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Coimbra Smart City Through a Public Lighting Network

Dissertation to fulfill the Master's degree in Smart and
Sustainable Cities

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RESUMO

A crise global denominada "alterações climáticas" que se reflete no clima, mais concretamente em fenómenos extremos a nível mundial, alguns com consequências mortais, e o efeito da guerra na Ucrânia nos custos da energia obriga-nos a uma reflexão profunda sobre duas questões fundamentais do nosso tempo, a energia e o ambiente.

A Agenda 2030 das Nações Unidas para o Desenvolvimento Sustentável é composta por 17 Objetivos de Desenvolvimento Sustentável (ODS) e foi aprovada em setembro de 2015, resultando do trabalho conjunto de governos e cidadãos de todo o mundo para criar um modelo global para acabar com a pobreza, promover a prosperidade e o bem-estar para todos, proteger o ambiente e combater as alterações climáticas. O ODS número 11 é sobre "Cidades e Comunidades Sustentáveis" [1].

A Resolução do Conselho de Ministros n.º 53/2020, de 10 de julho, aprova o Plano Nacional Energia e Clima 2030 (PNEC 2030) que surge no quadro das obrigações estabelecidas pelo Regulamento da Governação da União da Energia e da Ação Climática. O PNEC 2030 caracteriza a situação atual de Portugal em matéria de Energia e Clima, abrangendo as cinco dimensões previstas no Regulamento da Governação da União da Energia e da Ação Climática: descarbonização; eficiência energética; segurança do abastecimento; mercado interno da energia e investigação; inovação e competitividade [2].

A existência destes dois documentos estratégicos e os desafios colocados pela eficiência energética, aliados à grave crise económica que o sector energético atravessa, foram os principais motivadores para a elaboração desta dissertação.

A possibilidade de criar um sistema inteligente na rede de iluminação pública, tão importante para a vida humana, sobretudo em termos de segurança e conforto, utilizando tecnologias recentes e monitorizando/refletindo num laboratório vivo em Coimbra, foram os ingredientes finais que deram ainda mais suporte à lógica de desenvolvimento deste trabalho.

Palavras-chave: sustentabilidade, iluminação pública, eficiência energética, descarbonização, ODS

ABSTRACT

The global crisis called "climate change" that is reflected in the climate, more specifically in extreme events worldwide, some with deadly consequences, and the effect of the war in Ukraine on energy costs force us to reflect deeply on two critical issues of our time, energy, and the environment.

The United Nations 2030 Agenda for Sustainable Development consists of 17 Sustainable Development Goals (SDGs) and was approved in September 2015, resulting from the joint work of governments and citizens around the world to create a new global model to end poverty, promote prosperity and well-being for all, protect the environment, and combat climate change. SDG number 11 is on "Sustainable Cities and Communities" [1].

The Portuguese Council of Ministers Resolution n. º 53/2020, of July 10, approves the National Plan Energy and Climate 2030 (PNEC 2030) that arises in the framework of the obligations established by the Regulation of the Governance of the Energy Union and Climate Action. The PNEC 2030 characterizes the current situation in Portugal regarding Energy and Climate, covering five dimensions provided in the Regulation on the Governance of the Energy and Climate Action Union: decarbonization; energy efficiency; security of supply; internal energy market and research; innovation and competitiveness [2].

The existence of these two strategic documents and the challenges posed by "energy efficiency," combined with the severe economic crisis that the energy sector is undergoing, were the primary motivators for the preparation of this dissertation.

The possibility of creating an intelligent system on an existing network, so crucial for human life, especially in terms of safety and comfort, as is the public lighting, using recent technologies and monitoring/reflecting in a living lab in Coimbra, were the final ingredients that gave even more support to the logic of developing this work.

Keywords: sustainability; public lighting; energy efficiency; decarbonization; SDG

*This is for you, the ones who have believed and continue to believe that I
can always go further*

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LIST OF ABBREVIATIONS

CCT	Correlated Colour Temperature
Cd	Candela
CIE	International Commission on Illumination
CLO	Constant Lumen Output
CRI	Color Rendering Index
DLOR	Downward Light Output Ratio
DREEIP	Reference Document
EDP	EDP Distribuição - Energia SA
EN	European standard
E-REDES	E-REDES - Distribuição de Eletricidade, SA
HPS	High-pressure sodium
ISEC	Instituto Superior de Engenharia de Coimbra
LED	Light Emitting Diode
K	Kelvin
kW	Kilowatt
kWh	Kilowatt per hour
LoRaWAN	Long Rang Wide Area Network
LX-GPS	Lux meter sensor with integrated
m ²	Square meter
MF	Maintenance Factor
NB-IoT	Narrowband Internet of Things
PCB	Printed circuit board
PDIP	Public Lighting Masterplan
PEE	Coimbra Municipal Energy Efficiency Plan 2022/2023
S/P	Racio scotopic/photopic
SPD	spectral power distributions
TS	Transform station
ULOR	Upper Light Output Ratio

1 INTRODUCTION

1.1 Objectives

In order to rationalise consumption and cut costs, the main goal of this work is to track, analyse, and test an intelligent network built on the public lighting network of at least one city neighbourhood. In order to strengthen its position as a smart city, Coimbra City Council has taken another step toward sustainable and intelligent urban management.

The "pilot", named "FlexIP", was promoted through an agreement between the municipality of Coimbra and the electricity distribution company E-REDES. The "pilot" comprises about 170 light-emitting diode (LED) luminaires with a point-to-point communication module. The intention is to monitor the effective consumption of the luminaires and the electric network, using scenarios that will be created in terms of the variation of the luminous flux depending on the time of night, presence or absence of people, specific events, and others.

If there is time and availability of the manufacturers, it is intended to incorporate some sensors in the intelligent network, which, through the measured quantities, may interfere with other equipment connected there.

1.2 Methodologies

The methodology used to prepare this work was as follows:

- a) Georeferencing of existing transformer stations and luminaires in the study area;
- b) Systematise the electrical consumption of the luminaires during the year 2022 using the E-REDES platform;
- c) Developed luminotechnical studies with the software "DIALux" EVO [3];
- d) Measured luminotechnical levels, using a lux meter, to compare with the values of the study mentioned in the previous paragraph;
- e) Meet with the Residents Association to explain the aim and methodology of this work;
- f) Create and apply lighting scenarios during the days deemed necessary for the effect, using the E-REDES platform "FlexIP Management Platform";

- g) Satisfaction questionnaires were made for the residents so that they could give their opinion about the various lighting changes, both the replacement of the luminaires equipped with high-pressure sodium vapor lamps for LED technology and the scenarios created;
- h) Analysing the collected data.

1.3 Document structure

This document is divided into six chapters as follows:

- Chapter 1 – "Introduction" outlines the study's goals, the methodology used to carry it out, and the report's organisational structure.
- Chapter 2 – "The Public Lighting in Portugal and Coimbra" presents the weight of electricity consumption in Portugal and in the municipality of Coimbra, is physical public lighting network, the definition of energy service companies, and the related legislation will all be covered in this chapter.
- Chapter 3 – "Why Using Light Emitting Diode (LED)?" which will be very technical, will cover the concepts of white light seen through a prism, how human vision works and its reaction to light, the electromagnetic spectrum and the different types of vision depending on the levels of illumination.
- Chapter 4 – "The Public Lighting Project" not only presents the terminology and definitions relating to a public lighting project for carriageways, pedestrian/cycling areas, and gardens but also explains European legislation and reference documents issued in Portugal. Some European research works on dimming are analysed, and their conclusions are expressed.
- Chapter 5 – "Case Study – Quinta de S. Jerónimo" explains the methodology used for the proof of concept in a residential area, specifically the Quinta de S. Jerónimo urbanisation. Its physical public lighting network was characterised. Several tests were conducted to lower the luminous flux and assess the directness of the proportionality by measuring electrical usage and luminance. Residents were contacted to express their opinions on how they perceived the decrease in luminous flux, with the association and through online satisfaction surveys.
- Chapter 6 – "Conclusions and Future Perspectives" analyses the proof-of-concept results from the tests and compares them to some of the findings and methods in the research papers in Chapter 4 in order to draw conclusions. The goal is to find a correlation between the decline in luminous flux and the decline in consumption and cost. However, it is also essential to understand how the study area's users and residents feel about these declines to reconcile the equation's social and security aspects. This chapter also addresses future perspectives.

2 THE PUBLIC LIGHTING IN PORTUGAL AND COIMBRA

This chapter will present the legal framework for electricity distribution concession contracts, which include public lighting and energy saving companies (ESCO).

Data on electricity consumption, including public lighting, in Portugal and Coimbra will be presented.

Data collected from the register provided by E-REDES relating to the physical structure of the public lighting network will be shown.

We consulted the "Coimbra Municipal Energy Efficiency Plan 2022/2023" (PEE), which analyses data for the year 2021. For this reason, in order for the comparisons to make sense, energy data from the same year, 2021, was analysed in this thesis.

2.1 Concession Contracts

This subchapter will present some concession contracts related to electricity infrastructure, namely low voltage and street lighting between the Portuguese government and Portuguese municipalities. In Portugal, low voltage is under 1 kV.

- The Ministerial Order 454/2001, of 5 May 2001, approves the standard "low voltage electricity distribution concession" between the 278 municipalities in mainland Portugal and "EDP Distribuição - Energia SA" (EDP), that was on that date the national grid electricity distributor in low voltage (under 1 kV).

EDP has been renamed "E-REDES – Distribuição de Energia SA" (E-REDES).

[4].

- Based on this standard contract, on 3 July 2001, the municipality of Coimbra signed the "Renewal of the Concession Contract for the Distribution of Electrical Power in Low Voltage in the Municipality of Coimbra" with "EDP Distribuição - Energia SA". It also includes the public lighting network (see Appendix A).
- On 13 September 2016, the National Association of Portuguese Municipalities signed a Protocol with "EDP Distribuição - Energia SA", which consists of the amendment of Appendix A to the concession contract mentioned in the previous paragraph, which defines the "current" types of lighting levels; luminaires; lamps; supports and brackets to be used in the municipality's public lighting. This involved allowing the installation of LED luminaires in the public lighting network (see Appendix B).

- The Decree-Law n.º 15/2022, of 14 January 2022, establishes the organisation and operation of the National Electricity System, transposing Directive (EU) 2019/944 and Directive (EU) 2018/2001. According to article 110, the exploration of the national grid electricity transmission and the national grid electricity distribution is exercised through a concession contract under a public service regime, and its activities and the facilities that integrate it are considered public utility [5].

2.2 The Electricity Consumption

As already mentioned, the EEP 2022/2023 considered data from the year 2021, so "Por-data" was consulted for data from that same year, which is a database of certified statistics on Portugal, its municipalities and Europe with free access to various topics in society [6].

The consumption of electricity in Portugal in 2021 by sector of activity is shown in Figure 2.1:

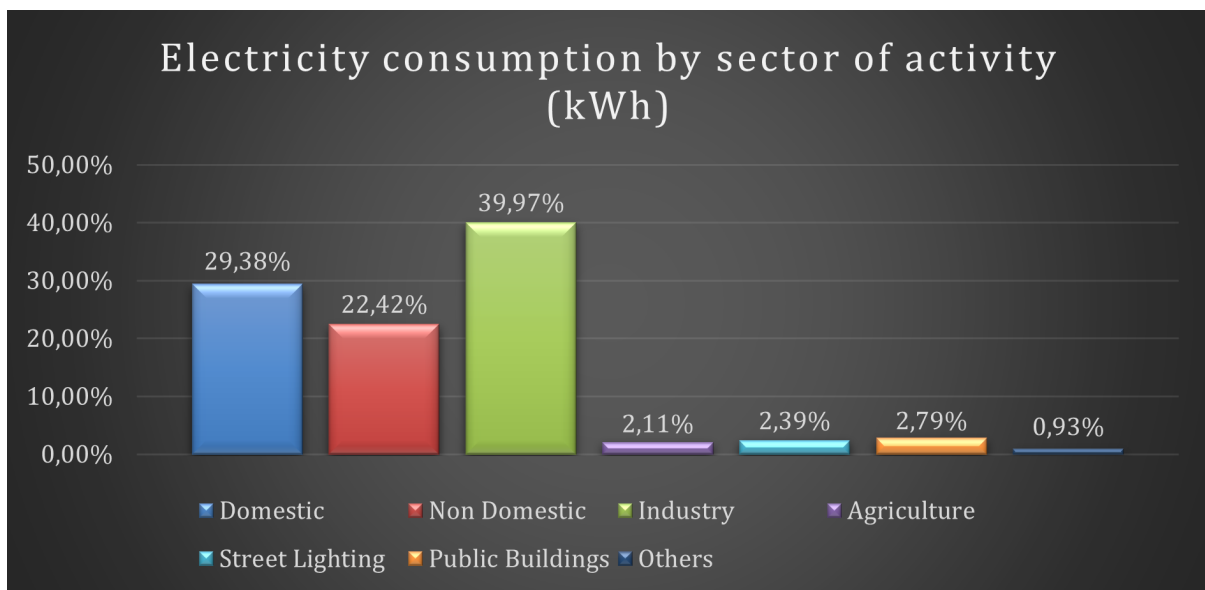


Figure 2.1: Electricity consumption by sector of activity – Portugal 2021 [6]

The graph in Figure 2.1 shows electricity consumption in 2021 by sector of activity, namely domestic, non-domestic, industry, agriculture, public lighting, public buildings and others.

It can be seen that industry is the sector that consumed the most electricity, with 39.97% of the total.

After industry, domestic and non-domestic are the most consuming sectors, with 29.38% and 22.42%, respectively.

Agriculture, public buildings and the "others" category consumed 2.79%, 2.11% and 0.93% per cent respectively.

Public lighting, which is analysed in this thesis, consumed 2.39% of the total energy consumed in 2021.

By consulting Coimbra's 2022/2023 municipal energy efficiency plan (EEP) of the municipality of Coimbra, the internal costs associated with the use of resources in 2021 are those shown in Figure 2.2 [7]:

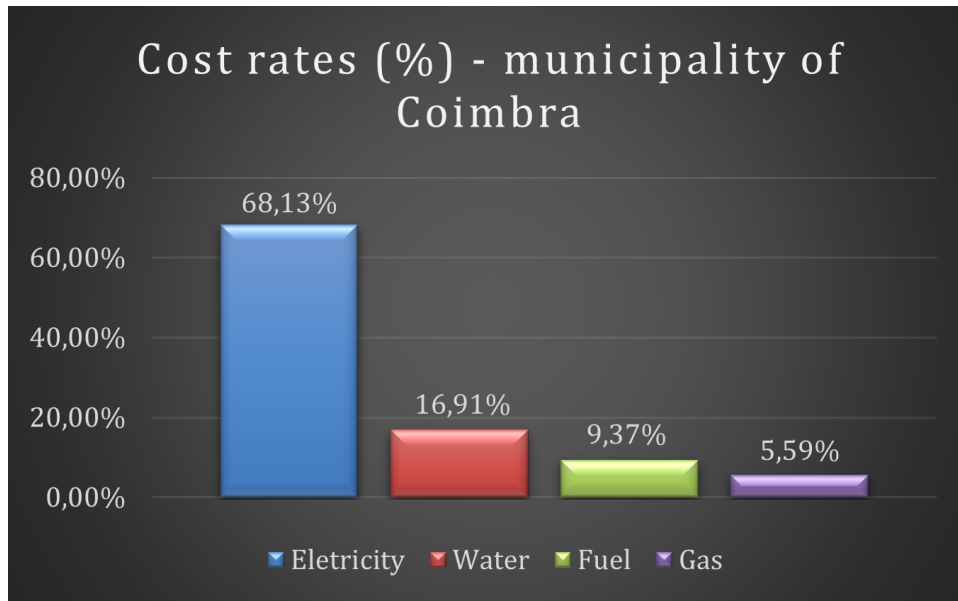


Figure 2.2: Internal costs associated with its use (2021) [7]

The graph in Figure 2.2 shows the costs of four sector groups, namely electricity, water, fuel and gas.

The "electricity" sector has the highest consumption, with around 68% of total consumption, making it clear that it is essential to reflect on it by identifying opportunities to rationalise consumption with good energy efficiency practices.

Right after the "electricity" sector comes the "water" sector with a weight of 16.91%. Although this sector is not part of this thesis, it is known that water is a scarce natural resource and that it is imperative to implement measures that lead to good water efficiency. The indisputable fact that it is impossible to live without water and the evidence of prolonged droughts that we have witnessed force us to reflect on this sector urgently.

This is followed by fuel, primarily for vehicles and municipal equipment, with 9.37 per cent, and lastly, but significantly, the costs of natural gas consumption, mainly for heating sanitary water and space heating, especially in school buildings, with a percentage of 5.59 per cent of the total.

Russia’s invasion of Ukraine in February 2022 has forced us to think seriously about energy and fuels, particularly natural gas and where it comes from, and how to combat rising costs at the European level, at least. Still resorting to the energy efficiency plan 2022/2023 of the municipality of Coimbra, the internal costs with electricity in 2021 are those shown in Figure 2.3 [7]:

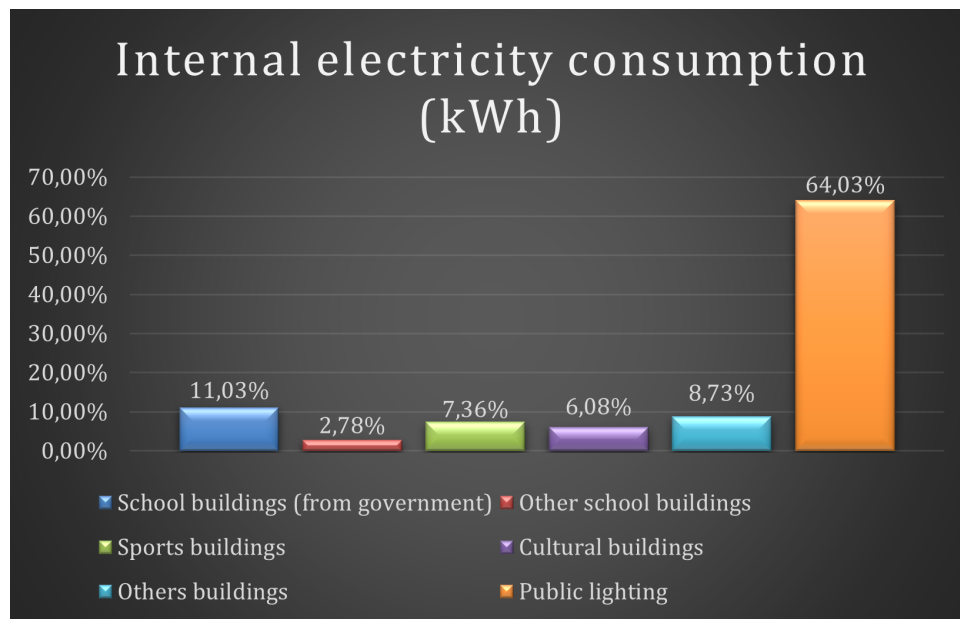


Figure 2.3: Internal costs with electricity in 2021 - municipality installations [7]

The graph in Figure 2.3 shows the facilities in the municipality that consume the most electricity in 2021, such as schools and cultural and sports buildings.

Considering that more than 64% of the internal electricity consumption is related to public lighting, corresponding to 18.857.432,06 KWh and a paid value of 2.749.176,49 € (by consulting the energy efficiency plan 2022/2023 (EEP) of the municipality of Coimbra), it is clear that a specific study is needed to make this network more efficient. There are 747 electricity supply contracts relating to public lighting [7].

However, there are other relevant costs that the municipality should analyse. School buildings from the government consumed around 11.03%. These are large High School buildings, which the Portuguese government has decided to decentralise by transferring responsibility for maintenance costs to the municipalities.

Sports buildings follow with 7.36%, including three municipal swimming pool complexes, one sports centre and one sports centre. Cultural buildings and other school buildings consumed 6.08% and 2.78%, respectively. The remaining buildings, mainly administrative ones, consumed 8.73%.

2.3 The Physical Public Lighting Network in Coimbra

By consulting the register provided by E-REDES, the number of luminaires installed in Coimbra, by type of technology, is as shown in the Table 2.1:

	Luminaires (units)
Fluorescent	26
Metal Halide	49
LED	16.538
Mercury Vapour	609
Others	276
High Pressure Sodium	22.067
Total	39.565

Table 2.1: Number of luminaires by type of technology – July 2023 [8]

The 39.565 luminaires are supplied by 720 public transformer substations (TS).

There are still 23.027 luminaires that do not use LED technology. High-pressure sodium is the most considerable non-LED quantity, with 22.067.

High-pressure sodium (HPS) technology is the most significant number of non-LED luminaires, with 21.805 units.

2.4 Energy Service Companies (ESCO)

As we have seen in the previous chapters, public lighting costs in a city are quite significant. This factor has forced municipalities to seek market solutions that enable them to reduce these costs.

Some municipalities have opted to switch off some luminaires, but this does not seem to us to be a technically logical and supported solution. The investment in infrastructure has already been made, and it does not seem to make sense to have equipment installed and not have it working. Firstly, for safety, technical and maintenance reasons, as the luminaires are subject to bad weather and ultraviolet rays, and the fact that they are not working can cause some components to deteriorate. However, not all municipalities have the financial resources to invest in changing technology, so they turn to private companies to share the responsibility of implementing solutions that reduce consumption and, therefore, costs. These private companies are called energy service companies (ESCO).

We can summarise the ESCO in three main characteristics [9]:

- Energy Service Companies promise energy cost savings and the delivery of the same level of service at a lower price. Various formats are available for perfor-

mance guarantees. It could be focused on the actual flow of energy savings from a project, it could specify that the energy savings will be enough to pay monthly debt service costs, or it could state that the same level of energy service is offered for less money;

- The compensation of ESCOs is directly correlated with the amount of energy saved;
- By guaranteeing savings, ESCOs can finance or help arrange financing for the operation of an energy system.

In Portugal, the Decree-Law n^o. 50/2021, of 15 June 2021 (DL50/2021), establishes the legal regime for energy efficiency management contracts to be signed between the State and energy service companies [10].

The Portuguese government must establish a qualification system for energy service companies to ensure the technical and economic qualification of market operators for timely compliance with energy efficiency management contracts.

To understand how ESCO fits into the Portuguese system, we present some definitions, as set out in DL50/2021:

The contract term cannot exceed 15 years (Article 13 of the DL50/2021).

Following Article 7, the contract price is the price the contracting authority is willing to pay and is the difference between the value, or part thereof, of additional energy savings achieved by the energy service company and the value of contractually guaranteed annual energy savings for the contracting authority.

Under Article 14, the energy services company has the following rights (In addition to others foreseen in the law or the contract):

- a) to exploit, on an exclusive basis, energy efficiency within the scope of the contract concluded and under the terms provided for therein;
- b) to receive the contractual price;
- c) to use, under the terms of the law and the contract, the assets of the public domain necessary for the execution of the contract;
- d) In case of surplus electricity production, to store it or sell it to third parties, sharing the benefits under the terms agreed upon in the contract.

By Article 16, the energy services company has the following obligations (In addition to others provided for by law or in the contract):

- a) Finance all the measures to improve energy efficiency and the production of electricity using production units for self-consumption to be implemented under the terms of the contract;

- b) Deliver the competent energy certificate for the buildings subject to intervention, when applicable;
- c) Inform the public contracting party, on a quarterly basis, of the production of electricity from combined heat and power units;
- d) Inform the public contracting party of any circumstance that may affect the normal execution of the contract;
- e) Apply, with the periodicity defined in the contract, the energy performance assessment criteria to measure the compliance with the contract, according to the protocol for measuring and verifying energy performance defined;
- f) Provide to the public contracting entity, or to whom he appoints for that purpose, any information or prepare specific reports about aspects related to the execution of the contract, as long as requested in writing;
- g) Obtain all licenses, certifications, accreditations and authorisations necessary for the exercise of the activities integrated or somehow related to the object of the contract, unless otherwise stipulated in the contract;
- h) Propose energy efficiency improvement measures that do not imply a reduction of the annual energy savings for the adjudicating entity or the extension of the contractual term.

2.5 Conclusions

In this chapter, it emerged that in 2021, in Portugal, industry, the domestic and non-domestic sectors were the three most significant electricity consumers.

Using the energy efficiency plan of the municipality of Coimbra (EEP), it was observed that, in 2021, it was with electricity that internal costs were higher, with around 68.13%. To see the difference with other uses, second place went to water, with 16,91% of the total. Regarding electricity, the most consumed speciality was public lighting with 64.03%. School buildings, recently decentralised by the government in the municipality, came second with 11,03%. This percentage of public lighting, 64.03%, corresponds to 18.857.432,06 KWh and a paid value of 2.749.176,49 € in 2021.

It turned out that there are still 23.027 luminaires that are not LED technology, for a total of 39.565. 720 transformer substations supply all luminaires.

It was explained what energy service companies (ESCO) are and that they were created because some municipalities do not have the financial resources to invest in changing technology in public lighting to reduce consumption. The associated principles and Portuguese legislation for energy service companies were explained.

3 WHY USING LIGHT EMITTING DIODE (LED)?

This chapter will explain the massive application of Light Emitting Diodes (LEDs) in lighting, interior installations, and external ones, with particular incidence for public lighting. The importance of this technology in the concept of smart cities will also be explained.

3.1 The White Light

Is the white light really white?

With a set of experiments that he published in 1672, Isaac Newton (1642–1726), a famous physicist and mathematician, is credited with creating the basis for contemporary science's knowledge of light and colour. He is the first person to comprehend the rainbow. Using a glass prism, he found that the white light coming from the sun is composed of lights of various colours, red, orange, yellow, green, blue, and violet, as illustrated in Figure 3.1:



Figure 3.1: Illustration of Isaac Newton with the glass prism [11]

The electromagnetic spectrum is the set of all possible electromagnetic wave frequencies. They extend from radio waves to gamma rays.

Scientists have realised that light behaves similarly to electromagnetic waves, oscillating and spreading in a vacuum with some fluctuation in time (frequency). We can relate it to sound and use it as an example. Since sound is a mechanical vibration of the air, low and high sounds have distinct frequencies. The visible light spectrum is the range of colours seen for a given range of frequencies, just like sound frequencies determine light colours.

Visible radiation is assumed to contain electromagnetic waves in the spectrum in a very narrow range, from 380 to 780 nm. Our eye perceives this range, but animals can register radiation of different lengths. Figure 3.2 shows the visible light spectrum.

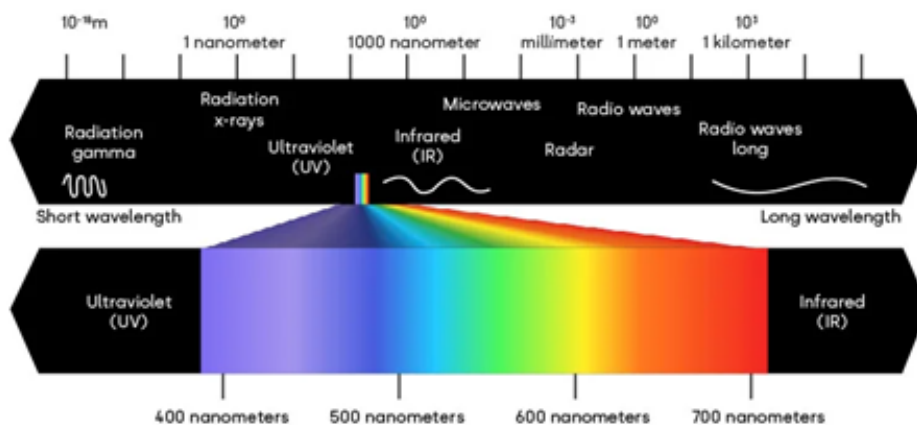


Figure 3.2: Spectrum of visible light [12]

3.2 The Human Vision

The human eye is sensitive to diverse sections of the spectrum that cover various wavelengths but cannot discriminate between individual wavelengths. This reaction shapes the fundamentals of the photometric principle. Rods and cones are components of the eye; although rods enable vision at various brightness levels, cones aid in recognising colour. The human eye's structure is depicted in Figure 3.3.

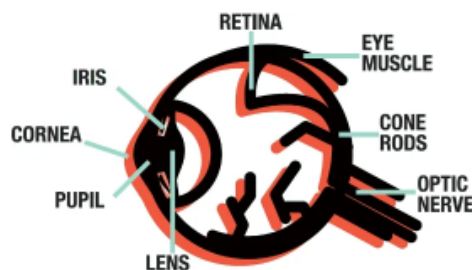


Figure 3.3: The human eye [13]

Based on these principles about the human eye structure, we will now describe three concepts that will make it easier to understand how LED technology has been implemented so quickly in street lighting.

Scotopic vision uses only rods to see, meaning objects are visible but appear in black and white, whereas photopic vision uses cones and provides colour. Mesopic vision combines the two and is used for most scenarios.

Figure 3.4 shows the Absorption Curve of the three kinds of vision.

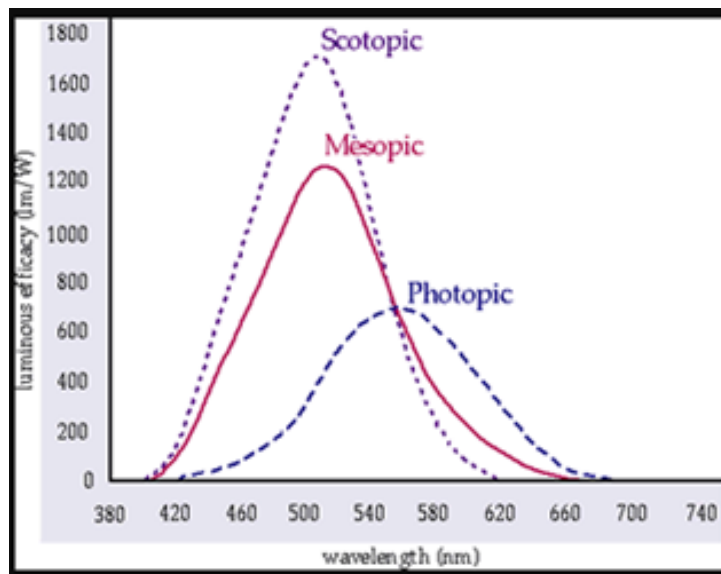


Figure 3.4: Absorption curve [14]

Figure 3.5 shows the human eye luminance level range and types of vision, correlated with luminance values in cd/m².

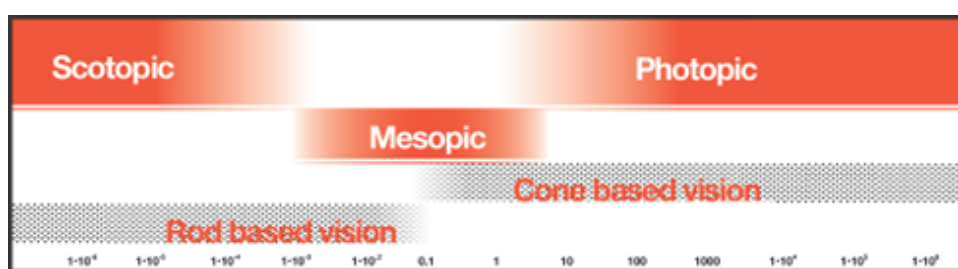


Figure 3.5: Human eye luminance level range and types of vision: cd/m² [13]

Photopic vision typically predominates under normal lighting conditions, such as during the day. It is based on three kinds of cones sensitive to short, middle, and long wavelength ranges, typically seen by the human eye as blue, green, and red, respectively (RGB). Cones are less light-sensitive than rods. However, they are not colour-sensitive since there is just one-rod type. Because of this, the human eye cannot discern between different hues in low light. However, rods are efficient when the light level is as low as 0.001 cd/m².

By doing international research about vision versus lighting, we discover that in numerous field studies, lighting researchers at the "Lighting Research Center" (LRC), Troy, New York, in the year 2004 have shown, by using what they describe as a "Unified System of Photometry", that a street lighting system may be created to consume less energy while preserving or enhancing perceptions of visibility, safety, and security. It is a measurement system that combines the photopic and scotopic luminous efficiency functions. It can be applied to any light level, including mesopic levels noticeable to the human eye [15, 16].

It is partly used to develop criteria for the high-pressure sodium (HPS) replacement lamp because they conclude that replacing traditional, yellowish HPS with cool-white light sources can reduce the amount of electric power used for lighting while maintaining or improving visibility in nighttime conditions.

The system offers the equivalent mesopic brightness for lights with different spectral power distributions, resulting in equivalent visual performance in low light. In four demonstrations and evaluations, the Lighting Research Center (LRC) used different lighting systems with shorter wavelength light to replace HPS street lighting. The vision function is carried out by a combination of cones and rods under mesopic lighting conditions, which are commonly present outdoors at night under dim lighting created by street and parking lot lighting. To lessen the luminance of the road surface while maintaining the same or greater visibility, outdoor electric light sources that are calibrated to how humans perceive under mesopic lighting conditions can be employed. There is a greater chance to save energy.

The researchers have found that the majority of the 13 million streetlights in the United States have the potential to drastically reduce energy use by as much as 50%, which results in yearly energy savings of 1 billion kWh and a decrease in CO₂ emissions from power plants of 546,000 tons (data for 2003).

3.3 The Scotopic/Photopic Ratio (S/P)

A lamp's Scotopic/Photopic ratio (S/P) refers to the proportion of photopic light to scotopic light. This ratio determines the perceived visual brightness of a light source. Because of this, a 150W light will appear just as bright, if not brighter, to the human eye than a metal halide or sodium vapour bulb that is twice as powerful.

Lumens are used to measure light (lux or foot candles). The S/P ratio of a lamp is crucial because it gives a figure that can be multiplied by the output reading of a lamp using a 1951 typical standard meter to calculate how much light it generates. These are referred to as visual lumens.

The light is measured using a traditional light meter or spectrometer to determine the photopic vision sensitivity curve. The scotopic sensitivity curve is calculated using a light meter calibrated to the scotopic and the same light source. The following readings form an S/P ratio that can be stated as a single number. In general, the brighter the light, the higher the number.

In order to understand why LED technology has dethroned high-pressure sodium vapour, researchers have created a table called the S/P ratio (scotopic/photopic), which transforms the photopic luminous flux into the scotopic equivalent by multiplying it by the S/P ratio, let us use the Table 3.1, where we can see the S/P for Various Light Sources [17].

Light Source	S/P Ratio
1700K Low Pressure Sodium (LPS)	0.25
2100K High Pressure Sodium (HPS)	0.40
2700K Incandescent	1.36
3000K Fluorescent (830)	1.29
3000K LED	1.21
3000K Quartz Halogen	1.50
3500K Fluorescent (735)	1.24
3500K Fluorescent (835)	1.41
3500K LED	1.41
4100K Fluorescent (741)	1.54
4100K Fluorescent (841)	1.65
4100K LED	1.65
4300K Metal Halide	1.49
5000K Fluorescent (850)	1.96
5000K LED	1.80
6000K LED	2.00
6500K Fluorescent (865)	2.20
6800K Mercury Vapor	0.80

Table 3.1: S/P Ratio Source Chart [17]

By consulting the Table 3.1, you can see that:

- S/P = 0,40 for High Pressure Sodium (HPS);
- S/P = 1,8 for LED at a colour temperature of 5.000K.

Considering a lamp with a 40.000 lumen photopic (HPS) value and multiplying it by 0,40 (S/P HPS), the effective scotopic lumens are 16.000. Dividing this value by 1,8 (S/P LED), we get 8889 lumens of LED, which is the photopic measurement.

So, from a scotopic perspective, 8.889 LED lumens are required to replace 40.000 lumens of HPS.

Figure 3.6 compares LED and HPS in the visible light spectrum.

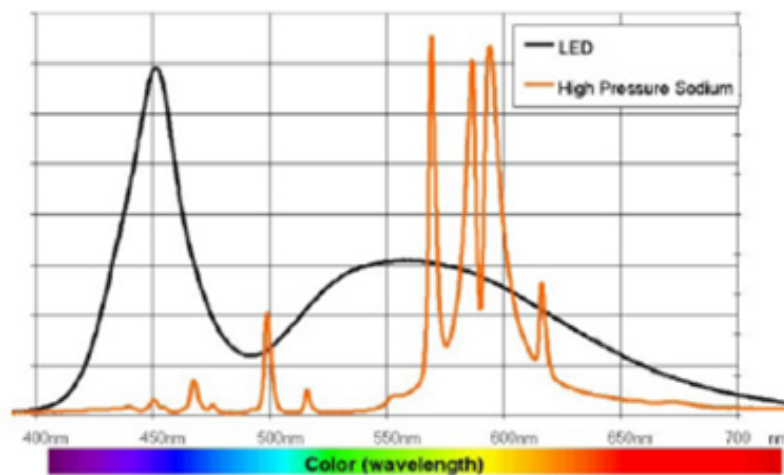


Figure 3.6: Comparison between LED and HPS [18]

3.4 LED luminaires in Public Lighting

The LEDs are fixed to a printed circuit board (PCB), the base where the components are placed to create an electric circuit. A functional lighting device is made by soldering a series of LEDs into a PCB [19].

Photometric lenses are used to enable the luminous flux to be directed towards the place to be illuminated and also to control light pollution.

Individual lenses are used for street lighting as they are highly efficient. Most manufacturers use polymethyl methacrylate (PMMA); in some cases, they are protected by a flat glass. They offer asymmetric photometry of the roadway that directs light to specific zones and avoids light loss and efficiency [20].

The Figure 3.7 shows a PCB and photometric lenses:

An LED driver is a self-contained power supply that regulates the power required for an LED or array of LEDs. The LEDs are low-energy lighting devices with a long lifespan and low energy consumption, hence the requirement for specialised power supplies. Like cruise control in a car, an LED light driver adjusts its power level as the temperature of the LED rises and falls. Without the proper LED light driver, the LEDs would overheat and become unstable, which would cause them to fail and perform poorly.

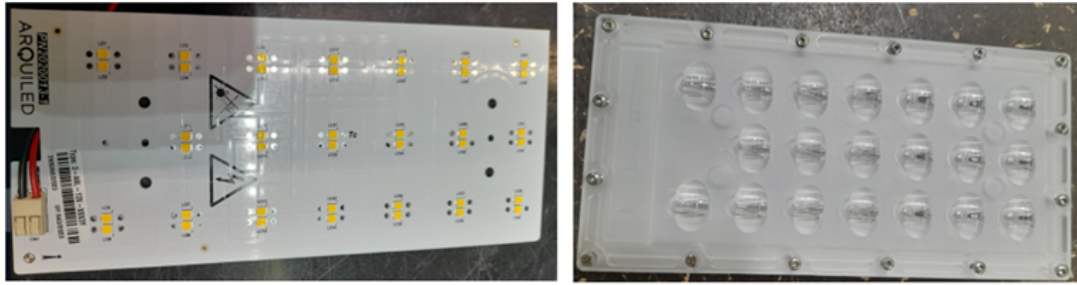


Figure 3.7: PCB (a) and photometric lenses (b) [21]

The self-contained LED driver is necessary to supply the LED with constant power to ensure the LEDs perform flawlessly [22].

Figure 3.8 shows a driver installed in a board (a) and mounted in a luminaire (b):

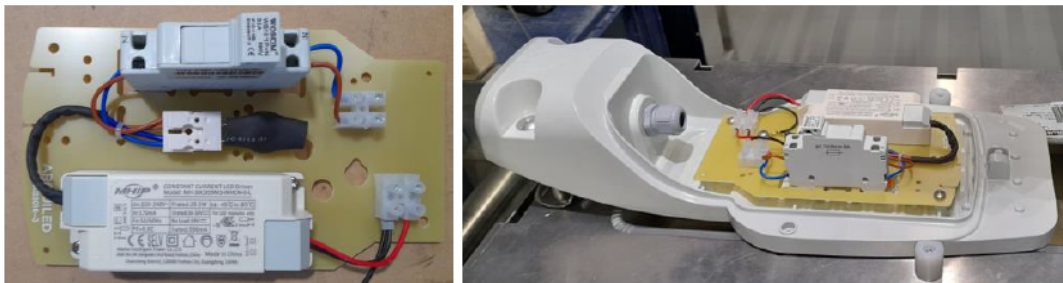


Figure 3.8: Driver installed in a board (a) and mounted in a luminaire (b) [21]

3.5 Conclusions

This chapter covered various theoretical concepts, from the composition of white light to the electromagnetic spectrum, more precisely identifying the frequencies of visible light. It explained how the human eye is sensitive to light and how its cones and rods work with the different illumination levels at night and during the day.

The concepts of photopic, scotopic and metopic vision were explained, as well as the human eye's sensitivity to the different luminance values present and the different wavelengths of light. In conclusion, considering the human eye is more sensitive to short wavelength light, which produces cool tones such as blue or green, as opposed to long wavelength light, which produces warm tones such as yellow and red, replacing HPS light with "cool" whiter/bluer light, such as LED, we can reduce the amount of electrical energy used for lighting, while maintaining or even improving visibility in night conditions. LEDs convert a large amount of electrical energy into visible light, unlike HPS lamps, because a significant part of the energy is converted into heat.

The composition of an LED street lighting luminaire was shown, including the components and accessories that ensure its operation.

4 THE PUBLIC LIGHTING PROJECT

This chapter will present the terminology and concepts relating to a public lighting project for carriageways, pedestrian/cycling areas and gardens, identifying European legislation and reference documents issued in Portugal on this subject. Some European research on dimming will be presented and analysed.

This chapter also identifies the technical requirements for implementing a street lighting project. For this purpose, the following documents are used for support:

- CIE 115:2010 "Lighting of roads for motor and pedestrian traffic" [23];
- BS EN 13201-2:2015 – “Road lighting Performance requirements” [24];
- Manual de Iluminação pública, 2016, Eletricidade de Portugal (EDP). Its is a manual written by the low-voltage electricity distributor in Portugal;
- "Documento de Referência – Eficiência Energética na Iluminação Pública – Parte I – Conceitos de luminotecnica" – 2018 (DREEIP_I). Its is a Portuguese reference document with luminotechnical concepts focusing on energy efficiency. It was created with the validation of several Portuguese official entities [25];
- “Documento de Referência – Eficiência Energética na Iluminação Pública – Parte II – Projeto de Iluminação Pública” – 2018 (DREEIP_II). Its a Portuguese reference document with the requirements for a street lighting project, focusing mainly on energy efficiency. It was created with the validation of several Portuguese official entities [26];
- “Plano Diretor de Iluminação Pública – PDIP – Município do Porto -janeiro 2023”. That is a "Public Lighting Master Plan" developed to the city of Oporto by its energy agency [27];
- “Iluminação Pública - Critérios de Projeto do Município do Porto – novembro 2022”. It is about defining the criteria for street lighting projects in Oporto and the necessary documentation that the respective project designers must deliver. [28].

4.1 Terms and Definitions

The following definitions and words apply to the public lighting project. The diagram below, Figure 4.1, illustrates the meanings of the luminance, luminous intensity, luminous flux, and illuminance.

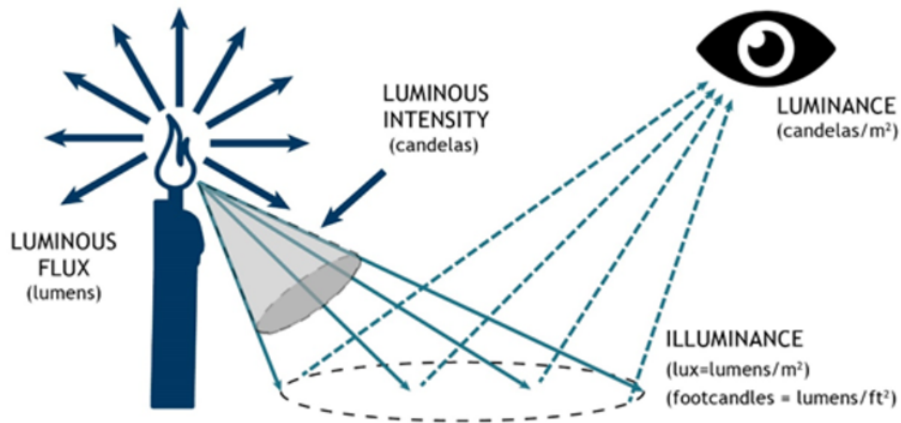


Figure 4.1: Definitions of luminance, luminance intensity, luminous flux and illuminance [29]

Luminous flux (lm) - a fraction of energy emitted by a natural or artificial light source in the form of electromagnetic waves that create the impression of light (400-700 nm). Measured in lumens [23, 25].

Luminous intensity (l) - is measured in candelas and is the quantity that expresses the distribution of luminous flux in space. This quantity measures luminous flux values in different directions [23, 25].

Candela (cd) - is the basic unit for measuring luminous intensity. One candela is equal to 1 lumen per steradian (lm/sr). It is defined as the luminous intensity going in a certain direction and is therefore related to the angle of aperture to the light [23, 25].

Luminance (L) – is the amount of luminous flux incident on, emerging from, or passing through an apparent surface of a primary or secondary light source at a fixed angle, as shown in the Figure 4.2 . It is measured in candelas per square meter (cd/m²) [23, 25].

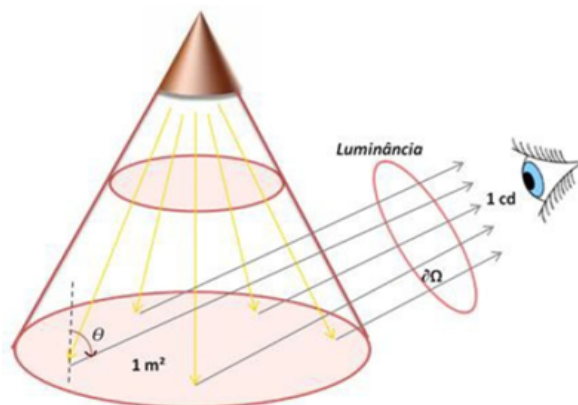


Figure 4.2: Luminance [25]

Illuminance (E) is the amount of light falling on or illuminating a given surface. It can also be defined as the number of lumens falling on 1m^2 , as shown in Figure 4.3. Measured in lux or lumens per square meter (lux or lm/m^2) [23, 25].

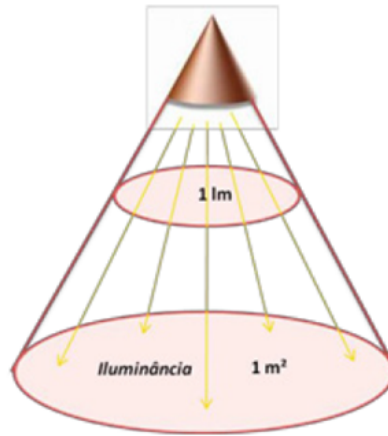


Figure 4.3: Illuminance [25]

Overall Uniformity of Road Luminance (U_o) – is the ratio between the minimum and average luminance values of a lighting installation. This criterion is essential for controlling the minimum visibility on the road [23, 25].

Longitudinal uniformity (of road surface luminance of a carriageway) (U_L) – is the lowest of the ratios determined for each driving lane of the carriageway as the ratio of the lowest to the highest luminance of the roadway surface determined in a line down the centre of the lane [23, 25].

Threshold increment TI (of an object at the road surface) (f_{TI}) - percentage increase in contrast of an object required to maintain threshold visibility when glared by luminaires of a street lighting system [23, 25].

Edge illuminance ratio EIR (of illumination of a strip adjacent to the carriageway of a road) (REI) – average horizontal illuminance on a strip just outside the edge of the carriageway in relation to the average mean horizontal illuminance on a strip inside the edge, the strips being the width of one lane of the carriageway [23, 25].

Luminous Efficiency (lm/W) - The luminous efficacy of a source is the ratio between the total luminous flux emitted by the source and the electrical power absorbed by it [30].

Energy Efficiency Index (EEI) - the energy efficiency of an IP installation is defined as the ratio between the product of the illuminated surface by the average illumination in service of the installation and the total power installed [30].

Color temperature (CCT) - Color temperature is a property of visible light determined by comparing its colour saturation with that of an ideal blackbody. In other words, it is the temperature at which a black body emits the same colour as the light source. Usually measured in Kelvin (K) [23, 25].

The higher the colour temperature, the lighter the colour tone of the light, as shown in Figure 4.4:

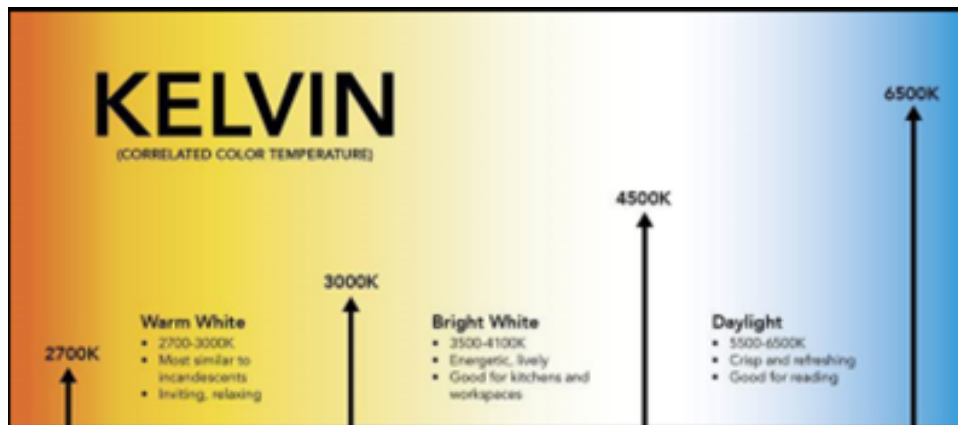


Figure 4.4: Color temperature [31]

Various colour temperatures can be seen on the same street in Figure 4.5.



Figure 4.5: From <3000K to >5000K [26]

The colour scale changes from a more orange colour, also known as warm (3000K), to blue, also known as cold (5000K).

There are various studies on applying the best colour temperatures, but let us mention that in the early days of LED technology, the colour temperatures used were the coldest to boost LED performance. Several luminaires were used with colour temperatures of around 5500K.

People began to find these cool tones strange because they were used to high-pressure sodium, which is quite warm, and today, also motivated by the evolution of LED technology, particularly its performance, temperatures of 3000K have been adopted for carriageways and 2700K for parks and gardens.

The EU Commission's Green Public Procurement (GPP) recommends installing warmer colour LEDs to restrict impacts on wildlife and sky quality and potential effects on human health. According to "Dark Sky Ireland", the adoption of 3000K lighting rather than 4000K results in a 37% reduction in blue light and moving to 2700K provides a 48% reduction and strongly urges the use of warm white lighting with a maximum CCT of 3000K, and lower values in more sensitive areas such as National Parks, or other sensitive habitats, and conservation regions (2200K or less) (see Appendix C).

Will this draft bring any energy efficiency reductions, i.e. the ratio between the luminous flux of the light source (lm) in relation to the electrical input power (W), will harm? To produce white light in an LED, a semiconductor chip that emits blue light is generally used. Part of this light is converted into light with longer wavelengths (green, yellow and red light) by means of a converter or phosphor mixture. The sum of all these colours results in white light. However, this conversion involves losses that increase with the wavelength of the converted light. This increase in loss is because the difference in energy between the light with a higher energy level (blue light) and the light with a lower energy level (red light) is converted into heat. For a lower colour temperature, more phosphor must be added, which reduces efficiency. Figure 4.6 shows the spectral power distributions (SPD) of typical LEDs at different CCT values [32].

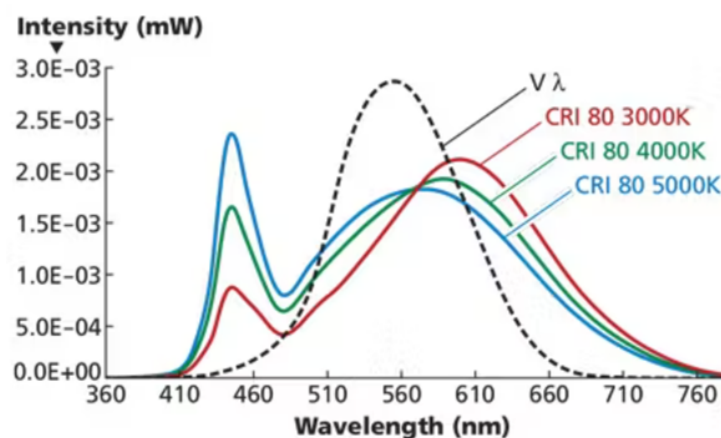


Figure 4.6: Relationship between CCT and efficiency [32]

Color Rendering Index (CRI) - compares a light source to a natural light source like the sun and measures how effectively a light source can replicate the colours of objects. A higher score on the CRI scale, which runs from 0 to 100, means that the light source can reproduce colours more accurately. Perfect colour rendering, often only possible with natural sunshine, has a CRI score 100. Good lighting has a CRI of 80 or higher, frequently used as a benchmark for indoor lighting [23, 25, 33].

A comparison of what colours look like under different CRI ratings is shown in Figure 4.7.

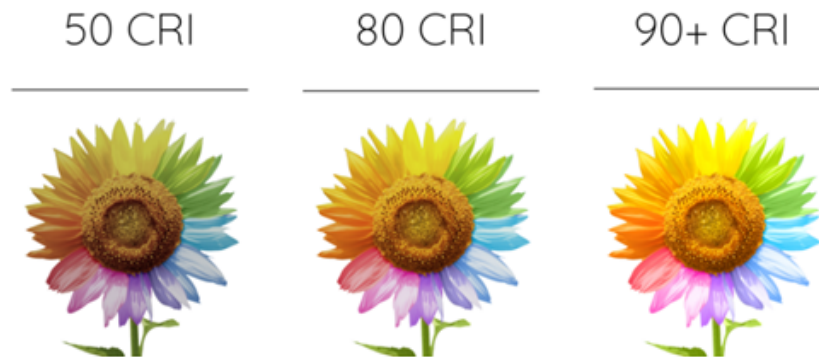


Figure 4.7: Comparison of different CRI [34]

Different CRI brings any energy efficiency reductions? Figure 4.8 shows typical SPDs for 4000K LEDs with different CRIs. The high red ratio of CRI 90 can be clearly seen. Producing this high proportion involves high losses. In addition, much of the red energy produced lies significantly outside the human eye's V_λ sensitivity curve, which leads to a further reduction in luminous efficacy [32].

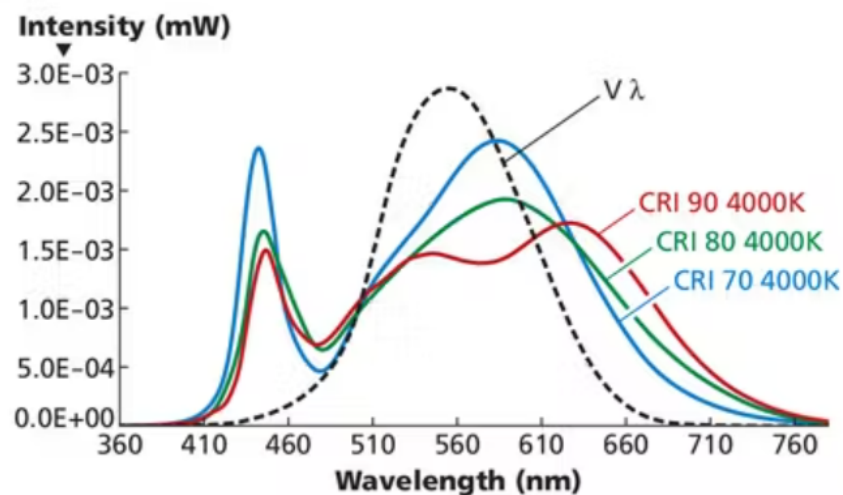


Figure 4.8: Comparison of different CRI [34]

Whereas the influence of different colour temperatures on the luminous efficacy of the LED is in the region of $\pm 5\%$, the influence of the CRI for different values is typically more in the region of $\pm 15\%$, as shown in the Figure 4.9.

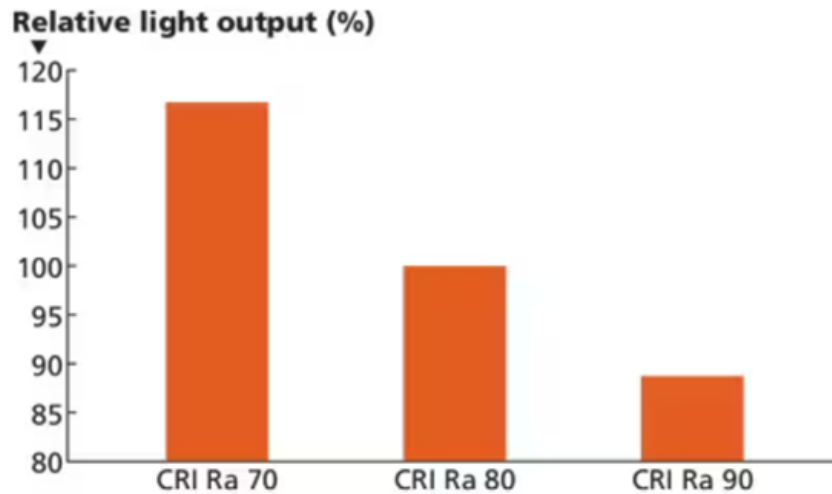


Figure 4.9: Comparison of different CRI [34]

Upper Light Output Ratio (ULOR) - The ratio of the luminous flux emitted by a luminaire above the horizontal to that emitted by the lamp [30, 35]. A luminaire's ULOR (Upward Light Output Ratio) and DLOR (Downward Light Output Ratio) are the ratios between the flux emitted by the luminaire upwards and downwards, respectively. These two definitions are extremely important for controlling light pollution in the sky. Figure 4.10 shows this relationship and its graphical terms:.

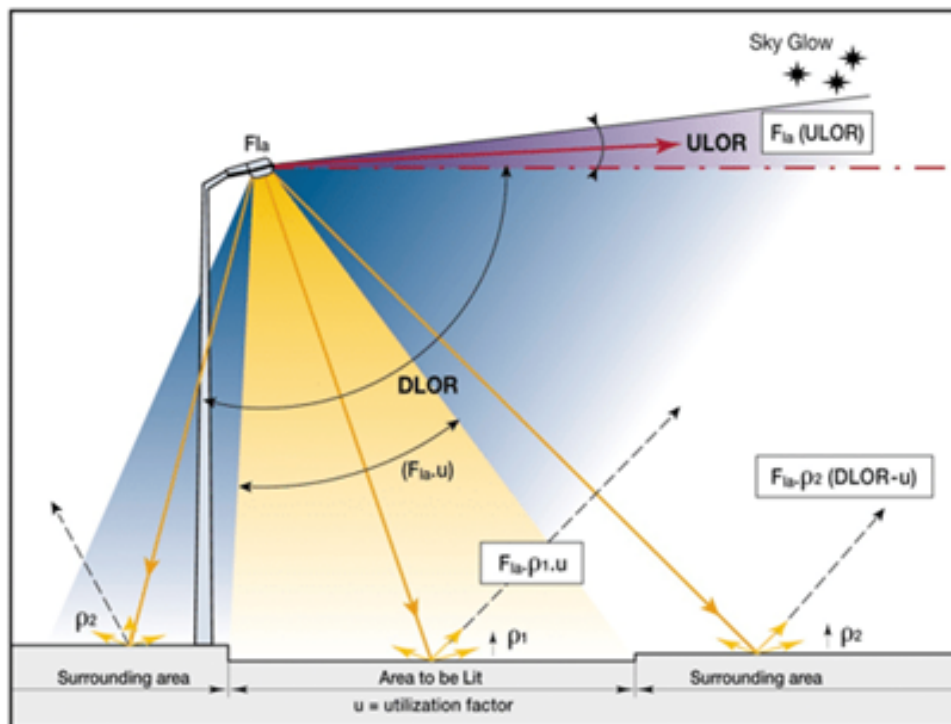


Figure 4.10: Index ULOR to put to 0 degrees in order to avoid light pollution [36]

Maintenance Factor (of an installation) (MF) – is the ratio of the illuminance at a given time ($E(t)$), to the initial illuminance (E_0), as shown at the Figure 4.11. The value of the maintenance factor may significantly affect the power of the light source to be installed, as well as the number of luminaires required to achieve the specified illuminance/luminance values.

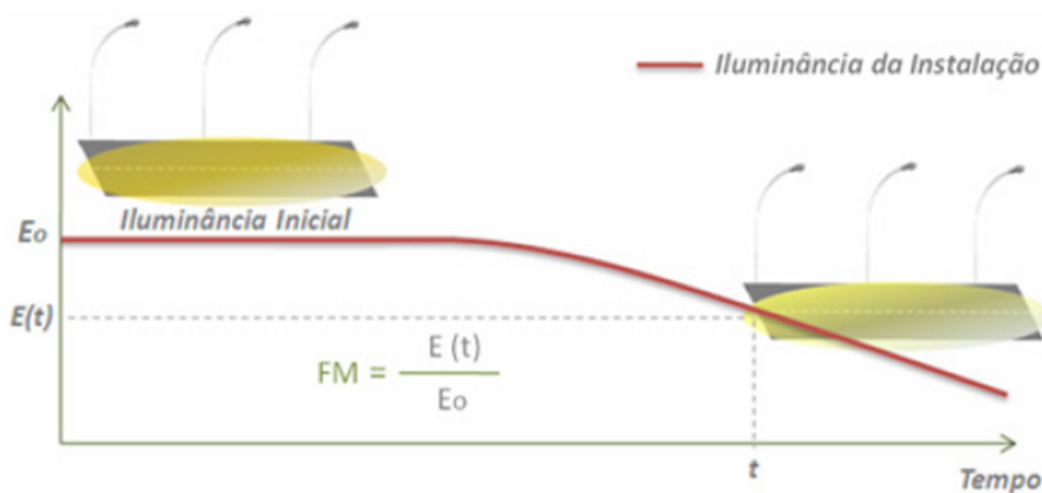


Figure 4.11: Depreciation of luminous flux over time [25]

In plainer terms, this is a scale between 0 - 1 that contrasts the current illuminance value with the starting value. If the result is 1, there has not been any depreciation, and the illuminance value has not changed since it was installed. All lighting systems degrade over time through ageing, dirt, vandalism, or other causes, resulting in loss of luminous flux. It is, therefore, necessary to calculate a depreciation factor that guarantees the levels of illumination required over the installation's life.

The LED industry and the Illuminating Engineering Society of North America (IESNA) created a standard for evaluating lumen maintenance of LED light sources, known as IES LM-80-08, to make it easier to compare the long-term performance of various LEDs. It only pertains to the individual LED package, array, or module, not a system-level test. The guideline does not offer instructions on extrapolating test results [37].

With data collection occurring at least once per 1000 hours, the testing report produced by a standard format will provide luminous flux for a given current for at least 6,000 hours. Testing must be done under tightly controlled operating circumstances, such as a constant DC drive current in a thermal chamber where the temperature of the LED and the surrounding air are kept within predetermined ranges. Three alternative LED casing temperatures will be tested: 55°C, 85°C, and a third temperature to be determined by the manufacturer, as shown in Figure 4.12.

Along with lumen preservation, the chromaticity changes during the measurement period [25].

The Illuminating Engineering Society (IES) presents document TM-21-11, a method to project the depreciation of the luminous flux of LED light sources from the data obtained by the procedures in IES document LM-80-08 [37].

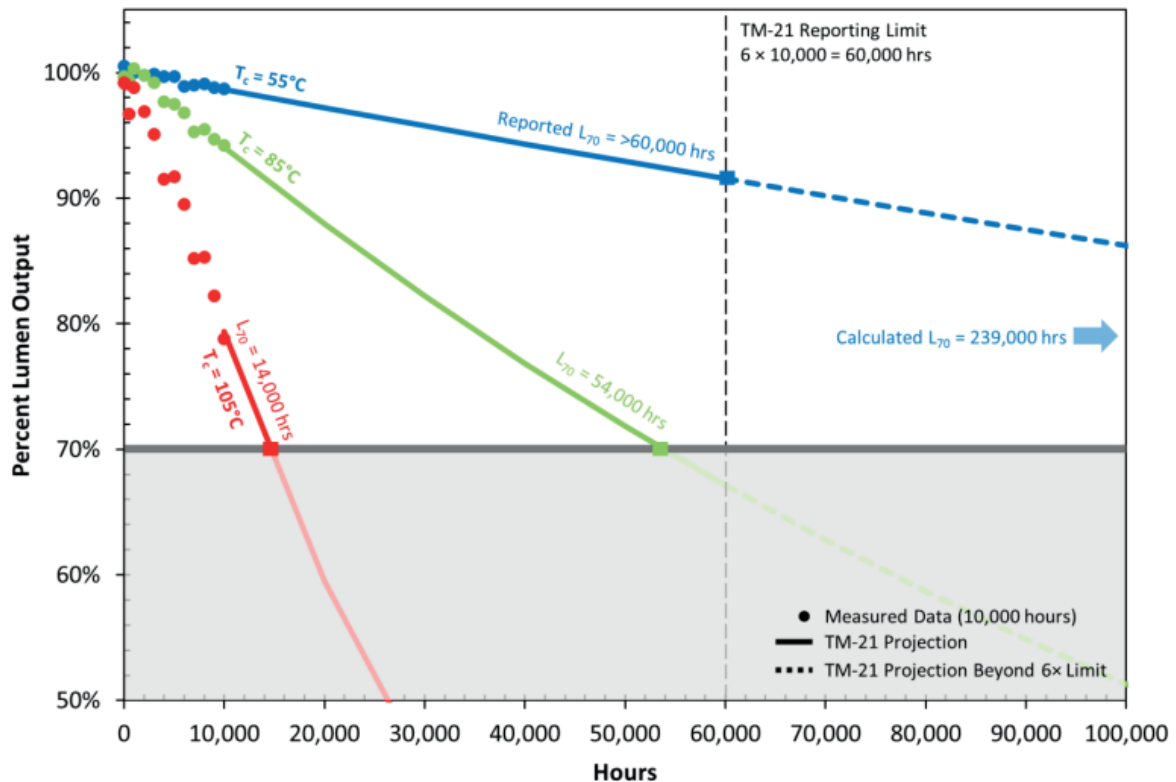


Figure 4.12: Depreciation of the luminous flux according to temperature [25]

Useful life is understood as the point at which the light emitted by an LED depreciates to a level where it is no longer considered suitable for a specific application. Typically, 30% luminous depreciation or loss of 70% of luminous flux, known as L70, is considered a threshold [37].

Regarding its behaviour over time, the LED life data is obtained initially from LM 80 and is extrapolated from TM21 onwards, generally based on a temperature of 25°C.

When it says, for example, L90B10@100.000 hours/25°C, it tells us that after 100.000 hours, the population of LEDs in a luminaire will have at least 90% of the initial flow, while 10% of this population has not reached this value [25].

Luminaires LED – in roadways, mainly composed of two separate parts made of high-pressure die-casted aluminium, optic, photometric engine, and driver current (which transforms alternating current into direct current AC/DC). The number of LEDs in combination with the driving current determines the intensity level of the light distribution.

Figure 4.13 shows one example of luminaire for roadways, identical to that used in the case study of this thesis.

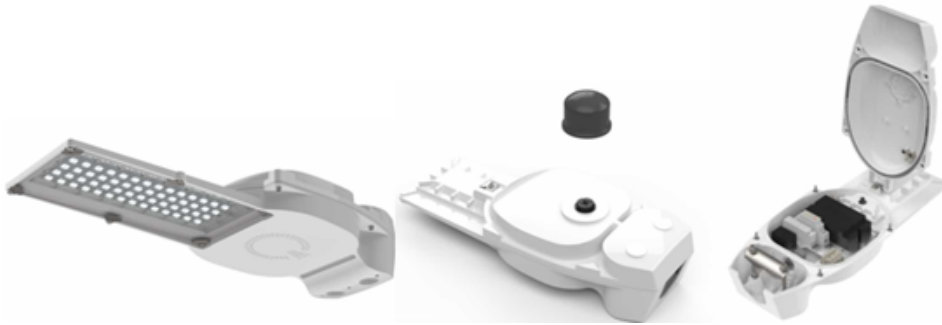


Figure 4.13: Luminaire "Argus" for roadways [21]

Figure 4.14 shows the other luminaire used in the case study of this thesis, mainly in the garden. Housing is composed of aluminium and polycarbonate to protect the photometric engine.



Figure 4.14: Luminaire "Bolle LED" [38]

When the luminaire is to be integrated into a lighting management system, it is necessary to install the smart streetlight controller, socket "Zhaga" or "NEMA", depending on the manufacturer.

Figure 4.15 shows one example of a "NEMA" controller used in the case study.

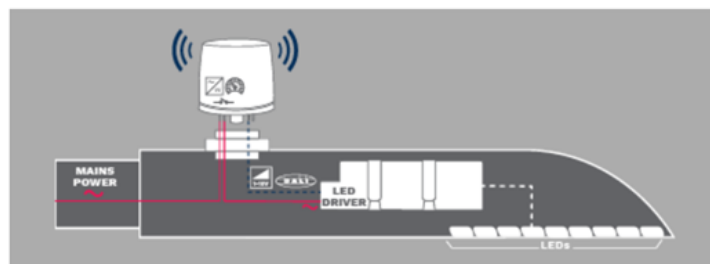


Figure 4.15: Electrical schema of the "NEMA" controller [38]

From the wiring diagram, you can see that the power supply to the controller comes directly from the public network, and it is from the controller that the luminaire is powered. If the controller has a fault, the luminaire will probably not work.

There are luminaires which use ZHAGA type, whose electrical diagram is shown in Figure 4.16:

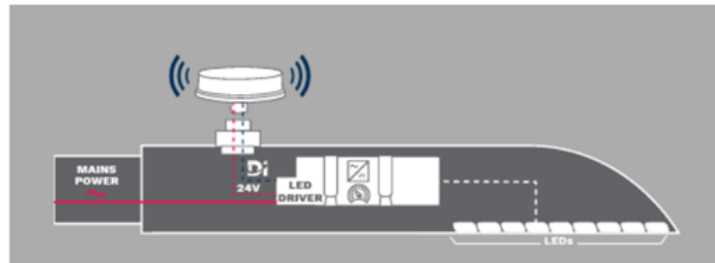


Figure 4.16: Electrical schema of the "ZHAGA" controller [38]

In this case, the driver electrically supplied the controller, so the drawback mentioned for "NEMA" does not occur.

Protection index (IP) - is an international standard. This index classifies the level of protection offered by equipment against intrusions by solids (e.g. dust) and liquids (e.g. water, oil). The higher the digits, the greater the protection [25].

Impact Protection (IK) - is an international standard that indicates how resistant a product is to impact. The higher the digits, the greater the protection [25].

Photometric and polar diagram – to represent the photometric information for street lighting luminaires, the most used coordinate system is the $(C-\gamma)$, as shown in the Figure 4.17 [39]:

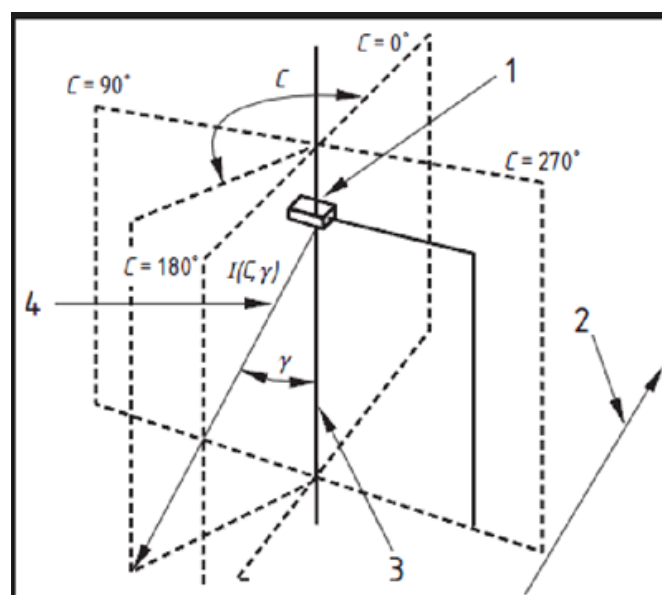


Figure 4.17: Coordinate system $(C-\gamma)$ [39]

In Figure 4.17, number 1 is the luminaire, number 2 is the longitudinal carriageway direction, number 3 is the photometric axis and number 4 is the vector "I".

The vector "I" (4) represents the value of the luminous intensity, while "C" and " γ " signal their direction.

C-0 and C-180 are the vertical planes to the right and left of the luminaire, respectively.

$\gamma = 0^\circ$ indicates the light intensity vector pointing vertically from the luminaire to the surface

$\gamma = 90^\circ$ corresponds to a horizontal vector to the luminaire.

In the event of asymmetry around the axis of the light source, the polar diagram must present the distribution curves in the vertical planes necessary for its characterization, with the inclusion of the plane where the maximum luminous intensity is mandatory.

The Figure 4.18 represents a polar diagram with asymmetry.

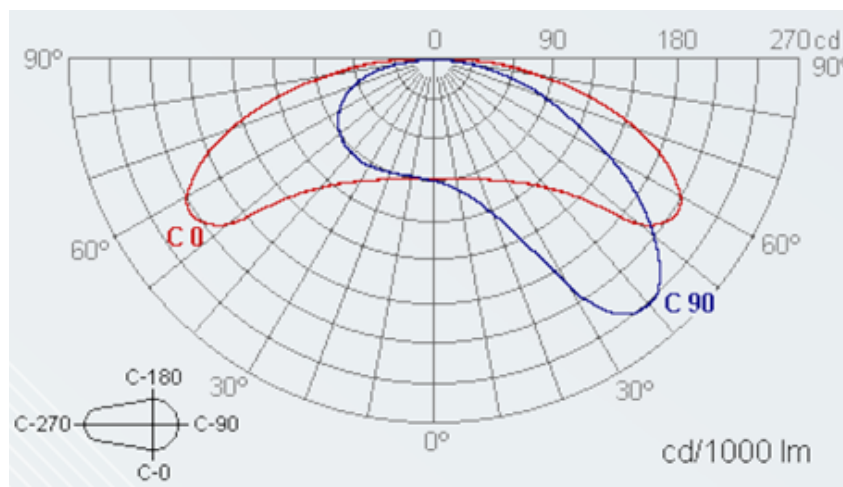


Figure 4.18: Representation of a polar diagram with asymmetry [30]

The colour red represents the longitudinal plane (C=0-180), and the colour blue represents the transverse plane (C=90-270) [30].

Isolux curves - by projecting the illuminance values emitted by the light source onto a surface, onto the same plane, and joining those with the same value with a line, an isolux curve is constructed. The various isolux curves form the isolux diagram, as shown in Figure 4.19.

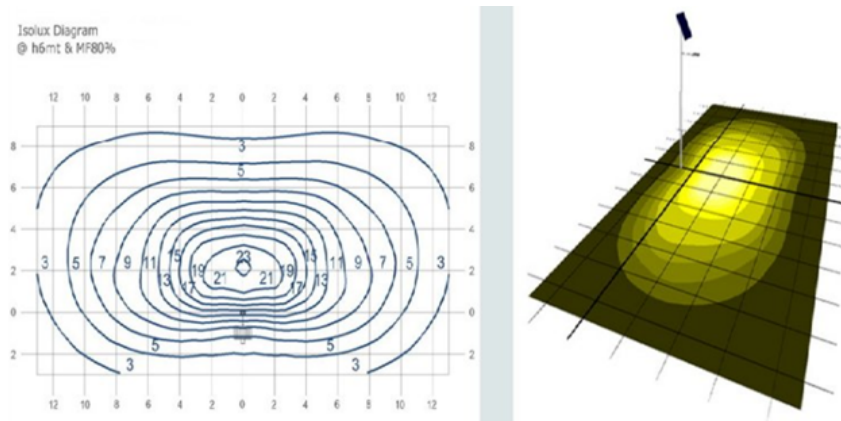


Figure 4.19: Isolux curves [40]

Dimming – imposing reductions in the electrical power in the public lighting system, which will be reflected in reducing the luminotechnical levels to reduce consumption.

4.2 Calculation of photometric quantities

By consulting the EN 13201-3:2003 "Road lighting - Part 3: Calculation of performance" [39], it turns out that the luminance calculation field is the one shown in Figure 4.20:

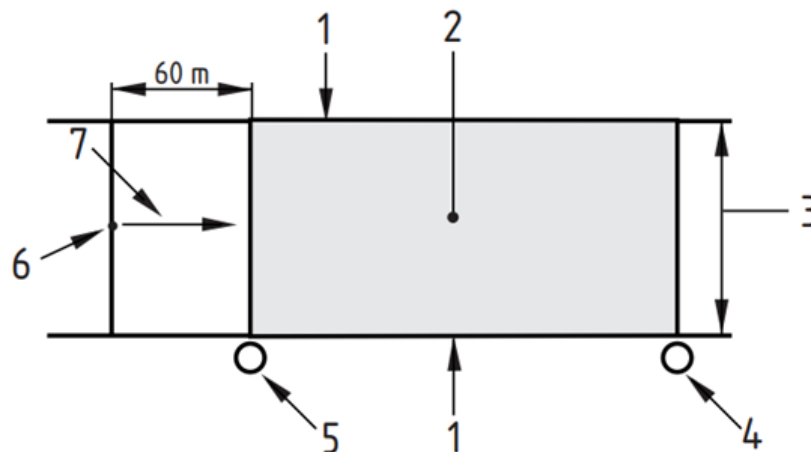


Figure 4.20: Field of calculation for luminance [3]

The meaning of the numbering is:

1. edge of the relevant area;
2. field of calculation;
3. width of the relevant area;
4. last luminaire in field of calculation;
5. first luminaire in field of calculation;

6. observer

7. observation direction.

Summarising, in the longitudinal direction of the relevant area, the field of calculation shall enclose two luminaires in the same row (4) and (5), the first luminaire being located 60 m ahead of the observer. The observer's eye is 1,5 m above the road level, and he is 23 years old.

The location of the measuring points, for luminance, is shown in the Figure 4.21:

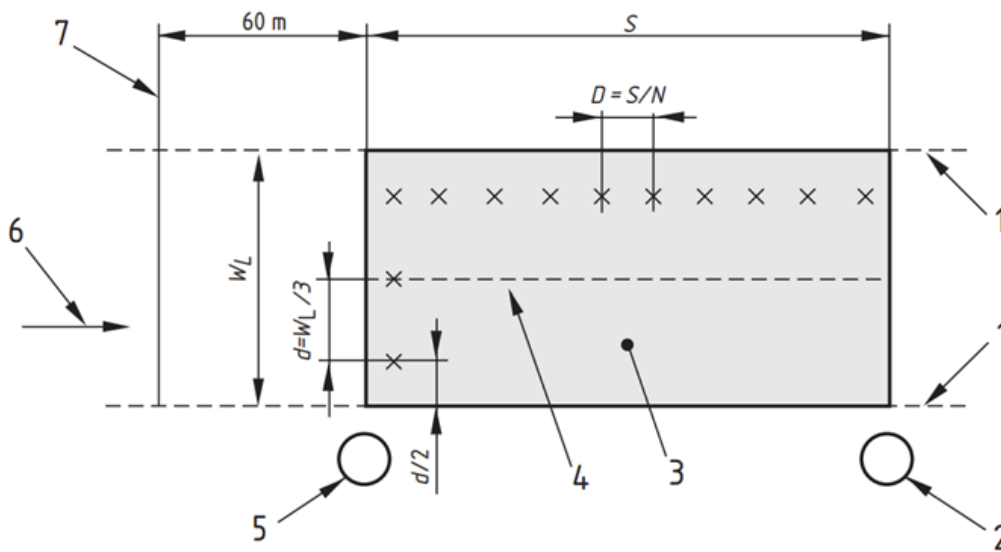


Figure 4.21: Position of calculation points - luminance [3]

The meaning of the numbering is:

1. edge of lane;
2. last luminaire in calculation field;
3. field of calculation;
4. centre-line of lane;
5. first luminaire in calculation field;
6. observation direction;
7. observer's longitudinal position.

X denotes lines of calculation points in the transverse and longitudinal directions (30 points).

Figure 4.22 shows the ideal position for the luminance meter in 3D format:

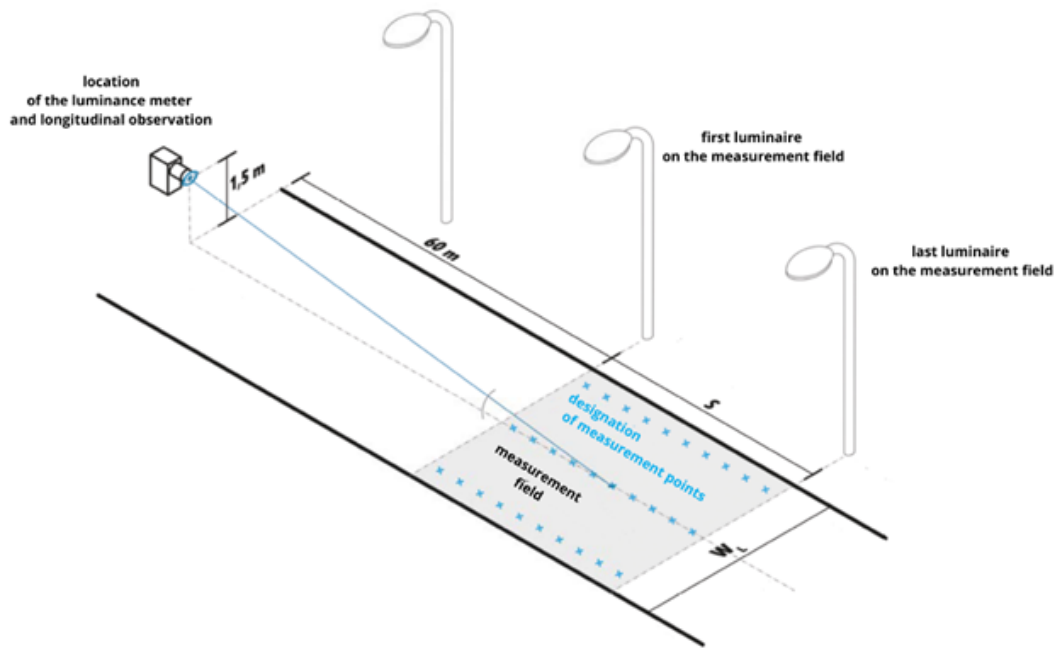


Figure 4.22: Ideal positioning of the luminance meter [41]

As we can see, the process of measuring luminance is not simple and is time-consuming. It involves measuring the luminance of 30 points. Technology has improved, and there is now equipment that uses a photograph and the appropriate software to obtain the values more quickly, as shown in Figure 4.23.

It was possible to obtain one of these pieces of equipment through cooperation between GL Optic from Poland, a company specialising in producing lighting measurement devices, and the Department of Lighting Technology of the Poznań University of Technology [41].



Figure 4.23: Luminance meter [41]

Even so, several conditions must be considered in order to measure luminance values correctly, for example, [41]:

- measurements must be taken after dusk, when the luminance of the road is no longer "additionally illuminated" by a skylight and in favourable weather conditions;
- it is recommended that the weather conditions do not significantly affect the measurements;
- high or low temperatures can affect the light output of lamps or the accuracy of measuring instruments;
- high-speed winds can cause luminaires to swing and lower the temperature of lamps and change their luminous flux, moisture in the road surface can have a significant impact on road luminance;
- the degree of transparency of the atmosphere influences light dispersion;
- must be a limitation of vehicle traffic during measurements if the measurements are made on roads in use;
- direct light and light reflected from the external installation should be eliminated;
- foreign light may come from shop windows, advertising boards, and traffic lights.

The location of the measuring points, for illuminance, is shown in the Figure 4.24:

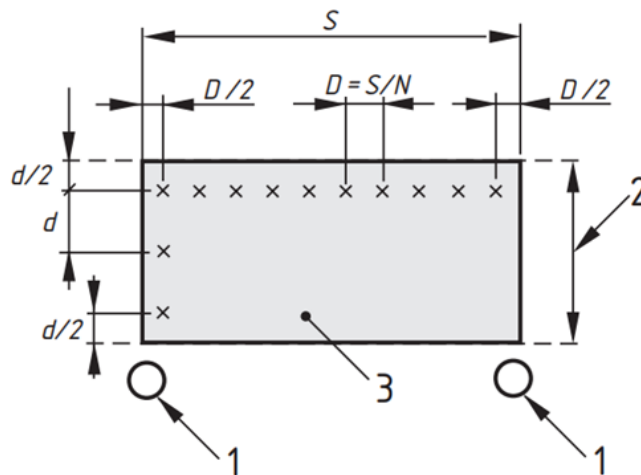


Figure 4.24: Position of calculation points - illuminance [3]

The meaning of the numbering is:

1. luminaire;
2. width of the relevant area;
3. field of calculation.

X denotes lines of calculation points in the transverse and longitudinal directions (30 points).

For these measurements, the equipment that should be used is a lux meter.

4.3 Lighting Classes

According to the CIE 115:2010 "Lighting of roads for motor and pedestrian traffic" (International Commission on Illumination) [23] there are three main purposes of road lighting:

1. To create the visual conditions necessary for all road users to perform their driving tasks safely;
2. To give pedestrians a sufficient sense of security and to enable them to see hazards, orient themselves, and recognize other pedestrians' faces;
3. To make the environment's appearance, particularly during the hours of darkness, e.g. to increase the readability of an urban area.

Since the needs of drivers, cyclists, and pedestrians vary, it is necessary to assess the relative importance of these factors when it comes to lighting specific roads or public areas. In all circumstances, road lighting installations should satisfy the necessary lighting specifications without sacrificing the visual aspects to reduce energy consumption.

A lighting class is defined by a set of photometric requirements aimed at the visual needs of various road users in certain types of road areas and environments in order to harmonize the criteria in the different EU countries [24]

4.3.1 Requirements for motorized traffic

The Class M applies to roads for motorised traffic, such as highways, suburban roads, access roads, minor roads, municipal roads, single-lane roads, and roads within the urban area with mixed traffic, where pedestrians, non-motorised and motorised vehicles meet, but where motorised vehicles predominate [24, 26]

The main lighting criteria for these classes are based on the luminance of the road surface and include average luminance, overall uniformity, and longitudinal uniformity for the dry road surface condition. Additional criteria relate to disability glare, quantified by the threshold rise TI, and the illumination of surrounding areas, quantified by the edge illuminance ratio EIR. An additional criterion used in some countries is the overall uniformity of luminance in wet conditions.

The Table 4.1 - M lighting classes show the values to be used in this class.

Class	Luminance of the road surface of the carriageway for the dry and wet road surface condition			Wet	Disability glare	Lighting of surroundings
	Dry conditions				Dry conditions	Dry conditions
	\bar{L} [minimum maintained] cd·m ²	U_o [minimum]	U_l^a [minimum]	U_{ow}^b [minimum]	f_{π}^c [maximum] %	R_{gl}^d [minimum]
M1	2,00	0,40	0,70	0,15	10	0,35
M2	1,50	0,40	0,70	0,15	10	0,35
M3	1,00	0,40	0,60	0,15	15	0,30
M4	0,75	0,40	0,60	0,15	15	0,30
M5	0,50	0,35	0,40	0,15	15	0,30
M6	0,30	0,35	0,40	0,15	20	0,30

Table 4.1: M lighting classes [24]

According to the CIE115:2010 methodology, these are the steps to take for determining the M class:

- Assign, appropriately, a weight factor to each specified passage (already assigned in the table for standardization purposes);
- Add up all these selected factors, obtaining a "Total" value;
- Enter this value into the equation: Index (M) = 6 - Total, giving the index of class M.

To define the parameters for lighting classes, we used the tables in the DREEIP_II [26], as we believe they allow a more detailed classification and determine the type of road that best reflects reality. For this purpose, Table 4.2 was used to select the parameter and the respective weighting value.

Parameter	Options	Weighting Value
Design speed	Very high	1
	High	0,5
	Moderate or low	0
Traffic volume	Very high	1
	High	0,5
	Moderate	0
	Low	-0,5
Traffic composition	Very low	-1
	Mixed with high percentage of non-motorized	2
	Mixed	1
Separation of carriageway	Motorized only	0
	No	1
Junction density	Yes	0
	High	1
Parked vehicles	Moderate	0
	Present	1
Ambient luminance	Not present	0
	High	1
	Moderate	0
Navigation task	Low	-1
	Very difficult	0,5
	Easy	0

Table 4.2: Parameters for the selection of a lighting class M [26]

To determine the options for design speed, traffic volume, and ambient luminance should use data from Table 4.3, Table 4.4, and Table 4.5:

Design speed	Values (km/h)
Moderate or low	[0;70]
High	[70;100]
Very high	Superior a 100

Table 4.3: Design speed [26]

Traffic volume	Vehicles per day
Very low	less than 4.000
Low	4.000 a 15.000
Moderate	15.000 a 25.000
High	25.000 a 40.000
Very high	up to 40.000

Table 4.4: Traffic volume [26]

Ambient luminance	Areas
Low	Rural areas, namely areas where public lighting is the only source of illumination
Moderate	Areas with lighting contribution of signage, advertising spots and residential contribution
High	Urban centres with a large amount of decorative lighting, shop windows and other outdoor lighting systems (e.g. car parks):

Table 4.5: Ambient luminance [26]

The C classes are intended for drivers of motorized vehicles and for use in conflict areas such as shopping streets, road intersections of some complexity, roundabouts, and queuing areas, where the conventions for road surface luminance calculations do not apply or are impracticable. The lighting criteria are based on horizontal illuminance and are expressed by the average and the overall uniformity. These classes also have applications for pedestrians and pedal cyclists [26].

The quality criterion to be followed for the conflict areas must be luminance; however, there will be cases in which, due to the distance and vision being less than 60 meters and in the presence of many different observers, it is impossible to calculate luminances. In these cases, the illuminance criterion must be applied.

The conflict zone must have a track classification that is one class higher than the highest class of the convergent lanes unless they are already M1 lanes. In this scenario, a 30% increase in the combat zone is required, as shown in Table 4.6 [26]:

Adjacent road class	Conflict area class
M1	M1+30%
M2	M1
M3	M2
M4	M3
M5	M4
M6	M5

Table 4.6: Conflict area class [26]

The lighting classes C0 to C5 are defined by the lighting criteria given for each class in Table 4.7:

Class	Horizontal illuminance	
	\bar{E} [minimum maintained] lx	U_0 [minimum]
C0	50	0,40
C1	30	0,40
C2	20,0	0,40
C3	15,0	0,40
C4	10,0	0,40
C5	7,50	0,40

Table 4.7: C lighting classes [24]

4.3.2 Requirements for non-motorized traffic

The P classes are designed for pedestrian and cycle lanes with mixed traffic predominately composed of pedestrians and non-motorized vehicles, as well as for all roadways where the average speed of moving motor vehicles is less than 50 km/h. Restricted access to vehicles. These users move at lower speeds, in spaces bounded or confined to their residential areas, with multiple viewing angles, do not have a roof to protect them from the impact of the nearest point of light and move in areas where the point of light is at a low height of between 3 and 5 metres. [26]

For the determination of the P class, should be used Table 4.8:

Class	Horizontal illuminance		Additional requirement if facial recognition is necessary	
	\bar{E}^a [minimum maintained] lx	E_{min} [maintained] lx	$E_{v,min}$ [maintained] lx	$E_{sc,min}$ [maintained] lx
P1	15,0	3,00	5,0	5,0
P2	10,0	2,00	3,0	2,0
P3	7,50	1,50	2,5	1,5
P4	5,00	1,00	1,5	1,0
P5	3,00	0,60	1,0	0,6
P6	2,00	0,40	0,6	0,2
P7	performance not determined	performance not determined		

^a To provide for uniformity, the actual value of the maintained average illuminance shall not exceed 1,5 times the minimum \bar{E} value indicated for the class.

Table 4.8: P lighting classes [24]

According to the CIE115:2010 methodology [23], these are the steps to take for determining the P class:

- Assign, appropriately, a weight factor to each specified passage (already assigned in the table for standardization purposes);
- Add up all these selected factors, obtaining a "Total" value;
- Enter this value into the equation: Index (P) = 6 - Total, giving the index of class P.

For the reasons already explained, we will use the tables in the DREEIP_II [26] to define the parameters for P classes. The Table 4.9 will be used.

Parameter	Options	Weighting Value
Design speed	Low	1
	Very low (walking speed)	0
Use intensity	Very high	1
	High	0,5
	Moderate	0
	Low	-0,5
	Very low	-1
Traffic composition	Pedestrians, cyclists and motorized traffic tráfego motorizado	2
	Pedestrians and motorized traffic	1
	Pedestrians and cyclists only	1
	Pedestrians only	0
	Cyclists only	0
Parked vehicles	Present	1
	Not present	0
Ambient luminance	High	1
	Moderate	0
	Low	-1
Facial recognition	Necessary	0,5
	Not necessary	0

Table 4.9: Parameters for the selection of a lighting class P [26]

4.4 Lighting pedestrian crossings

Consulting the "Pedestrian crossing" document from the Schröder company [38], we see that there are two fundamental concepts to be aware of when approaching the lighting of pedestrian crossings: horizontal lighting and vertical lighting. Horizontal illuminance enables the pedestrian to see the road markings and correctly use the pedestrian crossing. Vertical illuminance helps the motorist to see the pedestrian.

The Figure 4.25 shows these definitions graphically.

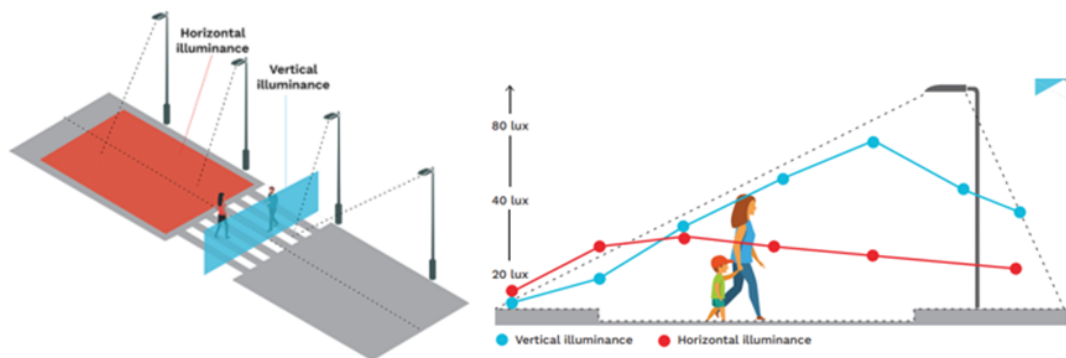


Figure 4.25: Horizontal and vertical illumination in graphic terms [38]

In addition, for good visibility of pedestrian crossings, the contrast created by a different colour temperature from the surrounding road lighting is an effective way to highlight the pedestrian crossing and attract drivers' attention.

The EN13201 standard does not specify anything about the lighting of pedestrian crossings. However, the DREEIP_II [26] does, and because we consider this issue significant for pedestrian safety, we will address it in this dissertation. It is a matter of assessing how pedestrian crossings can best be illuminated.

The lighting of crossings is intended to ensure that pedestrians can cross under the best possible conditions of safety, and the crossing must be provided with a level of illumination such that it is visible from a distance that induces the driver to drive defensively. This level of lighting also ensures that the driver can see the pedestrian correctly and that the pedestrian can easily identify the pedestrian crossing section of the roadway.

To make the pedestrian visible, the crossing area should have lighting that favours positive contrast, with the pedestrian illuminated against a dark background, achieved by good vertical lighting.

For this purpose, luminaires with asymmetric optics should be installed so that the orientation is to the right or the left, depending on the direction of traffic, to obtain a high level of vertical illumination up to a height of 1 metre. The colour temperature of these luminaires must contrast with the colour temperature of the rest of the road. The DREEIP_II [26] states that to ensure the above, the luminaires must be installed at

a height of between 5 and 6 metres, and their layout must follow the diagrams below in Figure 4.26.

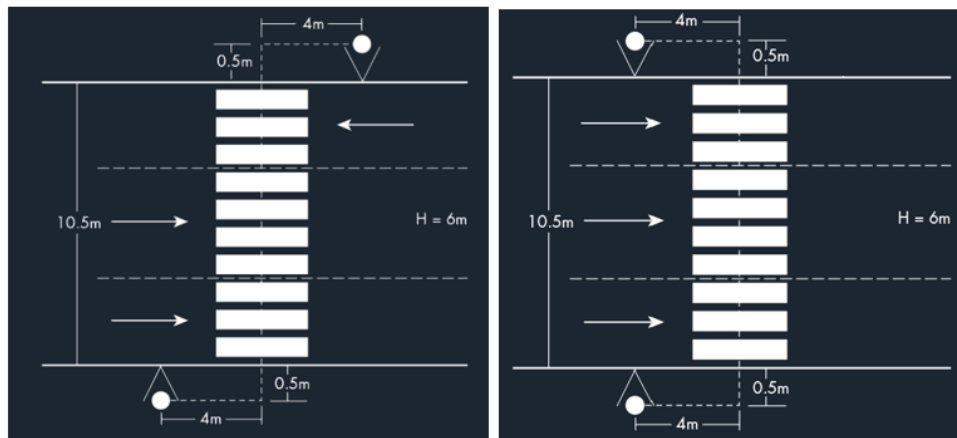


Figure 4.26: Illumination of pedestrian crossings a) 3 tracks 2 directions; b) 3 tracks 1 direction [26]

As mentioned, the EN 13201 standard specifies nothing for walkway lighting. However, it is common practice in much of Europe to use the following levels as a reference:

- Average vertical illumination on the centre line of the walkway at a height of 1m: $E_v \geq 40$ lux;
- Uniformity of vertical illumination in the lane in front of the driver (U_o): 0.20;
- Average horizontal illumination at the intersection at ground level $E \geq 80$ lux;
- Uniformity of horizontal illuminance (U_o): 0.30.

4.5 Control of Street Lights

As mentioned above, replacing luminaires with LED technology enables significant reductions in electricity consumption of around 50%.

LED luminaires now form a part of more intricate smart lighting infrastructures rather than being used as isolated components for lighting infrastructures. Individual luminaire control is made possible by smart streetlight controllers, while communication technologies link devices and street lighting management software together, as shown in Figure 4.27. Lighting fixtures are, therefore, given smart features and are currently a part of the connected lighting revolution, opening the door to smart cities [42].

Streetlight controllers can be mounted on the lamp by an integrator or installed inside the lamp by the manufacturer. Their capabilities go beyond simple remote on/off control, giving access to advanced functions like autonomous operation, intelligent scheduling, dimming, parameter measurements, and failure notifications (the electri-

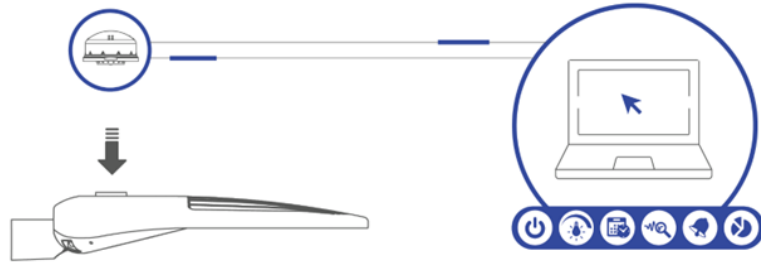


Figure 4.27: Individual luminaire control [42]

cal network must be energised 24 hours a day so that the controllers can always be active) as shown in Figure 4.28 [42].

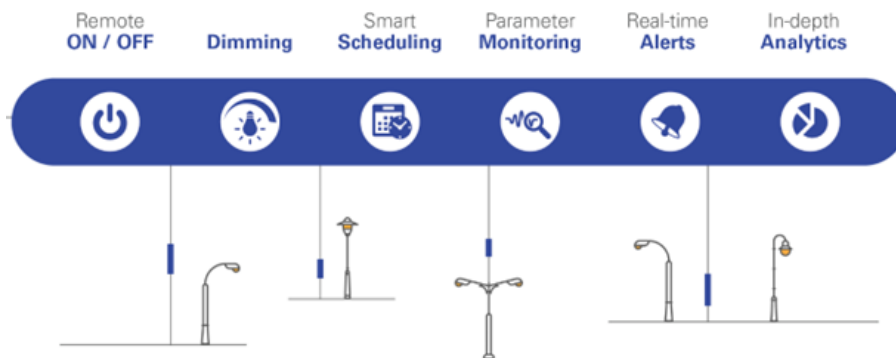


Figure 4.28: Functions permitted by streetlight controllers [42]

In order to find out more about existing public lighting control systems, we researched and selected the works that had good practical applicability and were in line with our reality.

One of the papers we selected is "A New Approach to Power Consumption Reduction of Street Lighting", Sędziwy and Leszek Kotulski, [43] so we will present its studies and conclusions. This work evaluates how ambient light can improve the system's efficiency and the lighting class reduction when car traffic decreases at night.

The authors first analysed the reduction of illumination costs with retrofit metal halide (MH) fixtures by LED luminaires for a two-lane carriageway and obtained a relative power reduction of 51,1%.

They then adjusted their luminous flux, reducing the power supply to the lowest level that ensures compliance with the requirements of lighting-class ME4a (0.75cd/m²).

Overall, energy consumption was reduced by 61,4%, as shown in the Table 4.10 and Figure 4.29:

Most public lighting infrastructure works according to the astronomical clock, which turns lamps on and off at times depending on a geographic location and the current day of the year. Control is carried out in the fundamental scenarios using predefined

	Lav [cd/m ²]	U _o	UI	TI [%]	SR [%]	P [W]
MH	0.81	0.63	0.60	8.0	68	168
LED	0.95	0.62	0.78	9.6	62.4	82.1
LED*	0.75	0.62	0.78	0.1	62.4	64.9*

Table 4.10: Values obtained with retrofit and adjusted LED [43]

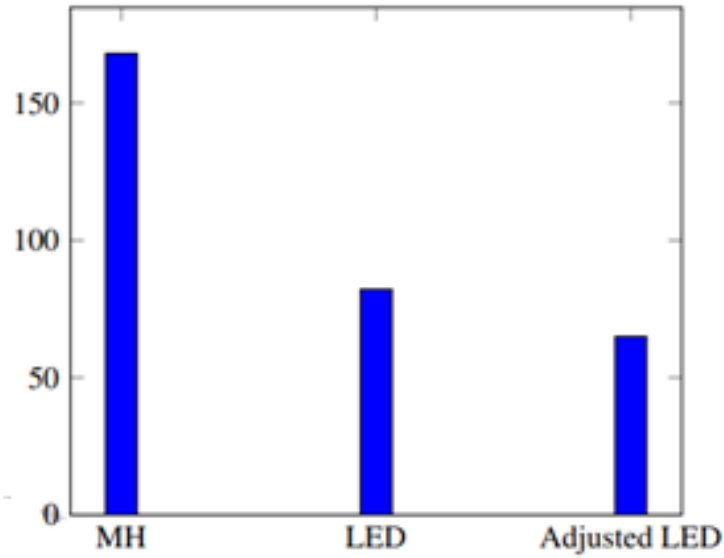


Figure 4.29: Comparison with retrofit and adjusted LED [43]

work schedules that specify dimming levels at specific hourly intervals.

For the study of the impact of ambient light, the authors considered that the general idea behind lighting control is to switch the system settings according to the daylight illuminance level, assuming that it can be measured using ambient light sensors.

For studying the lighting class reduction when car traffic decreases during the night, which is allowable by the standard CEN/TR 13201-1 (Standardization, 2004) [44], let watch the Figure 4.30, that shows the averaged daily traffic (ADT) intensity for subsequent quarters as measured by induction loops installed in a double carriageway road in the city of Cracow, Poland (Google Map, 2015). Annual average daily traffic (AADT) is the most important metric for assessing and predicting traffic volume in the transportation sector. It is employed, among other things, in infrastructure planning and design, traffic congestion monitoring, road safety estimation, and as an empirical tool to help allocate highway funding [45].

For instance, a lighting class will be lower during periods of lower traffic intensity than during higher traffic.

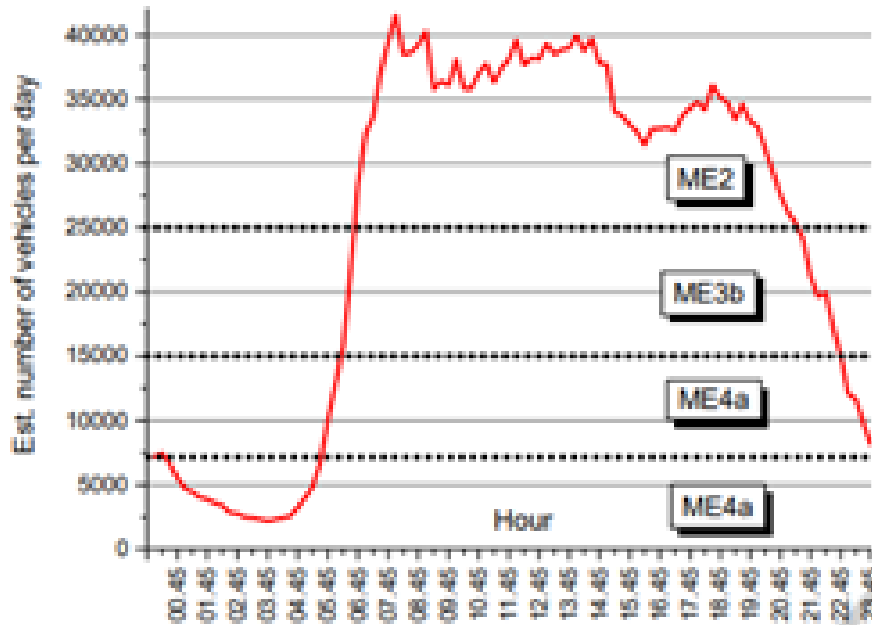


Figure 4.30: Average daily traffic intensity (ADT) - city of Krakow, Poland. The dotted lines separate lighting categories [43]

If so, the performance requirements for the first scenario will be less stringent than for the second scenario. Instead of being triggered by a predetermined schedule, lighting-class switching is initiated by changes that sensors detect. According to the standard, depending on how much traffic is present during the day, the lighting class for the considered road may be reduced from ME2 through ME3b to ME4a.

It should be noted that before implying a change in performance settings, any system state change detected by sensors (and leading to a lighting class update) must persist over a predetermined period, such as 15 minutes. A policy like this enables avoiding unpredictable changes brought on by the presence of a single vehicle. The authors considered that the system’s behaviour is adaptive and not predefined.

For the case studies presented, the actors concluded that it was 6% energy saving by considering ambient lighting and 23% regarding road class reduction.

The authors refer in their work to the Constant Lumen Output system (CLO), which compensates at the beginning of the installation’s service life for the depreciation of luminous flux and to avoid excess lighting. To ensure a predetermined lighting level for the duration of the luminaire, luminous depreciation that takes place over time must be considered, as shown in Figure 4.31. This entails increasing the initial power at the time of installation to account for slight depreciation in the absence of telemanagement. Throughout the luminaire’s service life, the power necessary to achieve the desired level - neither more nor less - can be precisely controlled by precisely controlling the luminous flux [46].

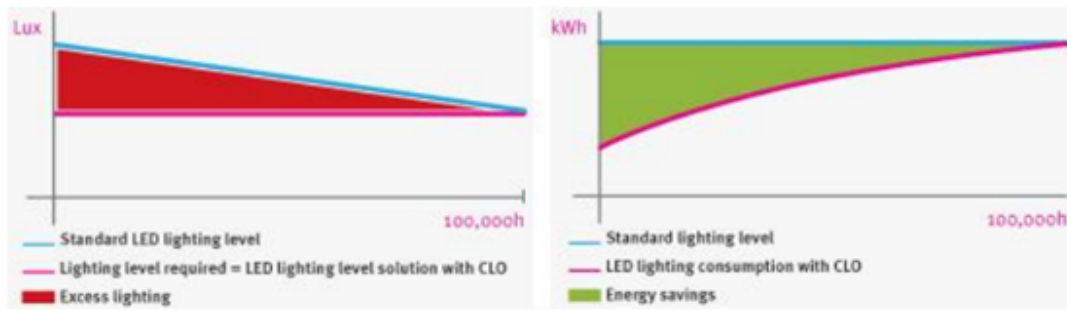


Figure 4.31: Constant Lumen Output (CLO) [46]

The other paper selected is "Concurrent Lighting System on Roads in Practice" by Sławomir Zalewski, [47]. It consists of an analysis of the public lighting control in Bożena Street in Poznań, a street with a length of 1300 metres, where 56 LED luminaires with an electrical power of 73W each are installed. It is a straight street of local importance. Traffic on it can be described as small or very small. A small number of houses are set back from the road.

Over a year (1 January to 31 December), consumption was monitored considering three scenarios: constant power, with a 50% constant power, and concurrent lighting system. This system entails the gradual illumination of subsequent luminaires, whose proper operation is crucial for both motorists' and pedestrians' viewing processes and the gradual dimming or extinguishing of those luminaires when their light output is no longer required. It is necessary to switch on a luminaire with maximum output at a suitable distance in front of the users and to dim it slightly at a suitable distance behind them, as shown in Figure 4.32:

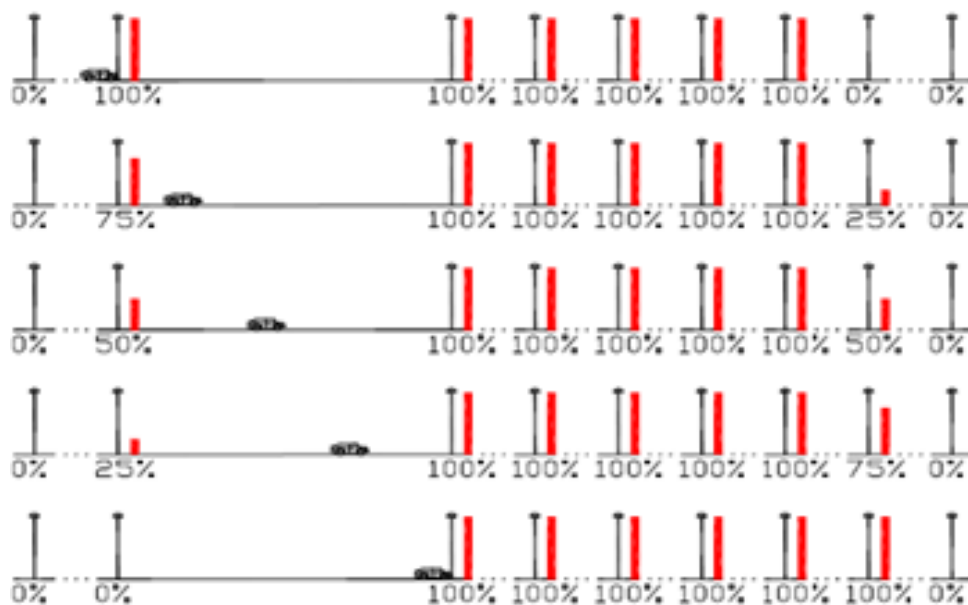


Figure 4.32: Example of concurrent lighting system

Controllers were installed in the luminaires, LonWorks PLC, that supervise the operation of the system with a control cabinet with a built-in astronomical clock that regulates the time to turn on and off the lighting system from night to morning. A motion detector was placed in each luminaire to collect information about the current position of each user.

Total minutes of system demand for electricity were calculated by adding the one-minute energy consumption in each of the three phases.

Figure 4.33 analyses the days 21 March, 21 June, 21 September and 21 December.

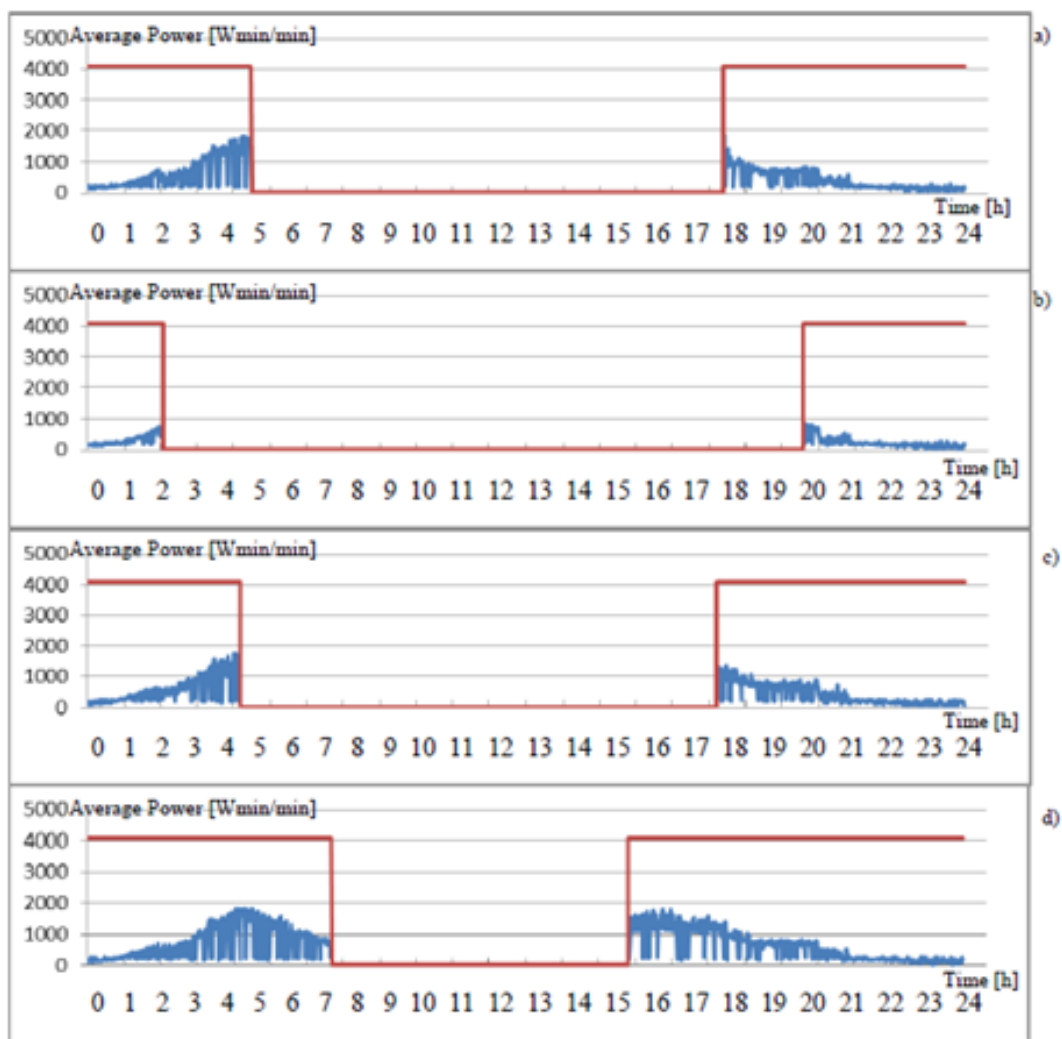


Figure 4.33: Analysis on 21 March, June, September, December

The red line means constant power mode, and the blue line means concurrent lighting mode. Regardless of the season, the waveforms are similar and fall into the same envelope. The differences primarily result from variations in system working times, which are influenced by seasonal variations in daily sunrises and sunsets. These waveforms allow for the identification of the late-night period, which lasted 4,5 hours from 10:00 pm to 2:30 am.

With these principles, the graph in Figure 4.34 was constructed, which shows waveforms of the daily energy consumption of the system when operating at constant power while following the sunrises and sunsets table (red line), when rated for a 4,5 hours power reduction by 50% (green line), and when operating in accordance with the concurrent lighting principles (blue line). The two first waveforms were determined theoretically on the time of switching on and off lighting read from the one-minute waveform of the tested system.

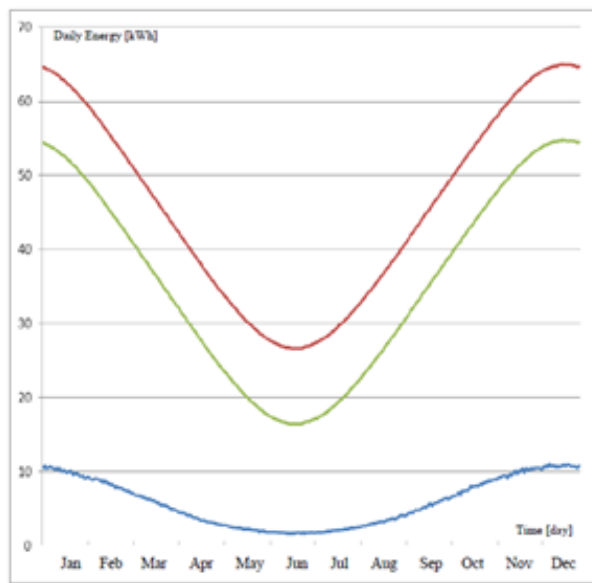


Figure 4.34: Daily energy consumption per year

It was concluded that introducing power limitations in the middle of the night reduces energy consumption by 22,4%

The operation with the concurrent lighting reduces 87,2%, compared to constant nominal power and 83,6%, as compared to working with the middle-night reduction.

However, the authors believe that the concurrent lighting system should not operate everywhere but only in selected locations, mainly for social reasons, as it is feared that there may be anxiety problems and increased insecurity. The concern cannot only be financial. There are still many questions about how residents and pedestrians will react to all the variations in lighting levels because they have not been adequately tested.

It also concluded that the lighting level reduction of the class Me3 to Me6 can give up to 70% savings, and the reduction of class Me5 to Me6 can give no more than 40% savings.

To evaluate how public lighting control is done in Portugal, some municipal councils, ESCO and luminaire manufacturers were consulted, and it was concluded that there is no standard control and that each municipality decides how to do it, most of the time without technical criteria. A maximum of 5 levels of regulation is used.

Some municipalities simply reduce it to 50% for 4 hours, however, some use the "Dim-regime Functionality 27" (DDF27), designed by the manufacturer Philips [48], as a

reference. This system, whose curve is shown in Figure 4.35, has three levels of regulation. From 11 pm to 1 am, it reduces to 75%, and from 1 am to turn on again, it reduces to 50%, estimating a saving of about 23%. It should be noted that these reductions are fixed throughout the year, with no analysis being made of the road conditions or its surroundings.

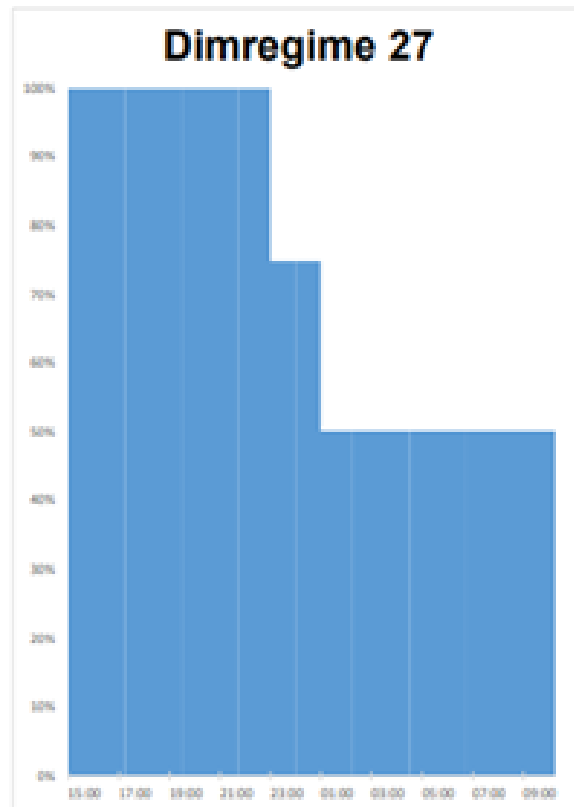


Figure 4.35: Dimregime Functionality 27 – DDF27 [48]

For the controllers attached to the luminaires to communicate with each other and the remote management system, there must be a wireless network. For this type of public lighting application, it is customary to use a Low Power Wide Area (LPWA), which is a category of wireless networks specifically designed for the Internet of Things (IoT), with some examples in Figure 4.36 (see Appendix D).

The most common systems are:

- NarrowBand Internet of Things (NarrowBand IoT, NB-IoT, LTE Cat-NB) – uses a mobile operator’s licensed LTE frequency range operator, avoiding interference from other devices;
- Long Range Wide Area Network (LoRaWAN) - transmits over free and generally accessible frequency ranges prone to interference from other users.

UE Type	Sigfox	LoRa	LTE-NB1/NB2	EC-GSM-IoT	LTE-CatM1	LTE-Cat0	LTE-Cat1
Standardization	proprietary	proprietary	3GPP-R13/14/15	3GPP-R13	3GPP-R13/14/15	3GPP-R12	3GPP-R8
Spectrum	Unlicensed 900MHz	Unlicensed 900MHz	Licensed GSM Licensed LTE	Licensed LTE	Licensed LTE	Licensed LTE	Licensed LTE
Channel bandwidth	100Hz	<125KHz	180KHz	200KHz	1.4-20MHz	1.4-20MHz	1.4-20MHz
Peak Data Rate (indicative)	<100bps	<50Kbps	<60Kbps <160Kbps	<74Kbps	<1Mbps	<2Mbps	<10Mbps
Device Peak Tx Power	14dBm	14dBm	23/20/14dBm	33/23dBm	23/20dBm	23dBm	23dBm
Latency peak	10s	10s	200ms-30s	500ms	100-150ms	10-30ms	10-30ms
MCL(Maximum Coupling Loss)	160dB	157dB	164dB	164dB	156dB	144dB	144dB
Mobility	low	low	Low-medium	high	high	high	high
Device Power Consumption	low	low	low	low	low-medium	low-medium	medium
Security	low	medium	high	high	high	high	high

Figure 4.36: Technologies used in IoT

In Figure 4.37, we can see a comparison between other characteristics of the two technologies:

Technical Data	NB-IoT (NB2)	LoRaWAN
Technology	open standard	proprietary
Licensed spectrum	yes	no
Max data rate (gross)	160 kbit/s (avg 60kbps)	5,47 kbit/s (SF7)
Worst case data rate (~144 dB link budget)	5-6 kbit/s	0,297 kbit/s (SF12)
Max. payload length (data per message)	> 1.000 B	51 B
Downlink capacity	unlimited	very low
Link budget / max. path loss (Uplink)	164 dB	141-146 dB
Link budget / max. path loss (Downlink)	164 dB	151-156 dB

Figure 4.37: Comparison between NB-IoT and LoRaWAN

Other comparisons:

- NB-IoT - Massive number of sensors, connected at higher speeds and reliability, better performance, lower data latency, higher reliability, higher device density, and higher cost for chipsets and implementation.
- LoRaWAN - low cost in scenarios with lower speeds and less reliable lower speeds and less reliable communications, very low speeds; less mobility, less reliability and density; low-cost chipsets and solutions; more local cases, less critical.

4.6 Lighting project

A lighting study must be carried out for any public lighting project.

The lighting study calculates how much artificial light is required in a given environment to meet our needs, always resulting in minimal energy waste.

The purpose of each environment, the amount of light required for the space, and the optimal lighting level for adequate visual comfort are just a few of the variables this study considers.

In resume, the main criteria taken into account to achieve the best results in the lighting project are the quantity of light, the quality of light and energy efficiency.

Most lighting designers use "DIALux evo" (DIALux) software for lighting studies [3]. "DIALux" is offered at no cost in 26 languages. "DIALux" is used by more than 750,000 professionals, including engineers, electricians, and lighting designers, to plan, calculate, and visualize light for both indoor and outdoor spaces using actual luminaires from more than 190 reputable luminaire manufacturers. [3]

We can determine the most suitable luminaire and the best light point distribution by conducting a lighting study in "DIALux" [3]. This tool examines elements like the luminous flux distribution, brightness, and uniformity.

To prepare and analyse the luminotechnical study, it is necessary to understand all the concepts explained in points 4.1 to 4.5.

Next, we will present some steps for the elaboration of a street project in "DIALux" [3], version 11.0:

The Figure 4.38 shows the initial appearance:

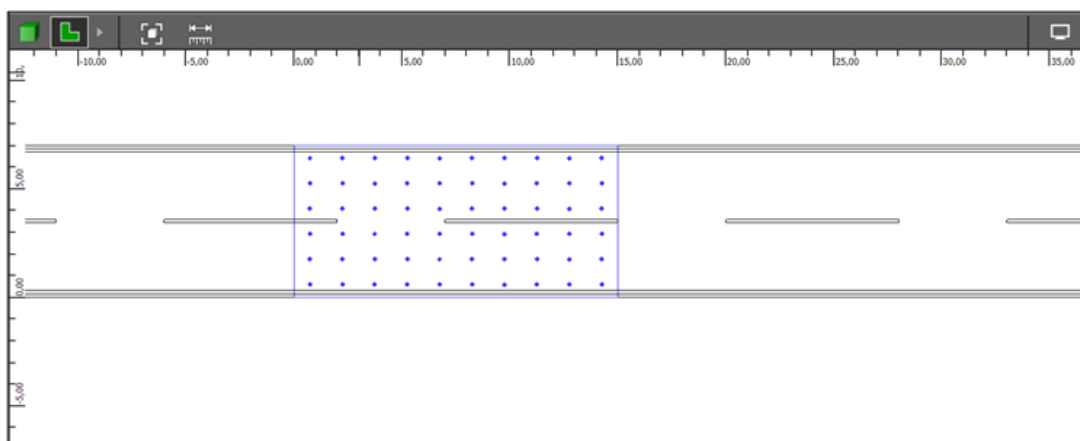


Figure 4.38: Initial appearance - street project in "DIALux" [3]

We can see an overview of the calculation zone. A pedestrian walkway, two lanes of traffic, and another pedestrian walkway are on the opposite side of the road.

The next step is to define the characteristics of the study area, the dimensions of the carriageways and sidewalks, illuminance classes, and roadway surface, as well as select the luminaires and the dimensions of the poles and their positioning, as shown in Figure 4.39 and Figure 4.40:

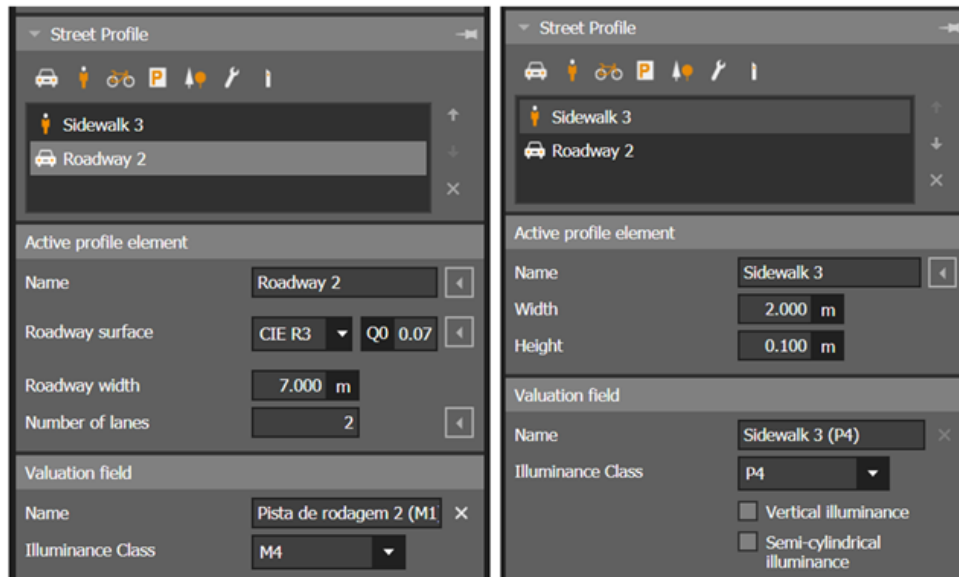


Figure 4.39: Characteristics and dimensions of the carriageways and sidewalks [3]

Next, we will define the characteristics and dimensions of the calculation area, namely the widths of pedestrian pavements, traffic lanes and the pavement composition.

Type M and P carriageway classes are defined.

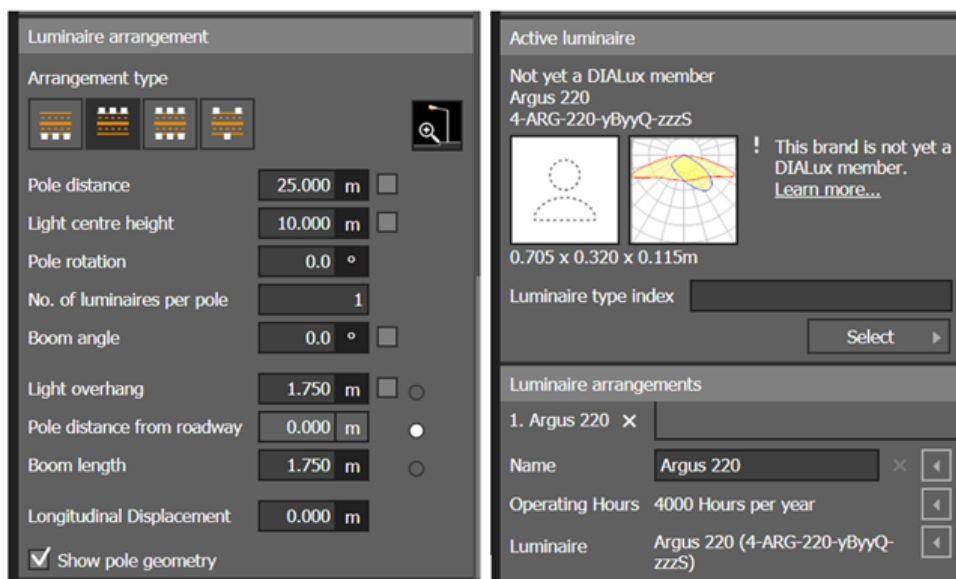


Figure 4.40: Characteristics and positioning of the poles and selection of the luminaires [3]

At this stage, we will define the poles and light fittings. In the case of the poles, their height and positioning in the study area, and the case of the luminaires, we will define the models and technical characteristics of the ones we want to study. DIALux considers a maintenance factor value of 0.80 to be adequate, and that was the value considered.

Finally, the presentation of the lighting results in graphs, 2D and 3D, as presented in Figure 4.41 and Figure 4.42.

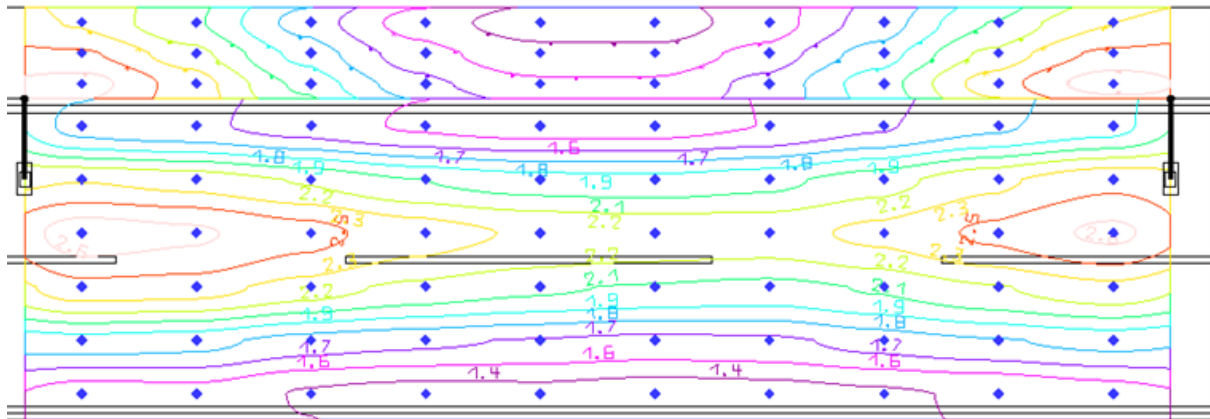


Figure 4.41: Results in 2D graph [3]

You can see the luminous results, isolux curves, in colour chart format.

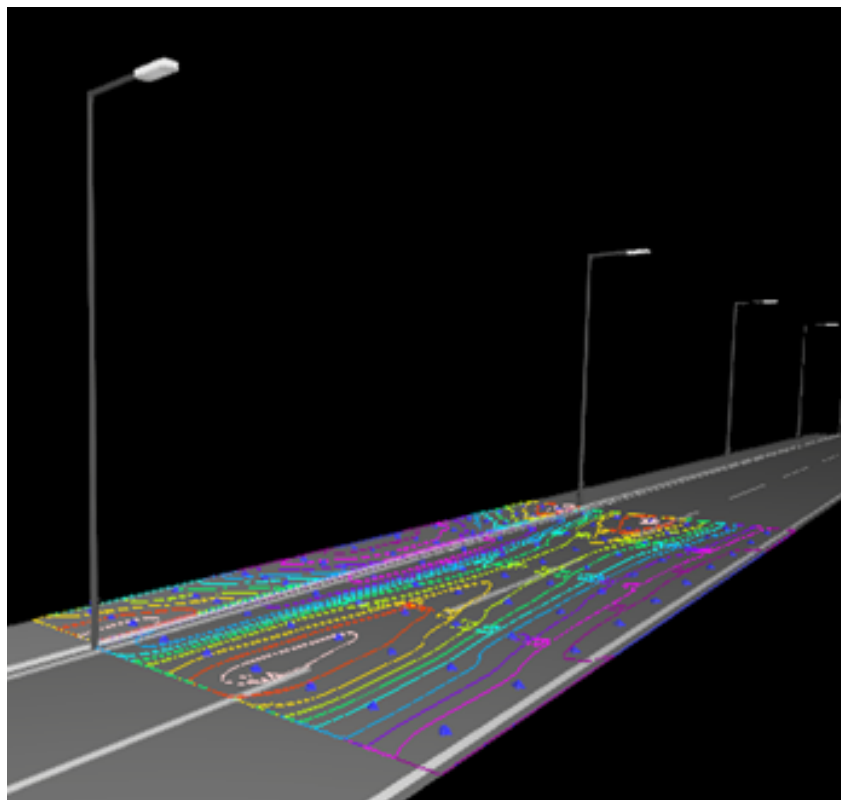


Figure 4.42: Results in 3D graph [3]

Table 4.11 shows the results obtained and their comparison with the values defined in the EN13201:2015 [24], verifying compliance with the respective requirements.

Summary (according to EN 13201:2015)

Results for valuation fields

A maintenance factor of 0.80 was used for calculating for the installation.

	Symbol	Calculated	Target	Check
Sidewalk 1 (P4)	E_{av}	23.03 lx	[5.00 - 7.50] lx	✗
	E_{min}	18.13 lx	≥ 1.00 lx	✓
Roadway 1 (M4)	L_{av}	1.94 cd/m ²	≥ 0.75 cd/m ²	✓
	U_0	0.63	≥ 0.40	✓
	U_1	0.84	≥ 0.60	✓
	TI	12 %	≤ 15 %	✓
	R_{gl}	0.72	≥ 0.30	✓

Table 4.11: Comparison between the values obtained and the EN13201:2015 [3]

4.7 Conclusions

This chapter explains the terminology and definitions relating to a public lighting project for carriageways, pedestrian/cycling areas and gardens, but also indicates and explains European legislation and reference documents issued in Portugal.

It was concluded that the levels of luminance, illuminance, uniformity, glare, and other variables, which apply to both pedestrian zones and carriageways, are listed in the same standards and not by the designer's choice.

This chapter will explain why there was a massive application of Light Emitting Diode (LED) in lighting, with particular incidence for public lighting. The importance of this technology in the concept of smart cities will also be explained.

An approach was taken to colour temperature (CCT) and the colour rendering index (CRI) and how their choice can influence the loss of energy efficiency. However, regarding colour temperature, there is much pressure from environmental associations, namely "dark sky", to use warm temperatures for human health reasons and close to 2000K in National Parks or other sensitive habitats.

Some pertinent conclusions about dimming in public lighting and how this action can contribute to lowering consumption and costs were reached through consultation of the identified research works.

Consulting the investigation work "A New Approach to Power Consumption Reduction of Street Lighting", Sędziwy and Leszek Kotulski found that they evaluate the ambient light impact and how it can improve the efficiency of the system and the lighting class reduction when car traffic decreases during the night. The authors analysed the reduction in lighting costs by switching from metal halide (MH) luminaires to LED ones for a two-lane carriageway and obtained a relative power reduction of 51.1%. They then adjusted their luminous flux to the lowest level, guaranteeing fulfilling the ME4a lighting class requirements (0.75cd/m²). Overall, energy consumption was reduced by 61.4% [43].

Then, the topic "control systems". Most of the public lighting infrastructure is carried out in the fundamental scenarios using predefined work schedules that specify dimming levels at specific hourly intervals, according to the astronomical clock, which turns lamps on and off depending on a geographic location and the current day of the year. For the study of the impact of ambient light, the authors considered that the general idea behind lighting control is to switch the system settings according to the daylight illuminance level, assuming that it can be measured using ambient light sensors. They concluded that it was 6% energy saving by considering ambient lighting. Another approach was implementing a control system that reduces the minimum levels required by lowering the lighting class due to reduced night-time traffic. In short, a lighting class will be lower during periods of lower traffic intensity than during periods of higher traffic. For example, a lighting class for a road under study could be reduced from ME2 to ME3b and then to ME4a. For the case studies presented, the authors concluded that reducing the lighting class of the road represented an energy saving of 23%.

The concept of Constant Lumen Output (CLO), used by luminaire manufacturers, was also analysed. Its purpose is to compensate for the depreciation of luminous flux at the beginning of the installation's useful life, avoiding excess lighting. It is a matter of increasing the initial power at installation to account for a slight depreciation in the absence of remote management. No in-depth analysis of this concept has been carried out.

The other paper selected is "Concurrent Lighting System on Roads in Practice" by Sławomir Zalewski. It consists of an analysis of the public lighting control in Bożena Street in Poznań, a street with a length of 1300 metres, where 56 LED luminaires with an electrical power of 73W each are installed. It is a straight street of local importance. Traffic on it can be described as small or very small. A small number of houses are set back from the road.

Consumption was monitored over one year, considering three scenarios:

- constant power;
- with a 50% constant power;
- a concurrent lighting system.

Concurrent lighting system entails the gradual illumination of subsequent luminaires, whose proper operation is crucial for both motorist's and pedestrians' viewing processes, and the gradual dimming or extinguishing of those luminaires when their light output is no longer required [47].

The main conclusions were that the introduction of limitations of power in the middle of the night reduces energy consumption by 22,4%, compared to constant nominal power; the operation with the concurrent lighting reduces 87,2%, compared to constant nominal power and 83,6% as compared to working with the middle-night reduction.

It also concluded that the lighting level reduction of class ME 3 to ME 6 can give up to 70% savings, and the reduction of class ME 5 to ME 6 can give no more than 40% savings.

Still, about lighting control, we highlighted the option taken by some municipalities in Portugal to implement reductions in luminous flux, but without analysing the resulting levels. A widely used system is to reduce it to 50% for 4 hours. Another is the "Dimregime Functionality 27" (DDF27), designed by the manufacturer Philips [48], as a reference. This system has three levels of regulation. From 11 pm to 1 am it reduces to 75% and from 1 am to turn on again it reduces to 50%. Represents an energy saving of 23%.

The subject of wireless communications for public lighting was discussed, and it was emphasised that it is customary to use a Low Power Wide Area (LPWA), a category of wireless networks specifically designed for the IoT. Two technologies were compared, namely NB-IoT and LoRaWAN. It was concluded that the best option is NB-IoT if a point-to-point communication system is required, with several pieces of data to be transmitted bilaterally and securely.

To analyse the results of a street or a park and garden in the DIALux software and analyse the results, we briefly explained the sequence of steps to be taken and the information we need to know about the street lighting project. Later, using the same software, by changing the luminaires, their electrical power and their photometry, we can optimise the final solution to be implemented from an energy efficiency point of view.

5 CASE STUDY – QUINTA DE S. JERÓNIMO

This chapter explains the methodology we used for the proof of concept (pilot) in a residential area, specifically the Quinta de S. Jerónimo urbanisation. We will describe the street lighting system’s physical characteristics. Various tests will reduce the luminous flux and evaluate the proportionality between electricity use and luminance/illuminance. Residents were contacted to get their thoughts on how they perceived the decrease in luminous flux. This area was chosen because it allows for the development of multi-valence studies. It has motorised vehicle routes connecting other areas, motorised vehicle routes for local access, and a large garden area with only pedestrian traffic.

5.1 Location and physical characteristics

The study area is inserted in a subdivision commonly known as Quinta de São Jerónimo. It is a noble city area belonging to the Olivais Parish Council. The streets to be studied are in the public domain. The streets included in the study are Edmundo Bettencourt, Mestre Acácio, Raposo Marques, and José Santos Bessa.

Figure 5.1 shows the study area.



Figure 5.1: Location of the study area [49]

The subdivision is in a high area of the city, and at road level, it can be accessed by two main roads, namely Avenida António Portugal (collector road network) and Avenida Dias da Silva. At the pedestrian level, it connects two large areas of the city, Solum and Celas. However, the difference in elevations is very significant, and there are many stairs, so it is not considered a commonly used option for all pedestrians at the crossing level. In the central area, there is a green zone of significant area. It has a lake of considerable size and a support building which is unoccupied. It has two swimming pools (for children and adults) and a building that serves as a restaurant, both of which are under a concession from the municipality of Coimbra. There is an amphitheatre with concrete benches, which are used for music shows in the summer.

The Edmundo Bettencourt Street is very long, so we will present it in the following sets of photographs, Figure 5.2 and Figure 5.3.



Figure 5.2: Edmundo Bettencourt Street I



Figure 5.3: Edmundo Bettencourt Street II

The Raposo Marques Street looks the way the Figure 5.4 documents. The José Santos Bessa Street has two different road profiles, as well as the respective lighting solutions, as we can see in Figure 5.5.



Figure 5.4: Raposo Marques



Figure 5.5: José Santos Bessa Street

There is a public swimming pool, a support building with a restaurant, a cafeteria, an emergency room, changing rooms and toilets. Several footpaths and an overpass link two opposite pedestrian areas over a vast lake with water from the existing mines. The water in the lake is very murky and unsuitable for bathers to use for water fun. The garden has a large lawn area, many planted trees, some large, and various shrubs and other plants.

The Mestre Acácio Street has as a lighting solution only columns of 4 meters with luminaires of the globe type, installed mostly in quincunx, as seen in Figure 5.6. Some green spaces and pedestrian zones are shown in Figure 5.7 and Figure 5.8.



Figure 5.6: Mestre Acácio Street



Figure 5.7: Green spaces and pedestrian zones I



Figure 5.8: Green spaces and pedestrian zones II

5.2 Luminaires Installed

The pilot consists of 170 luminaires, 124 globe-type units in pedestrian zones mounted on 4-metre metal poles, and 46 units installed in light roadway areas mounted on 10-metre metal poles.

The luminaires installed in the garden (mostly) are of the "Bolle" type, from the manufacturer "Schröder" [38], which consumes 35W and emits a luminous flux of 4354lm. The colour temperature is 3000K, CRI is 70. The luminaires installed to illuminate the road areas are of the "ARGUS 220" type from the "Arquiled" manufacturer. It consumes 96,3W and emits a luminous flux of 14062lm. The temperature colour is 4000K, CRI is 70. All of them have a point-to-point communication module. The communication will be done through a wireless network, specifically the Zigbee protocol. The georeferenced luminaires can be seen in Figure 5.9:



Figure 5.9: Geolocation of the luminaires

The different colours identify groups of luminaires that are all electrically connected to the same transformer substation.

5.3 Public lighting network

The electrical circuits that feed the 170 luminaires are from the public lighting network, which comes from three transformer substations. and they are energised 24 hours a day.

Before the luminaires were replaced with LED technology, other luminaires equipped with 150W (10 metres poles) and 100W (4 metres poles) high-pressure sodium vapour lamps were installed.

The distribution of the luminaires per transformer station is as follows (5.1):

Delivery Point Code	PT0002000088313187WK	PT0002000078848939YC	PT0002000078849671SQ
GIS reference	0603D2066200	0603D2066300	0603D2066400
Garden luminaires	21	62	41
Road luminaires	17	24	5
TOTAL	38	86	46

Table 5.1: Number of luminaires per transformer substation [8]

The three transformer stations are installed at the locations identified in 5.10:



Figure 5.10: Geolocation of transformer substation

It is possible to see the access to the transformer stations in 5.11:



Figure 5.11: Access of the TS a) 662; b) 663; c) 664

Inside the transformer stations are installed their general low voltage panel, as shown in Figure 5.12, which contains a meter to measure the consumption of public lighting and another that is a totaliser, as it also measures the low voltage electricity consumption that supplies the houses.



Figure 5.12: General low voltage panel a) 662; b) 663; c) 664

5.3.1 Energy Consumption

The difference in electricity consumption before and after replacing the luminaires will be presented. The following information was obtained for each transformer substation using the E-Redes platform [8] to compare consumption (kWh) in the first quarters of 2022 and 2023. The luminaires were replaced in June 2022.

Table 5.2 shows data from transformer substation PT0002000078848939YC:

kWh	january	february	march
2022	7578,54	6225,27	6098,78
2023	3310,20	2854,11	3050,84
Reduction	56,32%	54,15%	49,98%

Table 5.2: Data from PT0002000078848939YC [8]

The average monthly consumption of public lighting in this TS was around 6.500kWh. Its variation is minimal. The same values are presented in the graph of Figure 5.13:

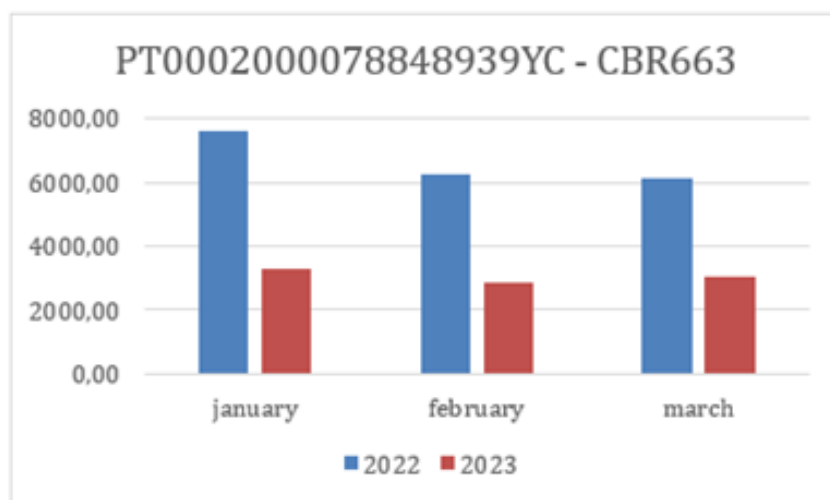


Figure 5.13: Comparison of PT0002000078848939YC data

We can conclude that the reduction in consumption resulting from replacing luminaires fitted with high-pressure sodium vapour lamps with LEDs is at least 50%

Table 5.3 shows data from transformer substation PT0002000078849671SQ:

kWh	january	february	march
2022	17772,42	15329,44	15146,12
2023	8360,47	7040,04	6835,62
Reduction	52,96%	54,07%	54,87%

Table 5.3: Data from PT0002000078849671SQ [8]

The average monthly consumption of public lighting in this TS was around 16.000kWh. Its variation is minimal.

The same values are presented in the graph of Figure 5.14:

We can conclude that the reduction in consumption resulting from replacing luminaires fitted with high-pressure sodium vapour lamps with LEDs is at least 54,07%

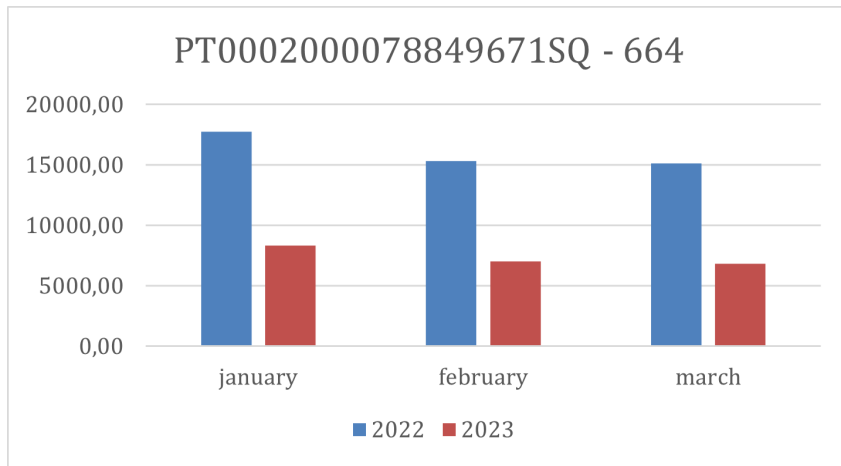


Figure 5.14: Comparison of PT0002000078849671SQ data

kWh	january	february	march
2022	8970,03	7646,01	7782,88
2023	4481,32	3782,58	3804,28
Reduction	50,04%	50,53%	51,12%

Table 5.4: Data from PT0002000088313187WK

Table 5.4 shows data from transformer substation PT0002000088313187WK:

The average monthly consumption of public lighting in this TS was around 8.100kWh. Its variation is minimal.

The same values are presented in the graph of Figure The same values are presented in the graph of Figure 5.15:

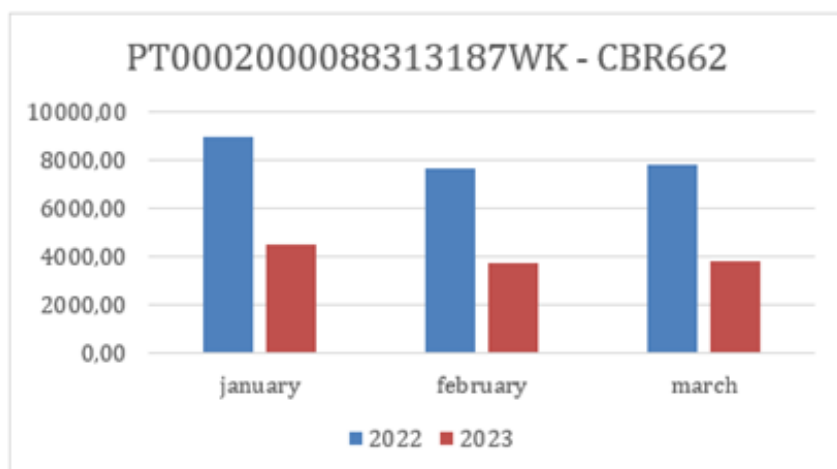


Figure 5.15: Comparison of PT0002000088313187WK data

We can conclude that the reduction in consumption resulting from the replacement of luminaires fitted with high-pressure sodium vapour lamps (HPS) with LEDs is at least 50%, not only because of the technology change but also because the consumption associated with the electromagnetic ballasts (HPS) is around 20% of the lamps' power.

5.4 Classification of the study zones

As stated in Subsection 4.3.1, class M is intended for roads for motorised traffic, such as motorways, roads peripheral to urban fabrics, access roads, secondary roads, single-track municipal roads, and roads within the urban perimeter with mixed traffic, where pedestrians, non-motorised, and motorised vehicles interact, but with a predominance of motorised vehicles and class C for conflict zones, which occur when motorways intersect or end in areas frequented by pedestrians, cyclists or other users, for example: junctions; roundabouts; changes to the geometry of the road, resulting in a reduction in the number or width of lanes; black spots/places with a high accident rate [24, 26].

As we consider the road geometry very uniform, as there are no roundabouts, and we believe that the junctions have good visibility and do not cause accidents, we have classified the roads in classes M, using the principles given in point 4.3 Requirements for motorised traffic. These classes include motorised traffic roads, including highways, access roads, minor roads, municipal roads, single-lane roads, and mixed-traffic urban areas where pedestrians, non-motorised, and motorised vehicles converge, but motorised vehicles are the majority.

The main lighting criteria for these classes are based on the luminance of the road surface and include average luminance, overall uniformity, and longitudinal uniformity for the dry road surface condition. Additional criteria relate to disability glare, quantified by the threshold rise TI, and the illumination of surrounding areas, quantified by the edge illuminance ratio EIR. An additional criterion used in some countries is the overall uniformity of luminance in wet conditions.

By analysing the road structure, it is possible to verify that there is a street that serves as a connection between two large areas, the Edmundo Bettencourt, and the others are for local access to the residents and are mostly dead-end streets. Furthermore, except for two small street sections, the lighting designer considered 10-meter columns and roadway-type luminaires for Edmundo Bettencourt Street and 4-meter columns and globe-type luminaires for the others. For this reason, we will consider two classes of lighting, whose difference will be in the traffic volume and ambient luminance.

Edmundo Bettencourt Street has two distinct street profiles: with and without parking. It does not make sense that the same street has two distinct lighting levels, so we will consider the option that imposes a higher lighting level. For the classification of this street, we consider the carriageway design speed to be between 0 and 70 km/h;

the traffic volume is between 4.000 and 15.000 per day, and the ambient luminance is moderate.

With these considerations, we obtain Table 5.5::

Parameter	Options	Weighting Value	Weighting Value
Design speed	Very high	1	0
	High	0,5	
	Moderate or low	0	
Traffic volume	Very high	1	-0,5
	High	0,5	
	Moderate	0	
	Low	-0,5	
	Very low	-1	
Traffic composition	Mixed with high percentage of non-motorized	2	1
	Mixed	1	
	Motorized only	0	
Separation of carriageway	No	1	1
	Yes	0	
Junction density	High	1	0
	Moderate	0	
Parked vehides	Present	1	1
	Not present	0	
Ambient luminance	High	1	0
	Moderate	0	
	Low	-1	
Navigation task	Very difficult	0,5	0,5
	Easy	0	

Table 5.5: Clearance of class M - Edmundo Bettencourt Street [24, 26]

Adding all the values indicated in the parameter "Weighting Value", the value is equal to 3, so by subtracting six from this value, we get a class M3. Next, let us take a look at Table 4.2 - M lighting classes. In this table, we can see the relative minimum values of the luminance of the road surface and include average luminance, overall uniformity, and longitudinal uniformity for the dry road surface condition. Additional criteria relate to disability glare, quantified by the threshold rise TI, and the illumination of surrounding areas, quantified by the edge illuminance ratio EIR.

The minimum values of the class M3 are:

- Luminance (L) – 1,0 cd/m²;
- Overall Uniformity of Road Luminance (U_o) – 0,40
- Longitudinal uniformity (of road surface luminance of a carriageway) (U₁) – 0,60;
- Threshold increment TI (of an object at the road surface) (fTI) – 15;
- Edge illuminance ratio EIR (of illumination of a strip adjacent to the carriageway of a road) (REI) – 0,30. For the other streets, we consider the carriageway's design

speed to be between 0 and 70 kW/h; the traffic volume is less than 4.000 per day, and the ambient luminance is low. With these considerations, we obtain the Table 5.6:

Parameter	Options	Weighting Value	Weighting Value
Design speed	Very high	1	0
	High	0,5	
	Moderate or low	0	
Traffic volume	Very high	1	-1
	High	0,5	
	Moderate	0	
	Low	-0,5	
	Very low	-1	
Traffic composition	Mixed with high percentage of non-motorized	2	1
	Mixed	1	
	Motorized only	0	
Separation of carriageway	No	1	1
	Yes	0	
Junction density	High	1	0
	Moderate	0	
Parked vehicles	Present	1	1
	Not present	0	
Ambient luminance	High	1	-1
	Moderate	0	
	Low	-1	
Navigation task	Very difficult	0,5	0,5
	Easy	0	

Table 5.6: Clearance of class M – Other Streets [24, 26]

Adding all the values indicated in the parameter "Weighting Value", the value equals 1,5, so by subtracting six from this value, we get a class M4,5. For security reasons, we select the class M4 whose minimum values, according to Table 5.6 - M lighting classes, are:

- Luminance (L) – 0,75 cd/m²;
- Overall Uniformity of Road Luminance (U_o) – 0,40
- Longitudinal uniformity (of road surface luminance of a carriageway) (U₁) – 0,60;
- Threshold increment TI (of an object at the road surface) (fTI) – 15;
- Edge illuminance ratio EIR (of illumination of a strip adjacent to the carriageway of a road) (REI) – 0,30.

We must consider two kinds of classification for the pedestrian lanes: inside the gardens with no motorised traffic, pedestrians only, and pedestrian walkways bordering the carriageways.

Now we will classify the pedestrian lanes inside the gardens by the method explained in Subsection 4.3.2 Requirements for non-motorised traffic, which defines the P classes

that are intended for all roads where the average speed of moving motor vehicles is less than 50 km/h, as well as for pedestrian and cycle lanes with mixed traffic that are primarily made up of pedestrians and non-motorised vehicles. Examples include bike lanes or promenades; parks and gardens; well-defined residential neighbourhoods or areas with almost exclusive traffic, cul-de-sacs, and clearly defined residential area exits; historic areas with roads reserved for pedestrians only or restricted access for motorised traffic.

Assigning the respective weights to the parameters, we obtain the Table 5.7:

Parameter	Options	Weighting Value	Weighting Value
Design speed	Low	1	0
	Very low (walking speed)	0	
Use intensity	Very high	1	0,5
	High	0,5	
	Moderate	0	
	Low	-0,5	
	Very low	-1	
Traffic composition	Pedestrians, cyclists and motorized traffic tráfego motorizado	2	0
	Pedestrians and motorized traffic	1	
	Pedestrians and cyclists only	1	
	Pedestrians only	0	
	Cyclists only	0	
Parked vehicles	Present	1	0
	Not present	0	
Ambient luminance	High	1	0
	Moderate	0	
	Low	-1	
Facial recognition	Necessary	0,5	0,5
	Not necessary	0	

Table 5.7: Clearance of class P – pedestrian lanes inside the gardens [24, 26]

Adding all the values indicated in the parameter "Weighting Value", the value is equal to 1. By subtracting six from this value, we get a class P5, whose minimum values, according to the Table 5.7 – P lighting classes. In this table, we can see the relative minimum values of the illuminance, horizontal and facial recognition, if necessary.

The minimum values of the class P5 are:

- Illuminance minimum maintained (E_a) – 3 lux;
- Illuminance maintained (E_{min}) – 0,6 lux;
- Illuminance maintained facial recognition ($E_{v,min}$) – 1 lux;
- Illuminance maintained facial recognition ($E_{sc,min}$) – 0,6 lux.

Now, we will classify the pedestrian walkways bordering the carriageways, again using the method explained in 4.4 Requirements for non-motorised traffic.

Assigning the respective weights to the parameters, we obtain the Table 5.8:

Parameter	Options	Weighting Value	Weighting Value
Design speed	Low	1	0
	Very low (walking speed)	0	
Use intensity	Very high	1	0,5
	High	0,5	
	Moderate	0	
	Low	-0,5	
	Very low	-1	
Traffic composition	Pedestrians, cyclists and motorized traffic tráfego motorizado	2	1
	Pedestrians and motorized traffic	1	
	Pedestrians and cyclists only	1	
	Pedestrians only	0	
	Cyclists only	0	
Parked vehicles	Present	1	1
	Not present	0	
Ambient luminance	High	1	0
	Moderate	0	
	Low	-1	
Facial recognition	Necessary	0,5	0,5
	Not necessary	0	

Table 5.8: Clearance of class P – pedestrian walkways [24, 26]

Adding all the values indicated in the parameter "Weighting Value", the value is equal to 3, so by subtracting six from this value, we get a class P3 whose minimum values, according to Table 5.7 – P lighting classes, are:

- Illuminance minimum maintained (E_a) – 7,5 lux;
- Illuminance maintained (E_{min}) – 1,5 lux;
- Illuminance maintained facial recognition ($E_{v,min}$) – 2,5 lux;
- Illuminance maintained facial recognition ($E_{sc,min}$) – 1,5 lux.

5.5 Tests and measurements

As mentioned in Section 1.2 Methodologies, which defines the methodology used to prepare this work, one of the objectives of this thesis is to measure luminotechnical levels using a lux meter to compare with the values obtained by using the "Dialux software" [3]. However, as explained in Section 4.2 Calculation of photometric quantities, which uses the EN 13201-3:2003 "Road lighting - Part 3: Calculation of performance", to identify methodologies for measuring luminance and illuminance, the task is not so simple, mainly because of the difficulty in providing the appropriate measuring equipment.

In the first instance, for class M, the minimum values indicated in the standards are luminances. We did not have any luminance meter available. Even if we did, the data collection method has many variables to consider, particularly the weather.

Closing the streets to take these measurements is necessary, something unthinkable in a residential area.

The lux meter available is not calibrated, so the readings we took cannot be considered valid, not least because they are very different from the expected values. The lux meter is of the brand "BK Precision 615" [50].

Various tests were carried out in the area to work on the data. It was not always possible to keep to the programme, timetable and predefined activities due to some logistical failures, which will be explained later. However, the tests' results and analysis are in the following sections.

The streets studied were José Santos Bessa, Edmundo Bettencourt, Mestre Acácio, and Raposo Marques 5.16:



Figure 5.16: Streets studied [49]

For taking readings of energy consumption, voltage, frequency and other electrical quantities, ISEC has provided three three-phase power quality analysers, of the brand "Chauvin Arnoux 8332" [51].

To access the measurements, it is necessary to install the specific software, and the values are provided through an Excel file (Figure 5.17).



Figure 5.17: Analyser data collection

Power analysers must be connected to the low-voltage switchboard of the TS. They have a set of cables to connect both the clamp meters, in series with the circuits for measuring electric current, and the clamps for measuring voltages, whose cables are connected in parallel to the respective busbar.

Only E-Redes employees or their contractors can access the interior of the TS.

Figure 5.18: shows E-Redes staff connecting a power analyser. Programming is done in advance in the office.



Figure 5.18: Installation of the energy analyser in TS

In order to collect the illuminance values, the company "Signify" provided a structure called "LX-GPS - Vehicle Mounted GPS Illuminance Measurement System" of the brand "AFEISA" [52] which was installed in a Coimbra City Hall vehicle, so that all the streets to be studied could be visited, as shown in Figure 5.19.



Figure 5.19: LX-GPS installed in a vehicle

Each of the three devices shown in Figure 5.20 is a lux meter with an integrated GPS sensor:

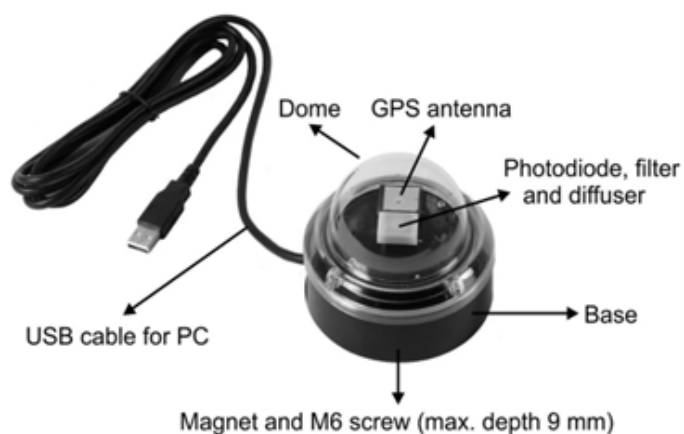


Figure 5.20: Lux meter sensor with integrated GPS

As with the power analysers, specific software must be installed to collect data from the LX-GPS (Figure 5.21). The data are provided in files of various extensions, but we have chosen to work with the "CSV" extension.

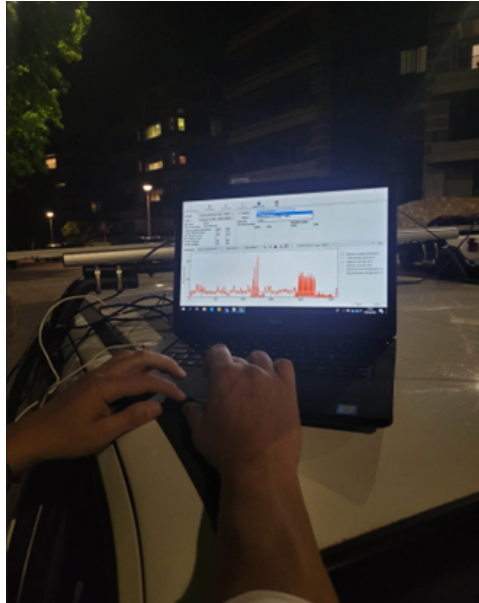


Figure 5.21: LX-GPS data collection [52]

5.5.1 Tests and measurements – April 20, 2023

Several tests were scheduled for April 20th, imposing light flux reductions of 75%, 50% and 25% to measure consumption/voltage and other effects on the electrical network, using energy analysers installed in the three TS. The intention was also to measure the illuminance of the streets using a luxmeter sensor (photodiode) with integrated GPS, as shown in Figure 5.19.

On April 17, the residents association was advised that flow regulation trials would occur on April 20. The media was also alerted, and several news items were published on the subject:

- Mundial FM

<https://mundialfm.sapo.pt/camara-de-coimbra-testa-solucoes-eficientes-de-iluminacao-na-quinta-de-s-jeronimo/> Publication in the magazine Smart Cities: <https://smart-cities.pt/scn-municipios/coimbra-2023-2-2/> (see Appendix E);

- Notícias de Coimbra

<https://www.noticiasdecoimbra.pt/coimbra-testa-solucoes-eficientes-de-iluminacao-na-quinta-de-s-jeronimo/> (see Appendix F);

- Município de Coimbra

<https://www.coimbra.pt/2023/04/cm-de-coimbra-testa-solucoes-eficientes-de-iluminacao-na-quinta-de-s-jeronimo/> (see Appendix G).

After taking the readings, it is intended to analyse all the data collected and compare them with the values measured by the E-Redes smart meters installed in the TS, collected from the respective platform, to understand the effect of these variations on the

energy costs reflected in the bill. Although not all luminaires communicated correctly, and only one power analyser was available, it was decided to maintain the work program because all the logistics had already been organised. For the night of April 20th, E-Redes was asked to implement the flow regulations presented in Table 5.9:

Time	Regulation
20:50	Set for 75%
21:22	Set for 50%
22:01	Set for 25%

Table 5.9: Regulation on 20 Abril

The start of each journey to measure the illuminances obtained in each setting was always made at the same location, in José dos Santos Bessa Street, the point identified in Figure 5.22:



Figure 5.22: Starting point of the journeys

The route started at José Santos Bessa Street, then turned right onto Edmundo Bettencourt Street, followed by Mestre Acácio Street (round trip), and then turned right onto Edmundo Bettencourt towards Francisco Sá Carneiro Street. Then we travelled the whole of Edmundo Bettencourt Street, turned left onto Raposo Marques Street, and at the end of the street, we turned right until the end of José Santos Bessa Street and returned to the starting point. It is a total of over 2500 metres covered in each setting.

After the tests, "LX-GPS" files of extension shape (shp) were imported to "ArcGIS Pro" [53]. Applying the heatmap aspect, the results are shown in Figure 5.25 (no regulation 100%), Figure 5.26 (75% regulation), Figure 5.27 (50% regulation), and Figure 5.28 (25% regulation).

The luxmeter is not calibrated, so the concern was to analyse the difference between the four configurations. The car will be driving on the road network and the standards give minimum luminance values, not illuminance values, as these are type M road classes. The colour symbology used is shown in Figure 5.23:

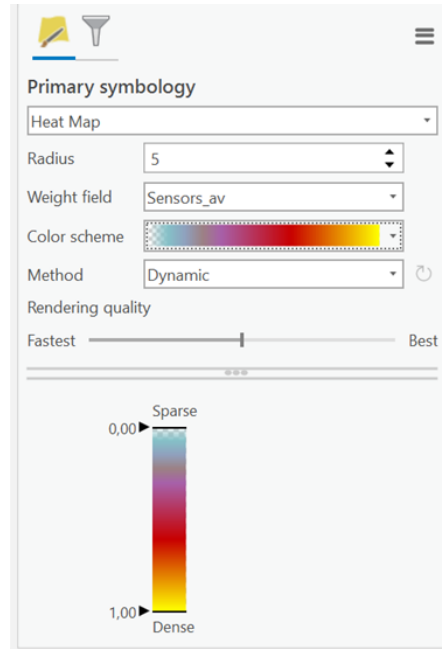


Figure 5.23: Symbology used for the heatmap [53]

From the colour scale, blue represents the lowest levels, closed to zero, and yellow the highest. With the luminaires working without dimming, it can be observed in Figure 5.24 that most streets have good lighting levels and uniformity, except the Mestre Acácio Street, where the uniformity is not the best, and there is a small area on José dos Santos Bessa Street where the lighting levels are lower than on the other streets.



Figure 5.24: Heat map with no regulation (100%) [53]

With the luminaires operating at 75% of the nominal flux, it can be observed in Figure 5.25 that the uniformity and the illuminance levels are good in most streets, with the observation that in a small area of José Bettencourt Street and José Raposo Marques Street, the illuminance levels are lower than in the rest of the streets.



Figure 5.25: Heat map with 75% regulation [53]

With the luminaires operating at 50% of the nominal flux, it can be observed in Figure 5.26 that the conditions are identical to the 75% setting. All in all, the uniformity has worsened a little.



Figure 5.26: Heat map with 50% regulation [53]

With the luminaires operating at 25% of the nominal flux, it can be observed in Figure 5.27 that the levels are pretty low overall. However, the uniformity is reasonable, which is to be expected.

Some areas have higher lighting levels because pedestrian routes are close to the road, where globe-type luminaires are installed on 4-metre columns.



Figure 5.27: Heat map with 25% regulation [53]

Through the "LX-GPS" software, we compared the results obtained without dimming (100%) and with regulation at 50% of its nominal flow to assess whether the values obtained have the same linearity as the parameterised.

The graphical mode comparison and the vehicle's distance travelled can be seen in Figure 5.28.

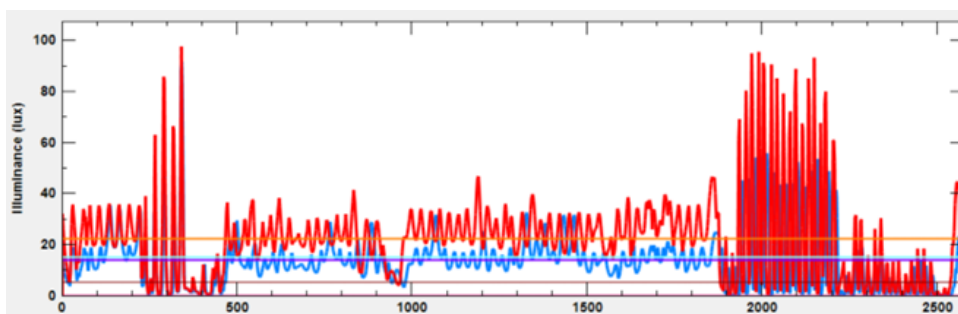


Figure 5.28: Comparison April 20 (100%) & April 20 (50%) [52]

Analysing the average illuminance, it is observed that the regulation at 50%, the values are slightly higher than expected, concluding that the parameterisation/result relationship is not linear, Figure 5.29.

It should be clarified that although it is mentioned that the analysis is with the "Right Sensor Illuminance (lux)", it is an error caused by how the lux meters are connected, as it is the middle sensor aligned with the centre of the car.

<u>Right Sensor Illuminance</u>	<u>Partial</u>	<u>Total</u>	<u>Partial</u>	<u>Total</u>
Average Illuminance (lux):	22.2	22.2	13.7	13.7
Max. Illuminance (lux):	97.7	97.7	91.7	91.7
Min. Illuminance (lux):	0.1	0.1	0	0
Average uniformity:	0.00	0.00	0.00	0.00
Extreme uniformity:	0.00	0.00	0.00	0.00

Figure 5.29: Comparison April 20 (100%) & April 20 (50%) – average illuminance [52]

The same analysis was carried out for the ratio between the regulation for 50% of the nominal flow rate and for 25%, and the following data was obtained in Figure 5.30 and Figure 5.31:

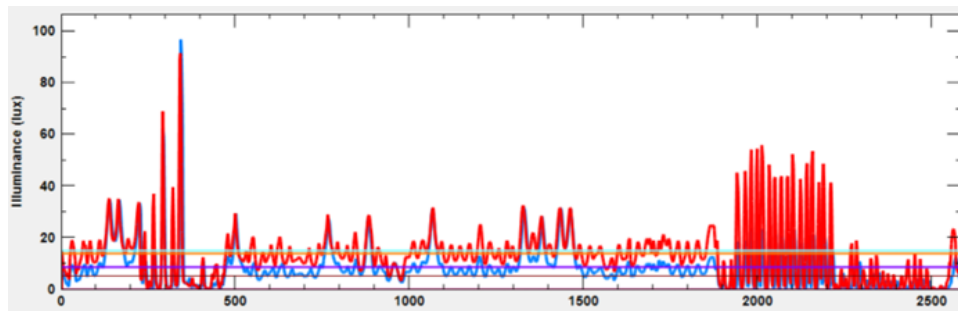


Figure 5.30: Comparison April 20 (50%) & April 20 (25%) [52]

<u>Right Sensor Illuminance</u>	<u>Partial</u>	<u>Total</u>	<u>Partial</u>	<u>Total</u>
Average Illuminance (lux):	13.7	13.7	8.4	8.4
Max. Illuminance (lux):	91.7	91.7	97	97
Min. Illuminance (lux):	0	0	0	0
Average uniformity:	0.00	0.00	0.00	0.00
Extreme uniformity:	0.00	0.00	0.00	0.00

Figure 5.31: Comparison April 20 (50%) & April 20 (25%) – average illuminance [52]

The conclusions were that the parameterisation/result relationship is not linear.

As mentioned above, although it is mentioned that the analysis is with the "Right Sensor Illuminance (lux)", as it is the middle sensor that is aligned with the centre of the car.

Later, we went to analyse the consumption data obtained by the only analyser installed in the TS CBR664, and the following results were obtained, Figure 5.32:

By analysing the graph, we can draw the following conclusions:

- Reductions in luminous flux were made on day 20;
- The reduction values do not correspond to those expected;

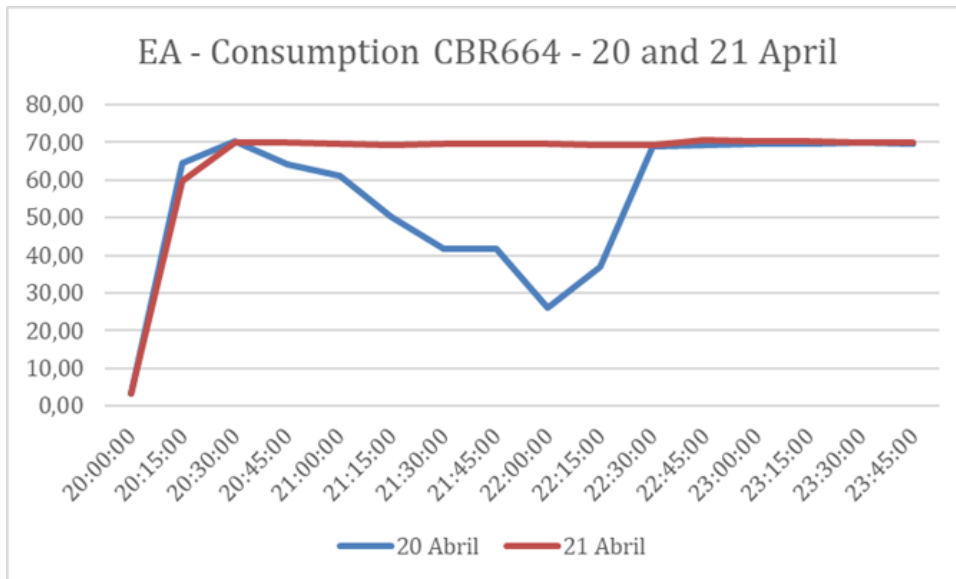


Figure 5.32: Data from EA – CBR664 [51]

- The consumption values are incorrect, even though dimming has occurred. It is assumed that there is some fault in the EA.

As mentioned above, the aim is to assess whether the flow regulations translate into a reduction in the amount payable on the electricity bill, so the data from the E-Redes platform of the three TS was exported, and the following graph, Figure 5.33, was constructed with them:

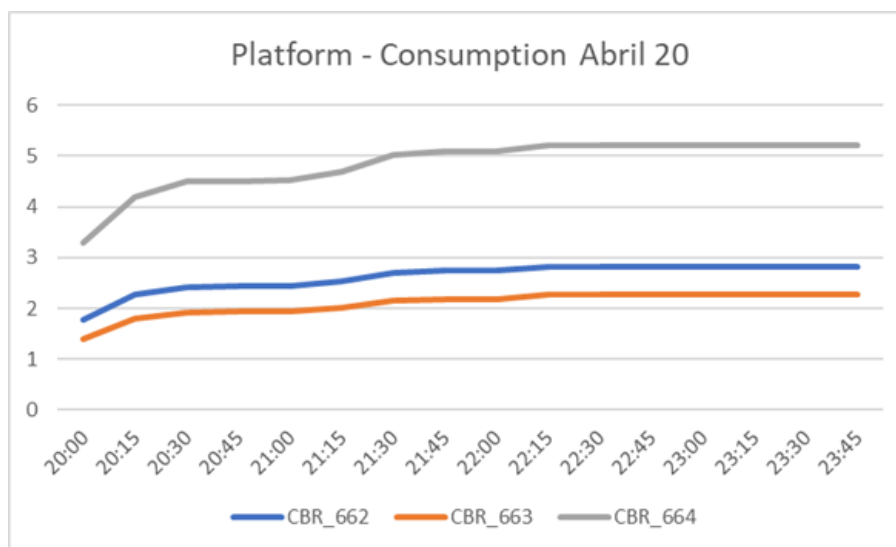


Figure 5.33: Consumption of the 3 TS on the 20th of April [51]

We can see that the dimming has not been reflected in the invoice value, which was unexpected.

5.5.2 Tests and measurements – June 23, 2023

There were several failures in the tests on 20 April. Namely, luminaires that were not communicating, the existence of a single energy analyser, and the regulations applied were not those intended; it was decided to make another campaign of tests.

To dispel doubts about the possibility that the white cover of the vehicle could misrepresent the values of the readings because of the reflections, it was decided to put a film of dark colour and measure the illuminance values again, as shown in Figure 5.34.

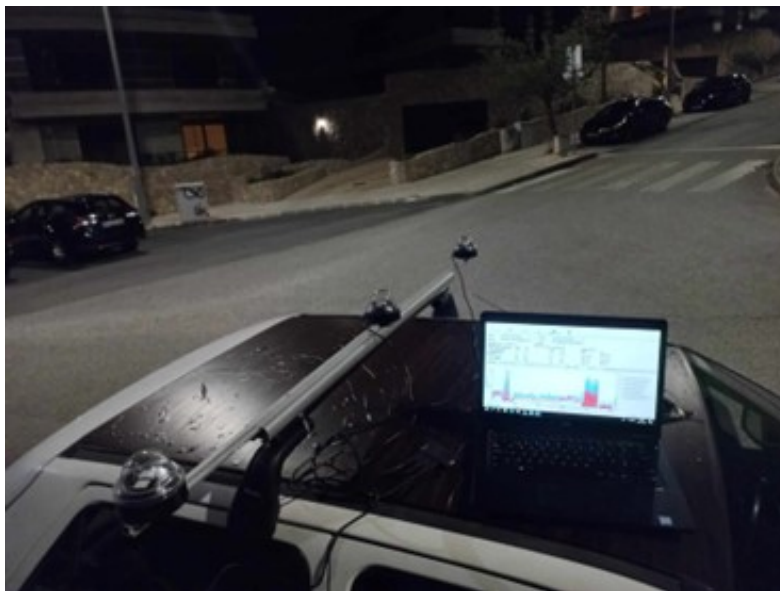


Figure 5.34: LX-GPS installed in the vehicle dark colour cover

The same luminous flux variations already done on 20 April were scheduled, with more readings, including for the rest of the weekend. The action plan was as follows:

- Pre-schedule the flow adjustments for 23, 24 and 25 June;
- Pre-install the energy analysers in the three TS;
- Measure consumption on 23 June directly at the general low voltage switchboards, using clamp meters used by an E-Redes employee in each of the three TS;
- Collect illuminance data with the LX-GPS-equipped vehicle;
- Analyse the data.

The residents' association and Media were notified by email that the tests would take place on 23 June. The media was also alerted. A questionnaire was prepared through Google (<https://forms.gle/fdNbgLRZkveXwt6S6>) was published in the media so that there is public participation and it is possible for residents and users of the area to give their opinion on the different levels of lighting.

You can consult this news via the following links:

- Município de Coimbra

<https://www.coimbra.pt/2023/06/cm-de-coimbra-prosegue-com-testes-de-solucoes-eficientes-de-iluminacao-na-quinta-de-s-jeronimo/> (see Appendix H)

- Mundial FM

<https://mundialfm.sapo.pt/camara-de-coimbra-prosegue-com-testes-de-solucoes-eficientes-de-iluminacao-na-quinta-de-s-jeronimo/> (see Appendix I)

The following programming, Table 5.10, was used:

Day	Schedule 1	Schedule 2	Level
23/06/2023	21h45	22h00	100%
23/06/2023	22h	22h30	Reduce to 75%
23/06/2023	22h30	23h00	Reduce to 50%
23/06/2023	23h	23h30	Reduce to 25%
24/06/2023 25/06/2023	0h	2h	Reduce to 75%
24/06/2023 25/06/2023	2h	5h	Reduce to 50%
24/06/2023 25/06/2023	5h	7h	Reduce to 25%

Table 5.10: Schedule used for 23, 24 and 25 June

This schedule was programmed on the E-Network platform, as shown in Figure 5.35 - Scheduled time on the E-Redes platform [54]:

PROGRAMA				
Hour		Fluxo %	L7	
Sunset		100	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
22	00	75	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
22	30	50	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
23	00	25	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
23	30	100	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
00	00	75	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
02	00	50	<input type="checkbox"/>	
HH	MM	Fluxo %	L7	
05	00	25	<input type="checkbox"/>	
Sunrise		00	<input type="checkbox"/>	

Figure 5.35: Scheduled time on the E-Redes platform [54]

Using the same methodology as on 20 April, including starting point and route, after the tests, "LX-GPS" files of extension shape (shp) were imported to "ArcGIS Pro" and applied the heatmap aspect.

The results obtained are identical to those of 23/04, so it was proven that the dark cover on the car made no difference. Considering no differences, it was decided not to present the heatmap.

A comparison was made of the levels obtained on the two days through the "LX-GPS" software, and the "no dimming" results are shown in Figure 5.36 - Comparison April 20 & June 23 – 100% [52]:

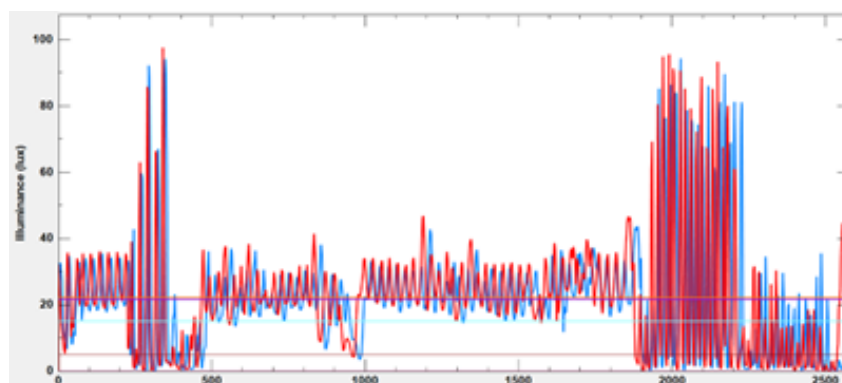


Figure 5.36: Comparison April 20 & June 23 – 100% [52]

Analysing the graph proves what has already been said: the figures are very similar. As we had already done for the results of 20 April, we compared the results obtained without regulation (100%) and with regulation at 50% of its nominal lighting level, Figure 5.37 and Figure 5.38, to assess whether the values obtained have the same linearity concerning the parameterised one.

Presentation of the comparison in graphical mode, along with the distance travelled by the vehicle.

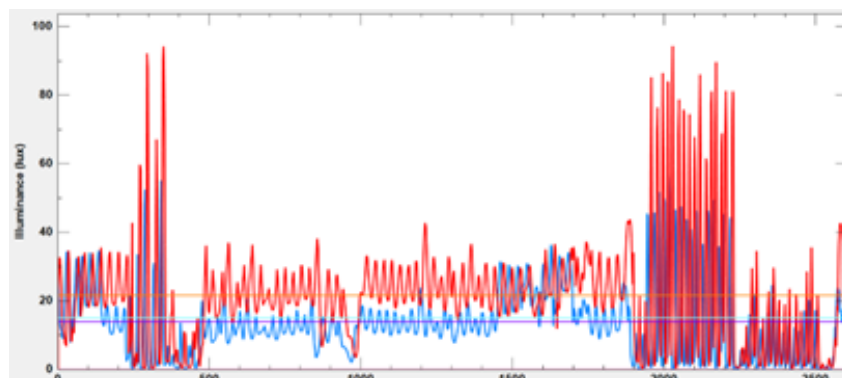


Figure 5.37: Comparison June 23 (100%) & June 23 (50%) [52]

<u>Right Sensor Illuminance</u>	<u>Partial</u>	<u>Total</u>	<u>Partial</u>	<u>Total</u>
Average Illuminance (lux):	21,6	21,6	13,8	13,8
Max. Illuminance (lux):	94,4	94,4	57	57
Min. Illuminance (lux):	0,2	0,2	0	0
Average uniformity:	0,01	0,01	0,00	0,00
Extreme uniformity:	0,00	0,00	0,00	0,00

Figure 5.38: Comparison June 23 (100%) & June 23 (50%) – average illuminance [52]

The analysis led to the same conclusion as in 5.4.1 Tests and measurements – April 20, 2023, that have been imposed light flux reductions of 75%, 50% and 25% and carried out measurements within the TS, it is observed that the regulation at 50%, the values are slightly higher than expected, concluding that the parameterisation/result relationship is not linear.

The same is true for comparing 50% and 25% dimming, where the illuminance values are not linear, and the 25% dimming values are more than half of the 50% dimming values, as shown in Figure 5.39.

It was also possible to verify that there is a set of luminaires to which no dimming was applied because the illuminance values are the same regardless of the dimming. By analysing the graphs, it is possible to ascertain that it happened between 1400 and 1700 metres, corresponding to the upper section of Edmundo Bettencourt Street.

Noticeably, there was no dimming between 1400 and 1700 metres, which may be a communication failure between the platform and the respective luminaires.

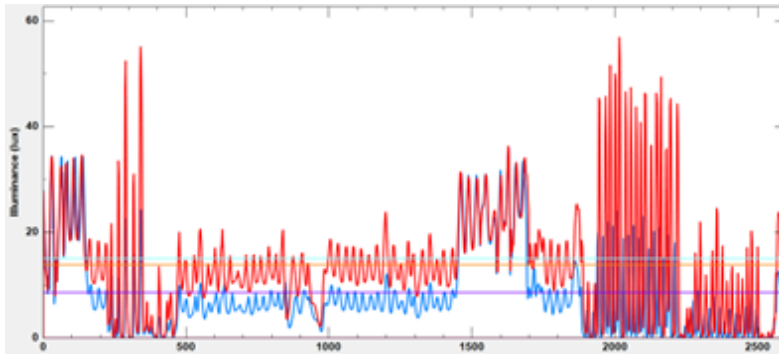


Figure 5.39: Comparison June 23 (50%) & June 23 (25%) [52]

It is emphasised again that although it is mentioned that the analysis is with the "Right Sensor Illuminance (lux)", it is an error caused by how the lux meters are connected, as it is the middle sensor aligned with the centre of the car.

We went to analyse the consumption data obtained by the three analysers installed in the 3 TS, and the following results, Figure 5.40, were obtained:

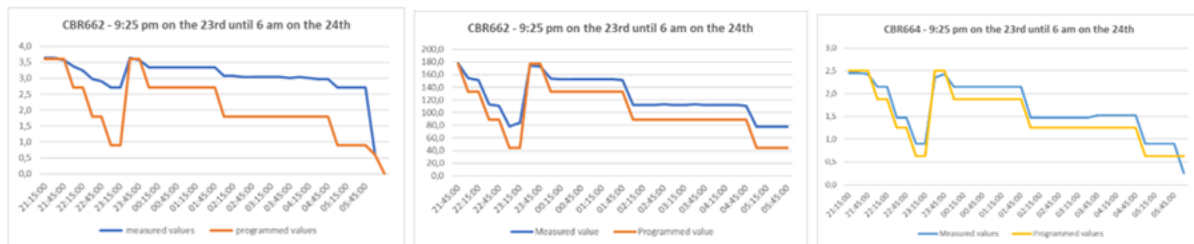


Figure 5.40: Values measured & programmed a) 662; b) 663; c) 664 [51]

Analysing the graphs, the difference between the measured and programmed values is minimal, except CBR662, whose measured have a higher margin of error than the programmed ones.

As already concluded in the analysis of the values measured with the "LX-GPS", in the 50% dimming, the measured values are slightly higher than expected, concluding that the parameterisation/result relationship is not linear. The same applies to the comparison between 50% and 25%.

Electricity consumption was also measured manually in each low-voltage switchboard using the clamp meter by E-Redes employees. The results are shown in the Table 5.11.

Hour	Regulation	Average (A)	Hour	Regulation	Average (A)	Hour	Regulation	Average (A)
21h45	Without	3,27	21h45	Without	6,43	21h45	Without	2,60
22h00	75%	2,97	22h00	75%	5,30	22h00	75%	2,23
22h30	50%	2,63	22h30	50%	3,60	22h30	50%	1,37
23h	25%	2,30	23h	25%	2,23	23h	25%	2,60

Table 5.11: Electric consumption manually measured a) 662; b) 663; c) 664

The value shown in Table 5.11 is the consumption average in the 3 phases (R, S, T).

It is again shown that the parameterisation/output relationship is not linear.

As already done in the previous test, it was confirmed whether the dimming would be reflected in the value of the electricity bills. The graph in Figure 5.41 was constructed by consulting the E-Redes platform, which contains data from the smart meters of the 3 TS.

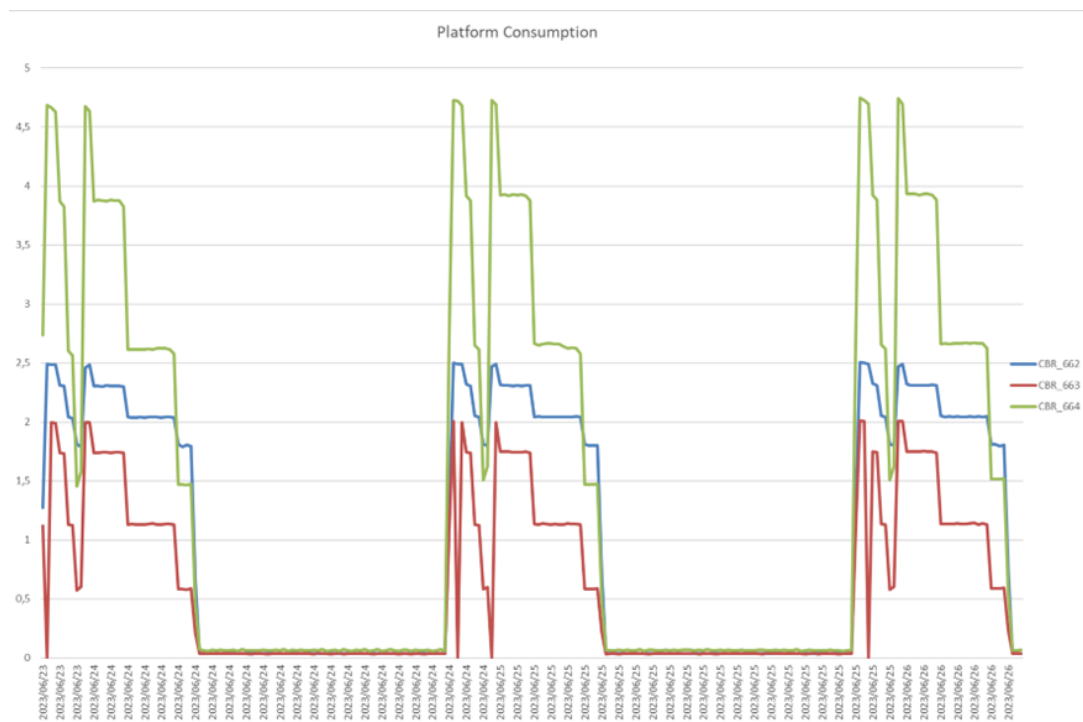


Figure 5.41: Consumption on 23, 24, 25 of June [51]

As can be seen in the curves of the graph, in this test, unlike on 20 April, the programmed values will be reflected in the electricity bill in each of the 3 TS. It was concluded again that the reduction curve is not linear.

When analysing data from Figure 5.41, in TS CBR662, the measured values have a more significant margin of error than the programmed values. As already mentioned, when analysing the illuminance values obtained by "LX-GPS", in the interval between 1400 metres and 1700 metres, no variation in flow was recorded in the luminaires, inferring that this is a communication failure between the platform and the respective luminaires. In this area, the luminaires are electrically powered by TS CBR_662. This is why the programmed dimming and results obtained are not linear; luminaires operate without any dimming, consuming the nominal power.

5.5.3 The green pedestrian areas

It was decided with the supervisor that this could be another thesis about the landscaped areas, but it was also decided to do some analysis, which we report on below. Four metre-high metal columns have been installed, and the light fittings used are the "Bolle" type, which has the technical characteristics presented above.

As presented in Section 5.4 Classification of streets, it is a class of type P that is designed for pedestrian and cycle lanes with mixed traffic that are predominately composed of pedestrians and non-motorised vehicles, as well as for all roadways where the average speed of moving motor vehicles is less than 50 km/h. These areas have been classified as class P5, whose minimum values, according to Table 4.8 – P lighting classes, which defines the minimum illuminance values for this type of class, are:

- Illuminance minimum maintained (E_a) – 3 lux;
- Illuminance maintained (E_{min}) – 0,6 lux;
- Illuminance maintained facial recognition ($E_{v,min}$) – 1 lux;
- Illuminance maintained facial recognition ($E_{sc,min}$) – 0,6 lux.

The entire garden area was loaded into DIALux, and the isolux curves shown in Figure 5.42 were obtained.

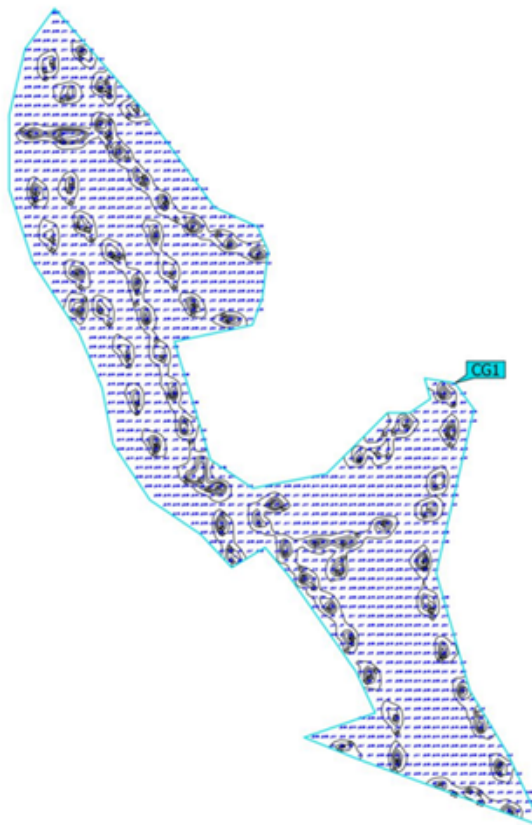


Figure 5.42: Isolux curves of the garden zones [3]

As we can see from the isolux curves, the uniformity is very low.

Figure 5.7 and Figure 5.8 show some photos of the green areas. There are stairs at almost every entrance to these areas, making access difficult for people with reduced mobility. Considering that 4-wheel vehicles cannot access these areas, it will not be possible to use the "LX-GPS". Despite this, and as already mentioned, the light meter that ISEC provided is not calibrated; some manual measurements were made, as shown in Figure 5.43:



Figure 5.43: Manual measurements with light meter [50]

As can be seen in 5.8 Identification of non-conformities, there are poorly positioned columns and planted trees that obstruct the distribution of lighting, which means that the uniformity is very poor. There are areas with illuminance values of practically zero lux, which emphasises that this area needs an in-depth study, as it will even be necessary to change the location of some columns and replace the luminaires.

5.5.4 Questionnaire analysis

As mentioned, a public questionnaire was developed using Google Forms (<https://forms.gle/fdNbgLRZkveXwt6S6>).

Some of the most relevant results are presented.

Question a): *"Do you think the switch to LED lighting has improved the visibility of roads, pavements and gardens at night?"*

Results: The results are shown in Figure 5.44:

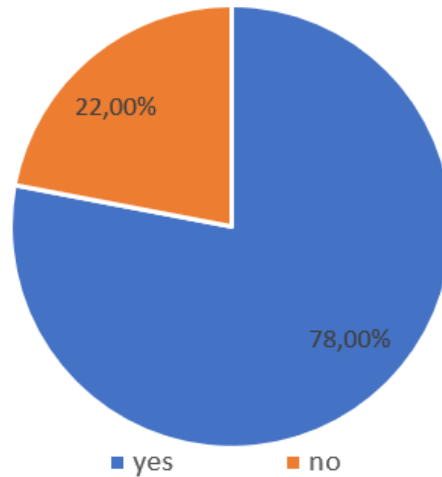


Figure 5.44: Results of question a)

Question b): *“With which of the levels did you feel safer?”*

Results: The results are shown in Figure 5.45:

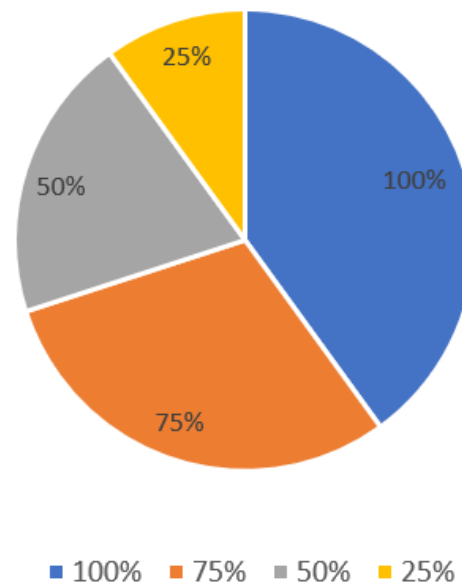


Figure 5.45: Results of question b)

Question c): *“Would you like to comment on this procedure for reducing flows?”*, allowed to develop the answer

Results: the most relevant were:

a) *“When dimming to 25‰, the difference is more noticeable in the small lamps. If you go ahead with the reduction to 50 or 25‰ in one of the night periods, you should ensure that the small lamps (globes) are at least 50‰. There is some discomfort /uncertainty and poor visibility when dimming to 25‰”;*

b) *“50% illumination is sufficient”.*

Question d): *"Are there any negative aspects or issues you would like to highlight about the new LED lighting?"* also allows us to develop the answer.

Results: the most relevant were:

a) *"There are more areas of shadow between the small lamps (globes), especially in front of the building entrances and on one of the staircases and garden paths. Reinforcing the placement of more globes would be ideal."*

b) *"Although the lighting is of better quality, it is noticeable that it is only effective in a small diameter (about 2-3 metres) around the lamp, at more than 4 metres there is no lighting capacity, which was previously the case with the yellow light. With this white light, it will be necessary to install more lamps with less distance between them."*

c) *"Increase the number of globes on the steps leading to the garden and in some areas within the garden (e.g. lake area and amphitheatre) and at some building entrances."*

d) *"Rua Dr José Santos Bessa is quite small compared to the other streets of Quinta São Jerónimo."*

We can summarise residents' views in a few main points. A large majority consider that visibility conditions have improved with LED lighting. However, they consider that the "BOLLE" luminaires do not illuminate well, and there is also mention of those installed in the gardens, with some asking for more luminaires.

Regarding the variations in luminous flux, the majority prefer no reduction, but one comment mentioned that the levels with the reduction to 50% are sufficient.

5.6 Pedestrian crossings

Based on what has already been mentioned in 4.4 Lighting pedestrian crossings, the EN13201 standard does not specify anything about the lighting of pedestrian crossings. However, it was decided to study this component for reasons of pedestrian safety.

A simulation of the technical solution and cost estimate was conducted to provide lighting for the pedestrian crossing on Mestre Acácio Street.

Considering that there is already a lighting column next to the pedestrian crossing, the following is required:

1. Replace the luminaire with another, namely "NEOS 2 LED 48@500mA 74W" (Pedestrian crossing photometry), from "Schröder" [38];
2. Fitting the existing column with "POHO GEN2" equipment and a "Schröder" Passive Infrared (PIR) sensor (which detects people near the pedestrian crossing and changes the light flux) [38];

3. Exterior controller OWLET IV NEMA for EXEDRA (lighting management system) [38].

The graphical solution is shown in the Figure 5.46:



Figure 5.46: a) equipment 2) and 3) b) equipment 1) [38]

The associated estimated costs are shown in Table 5.12:

DESCRIÇÃO	QT	UNIT PRICE	TOTAL
NEOS 2 LED 48@500mA 74W specific photometry	1	372,04 €	372,04 €
POHO GEN2 with Sensor PIR	1	175,00 €	175,00 €
Controller OWLET IV NEMA FOR EXEDRA	1	135,00 €	135,00 €

Table 5.12: Estimated costs for pedestrian crossing [38]

The total value of the investment is 682.04€ plus tax.

5.7 Lighting results and comparison with other solutions

In this sub-chapter, we will assess whether the luminaires, especially their electric powers, are the most suitable for roadways and pedestrian areas or whether there is more efficient equipment, always having as reference the minimum values of luminance, illuminance and other quantities already discussed above.

We made the calculations for Raposo Marques Street through DIALux, using the luminaire "ARGUS 140" and a maintenance factor of 0.8, which has the following lighting characteristics (Figure 5.47):

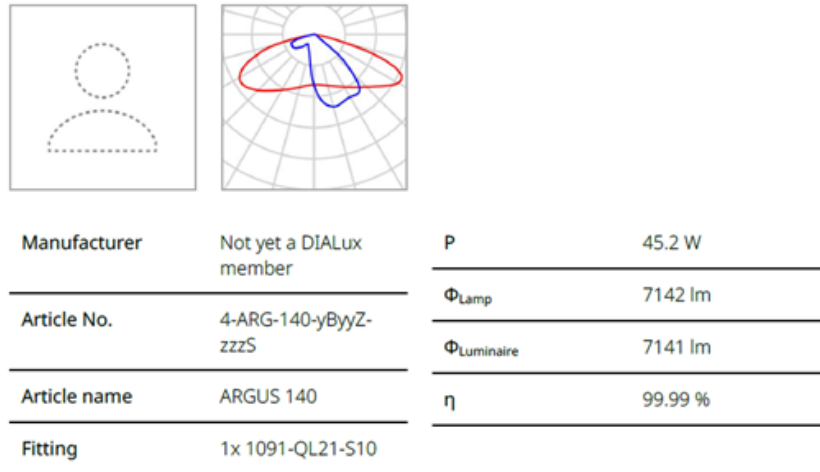


Figure 5.47: Characteristics of the “Argus 140” luminaire [3]

The results obtained are summarised in the Table 5.13:

Results for valuation fields

A maintenance factor of 0.80 was used for calculating for the installation.

	Symbol	Calculated	Target	Check
walkway_without (P3)	E_{av}	9.76 lx	[7.50 - 11.25] lx	✓
	E_{min}	8.27 lx	≥ 1.50 lx	✓
raposo_straight (M4)	L_{av}	0.78 cd/m ²	≥ 0.75 cd/m ²	✓
	U_o	0.55	≥ 0.40	✓
	U_i	0.87	≥ 0.60	✓
	TI	6 %	≤ 15 %	✓
	R_{gl}	0.81	≥ 0.30	✓
wakway_luminaires (P3)	E_{av}	8.95 lx	[7.50 - 11.25] lx	✓
	E_{min}	7.01 lx	≥ 1.50 lx	✓

Table 5.13: Results of the “Argus 140” luminaire in the Raposo Marques Street [3]

Analysing the results, it can be seen that this luminaire meets all the requirements of EN13201:2015. Considering that the installed luminaire, "ARGUS 220", has an electrical power of 96,3W and the "ARGUS 140" has an electrical power of 45,2W, we can see that we are consuming and paying more than twice as much as necessary.

We tested this same luminaire (ARGUS 140) for Edmundo Bettencourt Street, but there were luminance values on the road that did not meet the standards. This is because the classification of this street is class M3, which is more demanding than the M4, which is the class of Raposo Marques Street.

For this reason, to maintain the same family of luminaires, we tested the "ARGUS 230", which has the characteristics shown in Figure 5.48:

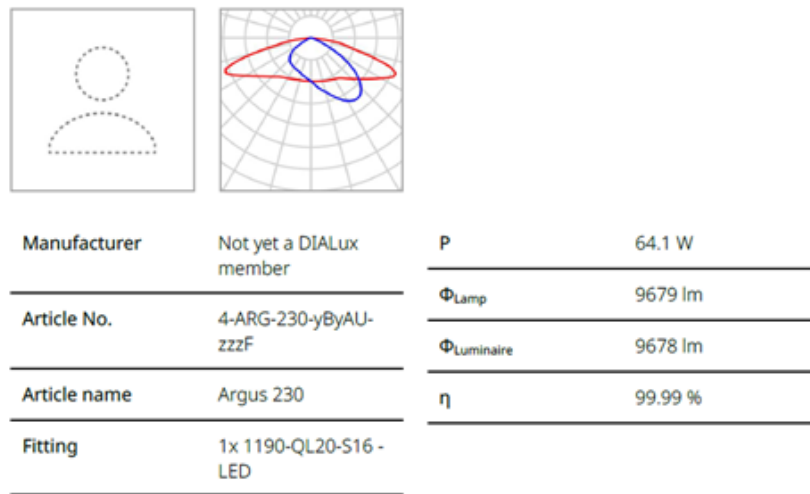


Figure 5.48: Characteristics of the "Argus 230" luminaire [3]

Moreover, the results obtained were as follows, set out in the Table 5.14:

Edmundo Bettencourt

Summary (according to EN 13201:2015)

Results for valuation fields

A maintenance factor of 0.80 was used for calculating for the installation.

	Symbol	Calculated	Target	Check
walkway_without (P3)	E_{av}	13.67 lx	[7.50 - 11.25] lx	✗
	E_{min}	10.50 lx	≥ 1.50 lx	✓
edmundo_satraigh (M3)	L_{av}	1.10 cd/m ²	≥ 1.00 cd/m ²	✓
	U_o	0.61	≥ 0.40	✓
	U_i	0.89	≥ 0.60	✓
	TI	10 %	≤ 15 %	✓
	$R_E^{(1)}$	0.77	-	
walkway_luminaires (P3)	E_{av}	11.60 lx	[7.50 - 11.25] lx	✗
	E_{min}	8.59 lx	≥ 1.50 lx	✓

Table 5.14: Results of the "Argus 230" luminaire in the José Bettencourt Street [3]

Analysing the results, it can be seen that this luminaire meets all the road requirements of the EN13201:2015 standard, but the illuminance values on the pavements are still slightly above the recommended.

Once again, comparing the power of the "ARGUS 230 ", 64,1W, with the "ARGUS 220", which is installed and has a power of 96,3W, we can see that we are consuming and paying 30% more than is necessary.

The values mentioned above are presented in Table 5.15 and the analysis of the cost reduction related to energy consumption per luminaire and, in total if they are replaced by the luminaires that the DIALux calculations have identified as more efficient.

	Power consumption (W)	Consumption per year (kWh) *	Costs per year (€) **	Number (Un)	Final costs per year (€)	Luminaire (€)	Luminaire with NEMA (€)
ARGUS 220	96,3	385,2	61,63	46	2 835,07	181,44	281,44
ARGUS 140	45,2	180,8	28,93	14	404,99	116,94	147,40
ARGUS 230	64,1	256,4	41,02	32	1 312,77	146,93	187,09

Table 5.15: Comparison of the various road luminaires. * Considering 4000h of annual operation. ** Considering 0,16€/kWh

Referring to the Table 5.15, we can conclude:

- Using the 46 ARGUS 240, the annual energy costs are 2.835,07€ and the purchase cost is 12.946,24€ (luminaire with NEMA controller) [21];
- Using the ARGUS 140 (14 units) and ARGUS 230 (32 units), the annual energy costs are 1.717,69€ (€404,99+1,312,77). This represents an energy cost reduction of 1.117,38€ per year (2.835,07€ - 1.717,69€);
- Using the ARGUS 140 (14 units) and ARGUS 230 (32 units), the acquisition cost is 8.050,48€ (2.063,60€+5.986,88), which represents a cost reduction of 4.895,76€ (12.946,24€-8.050,48€).

In Section 4.5 Control of Street Lights, several approaches were made to the criteria that can be applied to dimming in street lighting. To make it easier to understand, we will test with thresholds of the type of DDF27 mentioned in Figure 4.35, applying the following criteria:

- 4000h of annual operation, average value of 10,96h/day;
- Daily average operation of 3 hours at 100%; 2 hours at 75% and 5,96 hours at 50%;
- Annual average operation of 1095 hours at 100%, 730 hours at 75% and 2175 hours at 50%;
- 0,16€/kWh.

With these criteria and using the data in the Table 5.16:

	Consumption (W)	Consumption /year (kWh)	Final costs per year (€)	Consumption/year dimming (kWh)	Reduction (%)	Reduction /year (€)
ARGUS 220	96,30	385,20	2 835,07	262,90	31,75%	900,14
ARGUS 140	45,20	180,80	404,99	123,40	31,75%	128,58
ARGUS 230	64,10	256,40	1 312,77	174,99	31,75%	416,80

Table 5.16: Comparison with use of dimming

Referring to the Table 5.16, we can conclude:

- With the use of dimming in the 46 ARGUS 240, the annual reduction is 900,14€, which corresponds to a 31,75% reduction;
- With the use of dimming in the ARGUS 140 (14 units) and ARGUS 230 (32 units), the annual reduction is 545,39€, corresponding to a 31,75% reduction.

As already mentioned, globe-type luminaires consume an electrical power of 35W. From our experience, finding a more efficient solution seems complicated, but we went to experiment.

We began by conducting a lighting study of one of the streets with this type of lighting, namely José dos Santos Bessa Street.

The following results were obtained:

Figure 5.49 shows the technical characteristics of the "BOLLE" luminaire.

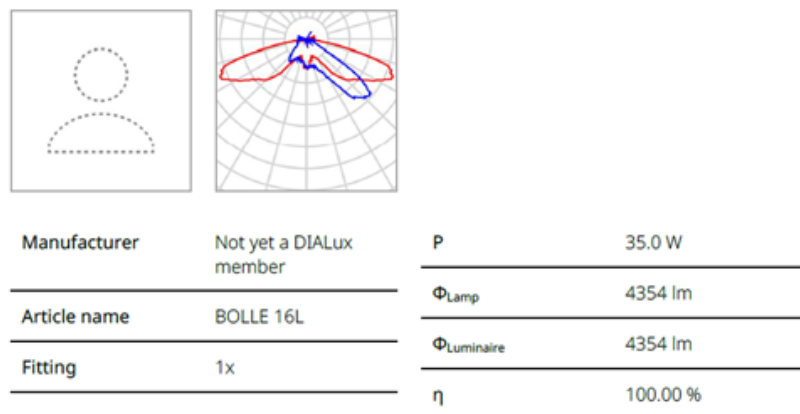


Figure 5.49: Characteristics of the "BOLLE" luminaire [3]

The global results were as follows in the Table 5.17.

Summary (according to EN 13201:2015)

Results for valuation fields

A maintenance factor of 0.80 was used for calculating for the installation.

	Symbol	Calculated	Target	Check
walk_tree (P4)	E_{av}	0.56 lx	[5.00 - 7.50] lx	✗
	E_{min}	0.45 lx	≥ 1.00 lx	✗
Roadway 1 (M4)	L_{av}	0.76 cd/m ²	≥ 0.75 cd/m ²	✓
	U_o	0.15	≥ 0.40	✗
	U_l	0.83	≥ 0.60	✓
	TI	19 %	≤ 15 %	✗
	R_{gl}	0.18	≥ 0.30	✗
walk_luminares (P3)	E_{av}	19.50 lx	[7.50 - 11.25] lx	✗
	E_{min}	12.26 lx	≥ 1.50 lx	✓

Table 5.17: Global results of the "BOLLE" luminaire in the José Santos Bessa [3]

The following conclusions can be drawn from analysing Table 5.17.

- In the roadway, the average Luminance (L_{av}) values comply, but the global uniformity is below the recommended one;
- On the sidewalk where the luminaires are installed, the average illuminance (E_{av}) values obtained are above those recommended, and the minimum illuminance (E_{min}) is well above the recommended;
- On the sidewalk opposite the luminaires, the value obtained is quite low, well below the recommended value.

These issues are driven by the width of the carriageway (13 metres) and the inter-distance between the luminaires, which are considerable (more than 16 metres).

Although it is not a procedure based on scientific studies, there is an empirical relationship that lighting designers use that relates the height of the columns and the width of the lanes, as well as their inter distance, which is summarised below:

- The maximum track width at which a column can be installed cannot exceed 1.5 times its height. In this case, the maximum inter distance would be 6 metres (4+2), but the track width is 13 metres;
- The maximum inter distance between 2 columns must not exceed four times their height. In this case, the maximum interdistance would be 16 metres (4x4).

Further tests were carried out to ensure no energy consumption increase, particularly by increasing the columns' height to 6 metres, and the values obtained were similar to the previous ones (see Appendix J). All the criteria were met only by replacing the

columns to a height of 8 metres (see Appendix K). It is noted that there were areas for improvement in the preparation of the project. For these reasons, mainly for security ones, considering the dimming scenario was not considered relevant.

5.8 Identification of non-conformities

Several non-compliances that adversely affect lighting levels have been identified in this subchapter. Some were bad design choices, but green spaces influenced others over the years, namely tree growth. However, some of these effects could have been mitigated before switching to LED technology because the globes with HPS lamps caused considerable light pollution, which could have masked the problems mentioned. Recall that in the questionnaire, someone referred to this effect.

Figure 5.50 and Figure 5.51 show staircase areas with two very different levels of illumination along the way, which causes serious safety problems:



Figure 5.50: Stairwell with two very different levels of lighting I

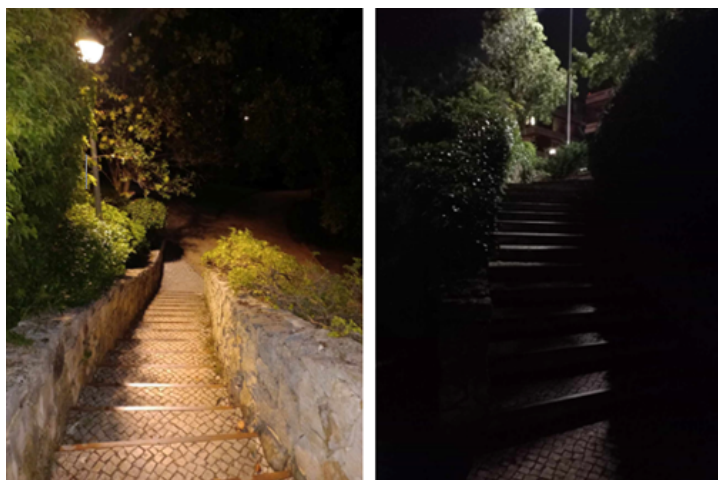


Figure 5.51: Stairwell with two very different levels of lighting II

Figure 5.52 shows the well-lit green spaces and the footpaths and stairs dark or with low uniformity problems.



Figure 5.52: Poor lighting in pedestrianised areas

Figure 5.53 shows what has already been mentioned and proven: the poor general uniformity of Rua José dos Santos Bessa.



Figure 5.53: Poor overall uniformity

5.9 Conclusions

This chapter explains the methodology used in the proof-of-concept studies. The luminous flux was reduced through various tests, and the proportionality between electricity consumption and luminance/illuminance will be assessed. Satisfaction questionnaires were sent out to residents/users in the area.

We can conclude that the reduction in consumption resulting from the replacement of luminaires is at least 50%, also because the consumption associated with the electro-magnetic ballasts (HPS) is around 20% of the lamps' power.

Roads were classified, and two classes were obtained between the streets, M3 and M4. The difference lies in "Traffic volume" and "Ambient luminance".

There were also two ratings for pedestrian zones, pavements and gardens, namely P3 and P5.

Regarding the tests and measurements, about the luminosity analysis of the streets with dimming, "LX-GPS" has measured that the lighting levels and uniformity are reasonable in most streets when there is no regulation. There is an exception in part of José dos Santos Bessa Street. With dimming, the uniformity naturally worsens, and by reducing it to 25%, the lighting levels and uniformity are very poor. It was found that the colour of the car cover does not influence the measurements and that there are luminaires that are not dimming, a problem possibly caused by a malfunctioning controller.

It was noted that the reduction in consumption directly affected invoicing.

However, the luminance values and reduced electricity consumption obtained with dimming are slightly higher than expected. As far as electrical consumption is concerned, it has to do with the electrical consumption of the controllers, and the fact that the grid is energised 24 hours a day.

The difficulty of measuring luminance and illuminance has become apparent. This is due to the requirement to use calibrated equipment, the difficulty of using it and the fact that external disturbances should be kept to a minimum, which is challenging to achieve in an outdoor environment.

The classification of the roads in class M instead of class C was justified because the road geometry is very uniform, there are no roundabouts, and we consider the junctions to have good visibility and not be accident-prone.

Analysing the answers to the questionnaire, it emerged that the majority prefer no light reduction, but one comment mentioned that the levels with the reduction to 50% are sufficient.

Using DIALux, it was concluded that there are more efficient luminaires to place in road areas and that the luminaire installed in Rua José dos Santos Bessa is not the most suitable, mainly because the street is very wide transversally. For the same luminaires, placing columns 8 metres high would be necessary, but this is not a technically suitable solution because the lighting values and uniformity would be high in the longitudinal direction.

Some non-conformities were identified during our visits to the area.

6 CONCLUSIONS AND FUTURE PERSPECTIVES

In this chapter, we will present the thesis conclusions we have reached and the prospects that should be considered.

6.1 Conclusions

The main conclusion of this thesis is that investments in the luminaires installed in the public lighting network can indeed significantly reduce electricity consumption and, consequently, costs, which is an essential contribution to SDG number 11, "Sustainable Cities and Communities".

In Coimbra in 2021, electricity costs were the most significant, with around 68.13%. In the same year, the cost of street lighting consumption was around 64.03%, corresponding to 18.857.432,06 KWh and a paid value of 2.749.176,49. It turned out that there are still 23.027 luminaires that are not LED technology, for a total of 39.565.

It was explained that the human eye is more sensitive to short wavelength light, which produces cool tones such as blue or green, as opposed to long wavelength light, which produces warm tones such as yellow and red, so replacing HPS with LED, we can reduce the amount of electrical energy used for lighting. LEDs convert a large amount of electrical energy into visible light, unlike HPS lamps, because a significant part of the energy is converted into heat.

If municipalities cannot afford to buy LED luminaires to replace the existing ones, they can turn to an energy services company (ESCO), whose legislation has been presented.

It was justified that by replacing luminaires with high-pressure sodium lamps with LED technology, consumption can be reduced by at least 50%. If we apply dimming, this reduction can be much higher. Various dimming solutions and the respective investment and savings costs were presented and compared.

Two possible communication systems were presented, NB-IoT and LoRaWAN, to turn the public lighting network into a smart grid. It was emphasized that it is customary to use a Low Power Wide Area (LPWA), which is a category of wireless networks specifically designed for the IoT. It was concluded that the best option is NB-IoT if a point-to-point communication system is required, with several pieces of data to be transmitted bilaterally and securely.

The "DIALux" software was presented, enabling the user to put data from a street or

park and analyze the results. It was explained what information we needed to know about the public lighting project.

It was concluded that there are more efficient luminaires to place in road areas and that the luminaire installed in Rua José dos Santos Bessa is not the most suitable, mainly because the street is very wide transversally.

When substituting technologies, the existing standards must be respected. Standards are not laws but guides to ensure that designers follow the same rules and criteria when planning lighting installations.

All lighting studies should be carried out to ensure that the luminaires to be installed are the most efficient, as it has been proven that simply changing them without analyzing them, even though they may be more efficient than the ones that were installed, is not enough, as it may be possible to save even more.

In existing installations, it is essential to reconnaissance terrain. The technical lighting calculation is only enough when considering what could harm the final result, namely lighting levels and uniformities. We are talking about the existence of trees and walls, but also reflections from lighting on buildings, advertising panels, and others.

The choice of luminaires, and especially their photometry, is a basic condition for the success of the final solution. Luminaires must illuminate what they are supposed to, without light pollution. Any watt consumed that is not transformed into lumen is a waste, and it is the same as throwing money out the window because its purpose is none.

By measuring and analyzing the data from the case study, it was possible to prove some of the facts investigated throughout the thesis. It was proven that the reduction in consumption resulting from replacing luminaires fitted with high-pressure sodium lamps with LEDs is at least 50%, and could reach 70%.

The luminance values and reduction in electricity consumption obtained with dimming are slightly higher than expected, concluding that the parameterization/result relationship is not linear. We assume that the electrical consumption concerns the controller's consumption.

The great frustration of this thesis was the enormous difficulty in measuring lighting levels because the variables that could lead to failures are many, and there is great difficulty in having adequate equipment available. Making a comparison with a room in a building, for example, what is measured is the illuminance, lumen per square meter, and in addition to the physical characteristics of the room, the colours of the walls, floor, and furniture are easy to perceive. On the street, the same illuminance values to be measured depending on the conditions not only of the surroundings but also on the weather conditions, namely the brightness of the sky, whether there are clouds and the configuration of the moon. Even if we wanted to correlate illuminance

with luminance, it is not possible to find any relationship from a scientific point of view that would allow us to make this correspondence in a simple way, not least because both quantities are important for assessing the quality of lighting in an environment, but they describe different aspects.

When it comes to measuring luminance values on roadways, everything is even more complicated because it is a quantity that is basically the value reflected from the ground and that is perceptible to the human eye, under various conditions. The measurement process and the necessary equipment were duly described, and it is necessary to completely close the streets to be measured, for example, which causes severe constraints to residents and users of these streets. In addition, weather conditions also have a significant effect, which adds to the fact that the standards use a person aged 23 as a reference. Therefore, if in new installations it is necessary to trust the luminaire manufacturers, particularly in the photometrics they provide, in existing installations, as was the case in the proof of concept, it is tough to measure without making gross errors. A set of measurement procedures should be created at the European level that guarantees the uniformity of the application of criteria among all participants in this critical spatiality, which is the lighting of public spaces.

6.2 Future Perspectives

With these conclusions, what future perspectives should be considered?

As already mentioned, the main conclusion of this thesis is that the technological upgrading of public lighting to LED luminaires does result in energy savings of 50 % on average. If a remote management system is also implemented, we could reach at least 70%. For this reason, it is essential to study this technological upgrading for other areas of the city, suggesting that it be done for heritage areas protected by the United Nations Educational, Scientific and Cultural Organisation (UNESCO). For this reason, the "FlexIP" project is being implemented in the historic downtown area, installing 100 "lantern" LED luminaires and a communication module for remote management. These luminaires, which consume 41W, replaced others that had 100W HPS lamps. The replacement was straightforward, with no changes to the location of the brackets, as can be seen in Figure 6.1:

The application of IoT sensors must be considered. Sensors for counting people and vehicles, air quality, detecting the volume of solid urban waste, and water efficiency in a garden irrigation system. However, in the area where this "FlexIP" project was implemented, 4 "lantern" type LED luminaires were installed with a multisensor, which is internally made up of a communication module for remote management and presence detection, but noise detection is coming soon. The luminaires are of the "Villa LED gen2 38W" type from the manufacturer "Signify"/" Philips". They are still in the testing



Figure 6.1: Luminaires and communication module

phase.

Another measure that we believe should be implemented is the replacement of the luminaires on the distributor roads, because there are several hundred that are equipped with 250W lamps, plus the losses of the electronic ballasts, which are in the order of 20%, can go up to 300W, and which could be replaced with LED luminaires of around 120W. That is a tremendous reduction in consumption.

When studying the decision to install a controller for the luminaires, it is essential to relate the cost of the controller to the power that is expected to be reduced by remote management because it may be more cost-effective for the dimming to be factory-programmed, with DDF27, for example, avoiding the installation of a controller, due to its cost and because it consumes energy, as already mentioned.

Another point to explore is the measurement of luminance and illuminance. The use of calibrated equipment is essential. In the case of roads, where it is necessary to find the M class for each road, it is essential to validate the luminance values to ensure that the expected levels are, in fact, met because we believe that it is not enough to validate the luminance studies presented by the luminaire manufacturers. As has already been shown, measuring luminances is a time-consuming and complicated procedure, but partnerships with companies should be sought for this purpose. Measuring illuminance is more straightforward, but it also considers external disturbances that must be considered, such as moonlight and the possibility of advertisements or shops with illuminated windows. It is easier to get a calibrated lux meter. However, the effects mentioned above must be considered, which is why we believe that the pedestrianized green areas of Quinta de S. Jerónimo should be the subject of a specific study, possibly a master's thesis. This methodology is valid for assessing classes P and C.

Last but not least, writing and publishing scientific articles on this subject is very important.

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Appendices

**A RENEWAL OF THE CONCESSION CONTRACT FOR THE
DISTRIBUTION OF ELECTRICAL POWER IN LOW VOLTAGE IN
THE MUNICIPALITY OF COIMBRA - 2001**


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Depositar Original no
2.º Património e Notariado
Cf. Cjas:
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D.º Administração Urbanística
Div. Equipamentos Electrotécnicos
D.º Administração Genl


Delib. de 9.4.2001 (017)
1 AM (20.4.2001)

RENOVAÇÃO DO CONTRATO DE CONCESSÃO DE DISTRIBUIÇÃO DE ENERGIA ELÉCTRICA EM BAIXA TENSÃO NO MUNICÍPIO DE COIMBRA

DASA
DDS
DEDT
SMASC
SMOUC
A.º C.º M.

 2.7.2001

SESIÃO DA CÂMARA MUNICIPAL
DE 2001/07/01
Deliberação em Minuta:
Tomada por unanimidade
O PRESIDENTE DA CÂMARA : O DIRECTOR DO DEPARTAMENTO
 

CAPÍTULO I

Objecto e âmbito da concessão



Artigo 1º

Objecto da concessão

- 1- A Câmara Municipal, outorgando em representação do Município de Coimbra (a seguir designada por Câmara), concede à EDP Distribuição - Energia, S.A. (a seguir designada por EDP Distribuição), a distribuição de energia eléctrica em baixa tensão na área do Município de Coimbra.
- 2- A distribuição concedida não abrange nem prejudica as instalações particulares devidamente autorizadas que sejam ou venham a ser alimentadas por energia eléctrica proveniente de produção própria.
- 3- O património e infra-estruturas afectos à concessão não poderão ser utilizados pela EDP Distribuição em actividades diferentes daquelas que constituem objecto da concessão, sem que haja sido acordado entre as partes o valor da compensação devida à Câmara.

Artigo 2º

Transferência de direitos e poderes

A concessão implica a transferência, para a EDP Distribuição, do exercício dos direitos e poderes da Câmara necessários à gestão e exploração do serviço público de distribuição de energia eléctrica em baixa tensão durante o prazo da concessão ou enquanto esta subsistir.

Artigo 3º

Exclusivo do exercício da actividade de distribuição de energia eléctrica em baixa tensão

- 1- A actividade concedida será exercida em regime de exclusivo, em toda a área do Município de Coimbra, competindo apenas à EDP Distribuição o fornecimento de energia eléctrica ao consumidor final.

2- O regime de exclusivo é contrapartida da obrigação de satisfazer em boas condições as necessidades colectivas em abastecimento de energia eléctrica em baixa tensão.

Artigo 4º

Utilização das vias públicas

- 1- Dentro da área da concessão, a EDP Distribuição terá o direito de utilizar as vias públicas, bem como os respectivos subsolos, para o estabelecimento e conservação de obras e canalizações aéreas ou subterrâneas de baixa, média ou alta tensão, com o fim de prover ao fornecimento de energia eléctrica.
- 2- Quando se torne necessária a realização de obras na via pública, a EDP Distribuição solicitará o seu licenciamento à Câmara, salvo acordo entre as partes ou se tal se revelar impossível ou inconveniente, em virtude de ocorrência de avaria ou caso de força maior.
- 3- O pedido de licença para a realização de obras na via pública será dirigido ao presidente da Câmara, devendo ser instruído com os seguintes elementos:
 - a) Planta à escala conveniente que localize a obra a realizar;
 - b) Memória descritiva sumária, de onde constem os tipos de pavimento a levantar, as respectivas extensões, a largura das valas e buracos, a profundidade de colocação dos equipamentos e ainda os prazos previstos para a realização das obras.
- 4- A licença prevista nos números anteriores deverá ser emitida no prazo de 15 dias úteis, decorrido o qual se considera tacitamente deferida.
- 5- A EDP Distribuição procederá à reposição do pavimento no prazo constante da licença ou no acordado com a Câmara, caso a caso e de acordo com as indicações desta.
- 6- Se a EDP Distribuição não proceder à reposição do pavimento no prazo estabelecido, a Câmara poderá executar esses trabalhos, facturando àquele os respectivos encargos.

7- A Câmara poderá exigir à EDP Distribuição a prestação de garantias do bom cumprimento da obrigação constante do número anterior se este exigir igualmente daquela a prestação de garantias.

8- Quando a Câmara necessite de realizar obras de interesse público geral que obriguem a deslocações de apoios de rede de distribuição ou de canalizações eléctricas, a EDP Distribuição executará os respectivos trabalhos, sem direito a indemnização, devendo ser prevenida com a antecedência mínima de trinta dias, sendo nestes casos a reposição dos pavimentos uma obrigação da Câmara.

9- Excluem-se do disposto no número anterior os trabalhos que possam resultar da interferência de obras municipais de grande volume, os quais serão, em todos os seus aspectos e para cada caso, objecto de prévio acordo entre a Câmara e a EDP Distribuição.

10- A Câmara ouvirá a EDP Distribuição sempre que preveja a realização de obras de que possam resultar trabalhos de deslocação de instalações, com vista a conciliar, na medida do possível, os interesses em presença.

Artigo 5º

Meios necessários ao exercício da concessão

1- A EDP Distribuição obriga-se a providenciar para que sejam postos à disposição da concessão os meios materiais e humanos necessários à boa execução da actividade concedida, a realizar todos os trabalhos necessários à boa conservação das instalações abrangidas pela concessão e, de um modo geral, a assegurar a continuidade de prestação do serviço público de distribuição de energia eléctrica em baixa tensão na área do Município de Coimbra.

2- A EDP Distribuição terá todos os direitos e obrigações a que por lei esteja vinculada, no âmbito do serviço público de distribuição de energia eléctrica em baixa tensão, em tudo o que não esteja especificamente estabelecido no presente contrato de concessão.



Artigo 6º
Instalações abrangidas pela concessão

Ficam fazendo parte integrante da concessão as seguintes instalações:

- a) As redes de distribuição de energia eléctrica em baixa tensão e as redes de iluminação pública, compreendendo as linhas, os ramais e as chegadas, bem como os aparelhos e acessórios ligados à sua exploração, que à data do início da concessão estavam a ser explorados pela EDP Distribuição;
- b) Os postos de transformação alimentadores das redes referidas na alínea anterior;
- c) Os postos de transformação e os direitos sobre os locais em que se encontram implantados, as redes de distribuição de energia eléctrica em baixa tensão, compreendendo as linhas, os ramais e as chegadas, as redes de iluminação pública, bem como os aparelhos e acessórios ligados à exploração da distribuição concedida, construídos ou instalados pela EDP Distribuição para cumprimento das obrigações da concessão, durante a vigência desta, independentemente de o seu custo ter ou não sido participado ou suportado por quaisquer entidades.

Artigo 7º
Instalações não abrangidas pela concessão

Ficam excluídas da presente concessão as subestações, as redes de média e alta tensão e os respectivos postos de seccionamento, bem como quaisquer outras instalações de média e alta tensão, edifícios e terrenos que o distribuidor de energia eléctrica em alta e média tensão possua, ou venha a possuir, na área do Município de Coimbra.

Artigo 8º
Afectação à concessão do património da Câmara ou de parte dele

- 1- Mantém-se propriedade da Câmara o património não transferido para a EDP, nos termos do Contrato de Concessão celebrado em 20 de Julho de 1988, ficando simplesmente afecto à exploração por esta.
- 2- O património referido no nº 1, bem como aquele outro correspondente às participações recebidas pela EDP Distribuição, nomeadamente nas urbanizações

e loteamentos, reverterá para a Câmara no final da concessão, sem qualquer encargo para esta.

- 3- A EDP Distribuição obriga-se a manter em bom estado de funcionamento, conservação e segurança, a expensas suas, os bens referidos nos pontos anteriores.

Artigo 9º

Características técnicas da distribuição

- 1- A energia será distribuída segundo o esquema de corrente alternada trifásica, podendo a alimentação da instalação de utilização do consumidor ser monofásica ou trifásica, consoante o número de fases da instalação, nos termos do Regulamento de Segurança de Instalações de Utilização de Energia Eléctrica.
- 2- O valor nominal da tensão da rede de distribuição está fixado no Regulamento da Rede de Distribuição, 230/400 V, com a tolerância estabelecida no Regulamento da Qualidade de Serviço.
- 3- O valor nominal da frequência da rede de distribuição está fixado no Regulamento da Rede de Distribuição, 50 Hz, com a tolerância estabelecida no Regulamento da Qualidade de Serviço.

Artigo 10º

Obrigações de fornecer energia

- 1- A EDP Distribuição fica obrigada a fornecer energia eléctrica em baixa tensão a qualquer interessado que a requisiere, desde que a potência requisitada não exceda 100 kVA, nas redes de distribuição dentro dos perímetros urbanos situados em municípios com mais de 100.000 habitantes e naqueles que são sede de distrito, e 50 kVA nas restantes redes de distribuição.
- 2- Tendo em conta o estabelecido no nº 4, a EDP Distribuição poderá exigir que o requisitante participe nos custos das acções imediatas ou diferidas necessárias ao reforço da rede, quando a potência requisitada ultrapassar:
- a) 20 kVA em localidades cuja potência média por posto de transformação seja menor ou igual a 100 kVA;

- b) 50 kVA em localidades cuja potência média por posto de transformação seja menor ou igual a 400 kVA e superior a 100 kVA;
- c) 100 kVA em localidades cuja potência média por posto de transformação seja superior a 400 kVA.
- 3- Tratando-se de prédios incluídos em urbanizações ou loteamentos, a EDP Distribuição apenas poderá exigir que o requisitante participe nos custos das acções imediatas ou diferidas necessárias ao reforço da rede, quando a potência requisitada ultrapassar a potência prevista no respectivo projecto da infra-estrutura de energia eléctrica.
- 4- Para os efeitos previstos no nº 2, não são considerados os postos de transformação de loteamentos e urbanizações.
- 5- Nos casos referidos no nº 2, a EDP Distribuição pode exigir ao requisitante que este ponha gratuitamente à sua disposição um local apropriado ao estabelecimento e exploração de um posto de transformação, com as dimensões mínimas por ele indicadas para cada categoria de rede.
- 6- A EDP Distribuição fica ainda obrigada a fornecer energia a qualquer interessado que a requirir, até ao limite máximo considerado no nº 1, quando se trate de empreendimentos inseridos em programas de incentivos ao desenvolvimento, nomeadamente do interior, aprovados pela Assembleia da República ou pelo Governo, desde que estas entidades a compensem da totalidade dos encargos acrescidos das obras de reforço das redes necessárias a esse fornecimento.
- 7- No caso de edifícios que comportam diversas instalações de utilização, mesmo que em regime de propriedade horizontal, cuja alimentação derive de uma ligação à rede comum, a potência requisitada será referida à ligação do edifício à rede comum, sem prejuízo de poder ser atribuída uma potência requisitada específica a cada instalação de utilização.
- 8- O fornecimento não depende, quanto ao requerente, de especiais requisitos de legitimidade da posse do local.

CAPÍTULO II



7

Início, duração, encargos, isenções, resgate e condições de fim da concessão

Artigo 11º

Início e duração da concessão

- 1- Considera-se como data de início do presente contrato o dia da sua assinatura. (2007/07/03)
- 2- A presente concessão é feita pelo prazo e nas condições de prorrogação estabelecidos no n.º 1 do artigo 3º do Decreto-Lei n.º 344-B/82, de 1 de Setembro, com a redacção que lhe foi dada pelo Decreto-Lei n.º 341/90, de 30 de Outubro.

Artigo 12º

Encargos da concessão e isenções

A concessão confere à Câmara o direito a uma renda e à EDP Distribuição o direito a isenções, nomeadamente quanto ao uso dos bens do domínio público municipal, as quais serão determinadas por portaria ministerial, sendo aquela e estas indissociáveis, pelo que nenhuma delas será devida separadamente.

Artigo 13º

Resgate e condições de fim da concessão

- 1- O resgate da concessão obedecerá ao disposto no n.º 3 do artigo 4.º do Decreto-Lei n.º 344-B/82, de 1 de Setembro, com a redacção que lhe foi dada pelo Decreto-Lei n.º 341/90, de 30 de Outubro.
- 2- A transferência do património próprio da EDP Distribuição para a Câmara, no termo da concessão, far-se-á de acordo com o estabelecido no artigo 7.º do Decreto-Lei a que se refere o número anterior.
- 3- A EDP Distribuição comunicará anualmente à Câmara o valor da indemnização a pagar por esta àquela, relativo às infra-estruturas eléctricas, num hipotético resgate da concessão, devendo aquele valor ser fundamentado e instruído, quando solicitado pela Câmara, com os elementos necessários ao seu esclarecimento.

- 4- A EDP Distribuição e a Câmara estabelecerão mecanismos destinados à inventariação física do património da concessão.

CAPÍTULO III

Relações entre a Câmara e a EDP Distribuição

Artigo 14º

Expansão das redes

Tendo em vista a expansão das redes de distribuição de energia eléctrica e a qualidade do serviço, a EDP Distribuição auscultará a Câmara, e esta, por sua vez, fornecer-lhe-á ou assegurará que lhe sejam fornecidos directamente, com a possível antecedência, quaisquer planos de desenvolvimento municipal, nomeadamente no que respeita à fixação de indústrias, à expansão urbanística ou outras actividades para as quais seja necessário o estabelecimento ou reforço, em tempo útil, de infra-estruturas eléctricas.

Artigo 15º

Acompanhamento da actividade da EDP Distribuição por parte da Câmara

A Câmara e a EDP Distribuição comprometem-se a assegurar o estabelecimento de contactos periódicos estreitos entre os seus técnicos ou representantes, com vista à análise e ao acompanhamento da execução dos planos de actividade da EDP Distribuição, das suas opções em matéria de investimentos e de aspectos essencialmente referentes à exploração do serviço, nomeadamente para o esclarecimento de dúvidas ou resolução de diferendos emergentes da execução do contrato.

Artigo 16º

Participação da Câmara na elaboração dos planos de actividade da EDP Distribuição

- 1- Na ausência de legislação que contemple as relações entre a Câmara e a EDP Distribuição, esta levará em conta, na elaboração dos seus planos de actividades, as solicitações que lhe forem apresentadas pela Câmara.

2- No que respeita especialmente à iluminação pública, a Câmara e a EDP Distribuição acordarão, até ao final de cada ano, sobre o plano de obras para o ano seguinte.

3- O valor mínimo do investimento correspondente a esse plano de obras será estabelecido decorridos três anos sobre a data da entrada em vigor do presente contrato.

4- Até que seja estabelecido o valor mínimo referido no número anterior, a EDP Distribuição obriga-se a realizar obras em volume anual semelhante à média dos últimos dois anos, com um investimento não inferior a 12% do valor da renda referida no artigo 12º, desde que tal seja solicitado pela Câmara.

Artigo 17º

Infra-estruturas de energia eléctrica

1- A Câmara obriga-se a incluir nos seus alvarás e licenciamentos, nomeadamente de loteamentos, urbanizações, unidades ou complexos hoteleiros, comerciais e industriais, as condições que a EDP Distribuição vier a estabelecer na apreciação dos respectivos projectos de infra-estruturas de energia eléctrica, desde que mereçam o acordo da Câmara.

2- Nos processos de licenciamento de loteamentos, de grandes empreendimentos e de obras de urbanização, a Câmara e a EDP Distribuição acordarão sobre os procedimentos tendentes a facilitar a articulação entre os serviços municipais, a EDP Distribuição e os promotores.

3- A fim de prever os corredores e espaços destinados quer às linhas eléctricas quer às instalações de transformação, a reservar para a expansão da sua rede, a EDP Distribuição deverá apresentar à Câmara programas de desenvolvimento, a curto ou médio prazo, das suas instalações de tensão nominal igual ou superior a 60 kV que incluam, nomeadamente, plantas à escala não inferior a 1:25000 dos traçados previstos para as linhas eléctricas e das subestações e postos de seccionamento.

4- A Câmara e a EDP Distribuição colaborarão, quando for caso disso, no desenvolvimento de cartografia digital de infra-estruturas necessárias à concessão.

**Artigo 18º****Elaboração de projectos e acompanhamento de obras**

- 1- A EDP Distribuição deverá, quando para isso for solicitada, proceder à elaboração dos projectos das infra-estruturas eléctricas das urbanizações a realizar pela Câmara e dar parecer sobre as propostas dos concursos abertos pela Câmara relativamente a obras de electrificação.
- 2- À EDP Distribuição competirá acompanhar a execução de toda e qualquer obra de electrificação a realizar na área da concessão, bem como fazer a sua vistoria e aprovação final.

Artigo 19º**Informação sobre a viabilidade de alimentação de novos edifícios e loteamentos**

- 1- A Câmara obriga-se, de acordo com a legislação aplicável, a consultar a EDP Distribuição sobre a viabilidade de alimentação, em energia eléctrica, de novos edifícios cujos projectos sejam submetidos à sua apreciação e em que os valores da potência prevista ultrapassem os limites consignados no nº 1 do artigo 10º e, bem assim, sobre os anteprojectos das infra-estruturas de energia eléctrica de urbanizações ou loteamentos, de iniciativa municipal ou particular.
- 2- A EDP Distribuição dará o seu parecer, que é vinculativo, no prazo de 10 dias úteis, no que se refere a edifícios, e de 45 dias úteis, no que respeita a urbanizações e loteamentos, valendo o silêncio como assentimento.

Artigo 20º**Zonas de protecção de linhas aéreas e percursos
para canalizações subterrâneas**

- 1- A Câmara prestará à EDP Distribuição a possível colaboração no que respeita à definição e manutenção de corredores ou zonas de protecção das linhas aéreas de transporte e distribuição de energia eléctrica, necessárias ao cabal cumprimento, por este, das suas obrigações, bem como para as alterações dos traçados daquelas linhas impostas por actos administrativos ou negócios jurídicos.

2- Havendo lugar ao pagamento de indemnizações pelo estabelecimento daqueles corredores, elas serão integralmente suportadas pela EDP Distribuição.

3- A Câmara prestará à EDP Distribuição a possível colaboração na definição dos percursos para a instalação de novas linhas aéreas e subterrâneas destinadas ao transporte e distribuição de energia eléctrica, tendo em conta o rigoroso cumprimento dos instrumentos de gestão territorial.

4- Para as linhas de tensão igual ou superior a 60 kV, deverão ser reservados corredores que permitam a sua manutenção, não devendo a Câmara, tendo em conta os instrumentos de gestão territorial, autorizar nesses corredores novas construções cuja altura e localização violem disposições regulamentares de segurança aplicáveis às linhas eléctricas.

5- Quando para tal for solicitada, a Câmara exercerá o seu empenho no sentido de obter a autorização dos proprietários dos terrenos que a EDP Distribuição se proponha atravessar com as linhas ou onde projecte implantar os respectivos apoios.

Artigo 21º

Terrenos para postos de transformação

1- Os terrenos necessários à instalação de novos postos de transformação serão adquiridos pela EDP Distribuição, podendo a Câmara disponibilizar gratuitamente, se o achar conveniente, terrenos seus ou sobre os quais tenha jurisdição.

2- Tratando-se de zonas densamente urbanizadas, a Câmara colaborará com a EDP Distribuição tendo em vista obter dos proprietários os terrenos necessários à implantação dos postos de transformação, de seccionamento e subestações, necessários ao regular funcionamento do serviço concedido.

3- Havendo lugar ao pagamento de indemnizações pela cedência dos terrenos referidos no número anterior, elas serão suportadas integralmente pela EDP Distribuição.

CAPÍTULO IV



Estabelecimento e conservação das redes de distribuição

Artigo 22º

Condições gerais do estabelecimento das redes

- 1- As redes de distribuição em baixa tensão serão estabelecidas pela EDP Distribuição com o desenvolvimento necessário e as características convenientes para a electrificação dos aglomerados populacionais a servir e deverão abranger as artérias, largos, praças, parques e jardins, segundo as indicações da Câmara.
- 2- Serão estabelecidas com condutores subterrâneos as redes de distribuição em baixa tensão a construir dentro dos núcleos urbanos onde o plano de urbanização, de pormenor ou a legislação em vigor o exijam e, bem assim, naqueles em que, pelo seu valor arquitectónico, se reconheça haver prejuízo pela existência de rede aérea ou, ainda, naqueles em que se verifique regular desenvolvimento de edifícios com mais de 3 pisos acima do solo.
- 3- Fora dos casos previstos no número anterior, as redes de distribuição em baixa tensão e de iluminação pública poderão ser constituídas por condutores aéreos.

Artigo 23º

Repartição de encargos no estabelecimento das redes de distribuição em baixa tensão

As condições de repartição de encargos no estabelecimento das redes de distribuição de energia eléctrica em baixa tensão abrangidas pela presente concessão serão as fixadas nos artigos seguintes deste capítulo.

Artigo 24º

Obras a realizar

Para efeitos do presente contrato de concessão, as obras novas a realizar pela EDP Distribuição consideram-se divididas em:

- a) Obras de electrificação de novas áreas urbanizadas, parques industriais ou comerciais, de iniciativa municipal ou particular e ainda as obras resultantes da recuperação de zonas de construção clandestina;
- b) Obras de expansão das redes de distribuição existentes, destinadas ao fornecimento de energia eléctrica às instalações de utilização surgidas pelo natural desenvolvimento dos aglomerados populacionais.

Artigo 25º


Estabelecimento das redes destinadas à electrificação de novas áreas urbanizadas

- 1- Sempre que o crescimento de qualquer aglomerado populacional já abastecido de energia eléctrica se faça pelo aparecimento de novos bairros ou núcleos habitacionais que exijam a instalação de um ou mais postos de transformação, as despesas resultantes do primeiro estabelecimento das correspondentes obras de electrificação (nelas se compreendendo o custo da rede de média tensão, dos postos de transformação e das redes de baixa tensão e de iluminação pública) ficam a cargo da entidade promotora do empreendimento.
- 2- Quando a construção de novos bairros ou núcleos habitacionais referidos no número anterior for feita gradualmente, a EDP Distribuição poderá proceder a um estabelecimento escalonado das obras, desde que garanta o fornecimento de energia eléctrica em baixa tensão em boas condições aos consumidores que a tenham requisitado.
- 3- Quando o empreendimento for de carácter social e deva ser participado pela Câmara, o encargo a suportar por esta será repartido, em partes iguais, entre ela e a EDP Distribuição.

Artigo 26º

Obras de expansão das redes existentes

- 1- As redes de distribuição em baixa tensão acompanharão o desenvolvimento dos aglomerados populacionais na medida em que estes se forem alargando numa regular sequência de edifícios, devendo os respectivos traçados ser objecto de acordo entre a EDP Distribuição e a Câmara.

- 
- 2- A EDP Distribuição suportará inteiramente os encargos resultantes das necessárias ampliações das redes existentes se o número de prédios susceptíveis de ligação for, em média, igual ou superior a 6 por hectómetro de traçado das referidas ampliações.
- 3- No caso de o número de prédios susceptíveis de ligação ser inferior a 6 por hectómetro de traçado da ampliação de rede a estabelecer, a execução dessa ampliação ficará condicionada ao pagamento à EDP Distribuição, pelos interessados, de forma equitativa, de uma importância variando linearmente entre 0% e 50% ao variar o número de interessados por hectómetro entre 6 e 0.
- 4- Para efeitos dos números anteriores, considera-se prédio susceptível de ligação todo o terreno ou parcela de terreno *aedificandi*, situado ao longo da via pública entre a rede existente e a ligação requisitada mais distante desta.
- 5- Em caso de dúvida quanto ao número de potenciais ligações, será pedido parecer à Câmara.
- 6- Quando a distância entre os prédios a ligar e o posto de transformação existente implicar a construção de um novo posto de transformação, a EDP Distribuição poderá exigir ao conjunto dos requisitantes das ligações o pagamento de 50% do custo total da infra-estrutura a realizar.

Artigo 27º

Trabalhos nas redes e outras instalações abrangidas pela concessão e respectivos encargos

- 1- Competem à EDP Distribuição, e constituem seu encargo, todos os trabalhos de conservação, reparação, remodelação e reforço das redes e outras instalações abrangidas pela concessão, por forma a serem convenientemente satisfeitas as necessidades de consumo de energia eléctrica.
- 2- A substituição, a solicitação da Câmara, das linhas aéreas em serviço abrangidas pela concessão, por cabos subterrâneos, não constitui encargo da EDP Distribuição, salvo se, verificando-se as condições previstas no nº 2 do artigo 22º, essa substituição se integrar em plano global de remoção dos restantes elementos aéreos, nomeadamente de transporte e recepção de sinal de telecomunicações.



CAPÍTULO V

Iluminação pública

Artigo 28.º

Condições de estabelecimento das redes de iluminação pública e respectivos encargos

- 1- A EDP Distribuição procederá, quando tal for solicitada pela Câmara, ao estabelecimento das redes de iluminação pública, de acordo com os projectos aprovados pela Câmara, tendo em conta o que se encontrar convencionado no plano de obras referido no nº 2 do artigo 16º.
- 2- Salvo indicação em contrário da Câmara, a rede de iluminação pública acompanhará a rede de distribuição em baixa tensão e será do mesmo tipo desta, ultrapassando-a nas suas extremidades na extensão correspondente a dois vãos ou 100 metros.
- 3- Os encargos suportados pela EDP Distribuição relativos ao primeiro estabelecimento das redes de iluminação pública serão calculados na mesma base em que forem calculados os encargos da rede de distribuição em baixa tensão, de acordo com o estabelecido no capítulo IV.
- 4- Dentro dos limites urbanos, definidos em instrumento de gestão territorial, a Câmara poderá solicitar a execução de rede de iluminação pública em áreas onde não exista rede de distribuição ou segundo traçado diferente desta, suportando a EDP Distribuição 50% dos encargos daí resultantes.
- 5- A Câmara poderá solicitar a execução de rede de iluminação pública em áreas onde não exista rede de distribuição ou segundo traçado diferente desta, fora dos perímetros urbanos, suportando, nesses casos, os respectivos encargos de primeiro estabelecimento, salvo se o consumo associado à nova rede assegurar o retorno do investimento, em prazo adequado, circunstância em que a Câmara e a EDP Distribuição repartirão entre si, caso a caso, o respectivo custo.

6- A gestão da iluminação pública é da inteira responsabilidade da Câmara no que respeita a níveis e horários de iluminação e ao tipo e número de aparelhos de iluminação e lâmpadas em serviço.

7- A EDP Distribuição obriga-se a implementar o sistema de comando de iluminação pública que for acordado com a Câmara, bem como a mantê-lo actualizado e em bom estado de funcionamento, garantindo a necessária assistência à rede de iluminação pública, salvo se outra solução for acordada.

Artigo 29º

Focos luminosos

- 1- Os aparelhos de iluminação e respectivos suportes a utilizar no Município serão escolhidos de entre os tipos normalizados existentes no mercado, tendo em conta a utilização racional da energia, sendo a indicação dos locais da sua instalação e a fixação da potência das lâmpadas da competência da Câmara, ouvida a EDP Distribuição.
- 2- Os aparelhos de iluminação serão instalados:
 - a) Nas redes aéreas, normalmente em apoios da rede;
 - b) Nas redes subterrâneas, em colunas ou consolas.
- 3- Na definição dos aparelhos de iluminação e lâmpadas a adoptar, como tipo corrente no Município, será tida em conta, para cada tipo de rede, a utilização de lâmpadas de adequado rendimento, com observância dos critérios de normalização e mais eficiente racionalização de energia, nos termos constantes de Anexo ao presente contrato (Anexo I).
- 4- O anexo referido no número anterior poderá ser revisto de cinco em cinco anos, se tal se justificar, tendo em conta a evolução tecnológica e ou a redução dos custos e dos consumos, sem pôr em causa os níveis de iluminação aconselháveis.

Artigo 30º**Condições de estabelecimento dos aparelhos de iluminação e respectivos suportes e correspondentes encargos**

- 1- A EDP Distribuição procederá, quando tal for solicitado pela Câmara, à instalação e montagem dos aparelhos de iluminação e respectivos suportes.
- 2- Nos casos de iniciativa da Câmara, de estabelecimento de novas redes de iluminação pública, a EDP Distribuição suportará o custo dos aparelhos de iluminação e lâmpadas de tipo corrente no Município, dos respectivos suportes em apoios da rede de distribuição e da mão-de-obra necessária à sua instalação, ligação e desmontagem. No caso de colunas, o seu custo, quando do tipo corrente no Município, e da respectiva instalação, será repartido igualmente entre a Câmara e a EDP Distribuição.
- 3- A Câmara poderá optar por colunas, aparelhos de iluminação ou lâmpadas de tipo diferente dos referidos no número anterior, ouvida a EDP Distribuição, suportando o excesso de custo, se o houver, por forma a que os encargos da EDP Distribuição não excedam os resultantes da aplicação do número anterior.
- 4- Nos casos, de iniciativa da EDP Distribuição, de estabelecimento de novas redes de iluminação pública ou expansão e remodelação das existentes, a EDP Distribuição deverá instalar, sem prejuízo do acordo prévio da Câmara, lâmpadas de adequado rendimento, tendo em atenção o estabelecido no nº 3 do artigo 29º, tendo a repartição dos encargos o enquadramento estabelecido neste capítulo, mas assumindo a EDP Distribuição a totalidade dos encargos correspondentes ao custo das lâmpadas de tipo corrente e da mão de obra necessária à sua instalação.
- 5- Para efeitos do estabelecido no número anterior, consideram-se de iniciativa da EDP Distribuição os trabalhos que não forem requisitados pela Câmara nem por qualquer outra entidade interessada que participe no estabelecimento da rede.
- 6- Nos casos, de iniciativa da Câmara, de remodelação de redes de iluminação pública para alteração dos suportes dos aparelhos de iluminação ou substituição de lâmpadas, tendo em atenção o estabelecido no n.º 3 do artigo 29º, decorrerão por conta daquela os respectivos encargos.

Artigo 31º**Conservação das instalações de iluminação pública
e correspondentes encargos**

- 1- Compete à EDP Distribuição manter em bom estado de conservação as instalações de iluminação pública.
- 2- A EDP Distribuição suportará inteiramente os encargos de conservação dos aparelhos de iluminação e dos respectivos suportes, quer constituam ou não apoios da rede de distribuição, desde que sejam do tipo corrente.
- 3- Quando os aparelhos de iluminação ou os respectivos suportes não sejam do tipo corrente, a EDP Distribuição suportará os custos de conservação na mesma proporção em que participou nos encargos da sua instalação.
- 4- Quando a Câmara optar pela utilização de material não padronizado, a conservação e substituição das instalações referidas no número anterior constitui seu encargo, considerando-se padronizado, para os efeitos do disposto no presente artigo, o material qualificado como corrente à data da assinatura do presente contrato.
- 5- A Câmara e a EDP Distribuição poderão acordar na transferência da responsabilidade pela conservação das instalações de iluminação pública, mediante acordo a estabelecer entre ambas.

CAPÍTULO VI**Tarifas e condições de venda de energia****Artigo 32º****Tarifas**

A EDP Distribuição praticará no Município de Coimbra as tarifas de venda de energia eléctrica em baixa tensão oficialmente fixadas, de acordo com o preceituado no artigo 32º do Decreto-Lei n.º182/95, de 27 de Julho.

Artigo 33º**Fornecimento e condições de venda de energia eléctrica
em baixa tensão a instalações municipais**

- 1- A EDP Distribuição fica obrigada a fornecer energia eléctrica em baixa tensão às instalações do Município sem exigir que a Câmara participe em acções imediatas ou diferidas de reforço das redes, desde que a potência requisitada não exceda os valores previstos no nº 1 do artigo 10º.

- 2- À energia consumida pela Câmara será aplicado o tarifário em vigor, considerando-se incluída na iluminação pública a iluminação de monumentos, sendo a liquidação dos correspondentes débitos efectuada de acordo com as regras aplicáveis aos restantes clientes.

CAPÍTULO VII**Condições gerais de fornecimento de energia****Artigo 34º****Permanência e continuidade do fornecimento**

O fornecimento de energia eléctrica é permanente e contínuo, só podendo ser interrompido nos casos previstos nas leis e regulamentos em vigor, nomeadamente no nº 3 do artigo 5º do Decreto-Lei nº 184/95, de 27 de Julho.

Artigo 35º**Responsabilidade durante a interrupção**

As instalações de utilização deverão ser consideradas em tensão durante a interrupção do fornecimento de energia eléctrica, sendo da responsabilidade dos respectivos consumidores quaisquer acidentes ou avarias que resultem do restabelecimento do fornecimento.

CAPÍTULO VIII

Litígios e penalidades

Artigo 36º

Julgamento de litígios

- 1- Os litígios que se levantarem entre a Câmara e a EDP Distribuição sobre a execução ou interpretação das cláusulas do presente contrato de concessão serão julgados por uma comissão constituída por três árbitros, sendo um nomeado pela Câmara, outro pela EDP Distribuição e o terceiro por acordo dos outros dois.
- 2- Caso não haja acordo e para todos os outros aspectos de funcionamento da comissão seguir-se-ão os termos do Código de Processo Civil que regulam a constituição e o funcionamento do tribunal arbitral.

Artigo 37º

Penalidades

- 1- As faltas de cumprimento, por parte da EDP Distribuição, das obrigações impostas pelo presente contrato de concessão serão punidas, independentemente das eventuais compensações e das indemnizações devidas pelos prejuízos a terceiros, com multa cujo valor será obtido pelo produto de certo número de kWh pela taxa de energia de horas cheias da tarifa de energia eléctrica em baixa tensão que vigorar nessa data, nas seguintes condições:
 - a) Por alteração das características técnicas da distribuição, definidas no artigo 9º, quando a infracção, devidamente comprovada, se verifique por um período superior a 15 minutos consecutivos, uma multa de valor correspondente a 1.000 kWh por cada dia em que a alteração tenha lugar;
 - b) Por interrupção do fornecimento de energia em caso diferente de qualquer dos considerados no artigo 34º do presente contrato, uma multa de valor correspondente a 250 kWh por cada hora, ou fracção superior a 15 minutos, e por cada posto de transformação alimentador da porção de rede afectada; se a interrupção tiver lugar na localidade sede do Município, uma multa de valor correspondente a 500 kWh;

c) Pela não apresentação ou incumprimento reiterado do plano de obras, uma multa de valor correspondente a 5.000 kWh.

2- As multas são pagas mediante aviso prévio da Câmara e constituem receita municipal.

CAPÍTULO IX

Disposições finais e transitórias

Artigo 38º

Compensação de dívidas

A EDP Distribuição poderá efectuar a compensação de quaisquer créditos que tenha sobre a Câmara, incluindo os resultantes de fornecimento de energia eléctrica para iluminação pública, com o montante de rendas vencidas pela concessão.

Artigo 39º

Casos omissos

Os casos omissos serão regulados pela aplicação das leis e regulamentos em vigor ou pela concertação entre as partes.

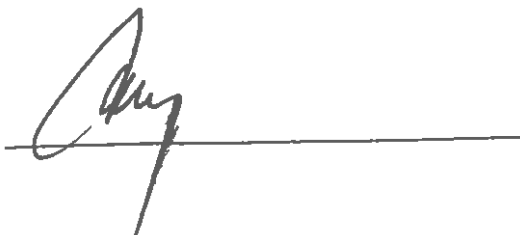
Artigo 40º

Obrigações extintas

O presente contrato de concessão substitui, para todos os efeitos e em todas as matérias e aspectos especificamente contemplados, o estabelecido no anterior contrato celebrado entre as partes, sem prejuízo da total validade deste até à data da sua substituição por aquele.

Coimbra, 03 de Junho de 2001

Pela Câmara Municipal
de Coimbra



Pela EDP Distribuição - Energia, S.A.



ANEXO I

Definição dos tipos "correntes" de focos luminosos a utilizar no Município

Para efeitos do estabelecido no artigo 29.º do presente contrato-tipo de concessão, adoptam-se como "correntes" os seguintes níveis de iluminação e tipos de armaduras, de lâmpadas e de apoios:

A - Zonas Rurais (Redes Aéreas e Subterrâneas)

A. 1. Iluminância e Uniformidades Globais Recomendadas

	Rede Subterrânea	Rede Aérea
- Centro, arruamentos e largos principais	15 lux	10 lux
- Periferias	10 lux	5 lux
- Uniformidade global (min/méd)	0.35	0.35

A.2. Lâmpadas

De arruamentos: VSAP 70 e 100W

De jardim: VSAP 70W e 100W
VM 80 e 125W

B - Zonas Urbanas e Sedes de Freguesia

B.1. Iluminância e Uniformidades Globais Recomendadas

- Arruamentos e largos principais	25 lux
- Periferias	20 lux
- Uniformidade global (min/méd)	0.4

B.2. Lâmpadas

De arruamentos: VSAP 70, 100, 150 e 250W

De jardim: VSAP 70W e 100W
VM 80 e 125W

C - Núcleos Antigos Delimitados

C.1. Iluminância e Uniformidades Globais Recomendadas

- Centro	20 lux
- Área envolvente	15 lux
- Uniformidade global (min/méd)	0.35

C.2. Lâmpadas

VSAP 70, 100,150 e 250W
VM 80 e 125W

D. Aparelhos de iluminação

D.1. Para Vias de Circulação Automóvel

D.1.1. Zonas não poluídas

Luminária fechada (com difusor), índices de Protecção mínimos:
compartimento de acessórios IP43, IK08
compartimento óptico IP54, IK08

D.1.2. Zonas de alta poluição

Luminária fechada (com difusor), índices de Protecção mínimos:
compartimento de acessórios IP43; IK08
compartimento óptico IP65; IK08

Nota: No caso da luminária ser de concepção tal que não haja uma distinção efectiva entre os dois compartimentos acima citados, isto é, por exemplo, no caso da abertura da tampa permitir o acesso não só ao compartimento óptico, mas também ao compartimento de acessórios, a luminária só terá um par de índices de protecção, que será, no mínimo o seguinte:

Se a luminária for para baixa poluição: IP54; IK08

Se a luminária for para alta poluição: IP65; IK08

Nota: Para efeitos da presente especificação, entende-se por zonas da alta poluição as seguintes:

- a) zonas perto da costa marítima
- b) zonas perto de complexos industriais
- c) zona urbanas com tráfego automóvel intenso
- d) zonas simultaneamente com características da alínea a) e/ou b) e/ou c).

As zonas de baixa poluição são todas as outras.

D .2. Para Jardins

Luminária Esférica (ou Bola), com índices de Protecção mínimos IP54; IK10, e 450mm de diâmetro, com equipamento (reflector) "anti-poluição luminosa".

D .3. Para Núcleos Antigos Delimitados

Material não padronizado, considerando-se, para efeitos de cálculo do encargo a suportar pela EDP Distribuição, os tipos correntes definidos nos pontos anteriores.

E. Braços e Colunas

E . 1. Para Redes Aéreas

Braços em tubo de ferro galvanizado, de acordo com o Projecto- tipo da Direcção Geral de Energia.

E .2. Para Redes Subterrâneas

Colunas metálicas galvanizadas a quente, de 8, 10 ou 12 m de altura útil, de secção octogonal, com braços idênticos, simples, duplos ou triplos, com comprimentos de 0.75 ou 1.25 m.

Colunas metálicas galvanizadas a quente, de altura útil 4 m, de secção octogonal.

E. 3. Para Núcleos Antigos Delimitados

Material não padronizado, considerando-se, para efeitos de cálculo do encargo a suportar pela EDP Distribuição, os tipos correntes definidos nos pontos anteriores.

**B RENEWAL OF THE CONCESSION CONTRACT FOR THE
DISTRIBUTION OF ELECTRICAL POWER IN LOW VOLTAGE IN
THE MUNICIPALITY OF COIMBRA - 2016**



ASSOCIAÇÃO NACIONAL
**MUNICÍPIOS
PORTUGUESES**



edp distribuição

PROTOCOLO

Entre:

ASSOCIAÇÃO NACIONAL DE MUNICÍPIOS PORTUGUESES (ANMP), com sede em Coimbra, na Avenida Marnoco e Sousa, 52, pessoa coletiva nº 501 627 413, neste ato representada por Manuel Augusto Soares Machado, na qualidade de Presidente do Conselho Directivo, adiante designada por ANMP;

e

EDP Distribuição - Energia, S.A. com sede na Rua Camilo Castelo Branco, nº 43, em Lisboa, com o capital social de € 200.000.000,00 (duzentos milhões euros), matriculada na Conservatória do Registo Comercial de Lisboa, com o número de matrícula e de pessoa coletiva 504 394 029, neste ato representada por João José Saraiva Torres, na qualidade de Presidente do Conselho de Administração, adiante designada por EDP Distribuição;

Em conjunto designadas por "Outorgantes",

Considerando que:

- A) A ANMP é uma associação de direito privado que tem como fim geral a promoção, defesa, dignificação e representação do poder local;
- B) A EDP Distribuição é a concessionária, em regime de serviço público, da exploração da rede nacional de distribuição de energia elétrica (em média tensão e alta tensão) e das redes de distribuição de energia elétrica em baixa tensão, no território do continente, por concessão, respetivamente, do Estado e dos Municípios, nos termos do Decreto-Lei n.º 29/2006, de 15 de fevereiro, com a redação que lhe foi dada pelo Decreto-Lei n.º 215-A/2012 de 8 de outubro, do Decreto-Lei n.º 172/2006, de 23 de agosto, com a redação que lhe foi dada pelo Decreto-Lei n.º 215-B/2012 de 8 de outubro;



- C) Enquanto concessionária da distribuição de energia elétrica em baixa tensão, de acordo com o disposto no contrato tipo de concessão aprovado pela Portaria nº 454/2001, de 5 de maio (doravante "Contrato Tipo de Concessão"), a EDP Distribuição é, designadamente, responsável pelo estabelecimento e, em regra, pela conservação das redes de iluminação pública dos municípios;
- D) Na prossecução da atividade referida no Considerando anterior, a EDP Distribuição tem vindo a instalar nas redes de iluminação pública os aparelhos de iluminação e respetivos suportes designados como "de tipo corrente" nos termos do Contrato Tipo de Concessão (doravante "Equipamentos de Tipo Corrente");
- E) Os Equipamentos de Tipo Corrente encontram-se identificados no Anexo I ao Contrato Tipo de Concessão, refletindo, ainda hoje, o paradigma tecnológico e de mercado de 2001;
- F) Nos termos do disposto no art.º 29º do Contrato Tipo de Concessão, o Anexo I pode ser revisto de cinco em cinco anos, se tal justificar, tendo em conta a evolução tecnológica e ou a redução dos custos e dos consumos, sem pôr em causa os níveis de iluminação aconselháveis;
- G) Nos termos do disposto no mesmo artigo, na definição de Equipamentos de Tipo Corrente, deverá ser, no entanto, tida em conta, para cada tipo de rede, a utilização de lâmpadas de adequado rendimento, com observância dos critérios de normalização e mais eficiente racionalização de energia;
- H) Tendo presente a evolução tecnológica e de mercado verificada nos aparelhos de iluminação e respetivos suportes desde 2001 e, nomeadamente, o grau de maturidade atingido pelas luminárias com tecnologia LED, a ANMP e a EDP Distribuição entenderam como oportuno proceder à revisão do Anexo I ao Contrato Tipo de Concessão;
- I) A ANMP e a EDP Distribuição pretendem formalizar o respetivo acordo quanto à nova redação do Anexo I ao Contrato Tipo de Concessão



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edp distribuição

decorrente do trabalho conjunto levado a cabo na sequência da manifestação referida no Considerando anterior;

Nestes termos, é celebrado o presente Protocolo ("Protocolo"), que se rege pelas seguintes cláusulas:

Cláusula Primeira

(Objeto)

Pelo presente Protocolo, os Outorgantes acordam na alteração do Anexo I ao contrato tipo de concessão da distribuição de energia elétrica em baixa tensão, aprovado pela Portaria nº 454/2001, de 5 de maio, nos termos da nova redação constante do Anexo A ao presente Protocolo e que dele faz parte integrante ("Novo Anexo I").

Cláusula Segunda

(Adesão dos municípios ao Novo Anexo I)

1. O Novo Anexo I será aplicável aos municípios, mediante a celebração de Protocolo para o efeito, entre cada município e a EDP Distribuição, sem prejuízo do disposto na Cláusula seguinte.
2. A ANMP e a EDP Distribuição envidarão os seus melhores esforços no sentido de facilitar a adesão dos municípios ao Novo Anexo I e a boa aplicação do mesmo, prestando-lhes todas as informações e esclarecimentos necessários e, bem assim, todo o acompanhamento adequado.
3. Tendo presente o disposto no número anterior, a ANMP procederá à divulgação do Novo Anexo I junto dos municípios seus associados, disso dando conhecimento à EDP Distribuição.

Cláusula Terceira

(Condição para a aplicação do Novo Anexo I)

1. A aplicação do Novo Anexo I aos contratos de concessão dos municípios que a ele pretendam aderir terá início mediante a assinatura de protocolo entre o Município e a EDP Distribuição.
2. O disposto em 1 ficará condicionado parcialmente para o tipo de luminárias LED inscrita nos itens B.2 e B.3 do anexo a este protocolo, até à conclusão dos procedimentos necessários para a aquisição, pela EDP Distribuição, dos aparelhos de iluminação e respetivos suportes nele previstos, nos termos consagrados na legislação aplicável e, bem assim, à existência de stock adequado dos mesmos para fazer face às necessidades dos municípios.

Cláusula Quarta

(Vigência)

O presente Protocolo entra em vigor na data da respetiva assinatura.

Cláusula Quinta

(Modificação ou Cessação do Protocolo)

O presente Protocolo só poderá ser modificado ou cancelado com o consentimento expresso de ambos os Outorgantes, por documento escrito, mencionando a vontade em modificá-lo ou cancelá-lo.

Este Protocolo é celebrado em dois exemplares, sendo um para cada um dos Outorgantes.

Coimbra, 13 de Setembro de 2016.



ASSOCIAÇÃO NACIONAL
MUNICÍPIOS
PORTUGUESES



distribuição

ANMP

EDP Distribuição - Energia, S.A.

Novo Anexo I

Definição dos tipos «correntes» de níveis de iluminação, luminárias, lâmpadas, apoios e braços a utilizar na iluminação pública do Município.

Para efeitos do estabelecido no artigo 29º do presente contrato tipo de concessão, adotam-se como «correntes» os seguintes níveis de iluminação, tipos de luminárias, lâmpadas, apoios e braços.

A- Níveis de iluminação e uniformidade global recomendada

A.1 – Zonas rurais e semiurbanas onde predomina a rede aérea

Zonas a iluminar	Emedmin (lux)	Emin, (lux)	U _o min (%)	Fluxo (lm)
Centro, arruamentos e largos principais	15	5	0,33	5600 ≤ ∅ ≤ 16500
Núcleos antigos delimitados	10	3	0,30	3100 ≤ ∅ ≤ 10500
Arruamentos secundários, passagens subterrâneas e viadutos	7,5	1,5	0,20	
Periferias	5	1	0,20	2100 ≤ ∅ ≤ 6600

$$U_o = E_{min}/E_{med}$$

A.2 – Zonas urbanas e semiurbanas onde predomina a rede subterrânea

Zonas a iluminar	Lmed min. (cd/m ²)	U _{omin} (%)	U _L min (%)	Fluxo (lm)
Centro, arruamentos, largos principais e núcleos antigos delimitados.	1,5	0,4	0,7	8900 ≤ ∅ ≤ 30000
Arruamentos secundários, passagens subterrâneas e viadutos.	0,75	0,4	0,7	4200 ≤ ∅ ≤ 16500
Periferias	0,5	0,35	0,4	3100 ≤ ∅ ≤ 6600

$$U_o - \text{uniformidade geral e } U_L - \text{uniformidade longitudinal; } U_o = L_{min}/L_{med} ; U_L = L_{min}/L_{max}$$

A.3 Jardins, parques públicos e zonas de lazer

Zonas a iluminar	Emed min lux	Emin (lux)	Fluxo (lm)
Jardins, parques públicos e zonas de lazer	10	3	1200 ≤ ∅ ≤ 10500

B – Tipos de luminárias, lâmpadas e sua aplicação

As tecnologias de lâmpadas a aplicar nas luminárias são:

- Lâmpada de vapor de sódio de alta pressão (VSAP) de potências de 50W, 70 W, 100 W, 150 W e 250 W;
- LED (Light Emiting Diode) com temperatura de cor compreendida entre 3000 K e 5000 K.

As luminárias LED apenas são consideradas material de tipo corrente para os casos de: i) estabelecimento de novas redes de iluminação pública (IP), ii) substituição de luminárias com lâmpadas de vapor de mercúrio, decorrente da remodelação de redes de IP, seja por iniciativa da Câmara, seja por iniciativa do concessionário e iii) substituição de luminárias obsoletas ou em más condições de conservação, conforme validado pelo concessionário. Neste último caso, se a substituição se referir a luminárias pontuais e não a um circuito inteiro, a Câmara poderá optar pela respetiva substituição por luminárias de vapor de sódio.

Nas luminárias LED a aplicar na proximidade de hospitais, em parques naturais, observatórios, áreas de proteção especial ou outras zonas justificadamente indicadas no Plano Diretor Municipal de Iluminação Pública como zonas especialmente sensíveis à poluição luminosa, o ULOR¹ não deve ultrapassar 1% para todas as classes de iluminação.

As lâmpadas serão utilizadas de forma a garantir os níveis de iluminação previstos em A.

B.1 - Luminárias de utilização universal

B.1.1 – Luminária equipada com lâmpada VSAP:

Fechada (com difusor), com ULOR <3% e com os seguintes graus de proteção mínimos:

- Compartimento de acessórios: IP43 e IK06;
- Compartimento ótico: IP65 e IK06.

B.1.2 – Luminária equipada com módulo (s) de LED

Luminária equipada com módulo (s) de LED e driver, com ULOR <3% e com os seguintes graus de proteção mínimos:

- Compartimento ótico inclui o módulo de LED: IP66 e IK06;
- Existindo compartimento de acessórios: IP54 e IK06. Caso o compartimento de acessórios inclua driver, o mesmo deve possuir IP65.

¹ ULOR (Upward Light Output Ratio) razão entre o fluxo emitido para cima sob condições específicas com a(s) fonte(s) de luz e com essa(s) mesma(s) fonte(s) operando fora da luminária.

B.2 - Luminárias para jardins, parques públicos e zonas de lazer

Em jardins, parques públicos e zonas de lazer a Câmara pode optar por luminárias diferentes das definidas em B.1., são alternativas as seguintes luminárias:

B.2.1 – Luminária equipada com lâmpadas VSAP

Luminária com difusor de forma esférica com calote superior opaca, de diâmetro de 450 a 500 mm, ou com outra configuração, com grau de proteção mínimos IP54 e IK08, e com ULOR <15%.

B.2.2 - Luminária equipada com módulo (s) LED

Luminária com difusor de forma esférica, com calote superior opaca de diâmetro 450 a 500mm ou com outra configuração, equipada com módulo de LED e driver, com ULOR <5% e com os seguintes graus de proteção mínimos:

- Compartimento ótico inclui o módulo de LED: IP66 e IK08.
- Existindo compartimento de acessórios: IP54 e IK08. Caso o compartimento de acessórios inclua driver, o mesmo deve possuir IP65.

Caso a Câmara opte pela instalação destes modelos LED, a aquisição será efetuada pelo concessionário e o custo correspondente será repartido igualmente entre a Câmara e o concessionário.

B.3 – Luminárias para núcleos antigos delimitados:

Em núcleos antigos delimitados a Câmara pode optar por luminárias diferentes das definidas em B.1., são alternativas as seguintes luminárias:

Luminárias tipo lanterna clássica de 4 ou 6 faces e do tipo troncocónicas ou esféricas com calote superior opaca, equipadas com módulo de LED e driver, com ULOR <5% e com os seguintes graus de proteção mínimos:

- Compartimento ótico inclui o módulo de LED: IP66 e IK08.
- Existindo compartimento de acessórios: IP54 e IK08. Caso o compartimento de acessórios inclua driver, o mesmo deve possuir IP65.

Caso a Câmara opte pela instalação destes modelos LED, a aquisição será efetuada pelo concessionário e o custo correspondente será repartido igualmente entre a Câmara e o concessionário.

C - Apoios e braços

C.1 - Para redes aéreas:

Postes de betão ou de madeira de 8 m, 9 m, 10 m e 12 m.

Braços em tubo de ferro galvanizado a quente, de diâmetro exterior 42mm e com projeções horizontais de 0,450 m, 0,750 m ou 1,250 m.

C.2 - Para redes subterrâneas:

C.2.1- Para vias de circulação automóvel

Colunas metálicas galvanizadas a quente de 6 m, 8 m, 10 m ou 12 m de altura útil, de secção octogonal ou tronco cónica, com ou sem braços. Havendo braço este deve ter igual geometria à da coluna e na zona de fixação da luminária o seu diâmetro exterior deve ser de 60 mm. O braço pode ser simples, duplo ou triplo, devendo cada um destes tipos ter projeções horizontais, respetivamente, de 0,450 m, 0,750 m ou 1,250 m.

C.2.2 - Para jardins e zonas de lazer

Colunas metálicas galvanizadas a quente de 4 m e 6 m de altura útil, de secção com geometria igual à anterior e com diâmetro exterior na parte superior igual a 60 mm. Havendo necessidade de braço, este deverá possuir a mesma geometria da coluna.

C.3- Para núcleos antigos delimitados

As luminárias são instaladas em colunas de 4 e 6 metros ou em consolas fixadas à parede.

Notas interpretativas

Nota interpretativa 1: Os encargos com a iluminação pública, a cargo do concessionário, serão objeto do plano de obras para a iluminação pública, a apresentar anualmente pelo concessionário.

Nota interpretativa 2: O investimento do concessionário em iluminação pública, com o enquadramento e limites definidos no contrato de concessão, inclui, designadamente, os custos suportados com a aquisição e instalação de luminárias e colunas.

Nota interpretativa 3: A aquisição de luminárias, lâmpadas, apoios e braços a utilizar na iluminação pública será, por regra, efetuada pelo concessionário no âmbito de procedimentos concursais com observância da legislação aplicável. A aquisição ou a instalação de equipamentos de iluminação pública que não estejam a cargo do concessionário deverão ser previamente acordadas por este, que definirá as especificações técnicas e condições aplicáveis.

C BEST PRACTISE PUBLIC LIGHTING - DARK SKY IRELAND



Executive Summary

The drive to reduce both costs and carbon production from public lighting is leading to the national adoption of more energy efficient light emitting diode (LED) lighting. Due to the longevity of LED lamps (typically 25 years), any equipment installed now will have a long-term effect, so we have a responsibility to implement the best choice in terms of lighting as well as its wider impact based on an informed balance of current evidence.

There are environmental and health impacts with high temperature LEDs containing more “blue-rich” light.

We promote the adoption of lower temperature (warmer colour) lighting, which provides the best balance of cost saving, road and personal safety through better balanced light and improved perception, as well as reducing environmental impact. We encourage both “trimming” (part-night lighting) and “dimming” policies to reduce the light burden in the night-time environment and, at the same time, produce significant cost savings.

Recommendations

These are in line with developing best environmental practice in other locations in the UK, across Europe, and globally and will make the most of the benefits of new LED technology. The following recommendations meet government obligations to reduce energy use, cost, and carbon emissions:

- Maximum energy can be saved through not lighting areas, therefore careful consideration should be given to evaluating the requirement for lit areas;
- Up to 30% savings are possible through careful lighting design;
- Current lighting installations are designed to maximum light level required, i.e. for maximum traffic. Timing and duration should be limited to when needed through “trimming” (also called “part-night lighting”) and/or level (through dimming);
- As light travelling close to, or above the horizontal, impacts strongly on the environment we recommend full cut-off lighting, with such lights having no light emitted above the horizontal, and with the minimum practical emitted within twenty degrees of the horizontal;
- Blue light in LEDs should be limited to warmer-coloured lighting (so-called “warm white” light, i.e. light with a Correlated Colour Temperature (CCT) at or below 3000K;
- The impact of existing “neutral white” light installations (i.e. lighting with CCT approx. 4000K) can be reduced by a reduction in the level of lighting, as described in UK British Standard 5489 which takes account of the influence of this light on night vision;
- Local authorities should have autonomy to reduce light levels or spectrum (such as the adoption of amber lighting) for the benefit of tourism, biodiversity and citizen wellbeing;
- A consistent local and national approach should be adopted so that lighting from national routes, for instance, does not undo the effects of improved local lighting.

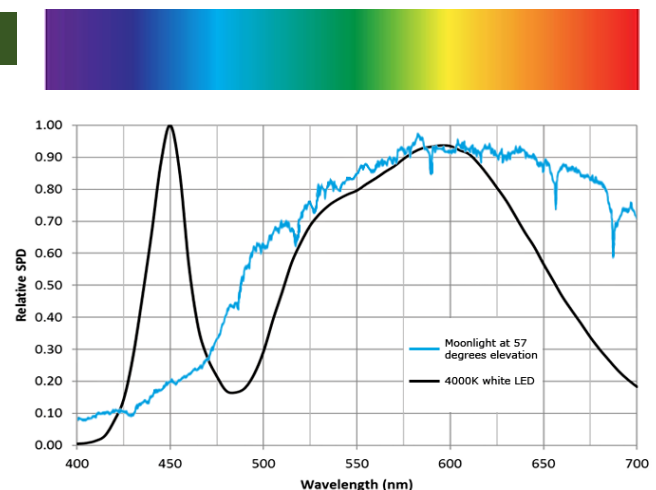


Figure 1 This figure shows a comparison between the intensity across the spectrum of a typical 4000K LED and that of the Full Moon when highest in the sky. The band at the top shows the colour at each point of the spectrum. Although it is sometimes said that such LED light is similar to moonlight, note that the LED output is significantly different in terms of both spectrum and intensity.

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PUBLIC LIGHTING

Visual perception

The purpose of street lighting is to permit better vision at night, while at the same time limiting the deleterious effect of the light itself, e.g. glare. Studies have shown that near-perfect colour discrimination is achieved for warm white lighting and does not improve significantly as the colour temperature is increased further.¹ On the contrary, the blue content of higher temperature lighting triggers contraction of the eye's pupil and subsequent dark adaptation time increases which can lead to poorer vision when passing beyond the lit area. Glare issues and eye response issues are even more important for older people.

Blue-rich lighting also scatters more in the atmosphere (e.g. the sky's colour is the result of scattered blue light from the Sun) and this scattered light affects darker regions nearby.

The best overall balance between visibility under all weather conditions, colour reproduction and glare has been found to be for LED light with a CCT of approximately 3000K.

Public Opinion

In conjunction with the Irish Times we have conducted a Citizen Science questionnaire which received 464 responses from Irish residents. Responses from city inhabitants noted changes in both night-time bird behaviour and the natural activity of insects, bats and foxes, with a moderate association between bird behaviour and the increase in local light over the recent past.² Elsewhere in Europe, residents report that public lighting was the most commonly identified source of light pollution and that commercial lighting was the most annoying source of light-at-night in a predominantly urban and educated sample with a high level of interest in astronomy (Lyytimaki and Rinne, 2013).

Safety

Anecdotally, current "neutral white" (CCT = 4000K) lighting is regarded as harsh and overly bright to the eye even when installed to the same level of lighting (lux level) as the units it replaces. The result is strong glare from the lighting source along with dark shadows, leading to higher contrast and lower lighting quality. Additionally, perceived safety correlates with better colour reproduction found in warmer white lighting as it is closer to a daylight balance. A major UK study has found that neither the move to part-night lighting nor dimming has had any impact on either traffic collisions or crime rates.³

Environmental

Ireland's nine bat species account for approximately one third of our native mammal species and are protected by law. Their insect prey, with a lifetime of one to two years, are particularly vulnerable to population changes and are strongly affected by the blue content of light. Larger declines in nocturnal insects have been seen relative to daytime species, though a recent study has implicated light pollution in the overall strong overall decline of all types of insects.⁴

Other diurnal species can also be affected by night-time light. For example, salmon will not pass a light barrier where the light intensity is comparable to full moonlight and are also sensitive to light at the blue end of the spectrum. Consideration should be given to the restriction of light level and duration in areas close to waterways, e.g. by rivers and on bridges and the use of warmer colour light. These waterways are also feeding zones for bat species.

The decline in biodiversity and insect populations was mentioned in a recent Dáil statement by the Minister for Culture, Heritage and the Gaeltacht when she expressed her commitment to encourage councils to maintain biodiversity. In the same statement she announced that the Government is creating a legal onus, or a biodiversity duty, on public bodies to have regard to policies, guidelines, and objectives to promote the conservation of biodiversity and the National Biodiversity Action Plan.⁵

Footnotes:

¹ Jin, H, Jin, S., Chen, L, Cen, S. and Kun, Y. 2015 "Research on the Lighting Performance of LED Street Lights With Different Color Temperatures," 7 (6), December 2015. <https://ieeexplore.ieee.org/document/7328247>

² <https://www.irishtimes.com/news/science/help-scientists-understand-the-influence-of-light-on-the-environment-1.3416898>

³ Local Authority Collaborators' National Evaluation of Reduced Night-time Streetlight (LANTERNS)

⁴ <https://doi.org/10.1016/j.biocon.2019.108259>

⁵ <https://www.oireachtas.ie/en/debates/debate/dail/2019-05-29/35/>

PUBLIC LIGHTING

Best Practice

In response to an American Medical Association report on the potential health impact of blue-rich lighting a number of major North American cities, including Montreal, San Diego and New York have abandoned plans to install 4000K LED street lights and instead adopted lamps with CCT of 3000K – or lower in some instances – which are endorsed by the AMA.¹ On the other side of the world, a number of New Zealand councils have installed warm white lighting of 3000K due to demand from citizens, with 2200K units in more environmentally sensitive areas.² The International Dark Sky Association anticipates that a move to 2700K lighting may become the norm over the next several years.³

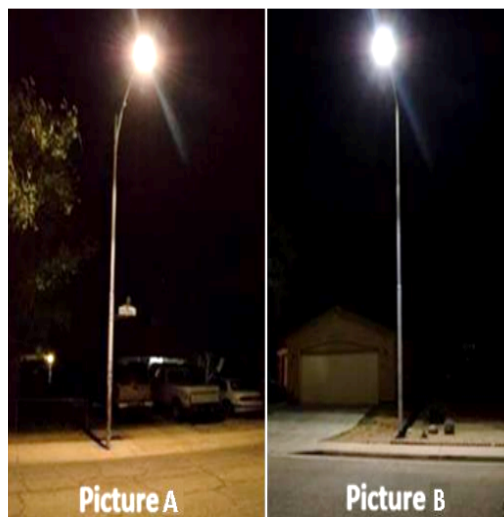
As an example of costs due to correcting lighting issues, the City of Davis in California was half way through an LED street relighting initiative when forceful complaints from residents halted the project. After public review of several alternatives, the streetlights selected are lower brightness and, at 2700K, much warmer. As many of high-CCT luminaires had already been installed under the original plan, the additional cost to the city for retrofitting these was \$350,000.⁴

Concerns for the implications of blue-rich lighting are raised in the UK's Chief Medical Officer's report for 2017. This document dedicates a full page to light pollution and health, referencing LEDs and blue rich lighting with the following comment:

"Local authorities [in the UK] have been replacing mercury and sodium street lights with LEDs. If this is done purely on the basis of energy efficiency and cost, it is possible to end up with installations that may not be fit for purpose."

The widespread installation of LEDs has taken place in a relatively short pace of time due to the rapid development of light technology and without assessment for environmental impacts. UNESCO's Earth Charter states the prevention of harm before it happens *"is the best method of environmental protection. When knowledge is limited, apply a precautionary approach:*

- Take action to avoid the possibility of serious or irreversible environmental harm even when scientific knowledge is incomplete or inconclusive.
- Place the burden of proof on those who argue that a proposed activity will not cause significant harm, and make the responsible parties liable for environmental harm."



Warm White
3000 kelvin

Neutral White
4000 kelvin

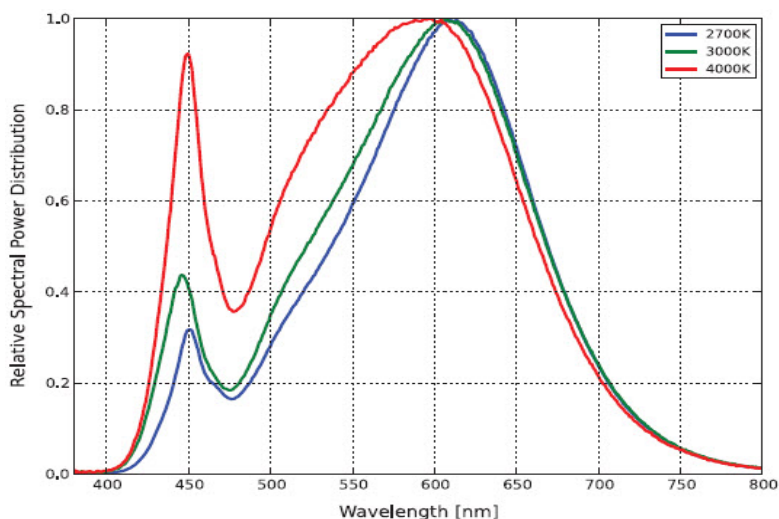


Figure 2 Adoption of 3000K lighting rather than 4000K results in a 37% reduction in blue light; moving to 2700K (suggested for more sensitive areas) provides a 48% reduction. The appearance of warm white and neutral white lighting is shown at night.

Footnotes:

¹ <https://luxreview.com/article/2017/02/will-tunable-street-lighting-first-silence-led-critics->

² <http://rnz.co.nz/news/national/403751/otago-to-get-lower-level-more-expensive-led-street-lights?fbclid=IwAR2pTb1TYyZLI6k0U7Vkb3QETA-iIH3XVPZuLyISWI0aNZLmHMK9IbXhMkg>

³ <http://darksky.org/our-work/lighting/lighting-for-citizens/3k/#list>

⁴ <https://www.lightshowwest.com/eco-effects-of-high-cct-led-lighting-outdoors-building-a-case>

The EU Commission's Green Public Procurement (GPP) document is intended to advise decision makers on implementation once the decision is taken to install new lighting. In terms of lighting levels it adheres to the principle of "as low as reasonably achievable" (ALARA) and also recommends that warmer colour LEDs be installed to restrict impacts on wildlife and sky quality as well as potential effects on human health. The document also recommends the installation of LEDs with CCT values of 3000K or less. The document also states that potential impacts on wildlife and skyglow, as well as human health, are sufficient justifications to set restrictions on blue light.

At least five EU countries have either enacted legislation or are adopting practices that restrict both the amount and blue content of public lighting. Warm white light with a CCT of 3000K or less will be the advised upper limit across these jurisdictions, with even lower temperature lighting down to 2200K or less (similar to current high pressure sodium lighting) being required in national parks or other sensitive habitats. In the UK the lighting industry is moving away from 4000K lighting and to 3000K, and the lighting industry is likely to move to even lower values over the next few years.

Warm white LED lighting with CCT of 3000K has been installed in Ballycroy, Co. Mayo, and Mallow, Co. Cork and both locations have been positively received. Both Kerry and Mayo County Councils are planning warm white lighting of 3000K or less to protect their dark sky areas and promote sustainable tourism.

Practical Guidelines

The information outlined in this document can probably be best summarised using the guidelines produced by the EU COST Action Loss of Night Network (LoNNe) to combat light pollution and a precautionary standpoint suggests these are also good guidelines from the points of view of environmental and human health aspects as well as in terms of energy-efficiency:¹

1. Every light needs to be justifiable
2. Limit the use of light to when it is needed
3. Direct the light to where it is needed
4. Reduce the light intensity to the minimum needed
5. Use light spectra adapted to the environment
6. When using white light, use sources with a "warm" colour temperature (less than 3000K)

In 2017 the High Court recognised the constitutional right to protect the environment and the precautionary principle is enshrined as one of the fundamental principles of the European Union.² We have a global responsibility to reduce our carbon emission as well as save costs and our national strategy to reduce public lighting impacts relies on the changeover to LED lighting. What we must not forget, however, is that the actions to reduce both energy use and carbon output have been taken with the aim of protecting the environment, hence we should consider the potential environmental consequences of our choices in the long-term.

We therefore recommend the adoption of lower CCT (warmer) lighting, which provides the best balance between efficiency, safety, and environmental impact.

The introduction of the current LED lighting, with a growth in installed units from a few percent to 16% over the past four years has resulted in an increase in intensity and blue-rich content, is a phenomenal change which has an environmental impact.

As an island nation, movements from adjacent areas cannot replace damage to our native species so we have an imperative to protect them in situ.

Dark Sky Ireland strongly urges the use of warm white lighting with a maximum CCT of 3000K, and lower values in more sensitive areas such as National Parks and conservation regions.

Given environmental, health and economic imperatives the onus should be on justifying the installation or increase of lighting rather than justifying its removal.

In practical terms, we recommend the adoption of the recommendations of the Campaign to Protect Rural England³ which were developed from the responses of 83 local authorities. Lighting policy documents, including designation of environmental zones, should be developed by each authority to provide a practical framework and to address potential legal issues.

Footnotes:

¹ EU Collaboration on Science & Technology ES1204
<http://www.cost-lonne.eu/recommendations/>

² <https://www.ecologic.eu/1126>

³ Campaign to Protect Rural England "Shedding Light"
https://www.cpre.org.uk/wp-content/uploads/2019/11/Shedding_light_leaflet.pdf

D WIRELESS NETWORKS FOR IOT



Cellular IoT

NB-IoT, LoRaWAN:
Análise comparativa

DSM | JAN22

Wireless Networks para IoT

Análise comparativa

Low Power Wide Area (LPWA) é uma categoria de redes wireless especificamente concebidas para a Internet das Coisas (IoT).

As tecnologias LPWA são adequadas para aplicações ou casos de uso IoT que dependem de elevada eficiência energética, baixo custo de hardware para implementações de larga escala com necessidade de cobertura elevada e, potencialmente também dentro de edifícios.

Nos últimos anos, várias tecnologias LPWA estabeleceram-se no mercado.

- **NarrowBand Internet of Things**
(NarrowBand IoT, NB-IoT, LTE Cat-NB)
- **Long Range Wide Area Network (LoRaWAN)**

Exemplos de casos de uso

- **Smart Metering**
(contadores, sensores em caves)
- **Smart Parking**
(estacionamentos conectados, sensores no chão e/ou garagens de cave)
- **Smart Waste Management**
(contentores de lixo municipais conectados)
- **Asset Tracking**
(casos de track and trace, de âmbito nacional de ativos de transportes como porta contentores, contentores, paletes)
- **Connected Buildings**
(sensores em pontes ou túneis, medindo temperatura, humidade e corrosão e identificando vulnerabilidades muito antes de ocorrerem danos visíveis)
- **Condition Monitoring**
(sensores em máquinas de construção e veículos, identificando cenários de avarias ou roubo)

Wireless Networks para IoT

Destaques



UE Type	Sigfox	LoRa	LTE-NB1/NB2	EC-GSM-IoT	LTE-CatM1	LTE-Cat0	LTE-Cat1
Standardization	proprietary	proprietary	3GPP-R13/14/15	3GPP-R13	3GPP-R13/14/15	3GPP-R12	3GPP-R8
Spectrum	Unlicensed 900MHz	Unlicensed 900MHz	Licensed GSM Licensed LTE	Licensed LTE	Licensed LTE	Licensed LTE	Licensed LTE
Channel bandwidth	100Hz	<125KHz	180KHz	200KHz	1.4-20MHz	1.4-20MHz	1.4-20MHz
Peak Data Rate (indicative)	<100bps	<50Kbps	<60Kbps <160Kbps	<74Kbps	<1Mbps	<2Mbps	<10Mbps
Device Peak Tx Power	14dBm	14dBm	23/20/14dBm	33/23dBm	23/20dBm	23dBm	23dBm
Latency peak	10s	10s	200ms-30s	500ms	100-150ms	10-30ms	10-30ms
MCL(Maximum Coupling Loss)	160dB	157dB	164dB	164dB	156dB	144dB	144dB
Mobility	low	low	Low-medium	high	high	high	high
Device Power Consumption	low	low	low	low	low-medium	low-medium	medium
Security	low	medium	high	high	high	high	high

Source: 3GPP, Lora Alliance, Huawei, Nokia, Ericsson.



Fiabilidade

Probabilidade da transmissão de dados ser bem sucedida

NB-IoT utiliza a gama de frequências LTE licenciada de um operador móvel, evitando interferências de outros dispositivos. **LoRaWAN**, por outro lado, tem de transmitir através de gamas de frequências gratuitas e geralmente acessíveis, propensas a interferências causadas por outros utilizadores.

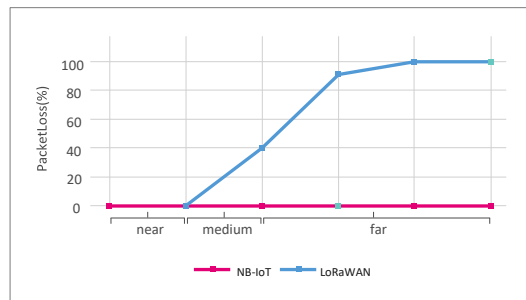
Technical Data	NB-IoT (NB2)	LoRaWAN
Technology	open standard	proprietary
Licensed spectrum	yes	no
Max data rate (gross)	160 kbit/s (avg 60kbps)	5,47 kbit/s (SF7)
Worst case data rate (~144 dB link budget)	5-6 kbit/s	0,297 kbit/s (SF12)
Max. payload length (data per message)	> 1.000 B	51 B
Downlink capacity	unlimited	very low
Link budget / max. path loss (Uplink)	164 dB	141-146 dB
Link budget / max. path loss (Downlink)	164 dB	151-156 dB

Source: Naumann H. & Oelers W. (2020)

A NB-IoT é a mais eficaz tecnologia de transmissão de dados.

LoRaWAN tem menos capacidade, traduzindo-se em uma transmissão menos fiável.

Packet loss per transmission distance (near/medium/far)



Source: "Test and Measurement of LPWAN and Cellular IoT Networks in a Unified Testbed." Sebastian E. J, Sikora A. (2019)



Rendimento

Quantidade de dados que podem ser enviados

NB-IoT não tem regras que limitam a capacidade de transmissão de dados. Limites para o **volume de dados** que pode ser **enviados por dia** são definidos apenas pela vida útil de serviço da bateria do dispositivo, condições de transmissão desfavoráveis ou para salvaguardar a qualidade da rede móvel.

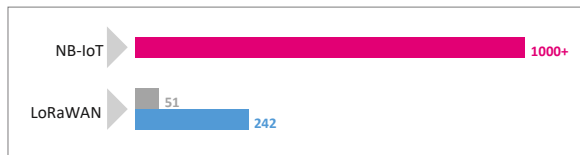
A disposição legal de *duty cycle* para o **LoRaWAN** adiciona limites para evitar a sobrecarga da rede.

Upload: Se com o LoRaWAN, o *duty cycle* (1%) impõe limites estritos, com o NB-IoT, não estando sujeito a limitações técnicas ou legais, são possíveis volumes de dados por mensagem superiores a 1 quilobyte.

Download: NB-IoT também permite a recepção em downlink de pacotes de dados maiores. Com LoRaWAN, atualizações de firmware são mais limitadas. Atualizações de firmware levam a maior consumo de energia, limitando mais a capacidade de downlink do LoRaWAN quando comparado com NB-IoT.

Para **uploads, downloads, volumes de dados por dia ou por mensagem ou o número de mensagens por dia**, o NB-IoT lidera em todos os aspetos.

Max. payload uplink (byte)



■ Spreading Factor 10 ■ Spreading Factor 7/8

Source: Naumann H. & Oelers W. (2020)

Alcance

Até onde as mensagens podem ser transmitidas

O ruído e a interferência têm um impacto negativo na utilização de LoRaWAN. Em contrapartida, a capacidade inerente ao NB-IoT da capacidade de envio de dados tantas vezes quanto necessário, é uma vantagem decisiva no que diz respeito ao nível de alcance.

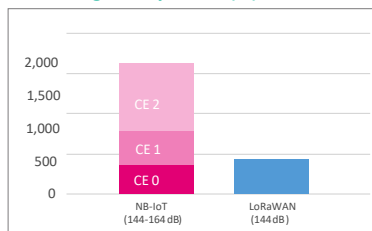
Num cenário típico de uso urbano, um dispositivo NB-IoT pode transmitir muito mais longe do que um dispositivo LoRaWAN sobre o qual ruídos e/ou interferências têm um impacto significativo.

A transmissão de dados NB-IoT tem um nível mais elevado de fiabilidade, especialmente em caves, onde o LoRaWAN em particular, está em grande desvantagem devido a potenciais fortes interferências causadas por outros utilizadores (e.g. centro comercial ou um parque empresarial)

NB-IoT pode até mesmo melhorar a penetração em edifícios usando uma funcionalidade de Coverage Enhancement.

NB-IoT: melhor cobertura e fiabilidade

Max. range in city indoor (m)



Coverage Enhancement (CE) Levels: CE 0 = good CE 1 = medium CE 2 = poor
Source: Naumann H. & Oelers W. (2020)

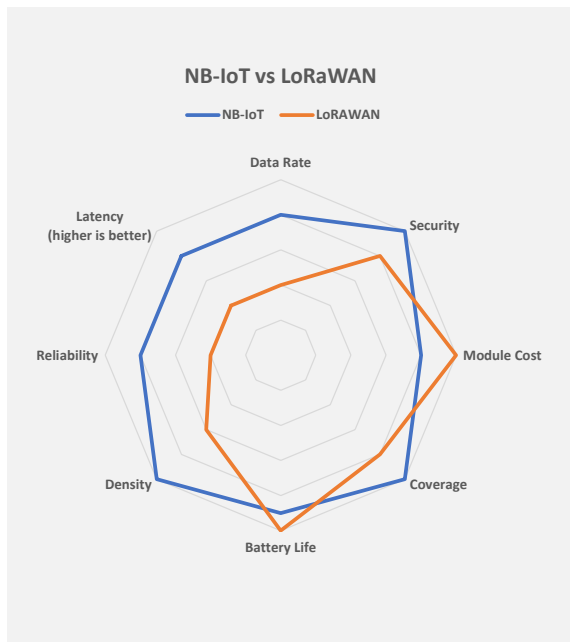
Test scenario:

- Large/Medium City (Hata Propagation Model)
- One Wall between Basestation/ Gateway & Device
- 28 dB Loss (Penetration Loss, Fading)
- Basestation/Gateway Height: 30m
- Device Height: 1m
- Bidirectional transfer with acknowledgement (UL/DL)



Wireless Networks para IoT

One size does not fit all



NB-IoT: Quantidade massiva de sensores, ligados a velocidades e fiabilidade mais elevadas

Melhor performance, latência de dados inferior, maior fiabilidade da comunicação e maior densidade dispositivos; Custo algo mais elevado para chipsets e implementação. Implementações nacionais

LoRaWAN : baixo custo em cenários de velocidades mais baixas e comunicações menos fiáveis

Muito baixas velocidades; menor mobilidade, menor fiabilidade e densidade; chipsets e soluções de baixo custo; casos mais locais, menos críticos

LoRa Caveats vs. NB-IoT

Espectro não licenciado: propenso a interferências, menor potência de emissão permitida, menor capacidade

Lower Throughput & higher latency: rendimento muito baixa, duty-cycle limitado, download limitado, aplicações com poucas necessidades de transmissão de dados

Security & Reliability: nível mais baixo de normalização, dispositivos de custo mais baixos, mais propensos a falhas de segurança



**E PUBLICATION ON 20 APRIL 2023 BY THE MEDIA OUTLET
MUNDIAL FM ABOUT THE STREET LIGHTING TESTS THAT WILL
TAKE PLACE THAT DAY**



No âmbito do projeto “FlexIP”, uma solução de iluminação pública LED que a Câmara Municipal (CM) de Coimbra está a implementar com a E-Redes na Quinta de S. Jerónimo e na Baixa da cidade, vão realizar-se, hoje, dia 20 de abril, testes na Quinta de S. Jerónimo para medir se os valores obtidos com a redução da iluminação em dois patamares se enquadram nas normas europeias. Simultaneamente, na Baixa, na rua do Moreno, vão introduzir-se multisensores de movimento, para gerir a intensidade da iluminação.

As alterações na iluminação na Quinta de S. Jerónimo vão decorrer a partir das 20h50 de hoje, dia 20 de abril, com uma redução de 25%, posteriormente, às 21h35, vai reduzir-se mais 25%, de modo a testar uma redução efetiva de 50%, sendo que a partir das 22h20 será restabelecida a normalidade. Este procedimento visa tornar o sistema de iluminação mais eficiente, sem comprometer a segurança e o conforto dos moradores e utentes da zona. Nesse sentido, a CM de Coimbra vai envolver a Associação de Moradores nesta iniciativa. Simultaneamente, na Baixa, na rua do Moreno, vão introduzir-se multisensores de movimento, para gerir a intensidade da iluminação.

Estes testes inserem-se no projeto “FlexIP”, que está a servir de base para a tese de Mestrado “Coimbra Smart City Through a Public Lighting Network”, denotando, mais uma vez, como o Município se articula com as instituições de ensino superior em prol do desenvolvimento da cidade. O projeto “FlexIP” torna a iluminação pública mais eficiente e reduz os consumos

elétricos e custos com energia na ordem dos 70 por cento. Com este piloto cria-se uma rede inteligente, em zonas específicas que, a par com outros projetos em curso, reforçam Coimbra como um laboratório vivo de experimentação, introduzem soluções de gestão inteligente e sustentável, como sensores para “rega inteligente”, contagem de veículos, temperatura, humidade, medição de CO2 e de partículas.

As novas luminárias – já foram substituídas 170 na Quinta de S. Jerónimo e 100 na Baixa – têm um sistema (“cut off”) que permite rentabilizar o funcionamento, emitindo luz somente para onde ela é necessária, ou seja, para o pavimento e não para os edifícios. As luminárias são, também, dotadas de um sistema de controlo (ponto-a-ponto) que permite comandar cada luminária individualmente. Ao que acresce ainda o facto de a tecnologia LED ser radicalmente menos poluidora do ponto de vista luminotécnico relativamente à anterior tecnologia de vapor de sódio de alta pressão.

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NOTICIAS DE COIMBRA ABOUT THE STREET LIGHTING TESTS
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Coimbra

Coimbra testa soluções eficientes de iluminação na Quinta de S. Jerónimo



Notícias de Coimbra | 8 meses atrás em 20-04-2023



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CÂMARA MUNICIPAL
DE
COIMBRA



20 Abril 2023

CM de
Coimbra
testa
soluções
eficientes



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Coimbra, the right place to be.



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**H PUBLICATION ON 22 JUNE 2023 BY THE MUNICIPALITY OF
COIMBRA OF THE STREET LIGHTING TESTS THAT WILL TAKE
PLACE THE FOLLOWING DAY**



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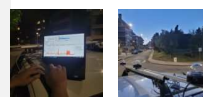
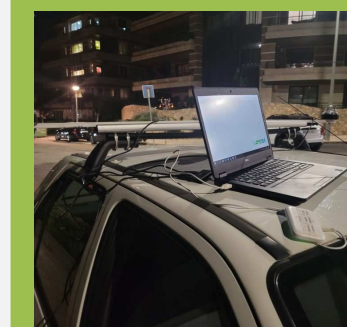
22 Junho 2023

CM de
Coimbra
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A Câmara Municipal (CM) de Coimbra vai realizar novos testes na Quinta de S. Jerónimo, para aferir do impacto de uma medida de eficiência energética relativa à redução da iluminação amanhã, dia 23 de junho, a partir das 22h00. A iniciativa decorre no âmbito do projeto “FlexIP”, uma solução de iluminação pública LED que a CM de Coimbra está a implementar com a E-Redes na Quinta de S. Jerónimo, assim como na Baixa.

As alterações da iluminação na Quinta de S. Jerónimo vão decorrer a partir das 22h00, com uma redução de 75% relativamente ao valor normal até às 22h30, de 50% das 22h30 às 23h00 e, por fim, de 25% das 23h00 às 23h30. Será depois restabelecida a normalidade. Este foi o horário selecionado





para permitir uma maior presença de pessoas. Após esta ação, apela-se à participação dos residentes/utilizadores da zona para o preenchimento de um formulário de satisfação através do link <https://forms.gle/fdNbgLRZkveXwt6S6>.

Este procedimento visa tornar o sistema mais eficiente, adaptando os níveis de iluminação para os valores definidos nas normas, podendo reduzir durante a madrugada, quando houver menos tráfego de pessoas e viaturas, sem comprometer a segurança e o conforto dos moradores e utentes da zona. Nesse sentido, a CM de Coimbra vai envolver igualmente a Associação de Moradores nesta iniciativa e procurar perceber a recetividade residentes/dos utilizadores.



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Com este piloto, cria-se uma rede inteligente, em zonas específicas que, a par com outros projetos em curso, reforçam Coimbra como um laboratório vivo de experimentação, introduzem soluções de gestão inteligente e sustentável, como sensores para “rega inteligente”, contagem de veículos, temperatura, humidade, medição de CO2 e de partículas.

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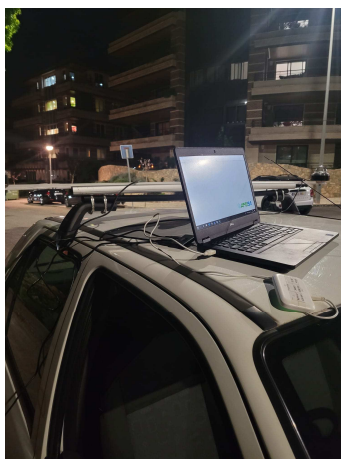


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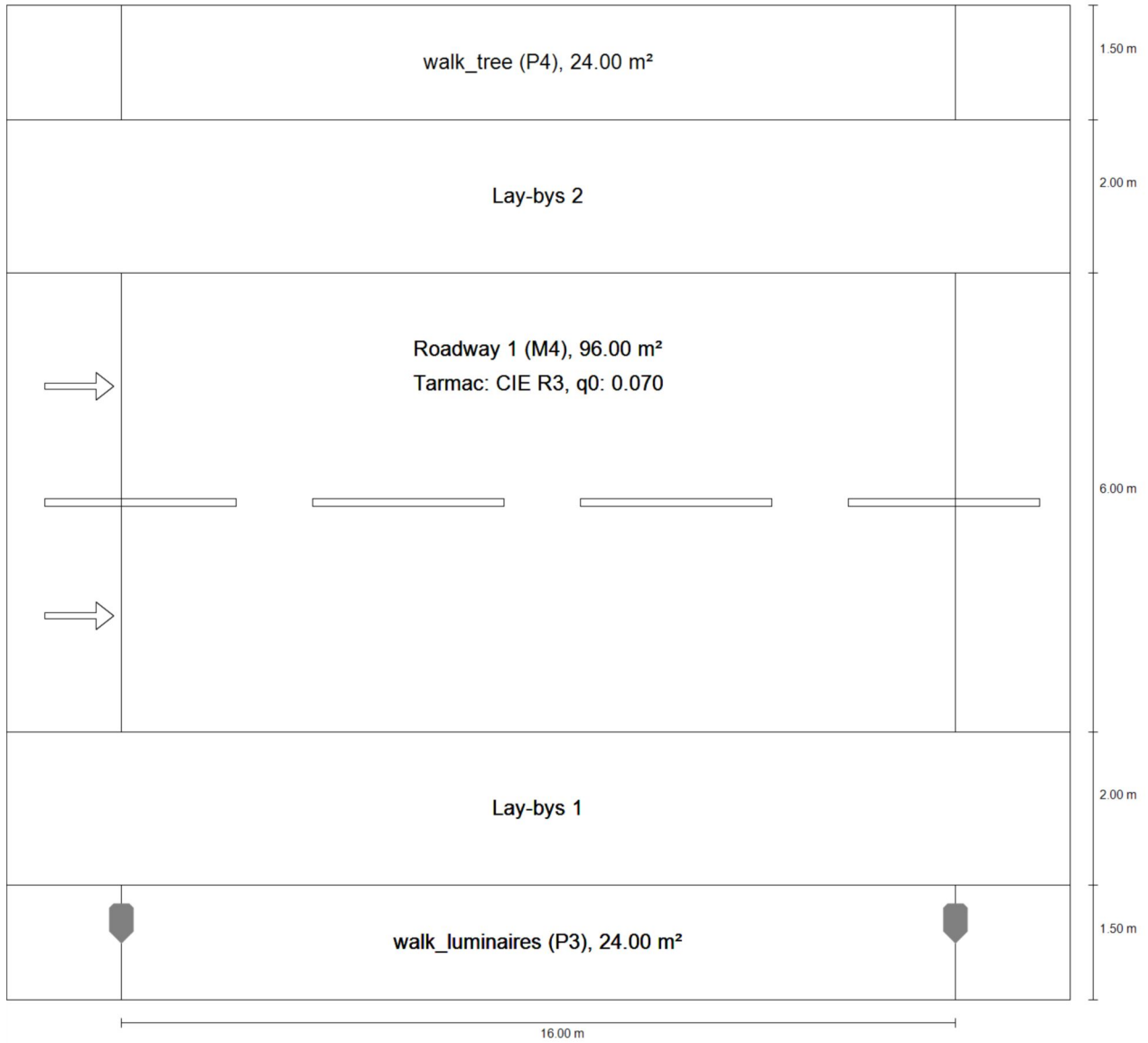
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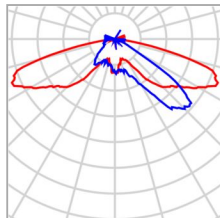
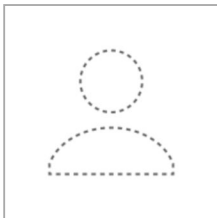
J LIGHTING STUDY - JOSÉ BESSA STREET 6M

Street 1

Summary (according to EN 13201:2015)



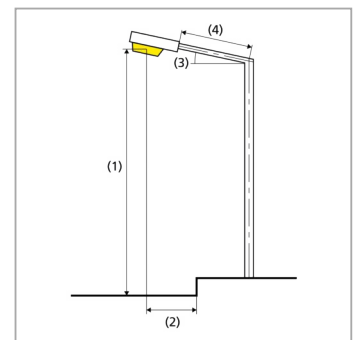
Street 1

Summary (according to EN 13201:2015)

Manufacturer	Not yet a DIALux member	P	35.0 W
Article name	BOLLE 16L	Φ_{Lamp}	4354 lm
Fitting	1x	$\Phi_{Luminaire}$	4354 lm
		η	100.00 %

BOLLE 16L (single side bottom)

Pole distance	16.000 m
(1) Light spot height	6.000 m
(2) Light point overhang	-2.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.000 m
Annual operating hours	4000 h: 100.0 %, 35.0 W
Wattage / route	2170.0 W/km
ULR / ULOR	0.03 / 0.03
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	$\geq 70^\circ$: 704 cd/klm $\geq 80^\circ$: 214 cd/klm $\geq 90^\circ$: 159 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	-
Glare index class	D.2
MF	0.80



Street 1

Summary (according to EN 13201:2015)

Results for valuation fields

A maintenance factor of 0.80 was used for calculating for the installation.

	Symbol	Calculated	Target	Check
walk_tree (P4)	E_{av}	2.09 lx	[5.00 - 7.50] lx	✗
	E_{min}	1.67 lx	≥ 1.00 lx	✓
Roadway 1 (M4)	L_{av}	0.87 cd/m ²	≥ 0.75 cd/m ²	✓
	U_o	0.48	≥ 0.40	✓
	U_l	0.83	≥ 0.60	✓
	TI	17 %	≤ 15 %	✗
	R_{EI}	0.35	≥ 0.30	✓
walk_luminaires (P3)	E_{av}	13.10 lx	[7.50 - 11.25] lx	✗
	E_{min}	10.71 lx	≥ 1.50 lx	✓

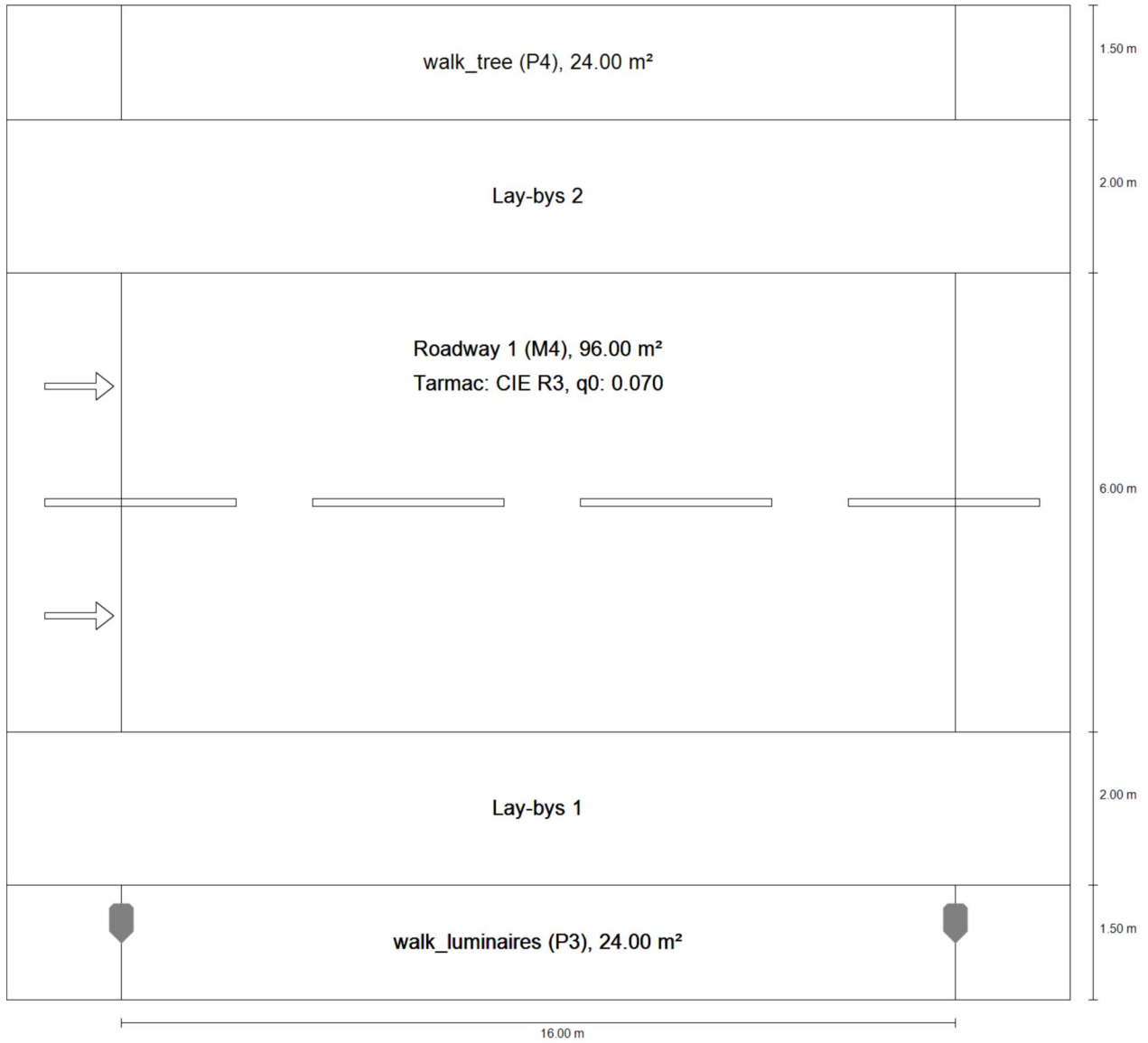
Results for energy efficiency indicators

	Symbol	Calculated	Energy Consumption
Street 1	D_p	0.020 W/lx*m ²	-
BOLLE 16L (single side bottom)	D_e	1.0 kWh/m ² yr	140.0 kWh/yr

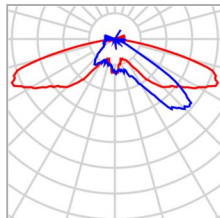
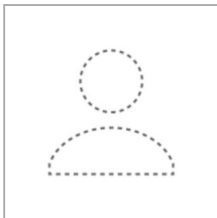
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Street 1

Summary (according to EN 13201:2015)



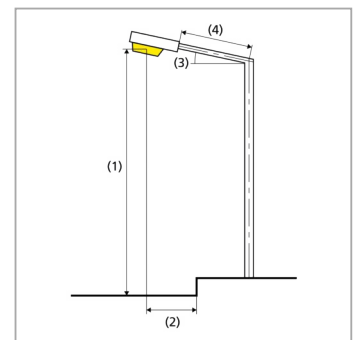
Street 1

Summary (according to EN 13201:2015)

Manufacturer	Not yet a DIALux member	P	35.0 W
Article name	BOLLE 16L	Φ_{Lamp}	4354 lm
Fitting	1x	$\Phi_{Luminaire}$	4354 lm
		η	100.00 %

BOLLE 16L (single side bottom)

Pole distance	16.000 m
(1) Light spot height	8.000 m
(2) Light point overhang	-2.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.000 m
Annual operating hours	4000 h: 100.0 %, 35.0 W
Wattage / route	2170.0 W/km
ULR / ULOR	0.03 / 0.03
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	$\geq 70^\circ$: 704 cd/klm $\geq 80^\circ$: 214 cd/klm $\geq 90^\circ$: 159 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	-
Glare index class	D.2
MF	0.80



Street 1

Summary (according to EN 13201:2015)

Results for valuation fields

A maintenance factor of 0.80 was used for calculating for the installation.

	Symbol	Calculated	Target	Check
walk_tree (P4)	E_{av}	6.26 lx	[5.00 - 7.50] lx	✓
	E_{min}	5.09 lx	≥ 1.00 lx	✓
Roadway 1 (M4)	L_{av}	0.80 cd/m ²	≥ 0.75 cd/m ²	✓
	U_o	0.59	≥ 0.40	✓
	U_l	0.85	≥ 0.60	✓
	TI	13 %	≤ 15 %	✓
	R_{EI}	0.69	≥ 0.30	✓
walk_luminaires (P3)	E_{av}	9.82 lx	[7.50 - 11.25] lx	✓
	E_{min}	8.48 lx	≥ 1.50 lx	✓

Results for energy efficiency indicators

	Symbol	Calculated	Energy Consumption
Street 1	D_p	0.022 W/lx*m ²	-
BOLLE 16L (single side bottom)	D_e	1.0 kWh/m ² yr	140.0 kWh/yr



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