"CLIENT II - International Partnerships for Sustainable Innovation"
LoSENS: LOCAL SUSTAINABLE ENERGY NETWORKS IN SENEGAL

LoSENS

WP4a:

Efficient Lighting System

WP4: Project Technicalities & Method

IfaS Institut für angewandtes Stoffstrommanagement

COMMUNE DE SAINT-LOUIS

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SUBJECT: ***WP4a: Efficient Lighting System***

LOCATION: City of Saint-Louis, Senegal

CATEGORY: Knowledge Transfer and Feasibility Assessment

SYNOPSIS: This report presents the findings of ***city Saint-Louis*** model region as part of ***"Local Sustainable Energy networks in Senegal"*** project with the objective of developing ***a Sustainable public (street) lighting*** system. This report provides a holistic, comprehensive methodology of planning for Saint-Louis current and future public lighting system as a showcase for further regions in Senegal to duplicate. WP4a provides an overview of the current street lighting situation in the city of Saint-Louis. This analysis identifies and evaluates the city's gaps. The Diamaguène district was selected as the representative district. The results obtained in this part of the city will be extrapolated to Senegal. The savings achieved will be presented in this report. The methodology deployed at large is Material Flow Assessment where different site measurements and investigations contribute to the establishment of a base data representative of the status quo for Saint-Louis in public lighting systems relevant efficiency.

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1 Executive Summary

The safety of people, and therefore of road users, is of paramount importance when planning towns and cities. Day and night, every citizen should feel safe from danger. This is only possible if streets are well lit at night.

There are a number of shortcomings in the quality of lighting in the city of Saint-Louis. On the one hand, consumption is very high in some places, despite technological progress, and on the other, some streets are not adequately lit.

To solve these problems, an inventory was carried out in the Diamaguène district to identify the lamps with low power consumption. These were replaced by high-quality LEDs.

A total of 100 LEDs has been installed. This change will result in better quality light, as well as savings of around XOF 4.4 million a year (€6,707) and an annual reduction of 16 tonnes of CO_2.

2 Context

Street lighting is an essential service provided by local municipal services. Providing good lighting at night ensures safety for properties, road users including pedestrians, cyclists and motorists, while preventing crime. Street lighting places a high demand on municipal budgets and can account for up to 38% of total electricity consumption and GHG emissions in cities (Asian Development Bank, 2017). To control the growing trends in global lighting demand and mitigate associated GHG emissions, energy efficiency serves as an urgent measure. There are various energy saving potentials in lighting. One of the primary sources of energy efficiency is lighting technology. The costs and emissions associated with street lighting could be reduced by up to 60% by using efficient lighting technologies. These savings will ultimately reduce the need to build new power plants and focus attention on extending lighting coverage to underserved areas and expanding energy access to rural communities (Asian Development Bank, 2017). Advanced lighting technologies with higher luminous efficacies are being developed and marketed by lighting manufacturers around the world. In recent years, the use of LED technology worldwide has increased significantly, from a 5% market share in 2013 to half of global lighting sales in 2019 (Zissis et al., 2021). Another important energy saving potential that has long been ignored by many lighting engineers, especially in street lighting, is in management and control systems. To achieve the maximum possible energy savings and avoid over-lighting, light must be placed exactly where needed, when needed and in the right quantities. These are important considerations for lighting management. Lighting planning and design is governed by a number of standards and guidelines established by international lighting organizations specializing in light and lighting research, namely the International Commission on Illumination (CIE) and the Illuminating Engineering Society of North America (IESNA). The International Energy Agency (IEA) estimates that the current share of lighting in global energy consumption is 19%; about 2,900 TWh. This share is expected to increase by 40% to 4,250 TWh by 2030 under current government policies (Zissis et al., 2021).

In Senegal, public lighting accounts for 2% of the country's electricity consumption (Saïd Ba, 2018). The country has set a number of energy efficiency targets in its national energy efficiency plan (PANEE) (Saïd Ba, 2018). For example, it was foreseen by 2020, to eliminate all incandescent lamps and encourage the use of energy-efficient lamps (*Plan Actions National d'Efficacité Energétique (PANEE) SENEGAL*, 2015). The country also aims to increase the coverage rate of its lighting network to 82%. This is expected to reach 99% by 2030 (Saïd Ba, 2018).

In this work package, a qualitative analysis of lighting in the Diamaguène neighborhood of Saint-Louis will be carried out, to determine possible modifications to the existing system, which should allow users benefit from better lighting conditions and feel more secure. However, an understanding of the basics of lighting remains essential.

3 Basics of Lightning

The management of a public lighting network requires some knowledge of electricity as well as lighting. This section reviews the basic concepts of lighting, mainly the composition of light, the photometric quantities that form the basis of any light control, the photometric conformity of a public lighting installation, and the luminous characteristics of lamps, which have a direct impact on the quality of the light emitted by the various types of lamps used in public lighting.

3.1 Composition of Light

The wavelength of light is in the visible range and is considered an electromagnetic wave. The watt is the unit of measurement of the power associated with light. Light is physically quantified using radiometric quantities. The human eye and brain are responsible for perceiving the color and brightness of light. It can react roughly to wavelengths between 380 and 780 nm of the much broader spectrum of electromagnetic radiation (Lenk & Lenk, 2017). This wavelength range is referred to as visible radiation (VIS). The range between 100 nm and 1 mm is frequently described as the optical radiation range and contains the closest non-visible ranges to ultraviolet and infrared radiation (Richter, 2019) (Figure 1). The response of the eye varies according to relative conditions and differs from one individual to another, making it quite complicated. Thus, photometric quantities are used to describe how light is perceived by the human eye (Saïd Ba, 2018)

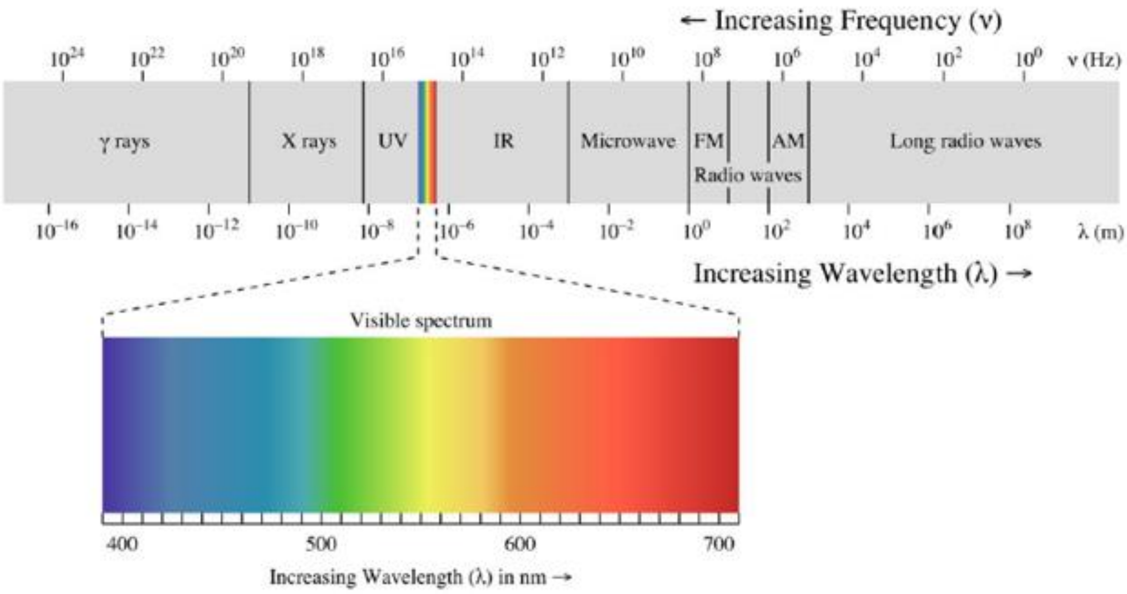


Figure 1 | Spectrum of Electromagnetic Radiations, (Lenk & Lenk, 2017)

Light composition is of great importance to truly and accurately reflect the objects it illuminates (Mehdi, 2018). The emission spectrum characterizing a light source is measured with a spectral photometer (Lenk & Lenk, 2017).

The amount and color of the light emitted, absorbed and reflected by surfaces are what lighting engineers are most concerned with in the design process (Saïd Ba, 2018).

Lumens and color temperature are the only specifications that matter to architects. For cockpit instrument designers, the most important factor is light intensity. On the other hand, brightness is the most important measure for LCD (liquid crystal display) design engineers. Irradiance is the important quantity for lighting designers, but perhaps the most important to the consumer is color rendering (Saïd Ba, 2018).

The low-pressure sodium lamp for example (Figure 2) emits a monochromatic orange light (wavelength 589 nm). It has a high luminous efficacy, but has the disadvantage of very poor color rendering, which affects the visibility of objects with colors other than orange and can in some cases cause significant visual damages (Richter, 2019).

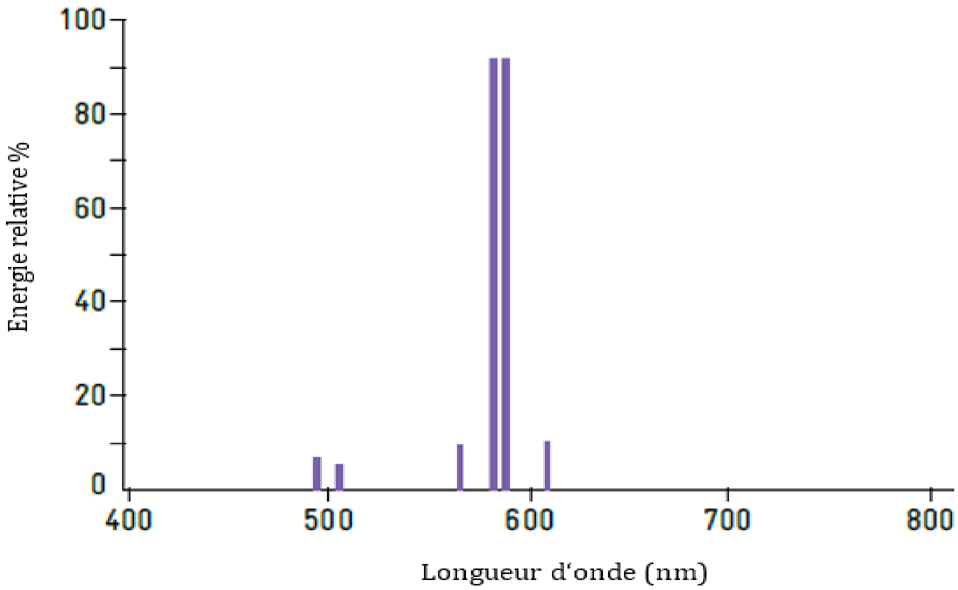


Figure 2 | Light Spectrum of a Low-Pressure Sodium Lamp, (Richter, 2019)

3.2 Photometric Quantities

Photometric quantities and their unit candela, lumen and lux are referred to as "subjective" because they depend on human vision. They are defined in relation to the vision of a "reference observer". The International Commission on Illumination (CIE) has modelled the sensitivity of the eye to define a spectral luminous efficacy curve (*AMEE*, n.d.).

Figure 3 shows the basic parameters used in lighting engineering in the context of street lighting. The main elements involved in lighting engineering are the light source and the illuminated object. Luminous intensity and luminous flux are related to the light source and illuminance, while luminance is related to the light source and the illuminated object (Pavlovic, 2020).

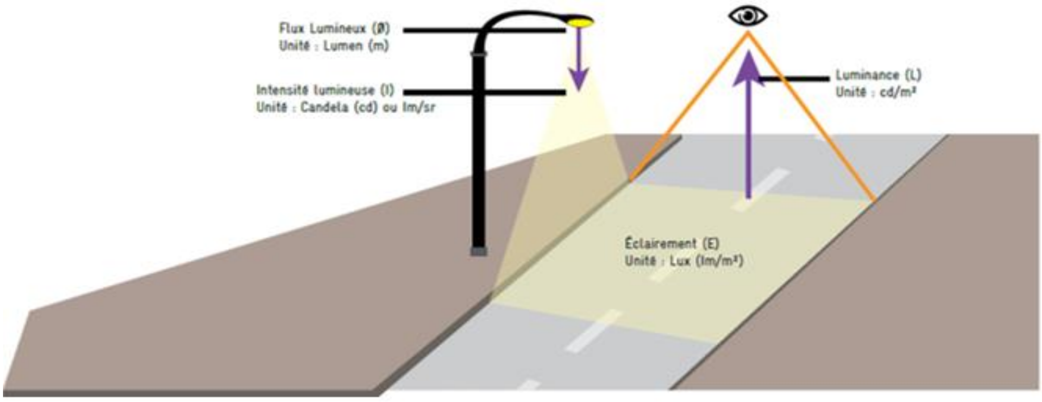


Figure 3 | Diagram of Photometric Quantities, Richter, 2019)

3.2.1 The Luminous Flux

Figure 4 | Luminous Flux, (licht.de, n.d.)

Luminous flux (Ø) is a measure of the power of light as perceived by the human eye. It is defined as the total amount of light emitted by a light source in all directions in space, regardless of the area it intercepts (Saïd Ba, 2018). Luminous flux, in lumen (lm), represents the flux of light created by a monochromatic light source radiating an optical power of (1/683) W at 555 nm, where the human eye is at its maximum sensitivity. Thus, the lumen is a unit of energy, and is in a sense the "light power" radiated by a source. It is on this basis that light sources are partially compared. Two sources emitting the same luminous flux will normally produce the same amount of light in the room. At the maximum sensitivity of the human eye, a green/yellow color with a wavelength of 555 nm. Luminous flux is used to identify the luminous and energy efficiencies of luminaires as well as their energy classes (Lenk & Lenk, 2017).

3.2.2 Illumination

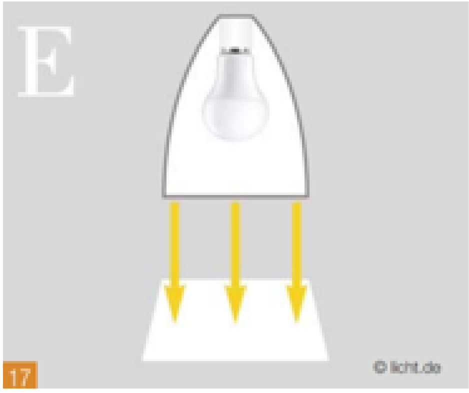


Figure 5 | Illumination E, (Pavlovic, 2020)

The luminous flux falls on various surfaces and illuminates them as it moves through space. To quantify the level of illumination of these surfaces, the illuminance quantity E is introduced, which measures the density of the luminous flux on the illuminated surface (*AMEE*, n.d.).

The illuminance (E) or luminous flux density is the amount of luminous flux Ø received by a surface A (Richter, 2019), according to the following formula (Lenk & Lenk, 2017).

$$Illuminance\ E\ =\ Luminous\ flux\ Ø\ /\ Illuminated\ surface\ area\ A.$$

Illuminance is the intensity with which the surface is illuminated. It is thus the fundamental quantitative parameter for determining the degree of illumination required in technical lighting standards (*AMEE*, n.d.). It is expressed in Lux (lx) or lm/m^2 (Lenk & Lenk, 2017).

A normal candle flame at one meter is a light source that emits one lumen of luminous flux. In this case the illuminance is equal to 1 lx (Lenk & Lenk, 2017).

Illuminance is used for the planning and design of interior lighting. Illuminance does not represent in any case the impression of brightness of a room, as this depends on the reflective characteristics of the room considered. A white room will give a much brighter impression than a dark room (Lenk & Lenk, 2017).

Illuminance is measured with a luxmeter. Outdoor values vary considerably: from 0.2 lx on a full moon night to more than 100,000 lx under a summer sun (Mehdi, 2018).

3.2.3 Luminous Efficacy

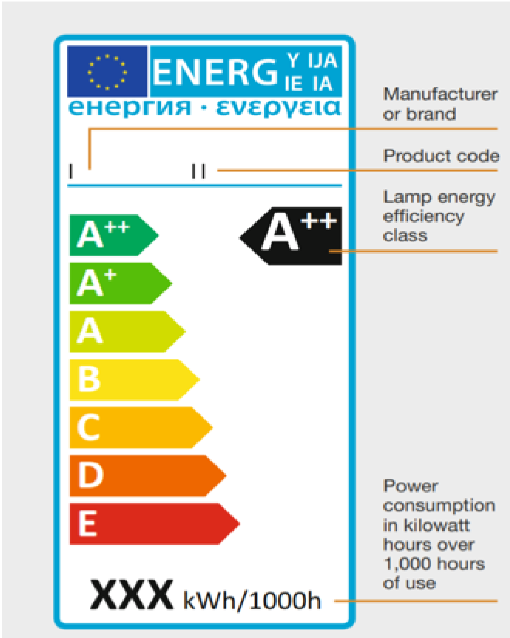


Figure 6 | Energy Label, (licht.de, n.d.)

Luminous efficacy is the ratio of the luminous flux emitted by the lamp to the electrical power consumed. The unit of measurement of luminous efficacy is lumen/Watt (lm/W). A standard 60 W incandescent bulb with a luminous flux of 700 lm has a luminous efficacy of 11.7 lm/W. At the same luminous flux (700 lm), a compact fluorescent lamp consumes 15 W. This lamp provides the same amount of light but consumes four times less energy. Its luminous efficacy is therefore four times higher (46.7 lm/W) (*AMEE*, n.d.). Hypothetically, the highest achievable value when all radiant power is converted into visible light is 683 lm/W. Luminous efficacy differs from one light source to another but is always well below the optimum value of 639 lm/W (Pavlovic, 2020). In simpler terms, luminous efficacy is a measure of the ability of a light source to produce visible light.

Usually, an energy label is included on the lamp packaging (Figure 6). It indicates the efficiency of the lamp by means of a color code and a letter: "A" is the most efficient and "G" is the least efficient. The label should also indicate the luminous flux and wattage of the lamp. The lifetime may also be given as an indication (licht.de, n.d.).

3.2.4 Solid Angle

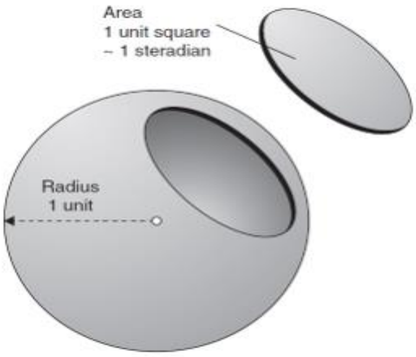


Figure 7 | Concept of Solid Angle, (Choudhury, 2014)

A plane angle defines a complete revolution, i.e. 360° or 2 radians. The solid angle extends this idea to the surface of a sphere. The solid angle in Figure 7, as viewed from the center of a sphere, contains a given area on the surface of that sphere. Dividing the size of this area by the square of the sphere's radius gives the solid angle, as shown in the equation below (Österreichische Energieagentur, 2017).

$$\boldsymbol{\omega = A/r^2}$$

The total area of the unit sphere represents the maximum solid angle which is 4π. Mathematically, the solid angle has no unit, but for practical reasons the steradian (sr) is used (Österreichische Energieagentur, 2017).

3.2.5 Luminous Intensity

Figure 8 | Light Intensity, (Pavlovic, 2020)

Light from a light source is not necessarily emitted uniformly in all directions. In order to know the intensity radiated in each direction, lighting designers have introduced the concept of luminous intensity (Richter, 2019).

This is calculated as the ratio of the luminous flux at Φ to the solid angle Ω, as shown in the equation below (Richter, 2019).

$$\boldsymbol{I = \Phi / \Omega}$$

At any unobstructed distance from the light source, the luminous flux contained in the solid angle remains constant, and the luminous intensity is not a function of the distance from the source. Luminous intensity is, in this way, considered a property of the light source and can be used to demonstrate the performance of the light source. Luminous intensity is considered in the International System of Units (SI) as a fundamental photometric quantity and is expressed in candelas (cd) (Pavlovic, 2020).

Relationship between luminous intensity I and illuminance E:

The relationship between luminous intensity and illuminance is illustrated by the equation below:

$$\boldsymbol{I = E * r^2}$$

Thus, at a distance r of 1 meter, the value of the luminous intensity I in cd is equal to the value of the illuminance E in lx (Pavlovic, 2020).

3.2.6 Luminance

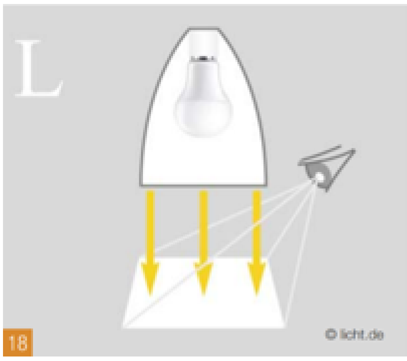


Figure 9 | Luminance

The brightness of a lighted or illuminated surface as perceived by the human eye is what defines the luminance metric (Pavlovic, 2020). It describes the luminous intensity of light moving in a given direction per unit area. It describes the amount of light that passes through or is emitted from a specific area and falls within a given solid angle (Österreichische Energieagentur, 2017). Luminance measures the intensity of light emitted or reflected from a defined area of the surface and is measured in candelas per square meter (cd/m^2) (licht.de, n.d.).

$$\boldsymbol{Luminance\ L = Luminous\ Intensity\ I\ /\ Surface\ areaA}$$

Luminance is an important measure for the organization of outdoor lighting. It is the only visible photometric quantity and represents the physiological impact of light on the eye (Richter, 2019). The human eye perceives brightness as an attribute of color. Thus, it could be said that the eye perceives differences in luminance but not differences in illuminance (under similar lighting conditions, different objects have different luminance because they have different reflection characteristics) (*AMEE*, n.d.). The human eye perceives luminance values ranging from 0.001 to 100,000 cd/m^2 (Association Française de L'éclairage, 2023).

3.3 Lamp Characteristics

3.3.1 Color Rendering Index

Figure 10 | Visual Comparison of Color Rendering for Different Lamp CRI Values, (Pavlovic, 2020)

To describe the color properties of a light source in lighting engineering, two measurement systems are used: the color rendering index (CRI) and the color correlated temperature (CCT). The first measure describes the appearance of an object illuminated by that light compared to its appearance under other standard light sources, while the second describes the appearance of the color of the light itself (Pavlovic, 2020).

The CRI quantifies the color rendering attributes of a light source (Bank, 2015). It is the main quantitative indicator of the ability of a light source to correctly reproduce the test colors of different objects compared to a reference light source (D65 sun, A halogen lamp). It ranges from 0 (monochromatic light sources) to 100 (perfect color rendering). Figure 10 shows a visual comparison of the color rendering for different CRI values (Pavlovic, 2020).

Table 1 | Color Rendering Groups of Light Sources

COLOR RENDERING GROUP	*CRI*	*IMPORTANCE*	*TYPICAL APPLICATIONS*
1A	IRC ≥ 90	Precise correspondence	Galleries, medical examinations, color mixing, TV broadcasting
1B	90> IRC ≥ 80	Accurate color judgement	Houses, hotels, offices, schools, hospitals
2	80> IRC ≥ 60	Moderate color rendering	Factories
3	60> IRC ≥ 40	The accuracy of the color rendering is not very important	Gross industry
4	40> IRC ≥ 20	The accuracy of color rendering is not important.	Rough work, acceptable in traffic lighting

Light sources are divided into color rendering groups as shown in

Table 1 (Pavlovic, 2020).

3.3.2 Color Temperature

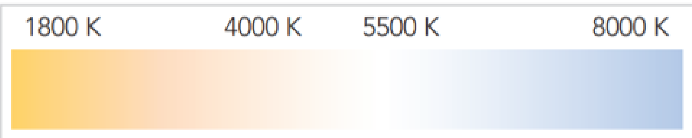


Figure 11 | Color Temperature, (Österreichische Energieagentur, 2017)

The color temperature of a light source is defined as the color of the light emitted and therefore gives an indication of the lighting environment created. It is expressed in Kelvins (K) and corresponds to the temperature at which a black body must be heated to emit a color identical to that of the source (*AMEE*, n.d.).

Depending on their types, the color temperature of incandescent light sources varies from 2,700 K to 3,200 K. The color temperature expresses the appearance of the color and can only be applied to light sources with a color like that of a black body, i.e. sources using thermal radiation. Luminescence is used by a number of modern light sources to obtain light, and the color appearance of their light spectrum deviates from their actual temperature. Instead, color correlated temperature (CCT) is used for these light sources. The equivalence between color appearance and color temperature is established in Figure 11 and

Table 2 (Pavlovic, 2020).

Table 2 | Color Appearance Groups of Light Sources

COLOR APPEARANCE GROUP	COLOR APPEARANCE	COLOR TEMPERATURE TC (K)
1	Hot	<3,300
2	Neutral	3,300…5,300
3	Cold	>5,300

Table 3 | Color Temperature Ranges of Different Light Sources (Mehdi, 2018)

SOURCE OF LIGHT	COLOR TEMPERATURE T_C (K)
Candles	1,900…2,500
Tungsten filament lamps	2,700…3,200
Daylight fluorescent lamps	2,700…6,500
High pressure sodium vapor lamps	2,000…2,500
Halogen metal vapor lamps	3,000…5,600
High pressure mercury lamps	3,400…4,000
LED lamps	2,700 … 7,000
Moonlight	4,100
Sunlight	5,000…5,800
Daylight (sun with clear sky)	5,800…6,500
Overcast sky	6,000…6,900

3.3.3 Light Intensity Distribution Curve

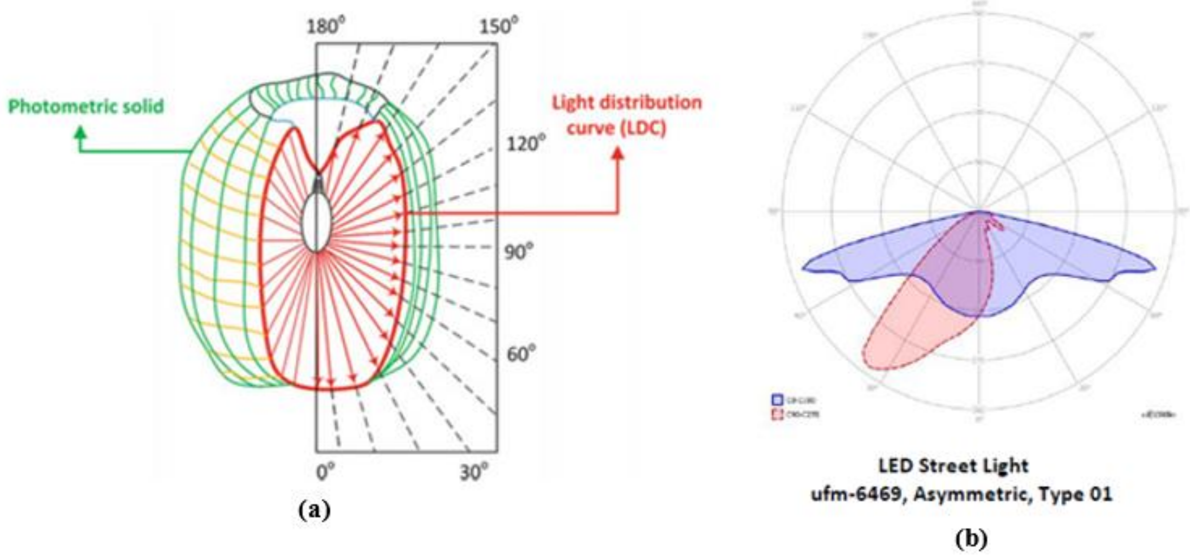


Figure 12 | Photometric Solid and Light Distribution Curve (Pavlovic, 2020)

Figure 12 (a) shows a three-dimensional photometric solid resulting from the distribution of the light intensity of a light source in all directions in space (Pavlovic, 2020). A cross-section of this graph yields a light intensity distribution curve as shown in Figure 12 (b). This graph describes the light intensity on a plane. The light intensity is presented as a function of the beam angle in a polar coordinate system. The light distribution curves are based on an output of 1000 lm, which allows comparison of different light sources (Pavlovic, 2020). One light distribution curve can be used to describe a luminaire in the case of a symmetrical luminaire while two curves are needed for axially symmetrical luminaires, usually represented in a diagram. The luminous intensity in any direction can be accurately determined by examining the photometric curve of a light source. Therefore, two coordinates help to establish the spatial directions from which light radiation is emitted (Pavlovic, 2020).

The light intensity distribution curve can be used to establish very quickly whether the light source has a wide or narrow light cone, whether the light is emitted upwards or downwards and also whether or not there are asymmetries (Mehdi, 2018).

3.3.4 Lamp Lifetime

This is defined as the average life of a batch of lamps: the number of operation hours before 50% of them are out of service (Mehdi, 2018). Examples of lifetimes:

- Conventional incandescent lamp: 1,000 hours,
- Low-voltage halogen spotlight: 2,000 to 4,000 hours,
- Compact fluorescent lamp: 6,000 to 12,000 hours,
- Fluorescent tube: 16,000 to 20,000 hours.

4 Components of a Street Lighting System

The components of a lighting system are classified according to their functions. They are generally described as follows:

- Structural systems: composed of poles and pole bases (foundations),
- Optical systems: composed of luminaires,
- Electrical systems: composed of lamps, ballasts and service cabinets (fuse boxes),

During the design phase of a lighting project, and to achieve minimum life cycle cost, while meeting the lighting requirements, these systems must be designed according to the requirements of the road. Selecting the appropriate lamp/ballast combination that produces high lumens per watt, as well as luminaires that meet the design requirements and minimize glare, light trespass and light pollution is essential to achieving an energy efficient design (Bank, 2015).

4.1 Structural Systems: Poles

The pole is the element that supports the luminaire. It can be straight or inclined, steel, aluminum, cast iron or wood, tubular, cylindrical-conical, octagonal, with or without a base plate (Mehdi, 2018).

Decisions on whether new street lighting designs and installations are required, and whether the project objectives can be achieved by upgrading the existing lighting system, should be based on the purpose and lighting requirement of the road. It should be determined whether the existing poles can be used and getting only the luminaires replaced, or whether the ground needs to be dug up for the laying of cables to upgrade the existing system. The exact location and number of poles should be decided in the case of new installations (Bank, 2015).

4.2 Optical Systems: Luminaires

Usually, basic lamps alone are not used in road lighting. The flux is directed to the area to be illuminated by means of mirrors (reflection) and lenses/prisms (refraction). These components are combined in a housing with other electrical equipment to form the luminaire. In some countries, road lights are called lanterns. The LED flux is usually directed by means of integrated lenses. Lighting engineers are interested in the overall efficiency and the distribution of light intensity of the luminaire, rather than that of the basic constituent lamp. They consider the ability of luminaires to maintain their light output over long periods of time, regardless of any degradation of the optical components (El-Zein, 2013).

4.3 Electrical Systems

4.3.1 Lamps

The lamp is the light-producing element, of which the main families being discharge lamps (fluorescent balloons, high pressure sodium, metal halide, etc.), filament lamps (halogen, incandescent) and semiconductors (LED module) (Mehdi, 2018).

The light source is the most relevant component of any street lighting system. The type of lamp in the luminaire determines the visual quality, cost and energy efficiency aspects of the system. An electric light source is essentially a device that converts electrical energy into visible light (lumens) or electromagnetic radiation. The most common types of luminaires used in street lighting today are high pressure sodium lamps (HPS or HPSV). Over the years, lamp technologies have evolved and are continuously evolving with increasing energy efficiency potentials (Bank, 2015).

4.3.2 Ballasts

The ballast is an electrical element for starting and operating lamps and can be ferromagnetic or electronic (Richter, 2019). All High Intensity Discharge (HID) and fluorescent lamps require ballasts for their operation. Ballasts perform three main functions: they provide the appropriate open circuit voltage to start the lamp, they match the lamps to one of the commonly available line voltages and, finally, they keep the lamp operating within its design parameters (El-Zein, 2013).

An ignitor is required to start the arc in sodium vapor lamps and metal halide (MH) lamps. For tubular fluorescent lamps used in street lighting, high frequency electronic ballasts are recommended to avoid flicker during low voltage conditions at peak hours and to optimize energy use. Another useful technology for saving energy in high pressure sodium vapor (HPSV) lamps and metal halide (MH) lamps is the new dimmable electronic ballast that allows both constant power and variable lighting. This ballast offers the advantage of maintaining the desired lux level during low and high voltage periods at night, thus ensuring good visibility for road users, especially during peak hours. Another advantage of using this technology is that capacitors and igniters are no longer required, this reduces maintenance costs (Bank, 2015).

4.3.3 Control Cabinets

The street lighting cabinet, also known as a control and protection cabinet, provides power to the network from the electrical distribution network. It contains metering, control and protection devices. A cabinet is usually composed of a section for metering electricity consumption, another section for controlling the lighting of the light points containing components such as clocks and contactors, with sections containing protection devices (circuit breaker, fuse, etc.) (Mehdi, 2018).

5 Types of Lamps

5.1 Incandescent Lamps

Incandescent lamps are the first electric lamps to be developed. The hot carbon filament of the lamp provides light when heated by an electric current in a vacuum. They progressed by using a tungsten filament in a clear glass bulb containing traces of an inert gas (Smith & Parmenter, 2016). In a typical incandescent lamp about 5% of the energy is converted to light in the visible spectrum, while the rest of the energy is radiated back as infrared energy and heat. Incandescent lamps have a low luminous efficacy compared to other lamps, but they have perfect color rendering and are fully dimmable. However, double winding and/or refinement of the gas filling, for example by the addition of krypton or xenon can increase luminous efficacy (licht.de, n.d.). During normal operation, temperatures of 470-520 K can be reached in the glass bulb of a 100 W incandescent lamp.

5.2 Fluorescent Lamps

Fluorescent lamps were the next generation of lamps, in the form of a glass tube with an electrode at each end. The tube contains mercury vapor, a small amount of inert gas and fluorescent powders that line its walls. An arc is produced by the current flowing between the electrodes and through the mercury vapor when a sufficiently high voltage is applied. Visible radiations are generated by this discharge, but mainly ultraviolet radiations. The fluorescence of phosphors is caused by ultraviolet radiations. To modify the spectrum of the emitted light to accentuate certain colors or to improve efficiency in the visible spectrum, luminophores and other additives are incorporated into lamps. These lamps require a ballast, which is essentially an inductor, to provide the initial high voltage pulse to initiate the discharge. The viability of the lamp increases with the arc length. To solve this problem, compact fluorescent lamps wrap the tube in a spiral shape. The rate of loss of electron emitting material from the electrodes determines the lifetime of a fluorescent lamp. This is affected by the number of times the lamps are switched on. The normal lifetime is 7,500 to 12,000 hours (compared to 750 to 1,000 hours for incandescent lamps). The assumption of 3 h of operation at each start-up is used to control the data on the average life of fluorescent lamps. In an ordinary fluorescent lamp, 21% of the input is converted into light, 37% into infrared and 42% into heat. Older fluorescent lamps were designated as T-12 (12/8 -inch diameter, or 1.5 inches) and used a magnetic ballast. They were largely replaced by T-8 lamps (8/8-inch diameter, or 1 inch) which used an electronic ballast around the beginning of 1980. Electronic ballasts are smaller, run quieter, produce less heat and increase light output and efficiency. T-5 lamps (5/8-inch diameter), having a better light quality and longer life have been used recently. However, they are more expensive**Fehler! Textmarke nicht definiert.** (Smith & Parmenter, 2016).

5.3 Sodium Lamps

Four basic components make up an HPS lamp, namely a sealed translucent ceramic arc tube, an outer bulb, main electrodes and a base (Jiang et al., 2015). Sodium lamps operate based on an electric current flowing through the sodium vapor (El-Zein, 2013). An HPS lamp requires an inductive ballast to control the flow of current through the arc and to provide the correct voltage to the arc (Smith & Parmenter, 2016). Energy is radiated over a band of wavelengths in the HPS lamp. The light is almost monochromatic, consisting of two lines at 589 and 589.5 nm in the high-pressure sodium lamp (El-Zein, 2013). HPS lamps are famous for their longevity and exceptionally high luminous efficacy of up to 150 lm/W. A very low premature failure rate of only 5% at 24,000h is observed in HPS variants for street lighting. The replacement intervals are therefore six years. However, in terms of light quality, compromises have to be made as the lamps have a color rendering index of only Ra ≤ 25 and give off a yellowish light. Few variants allow for a simple switch from a high-pressure mercury vapor lamp to a high-pressure sodium lamp (licht.de, n.d.).

5.4 Metal Halide Lamps

Metal halide lamps and mercury vapor lamps are similar but contain different metal halides. The metal halide dissociates into more halogen metal when the lamp reaches the required operating temperature. There are a few key points to this phenomenon. Firstly, metal halide lamps are 1.5 to 2.0 times more efficient than mercury vapor lamps. Secondly, metals provide "white light" with exceptional color rendering. Although the construction details and ballasts used for metal halide lamps are different from mercury vapor lamps, the essential concept is the same. (licht.de, n.d.)

The bright light of metal halide lamps is their impressive feature, which helps to create an attractive urban view. Lamps with the ceramic burner technology are very energy efficient, providing a luminous efficacy of up to 100 lm/W, and are therefore much more energy efficient than lamps with quartz burners. Thanks to their good color rendering and light quality, they are particularly suitable for prestigious applications such as the illumination of monuments, fountains or historical buildings. The variants specially developed for street lighting have a long service life and are optimized for long replacement intervals (licht.de, n.d.).

5.5 Mercury Vapor Lamp

Mercury vapor is included in sodium lamps. The passage of electric current through a metal vapor produces light. Mercury vapor lamps usually have two main electrodes and a starting electrode. The argon gas is ionized, and an arc is formed when voltage is applied to the starting electrode. This arc vaporizes the mercury and, inevitably, an arc is formed through the mercury. Once the arc is extinguished, it cannot be reactivated until the vapor pressure has been reduced to a level suitable for the applied voltage. This regularly takes between 3 and 8 minutes. The inductor provides an "inductive boost" to help initiate the discharge and limits the current through the lamp in the mercury vapor ballast. To correct the power factor of the inductor, a capacitor is used (Smith & Parmenter, 2016).

5.6 Light Emitting Diode Technology

Effective climate actions are needed to follow the landmark global Paris agreement. LED (Light Emitting Diode) lighting technology is known to be a ready-made technology for cities to implement in their transition to a low carbon economy, due to savings of up to 50-70% (Climate Group, 2015).

The world of lighting changed rapidly when the first Light Emitting Diodes (LEDs) were introduced in the mid-1990s. LEDs are amazingly efficient, durable, can be connected and are precisely controlled. Today, almost half of all outdoor luminaires and over 30% of indoor luminaires are made with LEDs (licht.de, n.d.). LED-based lighting is gradually becoming the preferred light source, dethroning both incandescent and fluorescent lamps. The barriers in relation to shape, color quality, limited lifetime, proximity to harmful nature of mercury, etc. that prevented consumers from benefiting from energy-efficient lighting, are all being addressed by LEDs. In the long run, LED-based lighting will be far better and cheaper than any other light source. LED lighting will be cheap, productive and most used (Lenk & Lenk, 2017).

The advantages of using LEDs for lighting are many. The most obvious is their productivity. Lighting accounts for 20% of energy consumption in the world today. The use of LEDs appears to reduce this to 4% or less.

LEDs offer customers a wide range of preferences and much greater adaptability than was previously conceivable in lighting: transiently through variable lighting qualities at different times of the day, spatially through targeted lighting control, and user-dependently through the arrangement of appropriate lighting for different customer groups (licht.de, n.d.).

LED technology promises a number of features, among which:

- **Long life**: commercial and industrial consumers need highly reliable and long-lasting lighting systems. Frequent bulb replacement can be costly (especially in situations with high ceilings). Indeed, maintenance is the main reason why a consumer chooses LEDs. A well-designed installation will have a lifetime of 30,000 to 50,000 hours (when the light is reduced by 30%) (El-Zein, 2013).
- **Limited environmental hazard (no mercury)**: LEDs contain no toxic materials and do not emit harmful UV (ultraviolet) radiations. Almost all metal halide and fluorescent lamps contain mercury (considered a toxic waste worldwide) (licht.de, n.d.).
- **Significantly reduced thermal radiation**: Because LEDs are so efficient, a greater percentage of electricity is converted into light and less into heat. This means that LEDs do not give off heat in the living/office space. AC power consumption can be reduced, as the lamps do not contribute to "heating" the interior of the rooms. Approximately 95 watts (95%) can be radiated into the lighting by a 100 W lamp (licht.de, n.d.).
- **No flickering and instant start**: LEDs can be switched on instantly and do not flicker. During start-up, all fluorescent bulbs flicker. In addition, metal halide and some others need time to warm up (sometimes up to 5 minutes) to reach full intensity (licht.de, n.d.).
- **No impact of frequent on/off switching**: frequent on/off switching does not affect LEDs (as it might be in case presence detectors are used). The lifetime of fluorescent and incandescent lamps is significantly reduced by frequent switching (licht.de, n.d.).
- **Dimmability and controllability**: LED installations are effortlessly dimmable; the driver contains dimming capability in most installations currently available. Many installations are dimmable by default. When selecting an LED luminaire for a project, it is important to ensure that the existing dimming system is compatible with the LED dimming protocol. This is not an issue for new installations (licht.de, n.d.).

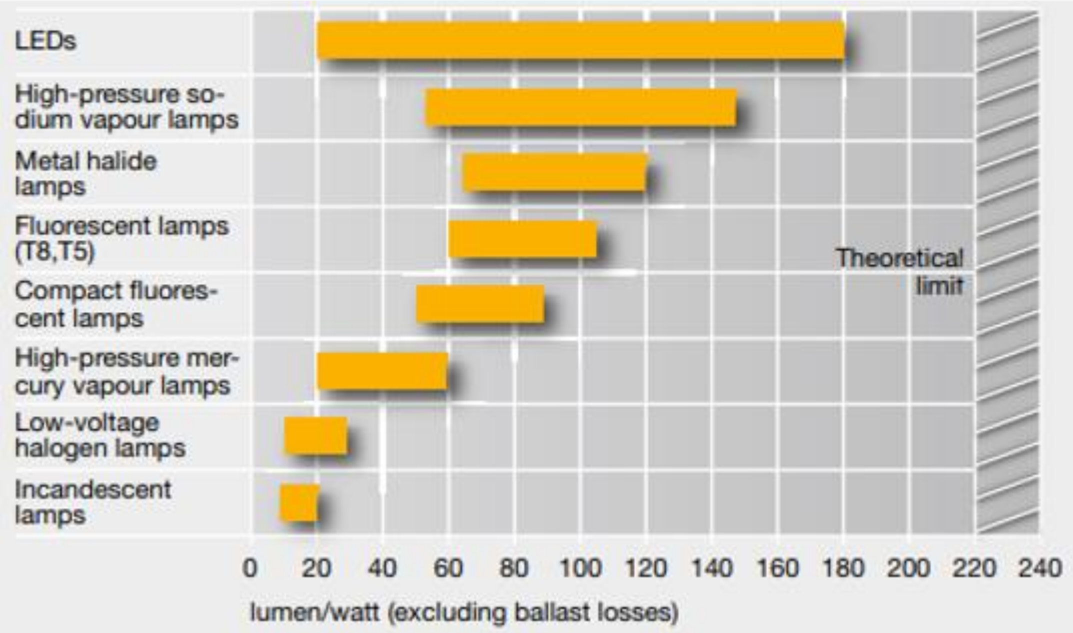


Figure 13 | Luminous Efficacy of Different Light Sources, (licht.de, n.d.)

Figure 13 is a graph comparing the luminous efficacy of different light sources. LED technology takes the lead with the highest luminous efficacy which can reach a theoretical value of 180 W/lm.

Figure 14 compares the different lighting technologies based on their photometric characteristics.

Type of Lamp	Luminous Efficacy (lm/W)	Color Rendering Properties	Lamp Life (hrs)	Remarks
High-pressure mercury vapor (MV)	35–65	Fair	10,000–15,000	High energy use, poor lamp life
Metal halide (MH)	70–130	Excellent	8,000–12,000	High luminous efficacy, poor lamp life
High-pressure sodium vapor (HPSV)	50–150	Fair	15,000–24,000	Energy-efficient, poor color rendering
Low-pressure sodium vapor	100–190	Very poor	18,000–24,000	Energy-efficient, very poor color rendering
Low-pressure mercury fluorescent tubular lamp (T12 and T8)	30–90	Good	5,000–10,000	Poor lamp life, medium-energy use; only available in low wattages
Energy-efficient fluorescent tubular lamp (T5)	100–120	Very good	15,000–20,000	Energy-efficient, long lamp life; only available in low wattages
Light-emitting diode (LED)	70–160	Good	40,000–90,000	High energy savings, low maintenance, long life, no mercury; high investment cost, nascent technology

Figure 14 | Comparison of Road Lighting Luminaires, (licht.de, n.d.)

6 International Standards for Street Lighting

A number of international standards have been developed to ensure that public lighting provides effective night-time visibility to reduce road accidents and increase human safety. Lighting standards in relation to the performance of luminaires, level and characteristics of the light provided and discussed in this section. At the international level, the International Commission on Illumination (CIE) and the Illuminating Engineering Society of North America (IES or IESNA) are the two main bodies responsible for developing and settings standards for street lighting. CIE 115 - Roadway Lighting for Motorized and Pedestrian Traffic, CIE 180 - Roadway Lighting for Developing Countries, and American National Standards Institute (ANSI)/IESNA RP-8 - American National Standard Practice for Roadway Lighting are the standards that address street lighting. These standards focus on two important criteria for street lighting: (i) minimum average light levels, which ensure minimum useful light at the street surface ; and (ii) uniformity proportions, which ensure a reasonable uniform distribution of light for a particular roadway area or application, such as an intersection, arterial road, or highway (Asian Development Bank, 2017).

The hazard potential of the road section in question determines the requirements for street lighting. The risk of collisions increases with traffic. The hazard index is significantly higher if the space on (and along) the road is used by different users, such as motorists, cyclists and pedestrians, due to the marked differences in speed, size and recognition. The clarity of the road is another parameter that depends on the alignment, width of the road and applied speed limit. All these factors should be considered when assessing the level of lighting required.

6.1 Brightness/Lighting Level

A basic requirement for good visibility outdoors is an adequate level of brightness (light level). To reduce the risk of accidents, it must take into account the visual objects laid down by road users without perturbing various activities. The most important factors are the reflective properties of the illuminated surface, luminance and illuminance (El-Zein, 2013).

For street lighting, the most important criterion is the illuminance level. Planning is based on different lighting variables and depends on speed limits. Luminance (cd/m^2) is the standard used when they are higher than 30 km/h, as in the case of national roads, motorways and even tunnels. Illuminance (lx) is the design criterion required where speed limits are 30 km/h or less, for example in reduced traffic areas or car parks (El-Zein, 2013).

Illuminance levels are defined by the CIE standards according to the following parameters (Mehdi, 2018) :

- The configuration of the public space and its types of users.
- The speed and level of traffic allowed.
- The type of roadway: shared or separate.
- Areas of vigilance (proximity of buildings open to the public, crossroads, etc.).
- Space and surface constraints (complexity, risk of aggression, etc.).
- Ambient light level which corresponds to the level of luminance, illuminance or glare of the environment in the field of view of the main illuminated surface.

6.2 Uniformity of Illuminance

For a space with the same use, uniformity of illuminance is essential to ensure the same average illuminance level throughout the space. Inconsistent illuminance is usually caused by poor distribution of luminaires and poor choice of equipment (licht.de, n.d.). The minimum levels of general (Uo) and longitudinal (Ul) uniformity are defined in the CIE standard depending on the lighting class.

The general uniformity of illuminance Uo refers to the extent to which the illuminance is well distributed over the area to be illuminated. Longitudinal uniformity Ul refers to the uniformity of luminance values taken along each longitudinal axis. In the case of a roadway, UI is the ratio of the lowest to the highest luminance of the road surface in the center line of a roadway (licht.de, n.d.).

6.3 Glare

Staring at a bright light source or rapidly alternating between a dark environment and a brightly lit area can cause glare. This ultimately causes visual discomfort which can lead to accidents, especially on roads. A poorly positioned, tilted or misaligned luminaire can also cause visual discomfort. The CIE standard defines the maximum glare index (GI) to be considered in a street lighting project (licht.de, n.d.).

Glare impairs visual performance and greatly reduces visual comfort. Glare can be reflected (due to light reflected from shiny surfaces) or direct (caused by luminaires, sunlight or bright daylight). Appropriate optics can limit glare from luminaires. When light from a source close to the object being viewed interferes with vision, veiled luminance occurs by generating a strong light stimulus and projecting scattered light onto the retina. The perception of contrast is reduced by scattering it on the retina like a veil. The classic example of a situation where veiled luminance can occur is driving at night with oncoming traffic. The brighter and closer the light source, the greater the visual impairment (licht.de, n.d.).

6.4 Color Rendering Index

Colors are not reproduced in the same way with different types of light sources. When the issue of color rendering is important for a project, light sources such as metal halide lamps or LEDs, with high color rendering indices, are preferred. **Fehler! Ungültiger Eigenverweis auf Textmarke.** provides an assessment of color rendering quality by CRI level (Mehdi, 2018).

Table 4 | Assessment of color rendering quality by CRI level

CRI	*COLOR QUALITY*
75 à 100	Excellent
60 à 75	Good
40 à 60	Normal
Below 40	Poor

CRI 20 to CRI 100 is the color rendering range of conventional lamps. It depends crucially on the quality of the light source. The color rendering is optimal, and all colors appear natural when the CRI is 100. CRI 60 and CRI 95 can be achieved by metal halide lamps. CRI 70 and CRI 95 is a very good color rendering for LEDs (licht.de, n.d.).

6.5 Light Color/Light Color Temperature

As previously mentioned, the intrinsic color of the light radiated by an artificial light source is the color of the light. The "warmer" the light appears, the lower the Kelvin (K) value of a lamp. Warm yellowish or reddish white light is produced by low color temperatures, as in the case of sodium vapor lamps, halogen lamps and warm white, fluorescent lamps. Cold, bluish white light, similar to daylight (at about 6,500 K), is produced by high color temperatures. A distinction is made between warm white below 3 300 K, neutral white from 3,300 to 5,300 K and daylight white above 5,300 K (licht.de, n.d.). Like sunlight, color temperature influences human visual comfort. It is usually determined by the nature of the space and the purpose of the lighting (Pavlovic, 2020).

7 LoSENS: Street Lightning in Saint-Louis

The Sustainable Energy Systems Network in Senegal is a German-Senegalese project on which IfaS has worked. The aim of the project is to develop a master plan for energy and environmental protection in two selected Senegalese model communities: the city of Saint-Louis in the north and the municipality of Balingore in the region of Ziguinchor in the south of Senegal.

The focus of this project is to promote renewable energy to support local energy policy and increase the rate of rural electrification and energy production, to reduce energy imports and dependence on fossil fuels. The project aims to expand the use of renewable energy and to develop energy efficiency solutions adapted to the Senegalese context, to reduce the environmental impacts of energy production and resource consumption (adelphi research gGmbH, 2020).

In a second phase, the project is about the development, implementation and monitoring of four demonstration projects of sustainable energy concepts, including the installation of LED lights for the public lighting network in the city of Saint-Louis (Figure 15), which is the focus of this work.

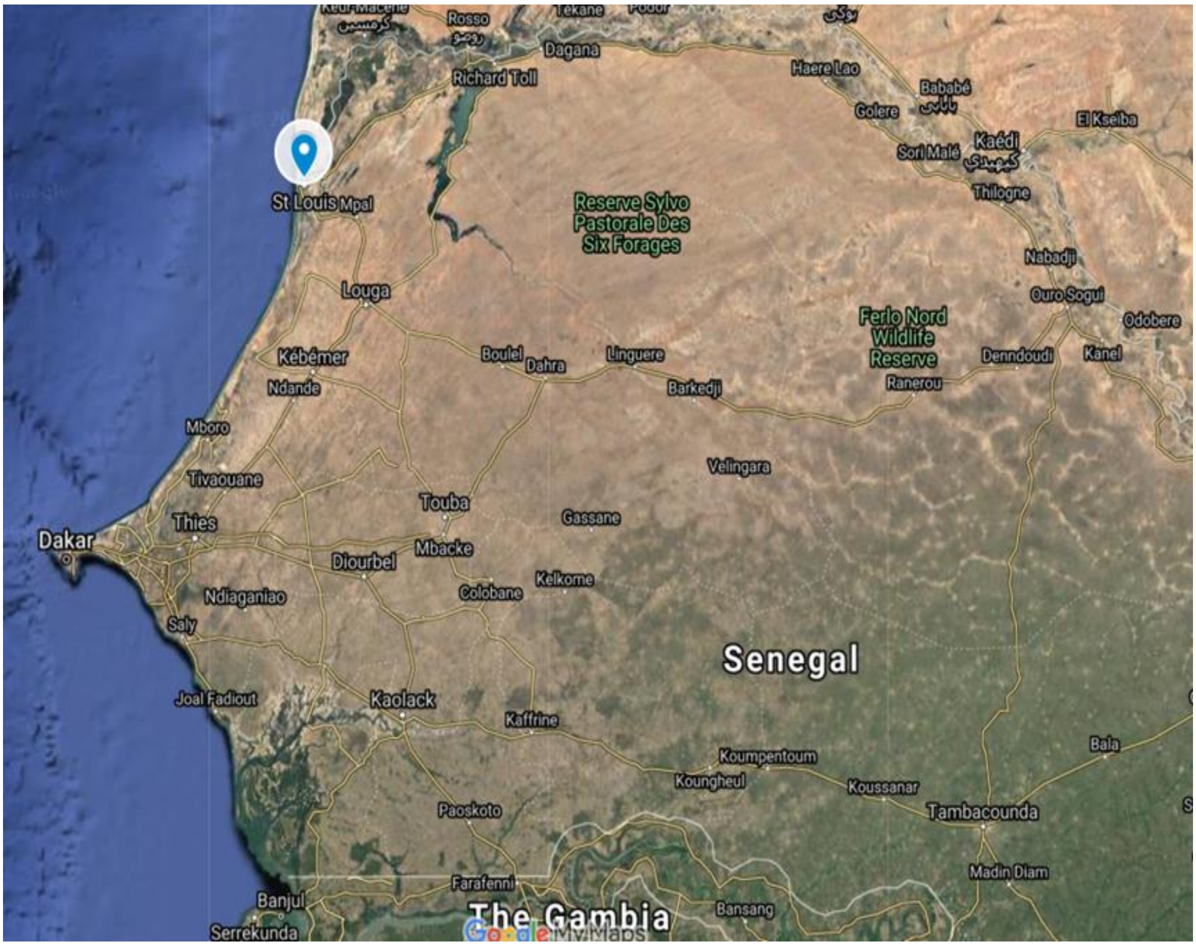


Figure 15 | Saint-Louis, Sénégal, (Google Maps, n.d.)

7.1 Assessment of the Current Public Lighting Network in Saint-Louis

As a first step, the status quo of the street lighting network in Saint-Louis was assessed through an inventory provided by the municipal utilities. This inventory contained an exhaustive list of all lighting units in the city. For each light point, the inventory indicated the neighborhood and street where it is installed and the date of installation, as well as other attributes related to the light cabinet, bulb type and date of installation, wattage rating, ballast and igniter types, type of mounting and bracket, and pole height.

Unfortunately, not all the above information was available for all districts in the city. A representative district (Diamaguène) with the most complete data was chosen, to develop a methodology that could then be applied to all other districts in the city. According to this inventory, the district has a total of 155 lighting units installed along 27 streets. The exact location of each lighting point, as well as the type of diffuser, the type of equipment, were missing, and the inventory was not up to date. In an attempt to locate the luminaires, the span was calculated and compared to the width of the road, but discrepancies were found, and a further inventory was required.

The second inventory made it possible to record the exact location of the luminaires, and to update the data from the first inventory. The inventory was carried out in collaboration with a student trainee from the University of Gaston Berger of Saint-Louis. The geographic information system for mapping application "Google My Maps", was used for this purpose. A map of Diamaguène was created, on which the location of each luminaire in the neighborhood was recorded using a GPS. The material needed to document the inventory was prepared in advance. This consists of an instruction document on how to proceed with data collection and an Excel spreadsheet to record the necessary data. The data recorded included the type of luminaire, its power rating, manufacturer, operational status, the height and material of the pole, daytime and nighttime photographs of the luminaires, which allowed the operational status of the luminaires to be verified as well as their physical appearance.

The inventory revealed the complexity of the street lighting network in the district and the city. According to the surveys, the district has 149 installed lighting units, compared to 155 units recorded in the first inventory. Table 5 summarizes the results of the inventory in terms of the type and number of luminaires of each technology on site, and Figure 16 shows the lighting levels in two different streets of the neighborhood.

Table 5 | Luminaire Type and Power Rating (Diamaguène)

TYPE OF LUMINAIRE	POWER (W)	NUMBER OF UNITS	NUMBER OF OPERATIONAL UNITS
HPS (Sodium lamps)	70	104	70
HPS	100	5	3
HPS	Unknown	1	-
Mercury vapor lamp	125	3	3
Mercury vapor lamp	Unknown	1	1
LED	80	16	16
LED	60	17	17

Figure 16 | Lighting Environment in Diamaguène, (© IfaS)

For the other two lighting units, the type of luminaire and the power rating could not be identified. Out of 149 luminaires, 110 are functional and the rest are defective. The LED lights installed in the district are solar LEDs. They were installed by the French company Fonroche as part of their largest solar LED project in the world. These lights are installed along five streets in the district (DG-06, DG-15, DG-17, DG-37 and National 2). The rest of the technologies are relatively old, dating from different periods. The map in Figure 17 illustrates the distribution of lighting units in the Diamaguène district (Google Maps, n.d.)

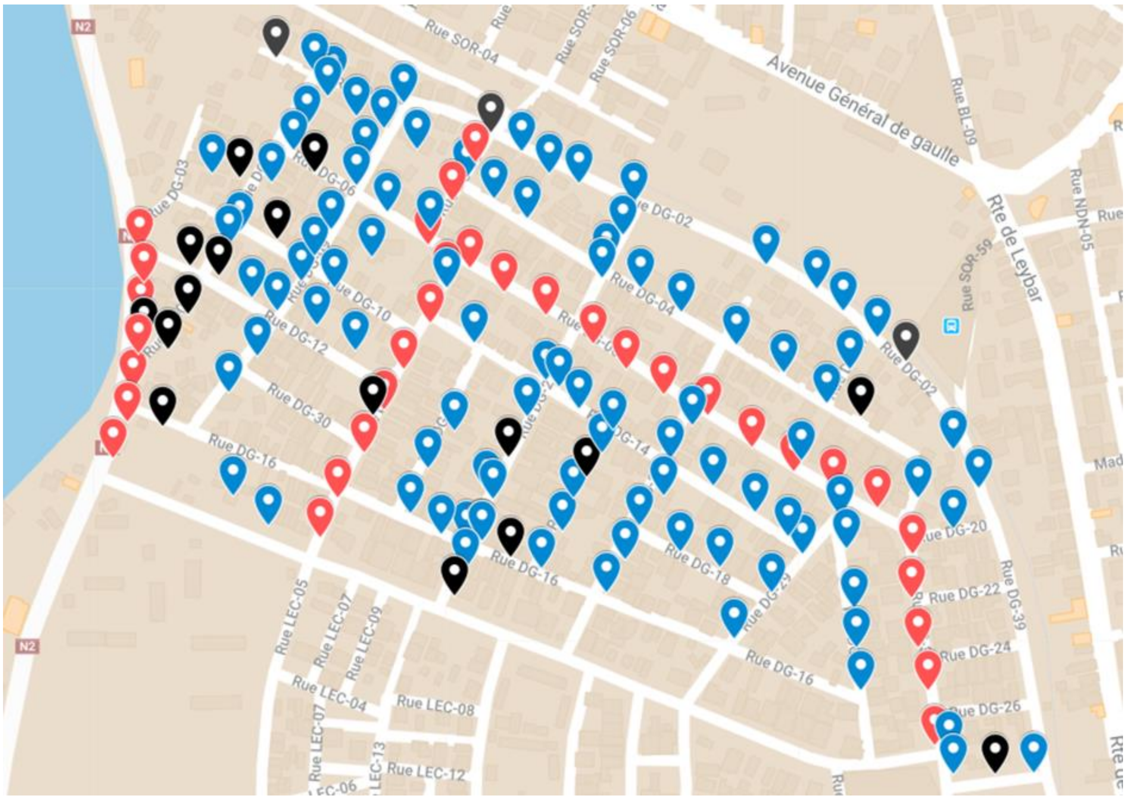


Figure 17 | Map of Lighting Units in Diamaguène, (© IfaS)

7.2 Simulating the Current Situation and Optimizing the Lighting in DIALux EVO

7.2.1 DIALux EVO Software

DIALux is one of the world's leading lighting design software packages. It offers its users the ease of planning, calculating and visualizing light for outdoor and indoor spaces. The software contains an extensive list of luminaire manufacturers from which real products can be used and tested to create the desired atmosphere for a given project. It also provides information on the distribution of light using false colors and value graphs in accordance with current international standards (CIE and IESNA).

For road lighting design, DIALux offers the possibility to first simulate the road profile in a single street view, and after performing the calculation, the optimized design can be transferred to the 3D street model, which should include any other infrastructure on the road (buildings, trees, ...). The 3D model should be built using either a CAD drawing or a Google Maps screenshot of the street in this case.

This study uses DIALux to first evaluate the baseline scenario of the lighting network of a representative street in Diamaguène. Then, the software is used to plan and evaluate two retrofitting scenarios; the first scenario suggests retrofitting the existing luminaires with LED luminaires without any changes to the network, and the second scenario builds on the first and suggests adding LED luminaires where necessary while using the existing infrastructure. DIALux is also used to plan and design a new lighting system with LED luminaires that comply with CIE lighting standards.

Some of the inputs to DIALux and the expected outputs are shown in Figure 18. These parameters are discussed in more detail in the next sections.

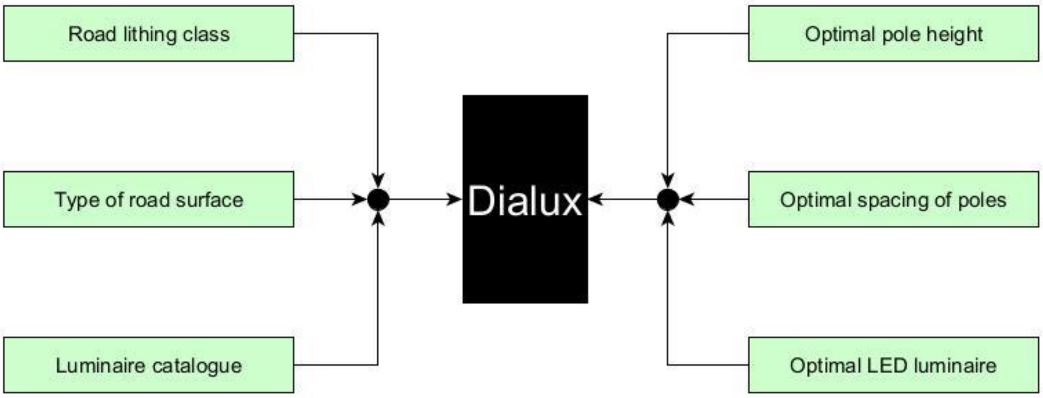


Figure 18 | Simplified Interface of the DIALux Simulation Software, (© IfaS)

7.2.2 Design Parameters

DIALux was first used to assess the current lighting situation in Diamaguène, Avenue Général de Gaulle and National Road No. 2. This assessment aimed at visualizing the current illuminance levels and light distribution, and determining whether the lighting scheme meets national and international lighting standards.

This section considers the analysis and design of lighting on a representative street in Diamaguène, Avenue Général de Gaulle, and National Road 2 (N2). Depending on the location, the use of the street, its covering, etc., DIALux distinguishes several lighting classes. Those of the streets mentioned above are grouped in the table below and the characteristics of the luminaires installed there are also presented.

Table 6 | Street Characteristics DG 25, Av. Général de Gaulle N2

CHARACTERISTIC	*DG 25*	*AVENUE G. DE GAULLE*	*N2*	*UNIT*
Width of the street	13	15	7	m
Number of tracks	1	1	1	
Type of pavement	Sand	Bitumen	Bitumen	
Height of lamp post	6.5	12	7	m

7.2.2.1 Selection of Street Lighting Class

The lighting classes of the streets studied were selected according to the EN13201:2015 model. These classes vary depending on whether the street is DG 25, Avenue Général de Gaulle or National 2 (N2), which justifies the fact that the recommendations of the CIE are different for each of these classes. The following table shows the classes used along this work and the location of application. Except for DG 25 and Avenue Général de Gaulle, both the "C" class for conflict areas and the "M" class for motorized areas can be assigned to National Road 2 (N2), since the latter, due to its length, crosses several cities with different characteristics and users.

Table 7 | Overview of Lighting Classes According to EN 13201 (Norbert Portz et al., 2017)

LIGHTING CLASS	***PLACE OF APPLICATION***
P	Lighting classes P1 to P7 are used for pedestrian areas, cycle paths, representative streets, residential streets, parking roads, car parks, school grounds, hard shoulder areas and other non-traffic road areas etc. Example: DG 25 Street
C	Lighting classes C0 to C5 are applied in the same way as classes M, but in this case for roads with conflict areas like road intersections, junctions, traffic circles, traffic jams at junctions, streets with pedestrians and cyclists, shopping streets and business streets, including underpasses and stairs. Example : Avenue Général de Gaulle, N2
M	Lighting classes M1 to M6 apply to roads with medium to high traffic speeds. Example: the N2

The number of the appropriate lighting class is based on the options selected for each parameter (speed, road users...) and is given by the following equation[1]:

$$\textit{Number of lighting class} = 6 - (\textit{sum of weighting factors of selected options})$$

The following tables show the different weighting factors used to define the class of streets according to the EN13201:2015 standard.

[1] Source : https://www.medway.gov.uk

Table 8 | CIE Lighting Class Selection Model for DG 25

PARAMETER	***OPTION***	***DESCRIPTION***	***WEIGHTING FACTOR FD***	***CHOSEN FD***
Travel speed	Low	V ≤ 30 km/h	1	1
	Very low (walking speed)	Very low (walking speed)	0	
Intensity of use	Busy		1	
	Normal		0	0
	Calm		-1	
Traffic composition	Pedestrians, cyclists and motorized traffic		2	2
	Pedestrians and motorized traffic		1	
	Pedestrians and cyclists only		1	
	Pedestrians only		0	
	Cyclists only		0	
Parked vehicle	Present		1	1
	Absent		0	
Ambient light[2]	High		1	
	Moderate		0	
	Low		-1	-1
Sum of the weighted factors				3
The corresponding lighting class for **DG** 25 is then **P3** (6-3=3).				

[2] Vitrines commerciales, expressions publicitaires, terrains de sport, zones de gare, zones de stockage

Table 9 | CIE Lighting Class Selection Model for Avenue Général de Gaulle

PARAMETER	***OPTION***	***DESCRIPTION***	***WEIGHTING FACTOR FD***	***CHOSEN FD***
Pavement separation	Yes		1	
	No		0	0
Travel speed	Very High	V >= 100 km/h	3	
	High	70 < V < 100 km/h	2	
	Average	40 < V <= 70 km/h	0	0
	Low	V <= 40 km/h	-1	
Traffic intensity	High		1	1
	Moyenne		0	
	Low		-1	
Traffic composition	Mixed with a high percentage of non-motorized		2	
	Mixed		1	1
	Only motorized		0	
Parked vehicle	Present		1	1
	Absent		0	
Ambient light	High		1	
	Moderate		0	0
	Low		-1	-1
Sum of the weighted factors				2
*The corresponding lighting class for **Avenue Général de Gaulle** is then **C4** (6-2=4).*				

Table 10 | CIE Lighting Class Selection Model for N2

PARAMETER	OPTION	DESCRIPTION	WEIGHTING FACTOR FD	CHOSEN FD
Control task	Dery Difficult		2	
	Difficult		1	
	Easy		0	0
Junction density	High	>3/km	1	1
	Moderate	<=3/km	0	0
Pavement separation	Yes		1	
	No		0	0
Travel speed	Very high	V >= 100 km/h	2	
	High	70 < V < 100 km/h	1	1
	Average	40 < V <= 70 km/h	-1	
	Low	V <= 40 km/h	-2	
Intensity of use	Busy		1	
	Normal		0	0
	Calm		-1	
Traffic composition	Mixed with a high percentage of non-motorized		2	
	Mixed		1	
	Only motorized		0	0
Parked vehicle	Present		1	1
	Absent		0	0
Ambient Light	High		1	
	Moderate		0	
	Low		-1	-1
Sum of weighted factors				1
*The corresponding lighting class for the **N2** is then **M5** (6-1=5).*				

The road surface is also a key factor that influences the results of the simulation in DIAlux. Indeed, DG 25 is covered with sand and dust, while Avenue Général de Gaulle and N2 are covered with asphalt (bitumen). To simplify the simulations, the CIE C2 pavement was assigned to these three streets, thus corresponding to asphalt (Moldvar Eric, n.d.).

The requirements of the EN 13201:2015 standards that must be respected by the lighting classes of these streets have been grouped in Table 11.

Table 11 | EN13201 Guidelines for Classes P3, C4, M5[3]

LIGHTING CLASS	***Em [lx]***	***lm[4][cd/m²]***	***Ul[5]***	***U0[6] [lx]***	***EMIN [lx]***	***TI [%]***	***ADDITIONAL REQUIREMENT IF FACIAL RECOGNITION IS REQUIRED***	
							Ev,min (lx)	Escmin (lx)
P3	>= 7.5 <= 11.25				>= 1.5	<= 25	>= 2.5	> =1.5
C4	>= 10			>= 0.68		<= 20		
M5		>= 0.75	>= 0.4	>= 0.6		<= 15		

7.2.2.2 Lighting Catalog:

The luminaires installed along DG 25 and Avenue Général de Gaulle are from the manufacturer NIKKON. The lamps are HPS (High Pressure Sodium Lamps), with a nominal power of at least 70 W. Its main characteristics and its light intensity distribution curve are shown in Figure 19.

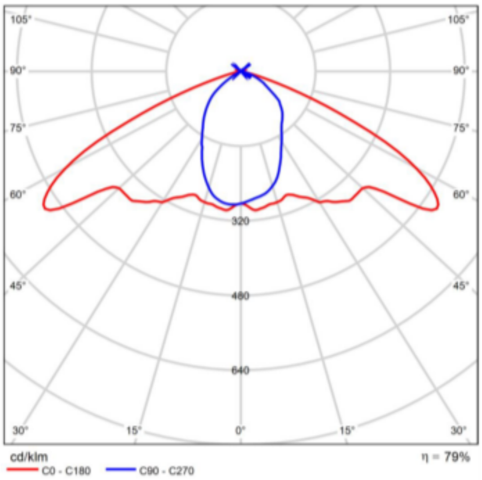
[3] Données extraites de DIAlux
[4] La luminance (cd/m²) est l'étalon utilisé lorsqu'elles sont supérieures à 30km/h, comme dans le cas des routes nationales, des autoroutes et même des tunnels.
[5] L'uniformité d'éclairement longitudinale Ul.
[6] L'uniformité d'éclairement générale désigne la mesure dans laquelle l'éclairement est bien réparti sur la surface à éclairer.

Product data sheet

NIKKON - S0070

NIKKON®

Article No.	S419-70
P	98.6 W
Φ_{Lamp}	6000 lm
$\Phi_{Luminaire}$	4764 lm
η	79.39 %
Luminous efficacy	48.3 lm/W
CCT	1900 K
CRI	17



Polar LDC

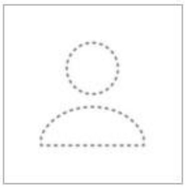
NIKKON S419-70 S0070 Street Lantern c/w HPS 70W Tube Lamp

Figure 19 | Datasheet of the Lamp from the Manufacturer NIKKON

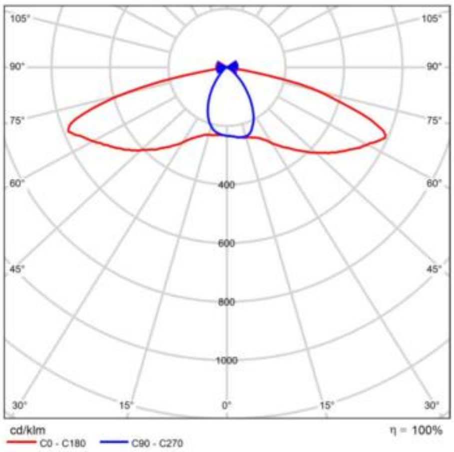
The luminaires used for the optimizations are from the manufacturer Lanz, which supplies very high-quality LEDs. The technical details of these lamps are summarized in Figure 20.

Product data sheet

Not yet a DIALux member - RALEDLAMP III V1, 3000K, asymetrisch, 36Watt



Article No.	RL3-12030-wW-3000K-36W
P	36.0 W
Φ_{Lamp}	5372 lm
$\Phi_{Luminaire}$	5372 lm
η	100.00 %
Luminous efficacy	149.2 lm/W
CCT	3000 K
CRI	100

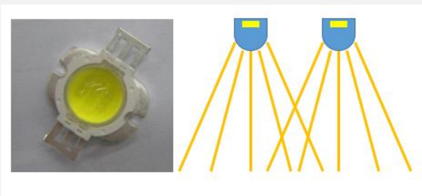
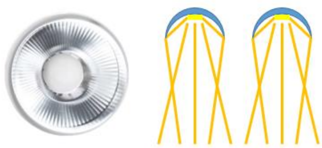


Polar LDC

Figure 20 | Technical Datasheet Lanz Lamp

Before moving on to the results of the various simulations, it is important to highlight the differences between the Lanz LEDs and the conventional LEDs on the market. The table below gives a clear overview of this. Instead of lenses, as is the case with other LEDs, Lanz luminaires use aluminum reflectors that prevent the emitted light from going in an undesired direction, but redirect it to the surface of the street that needs to be lit. This process of recovery of the emitted light enables losses reduction and increase in output.

Table 12 | Comparison of Lanz lamps with other LEDs

LEDs ON THE MARKET	***LEDs WITH REFLECTORS (LANZ LAMP)***
	
▪ Use of lenses ▪ Limited beam guidance ▪ Decreased quality of light ▪ 10% to 15% loss in the lamp	▪ LED with reflectors (Lanz lamp) ▪ Precise beam guidance using a highly efficient reflector made of specially treated aluminum. ▪ Homogeneous light distribution ▪ Direct light distribution, losses through the reflector between 3% and 5%.

7.3 Result of the Simulation

7.3.1 Result for DG 25

After introducing the road parameters and the type of luminaire currently used along DG 25 in the Diamaguène district of Saint-Louis, the spacings between poles were defined. Despite the irregular spacings noted in some places, a distance of 30 m was set. Although this street does not have sidewalks, they were inserted during the simulation, to better represent the DG 25 street and its luminaries, which are not always located at the edge of the roadway. This offset of the house poles was materialized by a two-meter (2 m) sidewalk on each side of the roadway, as shown in the following figure.

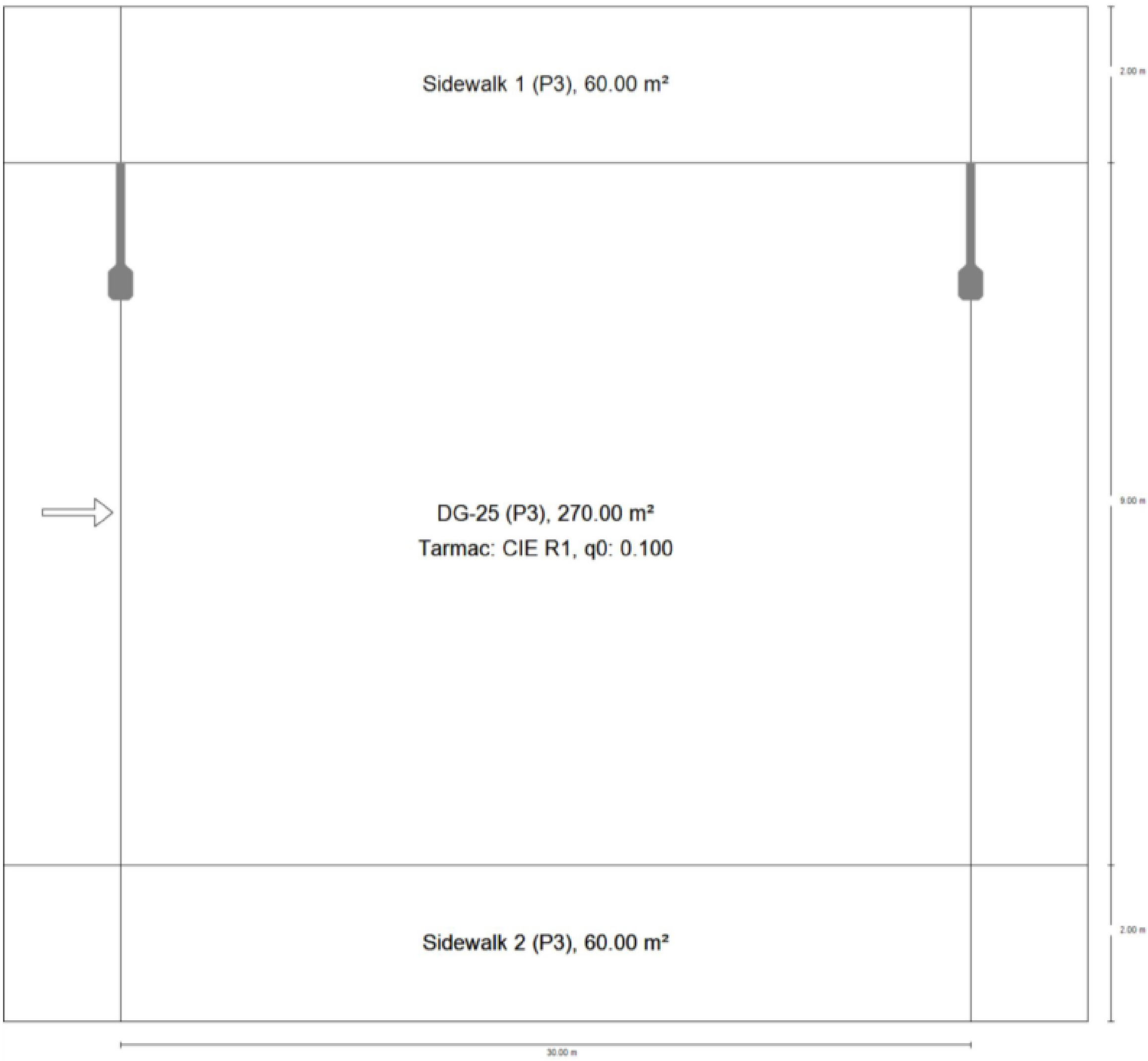


Figure 21 | Representation of the DG 25 Street in DIALux, (© IfaS)

The following figure shows the results obtained after the simulation. These show that the average horizontal illuminance and the minimum horizontal illuminance are respected on the sidewalk 1, while the pavement and sidewalk 2 would be poorly illuminated, thus not meeting the requirements of EN 13201:2015. Looking closely at these results and considering that a NIKKON lamp with a power of 98.16 W instead of 70 W, as in reality, was installed in some places (because the 70 W model could not be found in DIALux), these results would have been worse with a 70 W lamp and undoubtedly below the recommendations of the standard over the entire width of the road.

	Taille	Calculé	Consigne	Contrôlé
Trottoir 1 (P3)	E_{moy}	7.98 lx	[7.50 - 11.25] lx	✓
	E_{min}	1.87 lx	≥ 1.50 lx	✓
	$E_{v,min}$	0.05 lx	≥ 2.50 lx	✗
	$E_{sc,min}$	0.19 lx	≥ 1.50 lx	✗
DG-25 (P3)	E_{moy}	7.41 lx	[7.50 - 11.25] lx	✗
	E_{min}	1.44 lx	≥ 1.50 lx	✗
	$E_{sc,min}$	0.04 lx	≥ 1.50 lx	✗
	$E_{v,min}$	0.06 lx	≥ 2.50 lx	✗
	TI[(1)]	4 %	-	-
Trottoir 2 (P3)	E_{moy}	1.41 lx	[7.50 - 11.25] lx	✗
	E_{min}	0.58 lx	≥ 1.50 lx	✗
	$E_{v,min}$	0.06 lx	≥ 2.50 lx	✗
	$E_{sc,min}$	0.17 lx	≥ 1.50 lx	✗

(1) pour information, ne fait pas partie de l'évaluation

Figure 22 | Results for Evaluation Field (NIKKON lamp)

In order not to be limited to these values, a representation of the light distribution was necessary. Figure 23 illustrates this. Primarily, the light emitted increases with the proximity of the poles. This change in color from orange (more lighted street) to purple (less lighted street) allows us to see this black area that is in the middle and on the opposite side of the poles. This is in relation to the width of the road, the distribution curve of the luminaire, the spacing between the poles, etc.

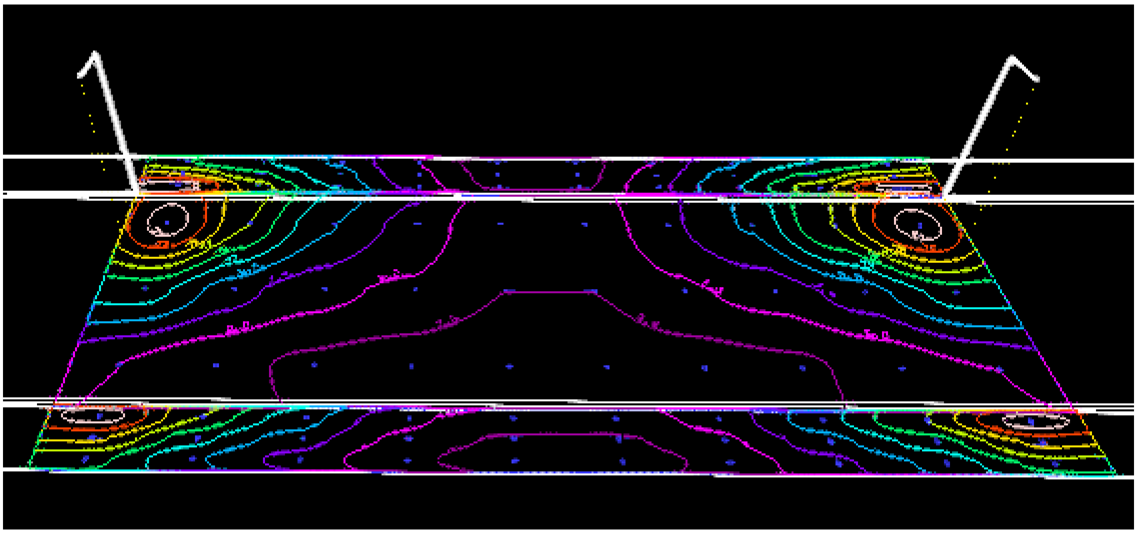


Figure 23 | Light Distribution on DG 25 (NIKKON lamp)

To correct this deficiency in light quality, the NIKKON luminaires were initially replaced with those from Lanz, this while maintaining the pole arrangement. Although the requirements of EN 13201:2015 are only partially met, these results are, with one exception, better than those obtained with the NIKKON lamps. Especially since the minimum illuminance (respected when using Lanz lamps) is a difficult factor to optimize.

	Taille	Calculé	Consigne	Contrôlé
Trottoir 1 (P3)	E_{moy}	6.69 lx	[7.50 - 11.25] lx	✗
	E_{min}	3.02 lx	≥ 1.50 lx	✓
	$E_{v,min}$	0.24 lx	≥ 2.50 lx	✗
	$E_{sc,min}$	0.63 lx	≥ 1.50 lx	✗
DG-25 (P3)	E_{moy}	9.48 lx	[7.50 - 11.25] lx	✓
	E_{min}	4.58 lx	≥ 1.50 lx	✓
	$E_{sc,min}$	0.24 lx	≥ 1.50 lx	✗
	$E_{v,min}$	0.38 lx	≥ 2.50 lx	✗
	TI(1)	13 %	-	-
Trottoir 2 (P3)	E_{moy}	2.99 lx	[7.50 - 11.25] lx	✗
	E_{min}	1.07 lx	≥ 1.50 lx	✗
	$E_{v,min}$	0.41 lx	≥ 2.50 lx	✗
	$E_{sc,min}$	0.42 lx	≥ 1.50 lx	✗

(1) pour information, ne fait pas partie de l'évaluation

Figure 24 | Results for Evaluation Field (Lanz lamp)

This improvement in lighting quality can also be seen by comparing the light distribution in Figure 23 (NIKKON lamp) with that in Figure 25 (Lanz lamp). Indeed, the area covered by darkness (purple color) is narrower and the sidewalk 1 opposite the luminaires is better lit. These details can be seen in Figure 25.

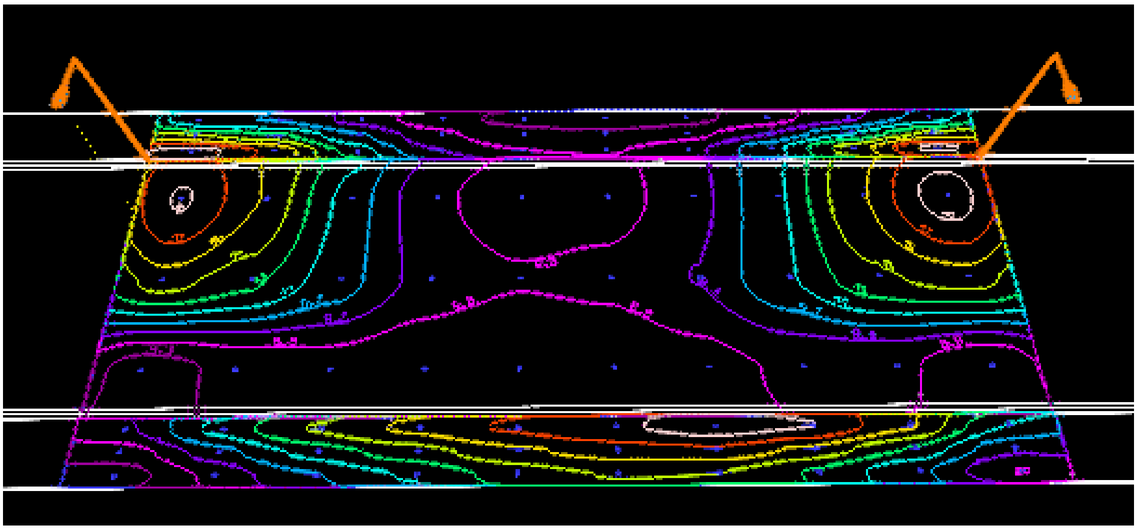


Figure 25 | Light Distribution on Street DG 25 (Lanz Lamp)

Although better, the results obtained with the Lanz lamps can be optimized by changing the pole arrangement. For the two previous simulations, a "one-lane layout" was used. The poles (6.5 m high) were placed on one side of the street with a spacing of 30 m and an arm tilt of 5°. For optimization, a spacing of 38 m between the poles (10 m high) was preferred, as well as an arm inclination of 10°. In addition to these modifications, a "staggered arrangement" was chosen. In this new configuration, the luminaires are present on both sides of the roadway, as shown in Figure 26.

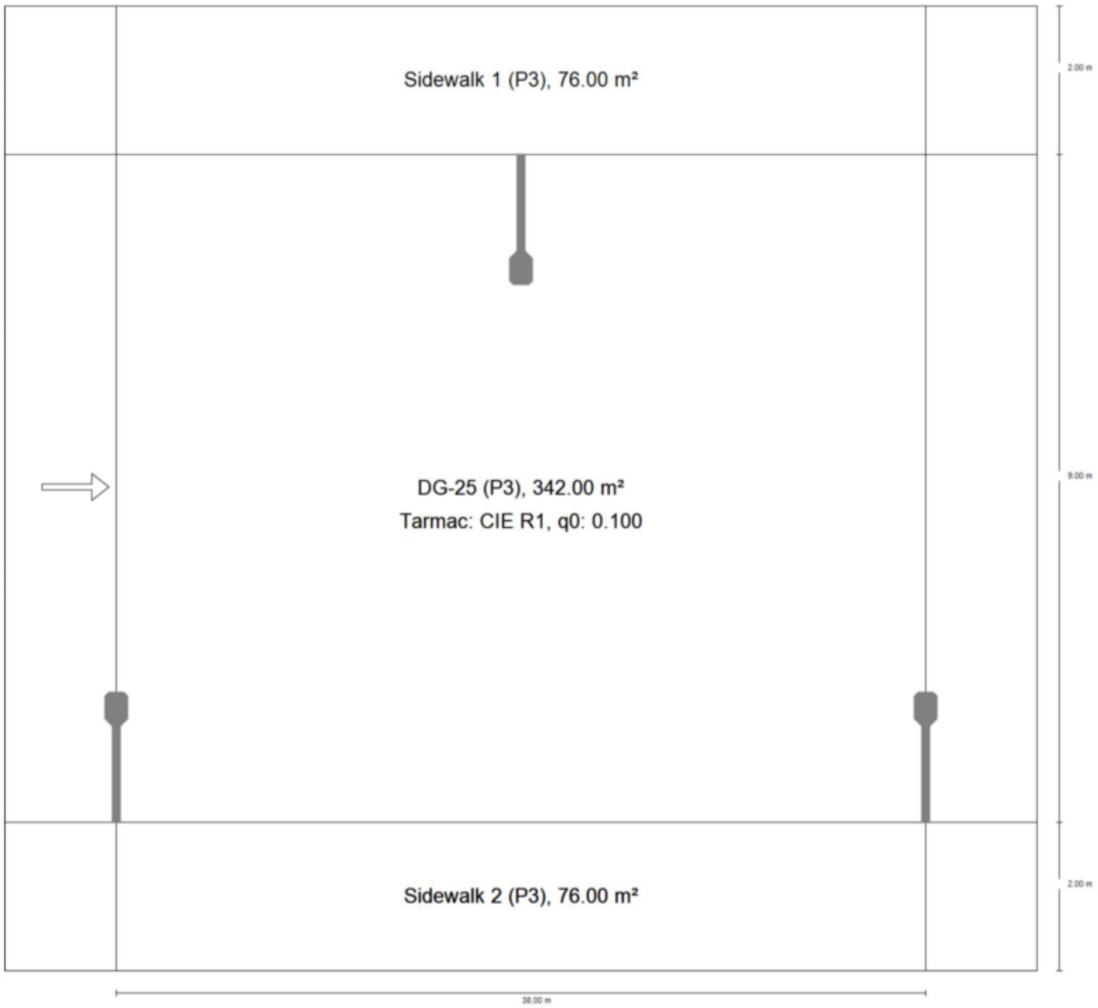


Figure 26 | Representation of the DG 25 street in DIALux (Staggered Arrangement)

The results of this arrangement are excellent. The requirements of the EN 13201:2015 standard are met. The table comparing the results to the requirements of EN 13201:2015 can be found in the following image.

	Taille	Calculé	Consigne	Contrôlé
Trottoir 1 (P3)	E_{moy}	7.65 lx	[7.50 - 11.25] lx	✓
	E_{min}	5.28 lx	≥ 1.50 lx	✓
	$E_{v,min}$	3.74 lx	≥ 2.50 lx	✓
	$E_{sc,min}$	3.08 lx	≥ 1.50 lx	✓
DG-25 (P3)	E_{moy}	11.07 lx	[7.50 - 11.25] lx	✓
	E_{min}	9.31 lx	≥ 1.50 lx	✓
	$E_{sc,min}$	3.36 lx	≥ 1.50 lx	✓
	$E_{v,min}$	4.82 lx	≥ 2.50 lx	✓
	TI[(1)]	6 %	-	-
Trottoir 2 (P3)	E_{moy}	7.63 lx	[7.50 - 11.25] lx	✓
	E_{min}	5.22 lx	≥ 1.50 lx	✓
	$E_{v,min}$	2.84 lx	≥ 2.50 lx	✓
	$E_{sc,min}$	2.44 lx	≥ 1.50 lx	✓

(1) pour information, ne fait pas partie de l'évaluation

Figure 27 | Results for Evaluation Field (Lanz lamp, Staggered Layout)

Figure 27 shows a visualization of the optimized lighting in Diamaguène. It can be seen that the purple (dark) areas have almost disappeared. However, the implementation of such a model requires a complete change of the current system (one-way layout). It would be better to use it for streets that are not yet lit, to limit the economic impact of these changes.

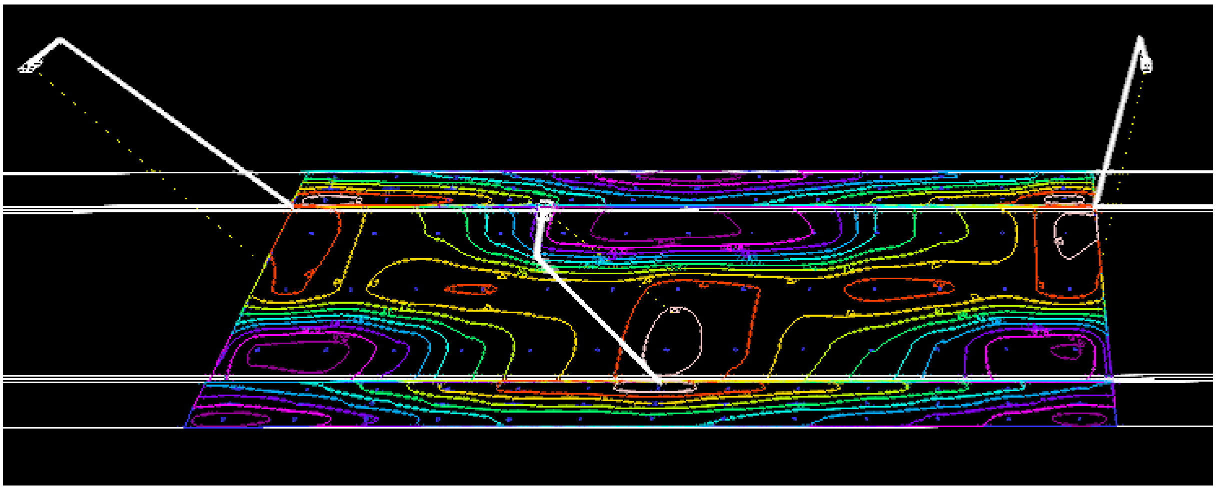


Figure 28 | Light Distribution on DG 25 Street (Lanz lamp, Staggered Arrangement)

For a better comparison, the results of these three simulations were entered into a table (Figure 29) and the light distribution images (Figure 30) placed side by side.

DG Street 25 (P3)		Current situation	Simulation with the Lanz lamp	Simulation with the Lanz lamp
Manufacturer		NIKKON	Lanz	Lanz
Lamp		S0070	RALEDLAMP III V1, 3000K, asymmetrical, 36Watt	RALEDLAMP III V1, 3000K, asymmetrical, 36Watt
Type of lamp		Halogène	LED	LED
Power		98,6 W	36 W	36 W
Pole spacing		30 m	30 m	38 m
Total luminous flux		4764 lm	5372 lm	5373 lm
Arm tilt		5°	5°	10°
Height of light point		6,5 m	6,5 m	10 m
Type of layout		One way layout	One way layout	Two-way staggered layout
Evaluation criteria				
Pavement 1	**Setpoint**	**Outcome**	Outcome 1	Optimization
Eav	[7,5 - 11,25] lx	7,98 lx	6,69 lx	7,65 lx
Emin	>= 1,5 lx	1,87 lx	3,02 lx	5,28 lx
Esc,min	>= 1,5 lx	0,19 lx	0,63 lx	3,08 lx
Ev,min	>= 2,5 lx	0,05 lx	0,24 lx	3,74 lx
DG-25	**Setpoint**			
Eav	[7,5 - 11,25] lx	7,41 lx	9,48 lx	11,07 lx
Emin	>= 1,5 lx	1,44 lx	4,58 lx	9,31 lx
Esc,min	>= 1,5 lx	0,04 lx	0,24 lx	3,36 lx
Ev,min	>= 2,5 lx	0,06 lx	0,38 lx	4,82 lx
Pavement 2	**Setpoint**			
Eav	[7,5 - 11,25] lx	1,41 lx	2,99 lx	7,63 lx
Emin	>= 1,5 lx	0,58 lx	1,07 lx	5,22 lx
Esc,min	>= 1,5 lx	0,17 lx	0,42 lx	2,44 lx
Ev,min	>= 2,5 lx	0,06 lx	0,41 lx	2,84 lx

Figure 29 | Comparison of Results for the Different Evaluation Fields (DG Street 25), (© IfaS)

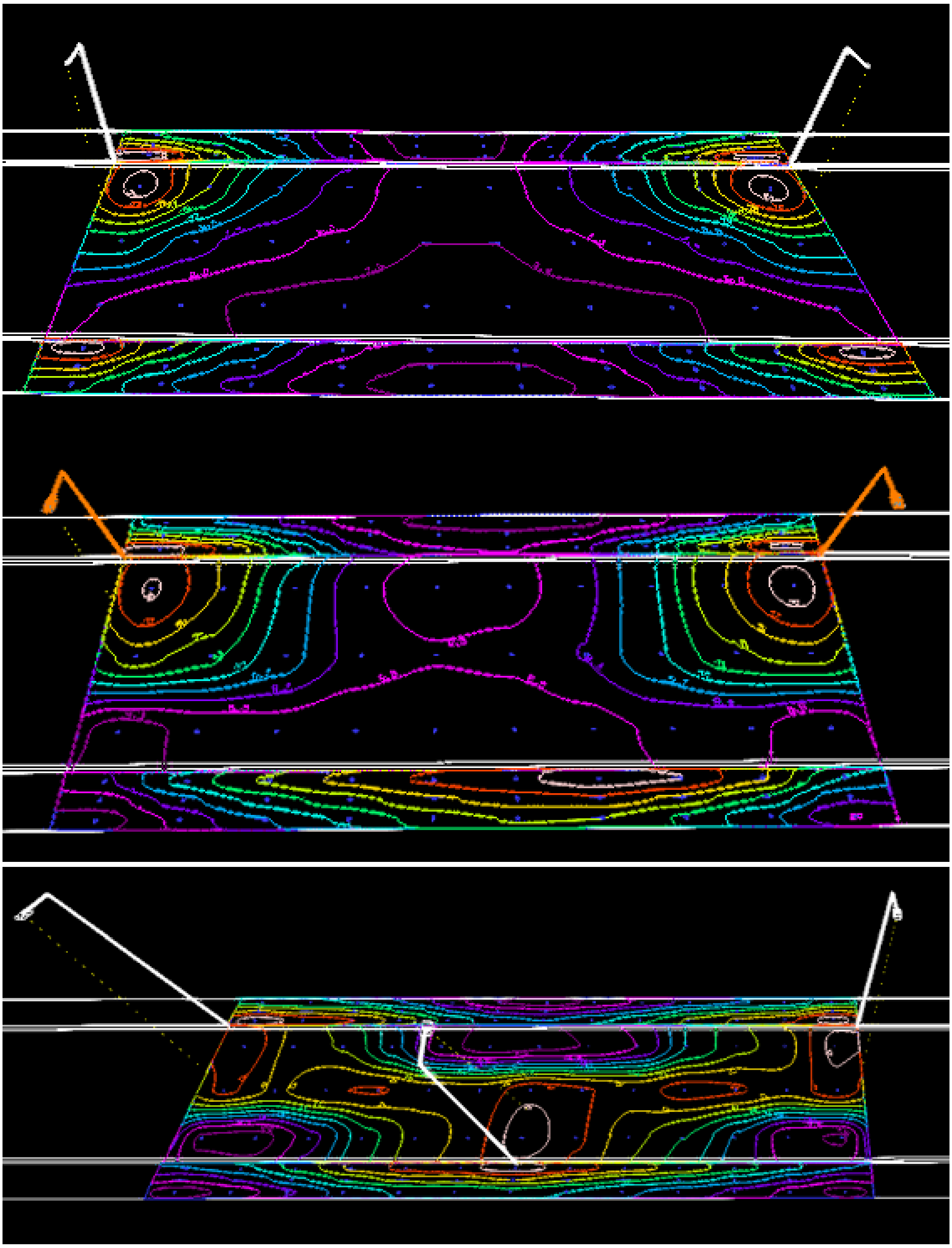


Figure 30 | Comparison of the Results of the Different Light Distributions on the DG 25 Street

7.3.2 Result for National N 2

In addition to DG 25, a simulation was done for a motorized road such as National Number 2 (N2), Générale de Gaulle Avenue in Saint-Louis.

On the National Number 2, the simulation was done only for the motorized zone (M5), because the conflict zone of National Number 2 will have the same requirements as the Avenue General de Gaulle Street.

As shown in Figure 31 and Figure 32, most of the requirements of EN 13201:2015 are met. The exception is the two sidewalks, which are moderately more illuminated, which should not be a major concern.

	Taille	Calculé	Consigne	Contrôlé
Trottoir 1 (P6)	E_{moy}	10.02 lx	[2.00 - 3.00] lx	✗
	E_{min}	2.33 lx	≥ 0.40 lx	✓
	$E_{sc,min}$	0.94 lx	≥ 0.20 lx	✓
	$E_{v,min}$	1.14 lx	≥ 0.60 lx	✓
N2 (M5)	L_{moy}	0.74 cd/m²	≥ 0.50 cd/m²	✓
	U_o	0.63	≥ 0.35	✓
	$U_l^{(2)}$	0.51	≥ 0.40	✓
	TI	14 %	≤ 15 %	✓
	$R_{EI}^{(1)}$	0.95	-	-
Trottoir 2 (P6)	E_{moy}	10.02 lx	[2.00 - 3.00] lx	✗
	E_{min}	2.33 lx	≥ 0.40 lx	✓
	$E_{sc,min}$	0.55 lx	≥ 0.20 lx	✓
	$E_{v,min}$	0.70 lx	≥ 0.60 lx	✓

Figure 31 | Results for Evaluation Field (Lanz lamp, National No. 2)

N2(M5)		Simulation avec la lampe de Lanz
Manufacturer		Lanz
Lamp		RALEDLAMP III V1, 3000K, asymetrique, 36Watt
Lamp type		LED
Power		36 W
Pole spacing		40 m
Total luminous flux		5373 lm
Arm tilt		5°
Height of light point		6,5 m
Type of layout		Disposition deux voies, en quinconce
Evaluation criteria		
Pavement 1(P6)	**Setpoint**	Optimization
Eav	>=2<=3 lx	10,02 lx
Emin	>=0,4 lx	2,33 lx
Esc,min	>=0,2 lx	0,94 lx
Ev,min	>=0,6 lx	1,14 lx
N2(M5)	**Setpoint**	
Lm	>=0,5 [cd/m²]	0,74 [cd/m²]
Uo	>=0,35 lx	0,63 lx
Ul	>= 0,4 lx	0,51 lx
TI	<= 15 lx	14 lx
Pavement 2(P6)	**Setpoint**	
Eav	>=2<=3 lx	10,02 lx
Emin	>=0,4 lx	2,33 lx
Esc,min	>=0,2 lx	0,55 lx
Ev,min	>=0,6 lx	0,7 lx

Figure 32 | Results for the Different Fields of Evaluation (N2 Street), (© IfaS)

A critical look at the representation of the N2 street (see Figure 33) shows that the roadway is narrow relative to the various sidewalks. Figure 34, which shows the distribution of light on the N2 street, also shows this large surface occupied by the sidewalk.

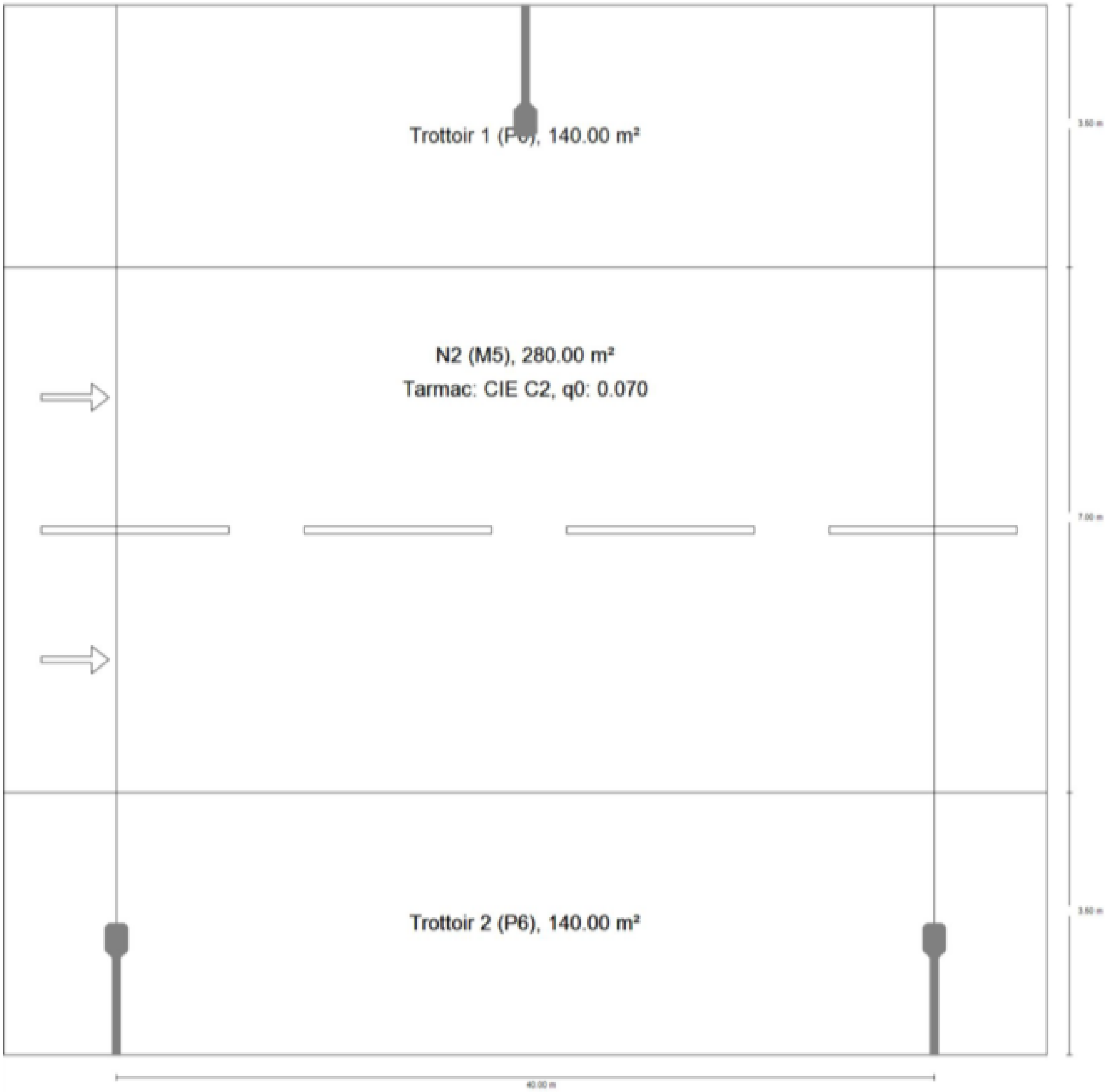


Figure 33 | Representation of the National Number 2 in DIALux (Staggered Layout)

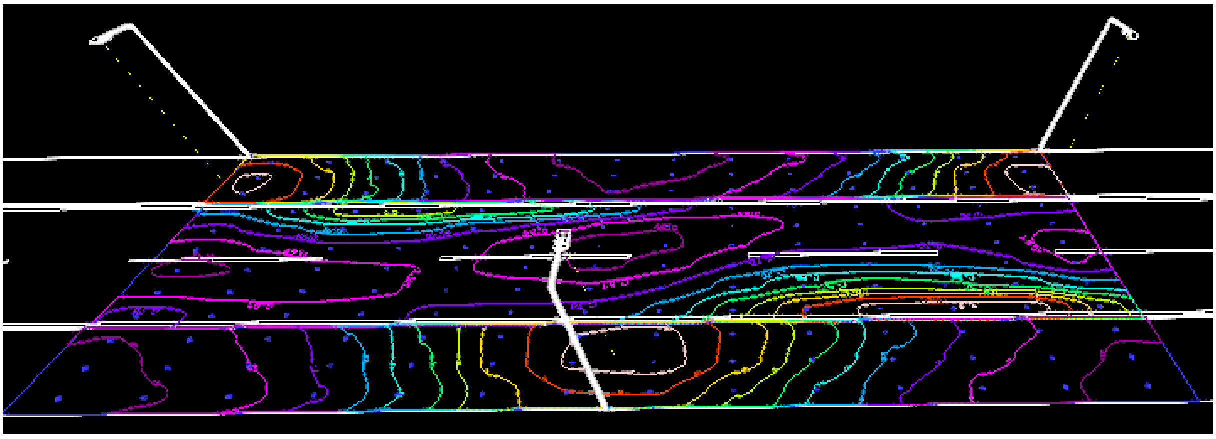


Figure 34 | Light Distribution on Street N2 (Lanz Lamp, Staggered Arrangement)

7.3.3 Result of the Avenue Général de Gaulle

As far as the Général de Gaulle Avenue is concerned, its representation has been made in DIALux in a partial way (Figure 35), the aim being the best visualization of the street. The other part is just the symmetry of it.

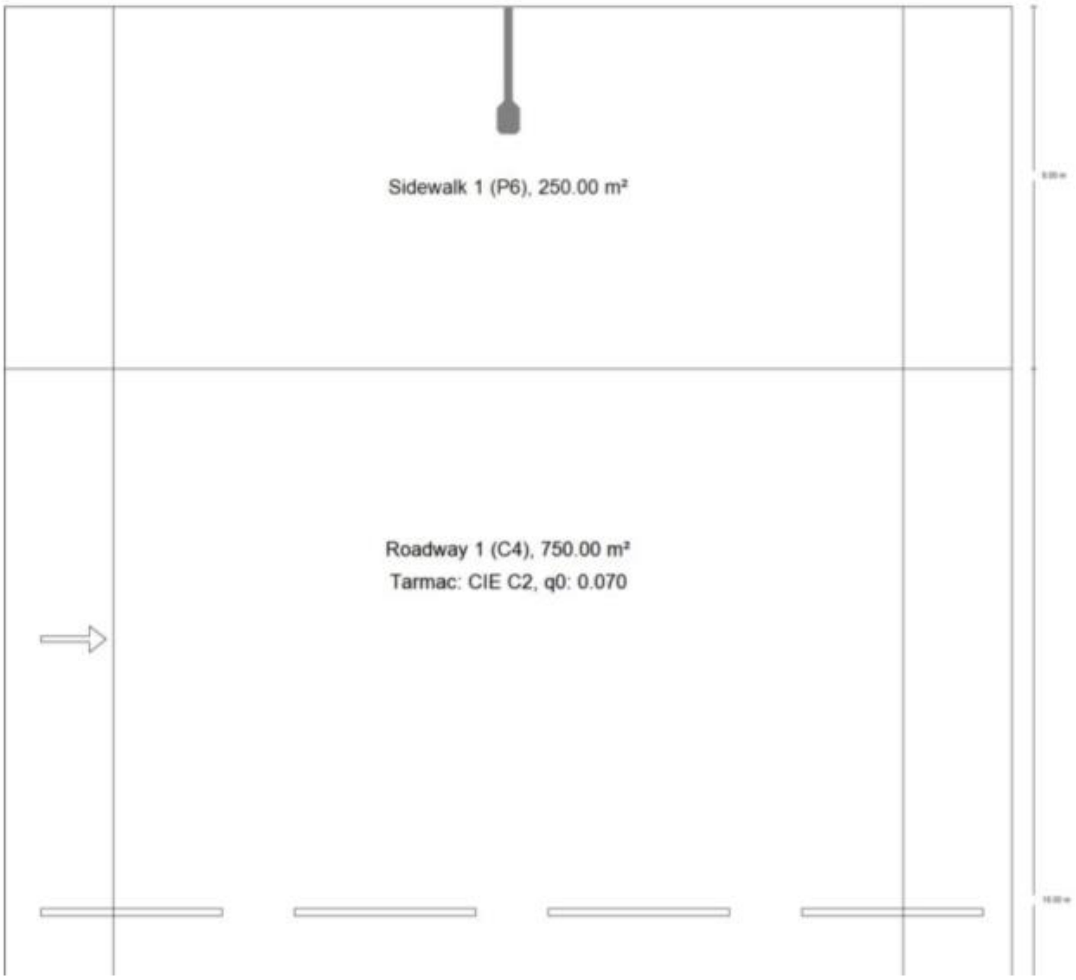


Figure 35 | Partial representation of the Avenue Général de Gaulle street in DIALux (Staggered layout)

The NIKKON lamps installed on Avenue de Gaulle provide good quality lighting, as shown in Figure 36 and Figure 37. However, it is important to note that the average illumination and the minimum vertical illumination are not respected. Considering that this street is heavily used by pedestrians, it is necessary to optimize these parameters, especially as the lamps installed have a high energy consumption.

	Taille	Calculé	Consigne	Contrôlé
Trottoir 1 (P6)	E_{moy}	2.87 lx	[2.00 - 3.00] lx	✓
	E_{min}	0.84 lx	≥ 0.40 lx	✓
	$E_{sc,min}$	0.25 lx	≥ 0.20 lx	✓
	$E_{v,min}$	0.26 lx	≥ 0.60 lx	✗
Chaussée 1 (C4)	E_{moy}	2.73 lx	≥ 10.00 lx	✗
	U_o	0.46	≥ 0.40	✓
	TI[1]	4 %	-	-
Trottoir 2 (P6)	E_{moy}	2.87 lx	[2.00 - 3.00] lx	✓
	E_{min}	0.83 lx	≥ 0.40 lx	✓
	$E_{sc,min}$	0.25 lx	≥ 0.20 lx	✓
	$E_{v,min}$	0.27 lx	≥ 0.60 lx	✗

Figure 36 | Results for Evaluation Field on the Avenue Général de Gaulle (NIKKON lamp)

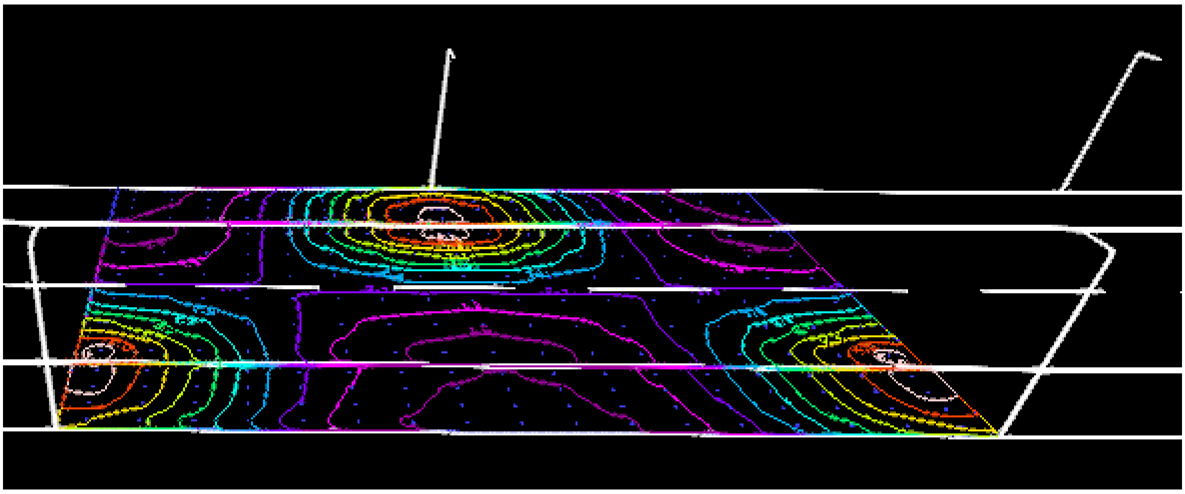


Figure 37 | Light Distribution on the Street Avenue Général de Gaulle (NIKKON lamp)

To optimize the quality of light, the NIKKON lamps have been replaced by Lanz lamps, which have 89 W of power less than the NIKKON lamps. With this change, the minimum vertical lighting will be up to standard, and the sidewalks will be brighter than average. This will also make the small businesses on Avenue Général de Gaulle feel safer. Although the average illumination does not meet the prescribed requirements, it is about twice as good as the result obtained with NIKKON lamps. Figure 38 and Figure 39 show the results obtained.

	Taille	Calculé	Consigne	Contrôlé
Trottoir 1 (P6)	E_{moy}	4.32 lx	[2.00 - 3.00] lx	✗
	E_{min}	2.27 lx	≥ 0.40 lx	✓
	$E_{sc,min}$	0.70 lx	≥ 0.20 lx	✓
	$E_{v,min}$	0.87 lx	≥ 0.60 lx	✓
Chaussée 1 (C4)	E_{moy}	4.28 lx	≥ 10.00 lx	✗
	U_o	0.68	≥ 0.40	✓
	TI[(1)]	8 %	-	-
Trottoir 2 (P6)	E_{moy}	4.33 lx	[2.00 - 3.00] lx	✗
	E_{min}	2.28 lx	≥ 0.40 lx	✓
	$E_{sc,min}$	0.55 lx	≥ 0.20 lx	✓
	$E_{v,min}$	0.64 lx	≥ 0.60 lx	✓

Figure 38 | Results for Evaluation Field of Avenue Général de Gaulle (Lanz lamp)

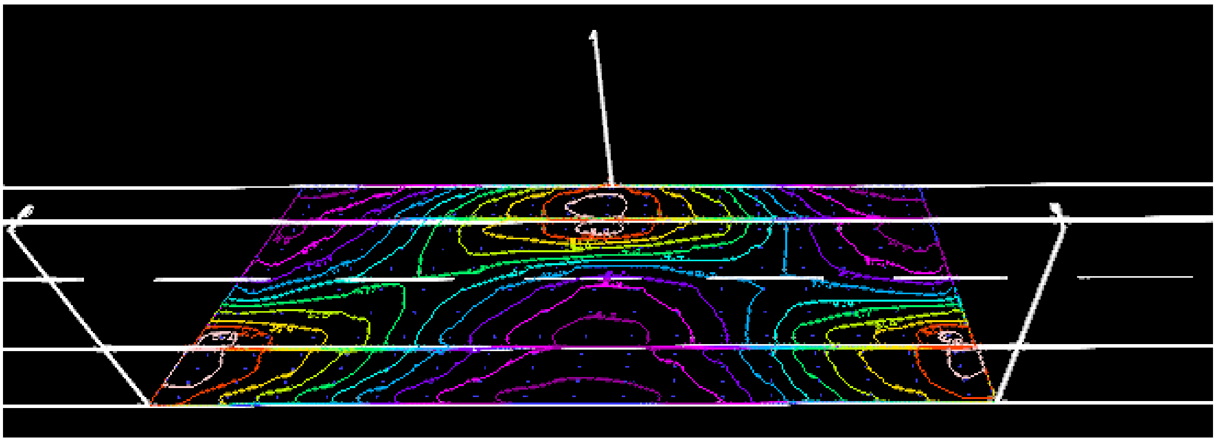


Figure 39 | Light Distribution on the Street Avenue Général de Gaulle (Lanz lamp)

For a better comparison, the results have been put side by side in Figure 40 and Figure 41. The image above in Figure 39 shows the light distribution with the NIKKON lamps. The disappearance of the purple areas, as seen in the lower image, is evidence of the fact that the spectrum covered by the Lanz lamps is broader.

Avenue G. de Gaulle C4)		Current situation	Simulation with the Lanz lamp
Manufacturer		NIKKON	Lanz
Lamp		S0070	RALEDLAMP III V1, 3000K, asymetrique, 36Watt
Type of lamp		Halogène	LED
Power		125W	36 W
Pole spacing		50 m	50 m
Total luminous flux		4764 lm	5372 lm
Arm tilt		0	7°
Height of light point		12 m	12 m
Type of layout		Two-way staggered layout	Two-way staggered layout
Evaluation criteria			
Pavement 1(P6)	**Setpoint**	**Outcome**	Outcome 1
Eav	>=2<=3 lx	2,87 lx	**4,32 lx > 3lx**
Emin	>=0,4 lx	0,84 lx	2,27 lx
Esc,min	>=0,2 lx	0,25 lx	0,70 lx
Ev,min	>=0,6 lx	0,26 lx	0,87 lx
Avenue G. de Gaulle C4)	**Setpoint**		
TI	<20%	4%	8%
Eav	>=10 lx	2,73 lx	**4,28 lx > 3lx**
Uo	>= 0,4	0,46 lx	0,68 lx
Pavement 2(P6)	**Setpoint**		
Eav	>=2<=3 lx	2,87 lx	4,33 lx
Emin	>=0,4 lx	0,83 lx	2,28 lx
Esc,min	>=0,2 lx	0,25 lx	0,55 lx
Ev,min	>=0,6 lx	0,27 lx	0,64 lx

Figure 40 | Comparison of Results for the Different Evaluation Fields (Avenue Général de Gaulle) , (© IfaS)

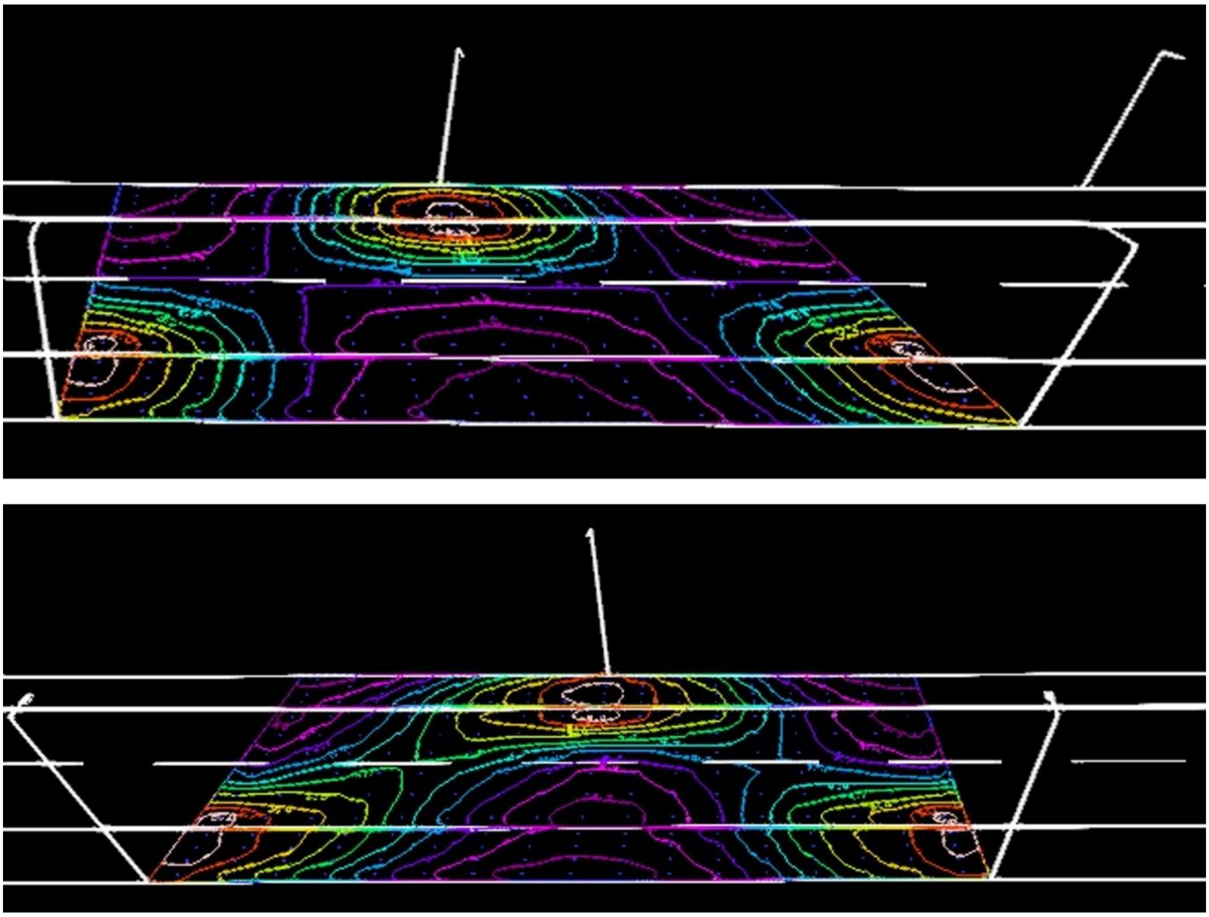


Figure 41 | Comparison of the Results of the Different Light Distributions on Avenue Général de Gaulle

7.4 Implementation: Technical Data, Tilt Angle

To obtain the results presented above, in addition to changing the lamps on the different streets, the construction parameters must be respected. These are summarized in Table 13 and Table 14.

Table 13 | Installation Parameters DG 25 Street

Pole distance	30.000 m
(1) Light spot height	6.500 m
(2) Light point overhang	1.500 m
(3) Boom inclination	5.0°
(4) Boom length	1.496 m
Annual operating hours	4000 h: 100.0 %, 36.0 W

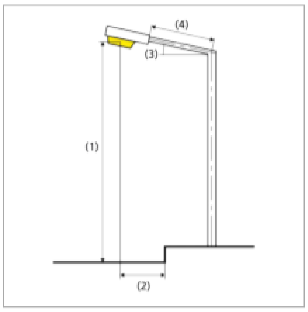
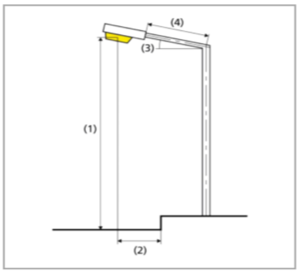


Table 14 | Installation Parameters Avenue Général de Gaulles

Pole distance	50.000 m
(1) Light spot height	12.000 m
(2) Light point overhang	-3.500 m
(3) Boom inclination	0.0°
(4) Boom length	1.500 m
Annual operating hours	4000 h: 100.0 %, 36.0 W
Consumption	1440.0 W/km



7.5 Estimated Savings and Goodwill

Because of its proximity to the stadium, the Mosque and to one of the important markets in the city of Saint-Louis, the Diamaguène neighborhood, where the quality of light was very poor (see 7.1), has been chosen for the installation of the lamps. Figure 42 shows the number of lamps that was replaced on each street. Although the total is 97 lamps, 3 mores lamps was planned to be replaced on neighboring streets, for a total of 100 lamps.

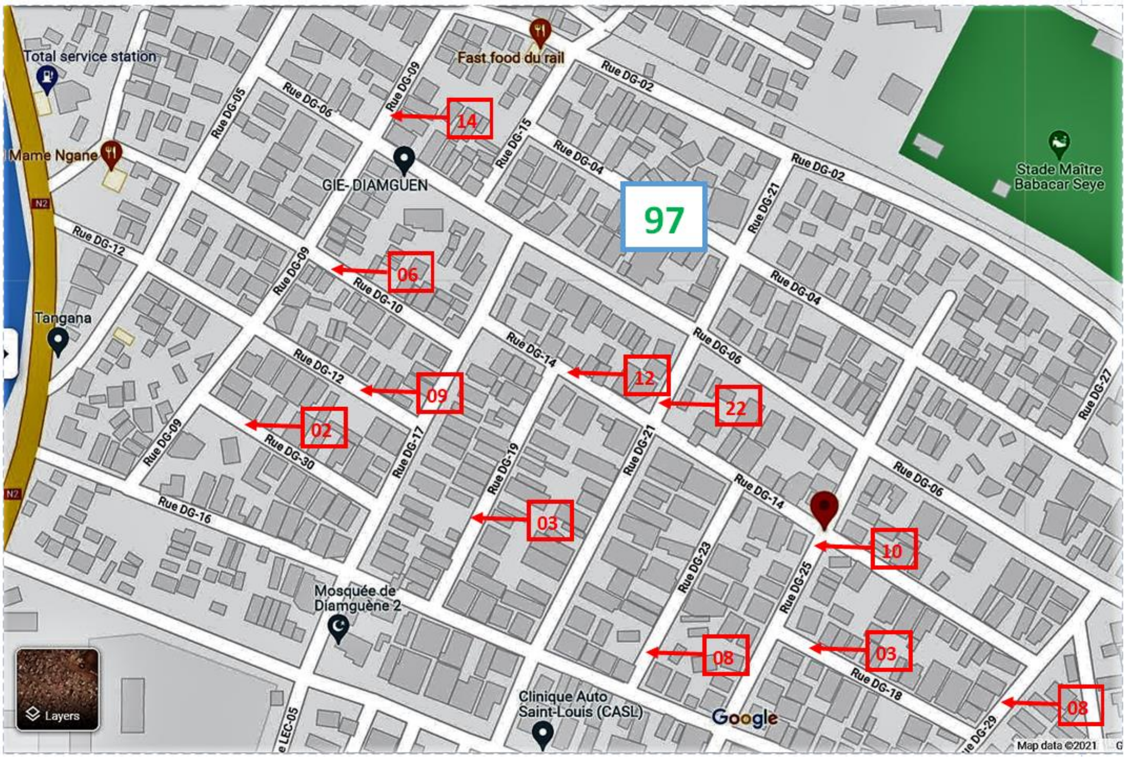


Figure 42 | Selected Streets for Lamp Replacement (Google Maps, n.d.)

The inventory carried out in the Diamaguène district provided information on the power of the various lamps installed in this area. It follows that the 100 lamps to be replaced consume a total power of 7,730 W, as shown in Table 15. Once replaced, this power will decrease by about 55% (4,238 W).

Table 15 | List of selected streets with the number of lamps and their total power in Watt.

SELECTED STREETS	***LENGTH [M]***	***NUMBER OF STREET LIGHTS***	***POWER OF THE CURRENT STREET LAMPS [W]***	***POWER OF LANZ'S STREET LAMPS [W]***
DG_09	323	14	1,105	504
DG_10	244	6	465	216
DG_12	245	9	720	324
DG_14	370	12	960	432
DG_18	136	3	240	108
DG_19	145	3	240	108
DG_21	400	22	1,760	792
DG_23	130	8	640	288
DG_25	250	10	800	360
DG_29	210	8	640	288
DG_30	125	2	160	72
11	2,578	97	**7,730**	**3,492**

With the installation of the 100 new lamps, 33.86 MWh per year of electrical energy will be reduced, which will also limit the emissions of CO_2 and other fine particles released during the production of electrical energy. Thus 16.15 tons of CO_{2e} could be saved per year by replacing 100 lamps. This energy saving will allow the municipality of Saint-Louis to save approximately 3.3 million CFA francs per year (4,967 €/a), without considering the possible increase in the price of electricity as well as the gains related to the "carbon price".

Table 16 | Calculation of Savings Related to the Replacement of Lamps in the Diamaguène Neighborhood

PARAMETER	*STATUS QUO*	*OPTIMIZATION*	*UNIT*
Power	7,730	3,492	W
Time of use per year	4,380	4,380	h/a
Energy consumed	33.86	15.29	MWh/a
Emission factor	0.67[7]		kg CO_{2e}/kWh
CO_{2e} emission	22.82	10.31	t/a
Cost per kWh (public lighting)	0.27[8]		€
Total cos	4,092	2,684,571	€/a
Energy savings	18.56		MWh/a
Savings per year	**4,967**		€/a
CO_{2e} reduction per year	16.15		t CO_{2e}/a

To better prepare for the installation phase of the 100 Lamps, a prototype was installed (Figure 43). This also enabled the familiarization with the realities on the field. The success of this installation as well as the quality of the light produced had a positive impact on the neighboring population and the lamp was appreciated by the technical service of the public lighting who requested that a part of the lamps be installed on the avenue Général de Gaulles, which is considered as the showcase of Saint-Louis. Moreover, the energy saving would be greater at this level, since the lamps installed there have a power of 125 W each, that is 3,750 W for the 30 Nikkon lamps installed along this street.

Figure 43 | Prototype of the Lanz lamp Installed at the Intersection of DG 14 and DG 21 in the Diamaguène District of Saint-Louis, (© IfaS)

[7] Source: (*The IFI Dataset of Default Grid Factors v3.1* n.d.)
[8] Source : https://www.senelec.sn/grille-tarifaire

NOTE: It was planned to install some of the lamps (30) on Avenue Général de Gaulles, as requested by the municipality's director of technical services, Mr. Sine Ali. Delays in the LoSENS project have not affected the plans of Saint-Louis town council, which has other projects planned for this road. The lights initially planned for this stretch of road were installed in the Diamaguène district (90 lamps) and near the new Saint-Louis airport (10 lamps), in Bango.

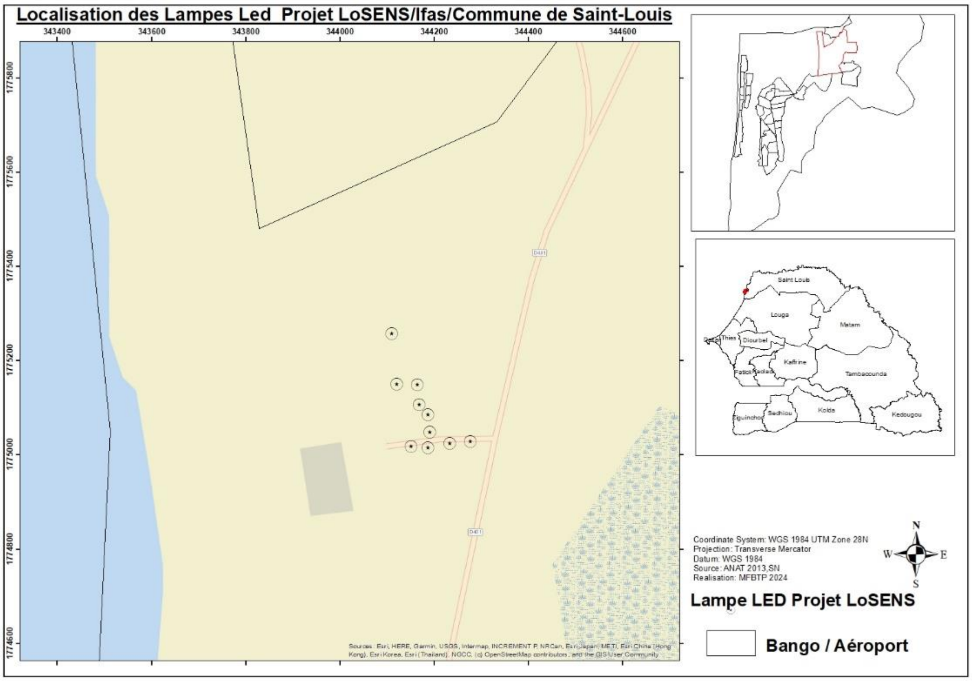


Figure 44 | Position of the Lamps in the Bango Neighborhood, (© IfaS)

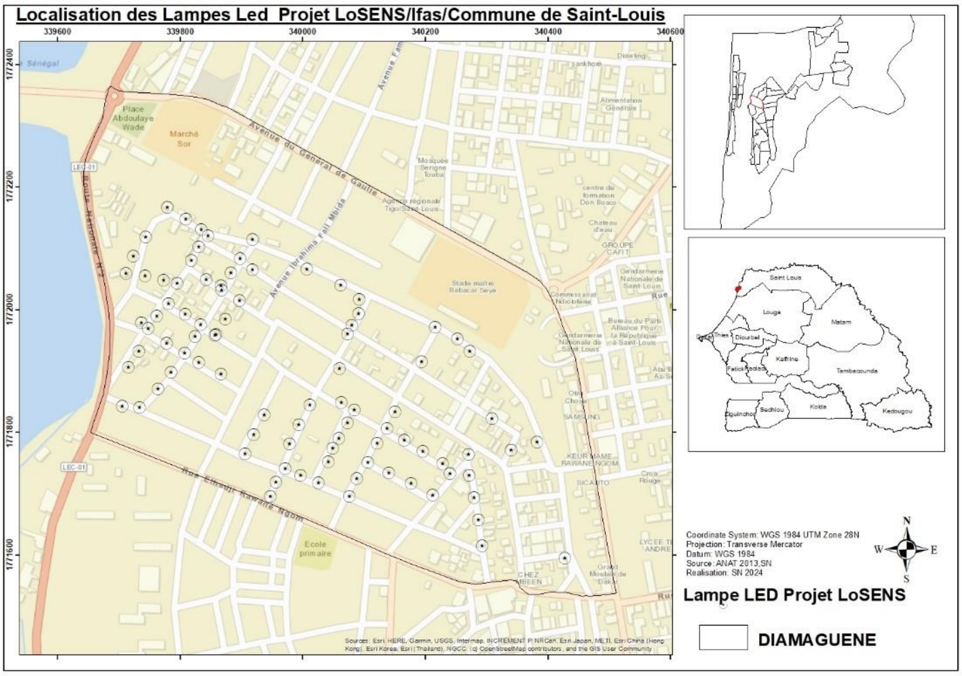


Figure 45 | Position of the Lamps in the Diamaguène Neighborhood, (© IfaS)

7.6 Installation and Monitoring after Installation

To achieve the results described above, not only must the lamps in the various streets be replaced, but certain building regulations must also be observed. These are summarized in Figure 46 and Figure 47.

Mastabstand	30.000 m
(1) Lichtpunkthöhe	6.500 m
(2) Lichtpunktüberhang	1.500 m
(3) Auslegerneigung	5.0°
(4) Auslegerlänge	1.496 m
Jährliche Betriebsstunden	4000 h: 100.0 %, 36.0 W

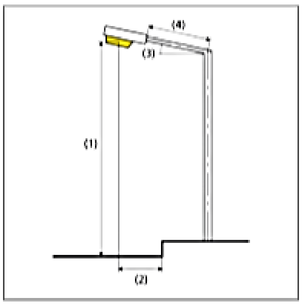


Figure 46 | Installation Settings on the "DG 25 Road"

Mastabstand	50.000 m
(1) Lichtpunkthöhe	12.000 m
(2) Lichtpunktüberhang	-3.500 m
(3) Auslegerneigung	0.0°
(4) Auslegerlänge	1.500 m
Jährliche Betriebsstunden	4000 h: 100.0 %, 36.0 W

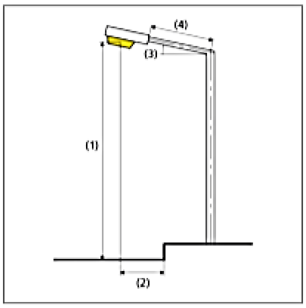


Figure 47 | Installation Settings on the "Avenue Général de Gaulles Road"

The installation steps of a prototype of the Lanz luminaire selected as part of this project were installed in the city of Saint-Louis in Senegal in February 2022.

Figure 48 documents the relevant work steps for installing and commissioning the luminaire.

Figure 48 | Images of the Installation Steps of a Prototype of the Lanz Luminaire in February 2022 in the Diamaguène District of Saint-Louis, (© IfaS)

Table 17 explains screens 1 to 16 and any errors that have occurred.

Table 17 | Description of the Installation Steps with Possible Errors

NUMBER	DESCRIPTION	PROBLEMS IN THE AREA MARKED IN RED
1	Overview of the installed luminaire	-
2	Adaptation of the luminaire to the situation on site: new bracket length is produced	-
3	The luminaire is tested after the long transport route	-
4		The cable of the luminaire is plugged in without the mains plug and the socket
5	Pole of which the luminaire is replaced	
6	Removed light	-
7		-
8		Deposited dust that must be removed during maintenance of light sources. Dust is conductive. If it is not removed in time, problems such as short circuits can occur.

9	The new extension arm length is wired.	The conductors are tied without luster terminals and are insulated with tape.
10	The luminaire is raised for installation	It is pulled up using a rope, which may slacken. The luminaire could then fall down, injure people and break. Impacts against the post cannot be ruled out either
11		-
12		-
13	The luminaire reaches the installer who is trying to align the lamp	The luminaire reaches the installer who is trying to align the lamp The work area is not marked, so there is a risk for these three people of being hit on the head by a falling object, as in picture 15, when the luminaire opened unexpectedly. It could also be that a tool falls.
14	Alignment of the luminaire	Only a rope holds the installer hanging from the post, as he is setting up the 15 kg luminaire during this time. For safety reasons, a lifting platform is required for such work. Installation can also be carried out without personal protective equipment, as shown in Fig. 9
15	Connecting the light to the mains	-
16	Trial operation	-

A direct comparison at the same location of the light quality before and after installation is unfortunately impossible, as the installation location was not predefined in advance. The condition of the post, its location (intersection) and the presence of a small business (shop) opposite justify this choice. Nevertheless, it can be concluded from Figure 49 that the junction of the streets "DG 14" and "DG 21" are better lit after installation (2 &3) than before (1).

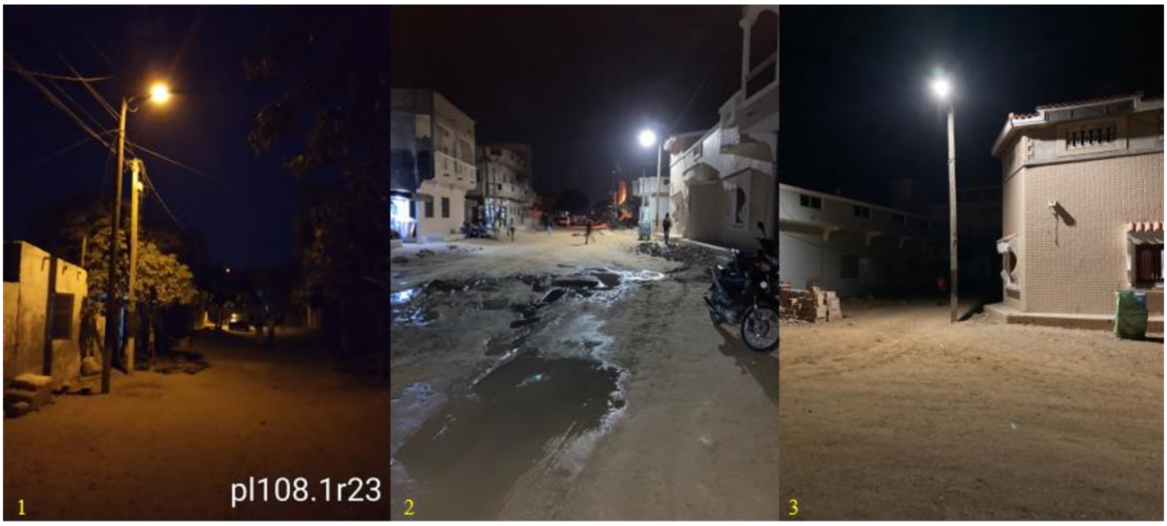


Figure 49 | Comparison of Light Quality Before and After Installation, (© IfaS)

Regardless of the type of installation and the light sources used, many parameters influence the quality of light. These are country-specific and cannot be generalized. Streetlights are installed with an “electrical ballast” unless the latter is already integrated into the light source. Ballasts are used for current limitation (ensuring constant currents and voltages at the output) and may contribute to dimming the luminaire (if it is an electronic ballast) (*Vorschaltgeräte | Licht.De*, n.d.). These components typically break down after a certain time (depending on the loads) and must therefore be replaced.

In Saint-Louis in Senegal, some streetlights are automatically switched off and on at 8 am and 6 pm. This function is only possible if the installation is fitted with a timer that regulates the switch-on and switch-off times (*Lichtmanagement-Anf | Licht.De*, n.d.). Over time, the timer becomes misaligned or inaccurate and should therefore be adjusted or cleaned as required. Mechanical timers wear out over time, while timers that contain a daylight utilization strategy photosensor should be cleaned (PremiumLightPro Project Consortium, 2017).

In addition to thunder, which can cause short circuits in the luminaire, there are transformers from the lamp that are not excluded from a breakdown. In addition, tree branches can cause a problem by cutting the power cables or destroying the luminaire when they fall/break.

Preventive maintenance is recommended to avoid or minimize these faults. The breakdowns that cannot be avoided can be eliminated by corrective maintenance. However, each measure is associated with corresponding (country-specific) costs. Since no literature was found on the composition of these costs for the country of Senegal, a cost estimate for the maintenance of street lighting is therefore presented, which was obtained from an electrician in the municipality of Balingore in Senegal during a survey. During this meeting, it was also possible to evaluate frequently occurring problems with street lighting that needed repair. Table 18 provides a better overview.

Table 18 | The Most Common Problems Encountered During the Maintenance of Street Lighting and the Associated Costs

PARAMETER	***COST***	***UNIT***
Replace bulb with all necessary components	53	€
Defective lamp	9	€
Defective transformer	18	€
Cable cut	-	
Light source covered by branches	-	
Defective switch protection	-	
Change or clean clock	-	
Labor costs	5	€/Lamp

Not all costs could be estimated, but it is important to note that the instability of the grid and the power outages are at the expense of a constantly functioning lighting system. It is therefore difficult to define the frequency with which the above-mentioned problems occur. The electrician recommends that the lights are serviced at least twice a year, which is currently only done once due to a lack of funds; even if there is a breakdown at a light point, it can take up to six months before the problem can be resolved.

Once the lamp cuffs had been manufactured, they were wired up before being installed. Figure 50 shows some of the installation stages. The installation was not carried out on the streets initially planned, as can be seen in Figure 44 and Figure 45. Nevertheless, the quality of the lighting was better than that of the halogen lamps. While around 5 lux could be measured directly 7 m below the pole, at least 25 lux was measured below the new lamps.

Figure 50 | A Few Installation Steps in Diamaguène

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