shown in Figure 2, indicating degradation of the optical material. Life test results further indicated that most luminaires experienced significant performance depreciation after three thousand hours of operation. Although the 40 W luminaire exhibited greater thermal and spectral stability up to this point, it did not comply with the CCT acceptance criteria at six thousand hours.

6.1 Maintenance of Luminous Flux

The depreciation of luminous flux was evaluated through photometric measurements conducted at multiple time intervals over six thousand hours of operation. The results indicate that luminous flux loss becomes more pronounced after three thousand hours, with the most significant degradation observed in the 150W and 200W luminaires. The 150W model exhibited an approximate luminous flux reduction of 25% at 6000 h, suggesting potential non-compliance with the maintenance criteria established by INMETRO Ordinance No. 25/2022.

The distinct luminous flux behaviors observed between the 150W and 80W luminaires are attributed to differences in thermal and optical stress associated with their respective operating power levels. Higher-power luminaires are subjected to increased thermal load, elevated LED junction temperatures, and higher photon density, which accelerate degradation mechanisms at both the LED package and system levels. Consequently, the 150 W luminaire presented a more pronounced luminous flux depreciation over time, whereas the 80 W model exhibited a comparatively more stable performance.

These results are consistent with findings reported in scientific literature, which indicate that luminous flux degradation in LED luminaires is primarily driven by the combined effects of thermally induced LED lumen depreciation and aging of optical components, particularly polymeric lenses and protective covers [14], [15]. Optical materials exposed to elevated temperatures and short-wavelength radiation are prone to yellowing and transmittance loss, leading to a reduction in effective luminous flux even when electrical operating conditions remain within specified limits [16].

To support the comparison between luminaires of different wattages, a deviation analysis was performed using coefficients of variation and temporal performance trends. This methodology enables the identification of systematic degradation effects while reducing the influence of measurement uncertainty, thereby confirming that the observed differences in luminous flux behavior are physically meaningful and directly related to operating conditions rather than experimental variability [13].

Overall, the results demonstrate that higher-power LED luminaires are more susceptible to accelerated photometric degradation due to combined thermal and optical stresses, underscoring the importance of system-level evaluation and extended aging tests for the assessment of long-term performance, durability, and regulatory compliance. In this context, it is recommended that the testing period be extended beyond 6,000 hours to enable a more robust evaluation, as this operating duration corresponds to stabilized and representative operating conditions of the luminaire components.

Table 4 Maintenance of Luminous Flux shows the measured luminous flux values in the different luminaires over 6000 h of operation:

Table 4: Maintenance of Luminous flux (lm)

Model	0h	1000h	2000h	3000h	6000h
40W	6953.8	6566.4	7307.3	7786.8	5640.6
80W	11551.7	11945.9	10997.6	12720.2	10363.8
150W	16072.2	15189.1	15958.1	14669.6	11977.2
200W	38992.3	29539.1	33002.6	43337.2	31493.9

6.2 Luminous Efficiency

The luminous efficiency followed a trajectory like the luminous flux. Fixtures with higher initial power showed greater sensitivity to thermal and optical degradation. The efficiency of the 150W model dropped from 116.88 lm/W to 86.00 lm/W by the end of the period, while the 200W model reduced from 195.73 lm/W to159.74 lm/W. Such values, although still technically acceptable under certain applications, indicate that optical systems (lenses and diffusers) strongly contribute to efficiency losses, even when the LEDs maintain their internal performance. Table 4 The analysis of the coefficient of variation (CV%) of luminous efficiency reinforces the observed trend. The 200W model showed the highest fluctuation, with a CV of 15.52%, followed by the 150W model (12.31%). The 40W and 80W models demonstrated greater stability over 6000h, with CVs of 11.45% and 7.85%, respectively.

These results indicate a more pronounced sensitivity to thermal and optical degradation in higher power models.

6.3 Correlated Color Temperature (CCT) and IRCA

The correlated color temperature (CCT) of the evaluated luminaires exhibited significant variations throughout the aging process, particularly for the 150 W and 200 W models. The 150 W luminaire showed a pronounced shift from 6822 K to 5311 K, characterizing a critical deviation in light coloration that is strongly associated with optical aging effects. This behavior is further corroborated by the reduction of the R9 index (saturated red) from +1 to −16, indicating selective spectral absorption typically linked to yellowing and partial opacification of polypropylene lenses, as evidenced in Figure 1.

The coefficient of variation (CV) of the CCT reinforces the observed spectral instability in higher-power luminaires, with values of 9.93% and 6.36% for the 150 W and 200 W models, respectively. In contrast, the 40 W and 80 W luminaires exhibited greater chromatic stability, with CVs of 5.92% and 3.35%, respectively. These results suggest a clear correlation between luminaire power, increased thermal and optical stress, and susceptibility to chromatic degradation. Such spectral shifts directly compromise color fidelity and may adversely affect visual perception and safety in public lighting applications.

According to CIE Publication 13.3, the Color Rendering Index (CRI), referred to in Portuguese as Índice de Reprodução de Cor (IRC), is defined as a metric for characterizing the color rendering properties of a light source relative to a reference illuminant. The general color rendering index, Ra, is calculated as the arithmetic mean of the first eight special color rendering indices (R1–R8), which represent color samples of moderate saturation and are widely adopted in technical specifications. However, Ra does not account for saturated colors or specific visual conditions. To address this limitation, the special color rendering indices R9 to R15 are defined as complementary parameters, representing highly saturated colors and specific samples, including saturated red (R9), skin tones, foliage, and other relevant materials. These indices are not included in the calculation of Ra and provide additional insight into spectral deficiencies of the light source.

Several studies have demonstrated that light sources with high Ra values may still exhibit poor reproduction of saturated red colors, a deficiency effectively captured by the R9 index [14], [17]–[20]. Therefore, R9 is widely recognized as a critical complementary metric for assessing the spectral quality and long-term color rendering performance of LED-based lighting systems, particularly in applications where accurate color perception is essential.

6.4 BUG Parameters and Photometric Distribution

Goniometric tests showed changes in the BUG parameters over time, especially in the glare index. The 80W model evolved from B2-U2-G2 to B3-U2-G2 after two thousand hours, indicating an increase in the glare component. Such variations may be associated with microfissures or imperfections in the lenses, which redirect light beams and affect spatial distribution. The 200W model, on the other hand, maintained the B4-U2-G4 classification throughout the entire test, demonstrating greater optical robustness and stability of the lens and reflector system.

Table 6 BUG Classification Over Time

Model	1000h	2000h	3000h
40W	B2-U1-G1	B2-U1-G1	B2-U1-G1
80W	**B2**-U2-G2	**B3**-U2-G2	B3-U2-G2
150W	B3-U1-G1	B3-U2-G1	B3-U2-G1
200W	B4-U2-G4	B4-U2-G4	B4-U2-G4

6.5 Impacts of the UVO

Test accelerated aging in UV chamber revealed degradations consistent with the results of photometric tests. A reduction in TCC was observed in all models, visible yellowing of the lenses, and loss of optical transparency. The 150W luminaire also showed the worst results in this test, indicating the fragility of its components against UV radiation. Figure 7 shows the main impacts recorded before and after six thousand hours of exposure.

Figure 7: The 150W Luminaire Recorded Before and After Six Thousand Hours of Exposure

The correlation between UV and TCC loss was clear and consistent among the models, strengthening the hypothesis that plastic diffusers represent the critical link in the optical durability of luminaires.

Table 7 Table 6 BUG Classification Over Time

Model	Initial Flux (lm)	Final Flux (lm)	Initial Efficiency (lm/W)	Final Efficiency (lm/W)	ΔR9
40W	6953.8	5640.6	172.55	140.98	-9
80W	11551.7	10363.79	143.28	129.06	-3
150W	16072.6	11977.2	116.88	86.00	-17
200W	38992.3	31493.88	195.73	159.74	-7

6.6 Comparison with LM-80

Model GL 421 The only model evaluated based on the manufacturer's LM-80 was the GL 421 (200W). The comparison between the measured values and the reference curves (85 ºC and 105 ºC) indicated compliance only up to 3000h, with performance exceeding expectations. However, at 6000h, the measured flux represented only 81% of the initial value, while the LM-80 curve suggested maintenance above 97%. The discrepancy suggests the direct influence of external elements to the LED, such as heat sinks, encapsulation, and lenses. Table 8 presents the percentage comparison between the predicted and measured flux, reinforcing the importance of the systemic analysis of the luminaire — not just the LED components in isolation.

Table 8 Data Referring to the LED Indicated in the LM80

Manufacturer: Hongli Zhihui Grip Co., Ltd. Guangzhou Branch Number: HL-EMC-3030DW-2C-S1-HR3 Part Type: Conjunto LED; Operating Current: DC 150mA; Nominal CCT: 2700K; Power: 1,02W; Current Density per LED die: 930.0019mA/mm^2; Power Density per LED die: 3.162W/mm^2		
LM-80 test details		
Total number of units tested per case temperature:	25	
Number of failures:	0	
Number of units measured:	25	
Test duration (hours):	9000	
Test drive current (mA) (mA):	150	
Temperature 1 (Tc, °C):	85	
Temperature 2 (Tc, °C):	105	
Temperature 3 (Tc, °C):	45	
In-Situ Input Data		
	Indicial	3000h
LED operating current per package/strip/module (mA):	44	43,9
In-Situ case temperature (Tc, °C):	43.9	42.7
Percentage of initial lumens to project to (e.g., for L70, enter 70):	70	70
Results:		
Time (t) for lumen maintenance projection (hours):	54.000	54.000
Lumen maintenance at time (t) (%):	84.51%	83%
Reported L70 (hours):	>54,000	>54,000

Table 8 shows the result of the extrapolation of useful life. The estimated L70 value was over 54,000 hours, confirming the thermal robustness of the system for this model. The wiring diagram of the measurement cables and the position of the thermocouple are presented in Figures 5 and 6, which accurately illustrate the experimental procedure.

7. CONCLUSIONS AND TECHNICAL RECOMMENDATIONS

This research clearly demonstrated that accelerated aging tests demonstrated a significant degradation of LED public luminaires after 6,000 hours of simulated operation. Luminous flux losses intensified after 3,000 hours, reaching approximately **25%** in the 150 W luminaire and **19%** in the 200 W model, while lower-power luminaires showed comparatively better stability.

Luminous efficacy decreased by up to **26%**, indicating that performance losses are strongly associated with optical degradation rather than electrical instability alone. Pronounced chromatic shifts were observed, with correlated color temperature reductions exceeding **1,500 K** in higher-power luminaires and **R9 decreases of up to 17 points**, confirming selective spectral degradation in the red region and the inadequacy of relying solely on Ra for long-term color quality assessment.

Goniometric measurements revealed changes in luminous distribution and glare-related BUG components for some models, while comparison with LM-80 data showed that luminaire-level luminous flux dropped to approximately **81%** of the initial value despite projected LED L70 values above **54,000 hours**.

These results quantitatively confirm that optical components are the primary limiting factor in the long-term photometric performance of LED public luminaires, highlighting the necessity of system-level aging evaluation in certification and specification processes.

The methodology used, based on IES standards LM-80, LM-79, TM-21, TM-28 and Brazilian regulations from INMETRO, ensures the credibility and robustness of the results obtained. The presence of ISTMT tests also allowed for the extrapolation of useful life based on thermal and optical data under real application conditions. It is recommended, based on the results:

- Revaluation of the criteria for selecting optical materials, prioritizing lenses with greater UV resistance and lower spectral variation.
- Mandatory inclusion of ISTMT tests in certification processes to ensure thermal compatibility and maintenance of luminous flux of the LEDs used.
- Application of more conservative methodologies in estimating useful life when LM-80 is not provided by the manufacturer.
- Creation of preventive maintenance programs based on photometric and thermal metrics collected in the field.
- The study contributes to the technical advancement in the field of public lighting, providing quantitative and methodological data that support public policies, regulations, and engineering decisions for more efficient, durable, and sustainable projects.
- It is recommended for
- Future study that the testing period be extended beyond 6,000 hours to allow for a more robust evaluation of long-term performance, as this operating duration corresponds to the phase in which the luminaire components reach stabilized and representative operating conditions.

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REFERENCES

[1] Y. KRAFTMAKHER, “Experiments with light-emitting diodes,” Am. J. Phys., vol. 79, no. 8, pp. 825–830, 2011, doi: 10.1119/1.3599072.

[2] R. B. SOARES FILHO, “Resposta humana à luz: alterações não visuais e o projeto luminotécnico residencial com LEDs,” p. 152, 2018.

[3] “Efficiency of LEDs: The highest luminous efficacy of a white LED,” Dial. https://www.dial.de/en-GB/projects/efficiency-of-leds-the-highest-luminousefficacy-of-a-white-led . [Accessed Jul. 06, 2025]

[4] F. B. Insights, “Lighting Market Size, Share & COVID-19 Impact Analysis, By Lighting Type (LED, CFL, LFL, HIDs, Halogen, and Incandescent), By Application (General Lighting, Automotive Lighting, Backlighting, and Others), By End User (Residential, Commercial, and Industri,” Semiconductor & Electronics / Lighting Market, 2022. [Online]. Available: https://www.fortunebusinessinsights.com/industry-reports/lighting-market-101542 . [Accessed Jul. 05, 2025]

[5] MarketandMarket, “LED Lighting Market Size, Share, Industry Growth and Analysis, by Product (lamp, Luminaire), Application (Indoor, Outdoor), Installation (New, Retrofit), Sales Channel (Direct, retail, E-commerce) and Region (North America, Europe, APAC, Rest of the World,” Fevereiro, 2024, 2024. [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/led-lighting-market-201130554.html. [Accessed: 25-Jun-2025].

[6] IEA (2023), Lighting efficacy by technology in the Net Zero Scenario, 2010-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/lighting-efficacy-by-technology-in-the-net-zero-scenario-2010-2030, License: CC BY 4.0.

[7] EMPRESA DE PESQUISA ENERGÉTICA - EPE., “Anuário Estatístico de Energia Elétrica 2023,” pp. 1–6, 2023, [Online]. Available: https://www.epe.gov.br/sitespt/publicacoes-dados-abertos/publicações/PublicacoesArquivos/publicacao-160/topico-168/anuario-factsheet.pdf

[8] ANSI/IES, “LM-80-15,” 2015.

[9] INMETRO, PORTARIA 62. 2022.

[10] ANSI/IES, “TM-21-21.pdf.” 2021.

[11] IES, LM-79. 2019.

[12] CIE 154 The maintenance of outdoor lighting systems. 2003.

[13] CIE 13.3-1995 - Method of Measuring and Specifying Colour Rendering Properties of Light Sources.

[14] Y. Ohno, “Color rendering and luminous efficacy of white LED spectra,” Optical Engineering, vol. 43, no. 11, pp. 2595–2599, 2004.

[15] M. Wei et al., “Spectral optimization of warm-white LED lamps with high CRI and R9,” AIP Advances, vol. 1, no. 3, p. 032160, 2011.

[16] K. Houser et al., “Review of measures for light-source color rendition,” Optics Express, vol. 21, no. 8, pp. 10393–10411, 2013.

[17] Y. Ohno, “Spectral design considerations for white LED color rendering,” Optics & Photonics News, vol. 16, no. 7, pp. 34–41, Jul. 2005.

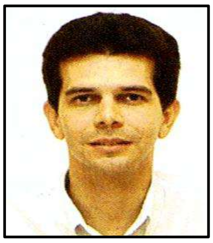
[18] C. Li, Y. Xu, Z. Wang, Y. Guo, and M. Wei, “Realizing superior white LEDs with both high color-rendering index and high luminous efficacy by using dual red phosphors,” RSC Advances, vol. 7, pp. 25964–25968, 2017.

[19] K. Houser, M. Wei, A. David, M. R. Krames, and X. Shen, “Review of measures for light-source color rendition and considerations for a two-measure system for characterizin

Alan Lopes Pombo. - Nació en Magé, Río de Janeiro, Brasil, es Técnico en Electrónica e Ingeniero Electricista, con posgrado en Ingeniería de Control y Automatización Industrial. Es Magíster en Ingeniería Eléctrica y Telecomunicaciones y Doctorando en Ingeniería Eléctrica y Telecomunicaciones en el PPGEET-UFF. Es funcionario del Instituto de Física de la Universidad Federal Fluminense (UFF), donde actúa como Metrologista e Ingeniero Desarrollador de Sistemas de Ensayo en el Laboratorio de Luminotecnia (LABLUX-UFF), desempeñándose en la interpretación de normas técnicas, definición de metodologías de ensayo, desarrollo de sistemas experimentales y expansión de los alcances de actuación y acreditación del laboratorio. Sus áreas de actuación e investigación incluyen el desarrollo de soluciones técnicas multidisciplinarias aplicadas a campos como Luminotecnia, Calidad de Energía, Sistemas Fotovoltaicos, Microondas, Altas Energías, Plasma y Espectroscopía Atómica. Actúa además como Analista de Normas Técnicas, consultor en desarrollo tecnológico y participa en Grupos de Trabajo junto al INMETRO, contribuyendo a la revisión normativa y a la elaboración de Análisis de Impacto Regulatorio (AIR).

Carlos Henriques Ventura do Rosário Oliveira. - Nació en Río de Janeiro, Brasil, en 1958. Recibió su título de Ingeniero Eléctrico en la Universidad Federal Fluminense (UFF) en 1983; Especialización en Servicios de Telecomunicaciones en la UFF en 2002; y su título de Maestro en Sistemas de Gestión en la Universidad Federal Fluminense, en Niterói, Brasil, en 2004. Se desempeña como profesor de la Universidad Federal Fluminense y sus campos de investigación están relacionados con la automatización y la luminotecnia.

Eduardo Lourenco de Sousa.- Nació en Río de Janeiro, Brasil, el 19 de noviembre de 1996, es Ingeniero Electricista, Máster y doctorando en Ingeniería Eléctrica por la Universidad Federal Fluminense, con investigación de maestría orientada a la certificación de equipos de iluminación, con énfasis en seguridad, eficiencia y compatibilidad electromagnética, actuando profesionalmente en el mantenimiento de sistemas eléctricos de media y alta tensión en los sectores industrial y offshore, además de desarrollar actividades técnicas y académicas relacionadas con la ingeniería eléctrica en el doctorado.



Marcio Zamboti Fortes. - Nació en Volta Redonda, Brasil en 1969. Recibió su título de Ingeniero Eléctrico de la Escola de Engenharia de Vassouras en 1991; de Master en Ingeniería Energética de la Universidade Federal de Itajuba en 2000; y su título de Doctor en Ingeniería Eléctra de la Universidade de São Paulo. Sus campos de investigación están relacionados con Eficiencia energética, calidad energética, fuentes renovables y gestión/mantenimiento de sistemas industriales.

Rafael Ayres Soares. - Nació en Rio de Janeiro, Brasil en 1991. Recibió su título de Ingeniero Eléctrico por la Universidade Federal Fluminense (UFF) en 2020; Es Magíster en Ingeniería Eléctrica y en el PPGEET-UFF (2025).Sus campos de investigación están relacionados con el Sistemas Fotovoltaicos y los aspectos de instalación, regulación e impacto en la red eléctrica de estos sistemas, calidad de energía e luminotecnia.