# Maintenance of street lighting systems using mobile phones

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**Abstract**

There is no doubt that street lighting systems have an important role in cities promoting comfort, as well as enhancing safety and security. These kinds of systems require maintenance in order to guarantee operation and reduce energy consumption. To help with certain maintenance tasks, a new smartphone application has been developed. The aim of this tool is to set up street lighting energy efficiency level at the same time that the illuminance level is evaluated. The benefit of this tool is that maintenance staff can assess energy efficiency on an easy and quick way, achieving a result report. In addition, a new Bluetooth device was created to perform the measurements, being necessary to perform a brief study about its accuracy compared with a mobile phone ambient light sensor and an external sensor.
**Keywords:** lighting measurement, lux meters, mobile sensors, energy efficiency

## 1. Introduction

Street lighting systems are an essential service for modern life which is able to increment night activities whilst reducing crime [18]. However, its main drawback is the high amount of energy needed to provide this service. At present, Spain has one of the highest consumption per lamp in the European Union. To solve this critical situation, the Spanish government established a new standard with the purpose of improving efficiency and energy saving in outdoor lighting: Royal Decree 1890/2008 [24]. To comply with its requirements, it is mandatory to verify operation every five years by measuring several factors including the illuminance level and uniformity.

The most common method to evaluate street lighting systems is through the illuminance level because data can be acquired easily for one street [27]. However, a drawback appears when maintenance staff has to evaluate several streets because the amount of man hours required to collect data from different systems using a luxmeter is huge. This is further compounded by enormous tasks of then processing said data [2].

Furthermore, many of the maintenance-related decisions depend on the reliable exchange of data between maintenance operations and strategic organization layers. Therefore, information and communications technology (ICT) has a fundamental importance for the implementation of an efficient maintenance management structure [8].

Keeping in mind that mobile systems, such as smartphones, have become the primary computing platform for many users [3] including personnel on the job site [15], a new tool has been developed taking advantage of the latest technology to simplify the evaluation of illuminance level of street lighting systems.

The premise of the use of smartphones as tools for environmental monitoring has been widely extended [1]. For that reason, we propose a solution based on the use of mobile devices running Android OS to help street lighting maintenance labors which is able to evaluate illuminance level and uniformity according to the requirements of the current standard. Besides, it is able to give the energy efficiency label, taking into account the current conditions.

Although most of current smartphones are equipped with an ambient light meter, which is commonly used for screen brightness control based on surroundings, its accuracy on lighting measurements cannot be compared with the accuracy of dedicated devices. For that reason, it has been created an external device which is able to measure the quantity of light in a point and send it to the mobile application through Bluetooth connection. To show the accuracy of these two different methods it has been carried out a study where measurements performed with both are compared with the values obtained with a calibrated external luxmeter.

The remainder of this paper is organized as follows: Section 2 outlines the state of the art. Section 3 shows the different methods to measure the lighting level. Section 4 describes the application's architecture and the final developed prototype. The results and discussion are showed on Section 5 where firstly the accuracy of the different measurement methods are evaluated and secondly the application is compared with another software. Finally, section 6 draws the concluding remarks of the manuscript.

## 2. State of art

As the study covers some fields, this section has been divided into three parts: Firstly, it describes the available applications which evaluate the light quality. Afterwards, it analyses different ways to assess energy efficiency. Finally, it describes how illuminance level can be measured efficiently

### Street Lighting Applications

World advances in street lighting systems together with the growing interesting on improving energy efficiency have led to several applications which evaluate energy efficiency of street lighting. In this field, the most important application is DIALux, which allows the creation of a 3D virtual world where real lighting effect may be recreated and seen more practically. It also provides information about power consumption of elements in order to guarantee compliance with the regulations [11]. The main strength of this tool is in its database of detailed manufacturer's information about the different elements. This provides more accurate evaluations.

Another available overseas tool to evaluate energy efficiency is SEAD Street lighting evaluation toolkit which provides an easy way to perform a first-order evaluation of light quality, energy consumption, and life cycle costs of efficient street lighting alternatives, helping to make more choices regarding street lighting fixtures which may achieve up to 50% in energy savings [26]. This tool is supported by Mexico's National Commission for Energy Efficiency, India's Bureau of Energy Efficiency, Natural Resources Canada, Swedish Energy Agency and U.S. Department of Energy.

The application called BTwin [14] was designed to design street lighting installation based on standards EN 12464-2 [9] allowing import the manufacturers' luminous files to give more

accuracy to the calculations. This program has an extended feature called AEwin which allows evaluating the installation energy efficiency and obtains the energy label before carrying out its implementation. To give more precision, the tool gives users the opportunity to take into account possible vertical obstacles, such as walls, which can affect to the lighting.
All these applications simulate ideal conditions, even taking into account maintenance factor. However, it is impossible to adjust the situations to the reality, being a requirement to measure the main parameters every five years.

If we focus on systems which allow evaluating the real situation of the installation, there is available an application which is able to provide the energy efficiency label, known as MAYJA [19]. But the main deficiency of this application is the need of knowing the illuminance average value, which must be calculated previously. Another disadvantage is the lack of information about the satisfaction of the normative, because it does not include the uniformity to give the energy label.

**Light efficiency evaluation**

Due to the large variety of tasks areas and activities, the use of only one measure to describe the energy efficiency of outdoor lighting installations seems impossible [27]. Therefore, a detailed study was considered to analyze the different ways used until now. The study done by Herring [13] proposed an evaluation focused on the amount of lumens per watt. The main drawback of this method is that it does not take into account external aspects as the speed limits of the road which is an important factor because the illuminance depends on the frequency of vehicular traffic.

Another evaluation way was proposed by the Slovenian government in 2007 [4] where it was used to measure the annual energy consumption per citizen per year. A main disadvantage of this proposal is that areas with high population density have easier to achieve lower level values than areas with low population density, where modern systems can help them to reach similar level.

In the research carried out by Kyba [17] kilowatt hours per kilometer per year was proposed because this measure allows apple-to-apple comparisons of radically different lighting systems. For example, adaptive lighting systems that dim or turn off lamps when not needed may use far less energy in a year than traditional systems.

According to the European standard EN 13201 [10], energy efficiency is defined in terms of installed power per surface area and per average illumination level, making distinction among lighting classes to evaluate the light required in each case. However, these lighting classes used in each country may not be equal than European standard. For example, comparing the lighting classification established on this European standard and Spanish standard [25], Table 1 shows that Spanish standard does not contemplate two lighting class.

Table 9. Horizontal illumination comparison of European and Spanish legislations

| Lighting Class | EN 13201-2:2003 | | R.D. 1890/2008 | |
|---|---|---|---|---|
| | Em (lux) | Emin (lux) | Em (lux) | Emin (lux) |
| S1 | 15 | 5 | 15 | 5 |
| S2 | 10 | 3 | 10 | 3 |
| S3 | 7.5 | 1.5 | 7.5 | 1.5 |
| S4 | 5 | 1 | 5 | 1 |
| S5 | 3 | 0.6 | | |
| S6 | 2 | 0.6 | | |

**Lighting quality measurement**

The first point to evaluate the street lighting installations consists of evaluating the quality of the illuminance. To perform this evaluation, Spanish standard R.D 1890/2008 was followed in order to adapt the evaluation to Spanish regulations, where the outdoor lighting is evaluated through an energy label.

First of all, it is necessary to know the sort of road to ensure that evaluated system complies with the current regulation. This division is important in order to specify the amount of required light to ensure citizens security, adapting the requirements in each context. Roads are divided into two sorts [6]:

- Functional street lighting. It encompasses lighting installations for motorways, dual carriageways, urban streets and roads.
- Ambient street lighting. It is generally placed on low supports in urban areas for lighting pedestrian and commercial areas, pavements, parks and gardens, historic centers and roads with low speeds limits.

Once the type of road is known, it is possible to check the minimum lighting requirements of the system which are established on the regulations. In case of not reach them, the evaluation will be the lower possible, using this application.

To perform the evaluation, it is required to obtain several values such as the average illuminance of the system. To obtain this magnitude, the regulations stablished a grid of 3x5 placed between two lamp posts. Figure 1 shows the places where it is necessary to set the measures.

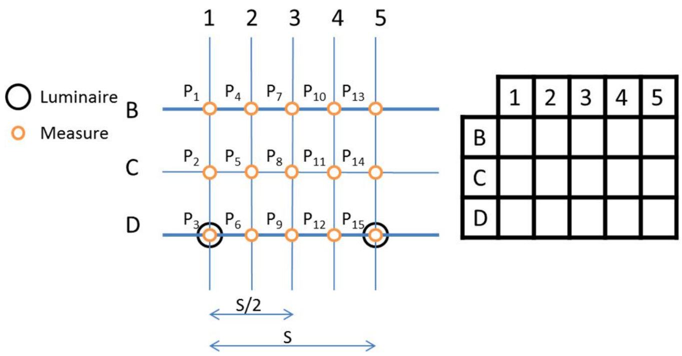



Fig. 8. Methodology used to do the measures of light

If both streetlights have the same characteristics this method can be simplified with the measure of only nine points. Although this simplification is considered on the standard, it has an uncertainty of about 10% in comparison with a more elaborate procedure [12], reason why the measure of all the points of the grid is required to do the evaluation.

Once the measures are made, it is possible to obtain the average illuminance thanks using the equation X:

$$E_m = \frac{E_1 + 2 * E_2 + E_3 + 2 * E_4 + 4 * E_5 + 2 * E_6 + E_7 + 2 * E_8 + E_9}{16} \text{ (lux)} \qquad (1)$$

Where:

- $E_1 = (B1 + B5)/2$
- $E_2 = (C1 + C5)/2$
- $E_3 = (D1 + D5)/2$
- $E_4 = (B2 + B4)/2$
- $E_5 = (C2 + C4)/2$
- $E_6 = (D2 + D4)/2$
- $E_7 = B3$
- $E_8 = C3$
- $E_9 = D3$

Once the previous value is calculated, it is possible to obtain the energy efficiency value through the following equation:

$$\varepsilon = \frac{S * E_m}{P} \left(\frac{m^2 * lux}{W}\right) \qquad (2)$$

Where:

- $\varepsilon$ is the energy efficiency parameter

- S is the illuminated area
- $E_m$ is the average illuminance

To provide an energy label of street lighting, it is necessary to calculate the energy efficiency index. This magnitude is defined as the quotient between the energy efficiency and the value of energy efficiency reference, as it is shown in equation 4.

$$I_\varepsilon = \frac{\varepsilon}{\varepsilon_R} \quad (3)$$

In addition to the previous evaluation of the energy efficiency, it is mandatory to check other value to guarantee the quality of the light: the uniformity average. This factor is a very significant magnitude because it is important for driver comfort as eyestrain may result from the continual variation of luminance as the driver travels down the road [23]. This magnitude can be calculated with the help of the equation 2:

$$U_m = \frac{E_{min}}{E_m} \ (\%) \quad (4)$$

Where:

- $E_m$ illuminance average
- $E_{min}$ minimum value of the measured points

## 3. Light measurement

In recent years, smartphones such as Android products or iPhones, among others, have prevailed as sophisticated multi-function mobile phones. In case of Android platform, it provides four different sensors that let us monitor several environmental properties as humidity, illuminance, ambient pressure and ambient temperature. All of these sensors are hardware-based and are not available in all of the products, and their presence depends of the manufacturer's decision. For that reason the light measurement has been developed in two different ways (mobile light sensor and external sensor device) in order to give to the user the option that best fits with their terminal.

**Mobile Light sensor**

Since smartphones have a built-in illuminance sensor for screen brightness control, they may be utilized as illuminance sensors for Intelligent Lighting System due to its capability to measure the intensity of the light in the phone's context. The location of this sensor in most smartphones is in the surface above the screen.

Nowadays, this sensor is commonly used to adjust the brightness of the device automatically based on surrounding, thus helping in saving battery power while optimizing the visibility [7]. However, it can be used in different fields. In case of Physics labs, light sensors are common devices, and in the teaching practices, the use of their own phone by students increases the interest and motivation performing experiments.

Despite smartphone's light sensors reading being a highly accurate and straightforward technology compared to other sensor technologies, they cannot be compared with the data obtained from the device's dedicated hardware [7]. However, the results can be useful in practical cases as in the undergraduate physics laboratory [25] where a high level of accuracy is nor needed.

Android OS allows us to access the mobile sensors values through APIs which will collect the data while the app is running. Unlike most motion and position sensors, which return a multi-dimensional array of sensor values, environment sensors, like light sensor, return a single value for each data event [5].

**External sensor device**

To guarantee the best possible accuracy, and the use of the application in as many devices as possible, an extra option to make measurements through an external devices has been developed. For this option, an external device, called 'Alcalux', which can communicate with our smartphones without cables, has been made. To choose the best option of communication, and taking into account that the battery life is the most important factor for mobile users [16], the different possibilities of data transmission, and the energy consumption of each one, have been studied. On that aspect, the best option is Bluetooth because of its low power consumption compared with other wireless communication systems, such as Wi-Fi, as is shown in the study carried out by Perrocci et al [21]. Another important aspect to take into account is that Bluetooth is embedded in nearly all Smartphones.

In order to enable Bluetooth in the external device, an embedded module (RN-42 from Rovingnetworks [23]) was chosen for its simplicity and relative low power consumption (about 30mA during the transmission, 3mA when it is connected and 26μA in sleep mode).

The data transmitting process simulates a messages pipe where the Bluetooth module receives data from the UART of the microcontroller and transmit the information through the wireless connection, this process being transparent to the final user. Figure 2 shows a data transmitting process diagram.

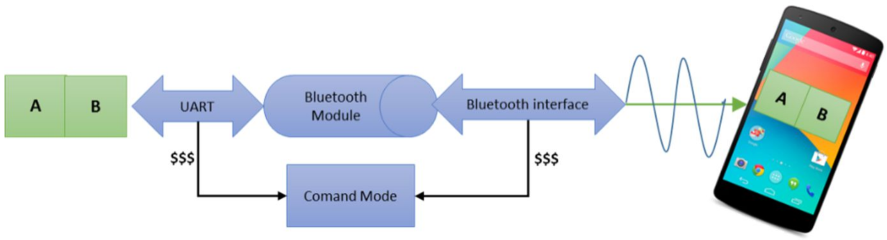



Fig. 9. Alcalux data transmitting process

Despite the present study only covering illuminance measurement, the created device is able to control several parameters such as light, presence or temperature, being possible to set the clock information and store the data on an EEPROM memory. To avoid an amount excessive information on the stored memory, the device has been developed with the possibility to configure the time between stored measured in a range between 2 and 65524 seconds. The final result is a device of a cell phone size which is able to obtain parameters of the performance and send it to our smartphone. Figure 3 shows the developed device.

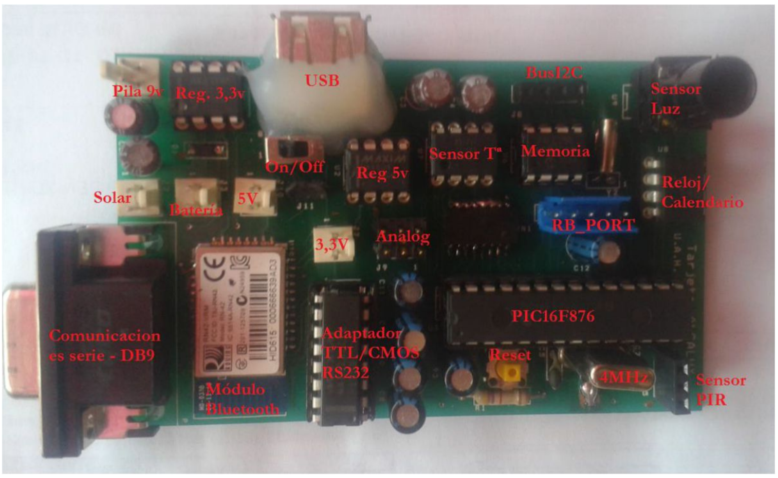



Fig. 10. Alcalux sensor board

## 4. Application architecture and prototype

To evaluate the street lighting energy efficiency, a new application called ENCEL (ENergy CErtification in street Lighting) is proposed on this paper. The application has been developed as smartphone application in order to make easier the evaluation of this kind of installations by maintenance managers, providing extra information related with the standards compliance. The aim of this application is to provide maintenance managers a powerful tool to evaluate their installations. The application architecture and its use are explained in the following sections.

## Architecture

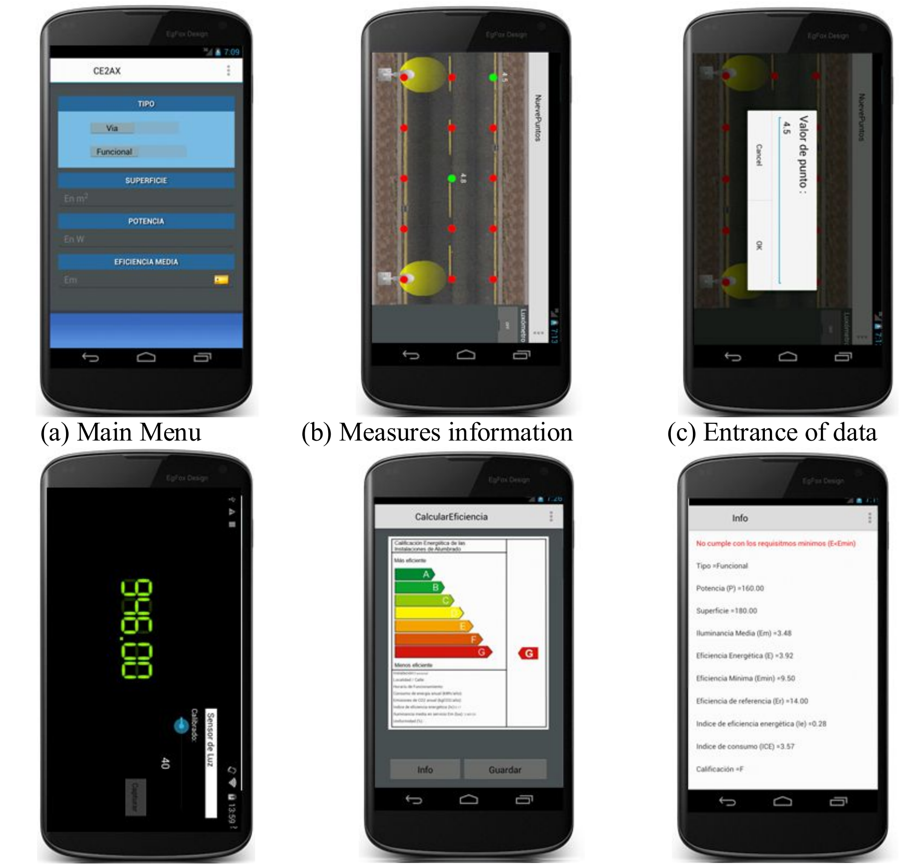
The first point before starting to develop the application passes through identifying its main components: the Activities, which represent the graphical user interface of the application; and the Services, which allow background execution. Accordingly, the developed application has been divided into four different activities:

1. “insert_values_activity”. It is the responsible for collecting of data to evaluate the installation’s lighting efficiency. It also provides access to the activity which calculates illuminance average.
2. “9points_activity”. This activity allows user to obtain the average illuminance through a grid where it is possible to enter the values for the different measured points. Once all the points have been completed the activity sends the result to the previous activity.
3. “luxometer_activity”. This activity makes the opportunity of measure the amount of light directly from the device, offering three different ways of take this measure: from the light sensor, from the camera or via Bluetooth from external device.
4. “energy_label_activity”. Once the energy efficiency is calculated, this activity shows the energy label corresponding to the street lighting installation.
5. “info_activity”. In case the user wants more information about the evaluation of the street lighting energy efficiency the application will provide him some values which can be useful in order to find lighting problems.

Once the different activities have been identified, the next point is setting the relationship between those activities.

## Evaluation system

Once the application architecture has been stabilized, the next step consists of adapting these requirements to the different application’s screens. Figure 5 shows the different screens designed for the mobile application.




(a) Main Menu (b) Measures information (c) Entrance of data

(d)Light measurement (d) Energy Label (e) Evaluation’s data

Fig. 11. Application Screen Shots

The first application's screen shows the main menu where the application ask for the information to be able to do the evaluation (Figure 4 (a)). In this menu it is required to fill out the following information:

- Type of Street lighting. Where the user can choose between two different types: functional and ambient street lighting.
- Surface. This value refers to the surface of assessment grid where the measurements were taken, which must cover the stretch of road comprised between two consecutive luminaires, with a length of separation.
- Power of the installation. In this case, the power considered must take into account the value of the lamps and ballasts power of the luminaries which involved on the light evaluated.
- Illuminance average. This value refers to the average of light measured on the evaluated grid.

As illuminance average requires to make the measures of different points to use these data into the equation, an extra functionality where the measured points can be inserted, directly obtaining the equation result, has been developed. Figure 4 (b) shows the measurement grid where it can be appreciated several points without input value in red and others in green with the value introduced. Figure 4 (c) shows the input of one of the measures.

Once all the information required to do the evaluation has been introduced in the application, it will show the corresponding energy label as can be seen in Figure 4 (d). It is possible to check the complete information of the evaluation, giving also specific information about the standards compliance (Figure 4 (e)).

## 5. Results and Discussion

The study of the application developed consists of two experiments that were conducted to evaluate it from the following point views:

- **Light sensors accuracy**: To know if the sensors used are useful to make the evaluation of a street lighting efficiency.
- **Case of study of the application**: The best way to know the accuracy of the application is using it in real scenarios and comparing the results with other applications.

### Light sensors accuracy

To verify the performance of illuminance sensors, their measurements were compared with the measured values of an externally calibrated illuminance meter (PCE-174 model [20]). On one hand, it is important to highlight that there will always be slight differences between light meters, even if they are identical models the results may not be equal. On the other hand, a light meter can never be 100% accurate due to the fact that this kind of appliances can drift over time. For that reason, it is important to ensure that the light meters used are all calibrated against a known reference to ensure it is reading accurately. A calibrated luxmeter yields accurate and consistent measurements over many years. To calibrate each device we will use a calibrated external luxmeter, measuring the light in a point. Next, we have to measure the same point with each of our light sensors to known the deviation of each one.

Once the sensors have been calibrated, the next step is to set several points of measurement. To study their accuracy, different measures have been selected in order to know their behavior through different intensities of light and different light sources. To take the measurements the standard lux meter used as a reference is placed at the location. Once the measurement is taken, the lux meter is replaced by the external device, and then by the mobile light sensor. Figure 6 shows the behavior of the sensors in each of the different measured points.

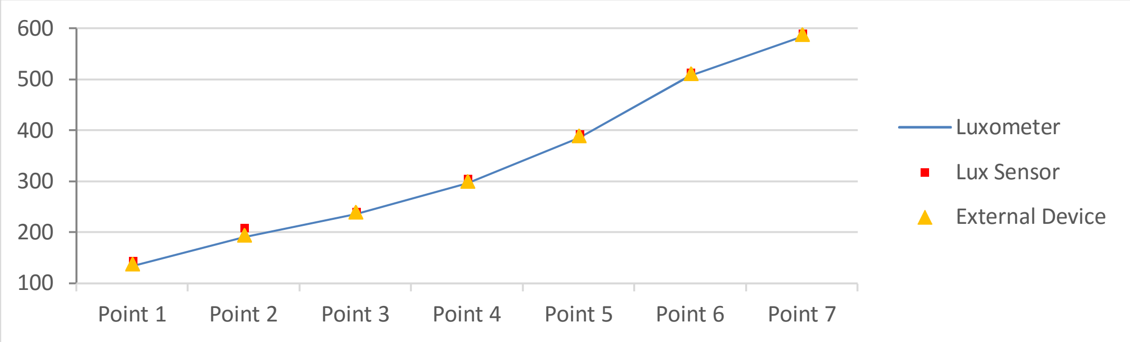



Fig. 12. Results of illumination measurement using a mobile lux meter and an external device compared to the measurement under a standard lux meter

Studying the measured points with the luxmeter used as reference, it can be seen how the mobile lux sensor has a 3.5% of error, while the external device has only a 1.2% of error. This variation may be originated from position and angle misalignments when we put in placed the devices.

**Application cases of study**

Several cases studies were conducted in a town of Spain (Villaluenga de la Sagra, Toledo) to check the performance of the application and to analyze the main difference between the application and other evaluation tools such as DIALux (used to obtain Illuminance and Uniformity values) and MAYJA (used to obtain the energy efficiency label).

The location selected were two streets (ambient street lighting) equipped with Master City White CDO-TT Plus 70W828 lamps [22] and conventional ballast. These streets have one-side configuration. Table 5 shows the characteristics of the street lighting systems evaluated.

Table 10. Characteristics of streets measured

| Street | Kind of lamp | Kind of Ballast | Area | Configuration |
|---|---|---|---|---|
| Padilla | Master City White 70W | Conventional | 30x6m | One-sided |
| Valdeculebras | Master City White 70W | Conventional | 35x6m | One-sided |

To take the measurements, a PCE-174 [20] digital illuminance meter was used. As Spanish regulations do not specify the height at which measurement must be taken, the recommendation given by the European standards [10] was followed. This standard establishes that all the measures have to be done at 200mm from the ground. Table 2 and Table 3 show the values obtained with the illuminance meter and Figure 7 shows the results obtained with DIALux.

Table 11. Padilla Street measures

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **B** | 4.5 | 1.9 | 0.6 | 1.9 | 4.5 |
| **C** | 8.5 | 3 | 0.6 | 3 | 8.5 |
| **D** | 9.1 | 3.4 | 0.7 | 3.4 | 9.1 |

Table 12. Valdeculebras Street measures

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **B** | 1.5 | 0.5 | 0.1 | 0.5 | 1.5 |
| **C** | 2.5 | 0.9 | 0.1 | 0.9 | 2.7 |
| **D** | 7 | 1.2 | 0.2 | 1.2 | 7 |

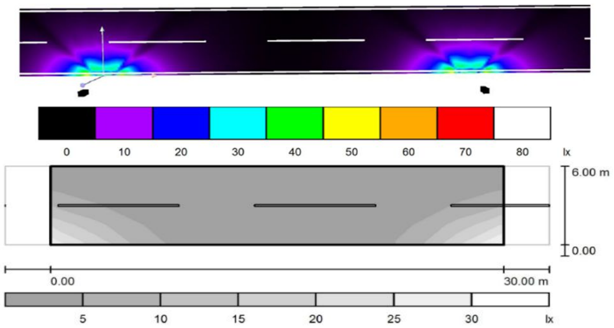


Fig. 13. DIALux simulation of Padilla Street's street lighting

Once the above data is fed into the application, the energy label appears. In the case of the evaluated systems, the value obtained is G. Neither of them meet minimum requirements (uniformity). Table 4 shows the evaluation and variables obtained.

Table 13. Values obtained after evaluation

| Street | Em | Um | Ɛ | Compliance of Ɛmin | Compliance of Um | Energy Label |
|---|---|---|---|---|---|---|
| Padilla | 3.481 | 0.172 | 3.73 | No | No | G |
| Valdeculebras | 1.337 | 0.075 | 1.67 | No | No | G |

As it can be seen, the energy label given for both systems is the same, G, because neither of them met the following requirements:

- None of facilities reaches the minimum energy efficiency value of at least 9.50.
- Uniformity average value is far from the minimum of 0.4%. For the Padilla Street is 0.172 and for the Valdeculebras Street is 0.075.

## 6. Conclusion and open issues

The contribution of this research is a new mobile application to make more efficient maintenance labor, evaluating illuminance and uniformity parameters. Moreover, it checks the performance of the minimum requirements of the current standard and gives the energy label, which must be done every five years. The fact that the tool is a mobile application gives the maintenance staff the opportunity to check the value of street lighting energy efficiency directly easily and instantaneously.

The implemented system was subjected to a practical and technical evaluation. In the former, the accuracy of the different lighting devices were studied in detail. Results showed that it is possible to take the measurement of lighting using different devices. The latter evaluation, compared the results of the application with other tools. Some differences were detected. The most important points observed were:

- The application developed takes into account the compliance of standards requirements to give the energy label. In case of breach, the energy label corresponds to the lowest value. However, MAYJA does not take into account the compliance of these requirements to give the evaluation.
- Thanks to the simulation done with DIALux, it is possible to corroborate the fact that the maintenance factor directly affects illuminance levels. In the particular case analyzed, the maintenance factor has caused a decreasing of 50% of light output.
- The values of uniformity given by simulation programs remain constant, making impossible to check the effect of time on street lighting systems.

As a result, this study shows the development of a new application that works successfully as a street lighting maintenance tool, giving maintenance staff the possibility of perform the evaluation of the system with a mobile phone. Therefore, mobile technologies can achieve an improvement in the street lighting evaluation due its potential as a measurement tool and its great potential to transform the process and, possibly even, the outcome of the street lighting evaluation.

In summary, using the current mobile technologies, we have been able to refine the process of street lighting evaluation.

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