Chapter

Control Systems and Ornamental Lighting. A Case Study: Illumination of the Facade of Santiago Hospital in Úbeda (Jaén)

Juan Cantizani Oliva, Eduardo Ruiz Vela and José Zamora Salido

Abstract

We propose the analysis of the control systems associated with ornamental lighting applied to the architectural and monumental heritage from our teaching experience developed since 2017 at the University of Córdoba—Illumination Faculty of Philosophy of Córdoba, year 2017, and Center of Experimental Culture in the Plaza de la Corredera, year 2018—and the lighting project of the facade of the Hospital de Santiago de Úbeda, Jaén. The DMX system is the one which mostly fulfill the requirements of this kind of lighting. Its implementation is increasingly simple and is associated in many cases with the type of luminaire to be used and the particularity of differential wiring. This solution allows a personalized, creative, and dynamic control and the adaptation of the daily lighting to different events of singular character. It can be used as an instrument of economic revitalization of the tourist and commercial sectors, and of diffusion of the architectural and historical heritage values. The application of the Internet of Things (IoT) and Big Data could allow the creation of a predictive model that helps the spectral design of light sources and an objective tool that contributes to the confluence of art and science.

Keywords: ornamental, architectural lighting, control systems, personalized, creative and dynamic control, DMX, differential wiring

1. Introduction

In recent years, architectural lighting has acquired special relevance as an instrument to vindicate the architectural and historical values of heritage, and as a revitalizing economical element linked to tourist and commercial sectors [1]. Its concept has recently changed from a purely functional and security one, to a more qualitative conception that contributes to the embellishment and singularization of the city's heritage [2, 3].

The benefits of including control systems in lighting are unquestionable—light intensity regulation allows to reduce energy consumption enabling its adaptation to different rates and changes [4]. Traditionally, control systems related to architectural lighting have been associated with exterior lighting. The origin of this technology lies in cinematography and entertainment. Until few years ago, the most widespread system was the linear analogical control, which was limited by the number of channels, contacts, and connectors. With the arrival of microprocessors, the use of transmission systems using private protocols, incompatible with each other, began. Thus, in 1986, the DMX512 aroused at the request of the USITT (American Institute of theatrical technologies) to turn the communication system into an efficient standard [5].

Recently, the DXM protocol is acquiring a great development in the field of outdoor lighting and especially applied to the architectural and entertainment types, which together with the potential offered by LED technology, intelligent lighting associated with Big Data and the Internet of Things (IoT) [6]; they make illumination that can be understood as a language "light as a language," with the ability to express and transmit different situations and events.

2. Methodology

The analysis and the classification of the different types of control are very complex since most of the available information comes from trading houses, which use different denominations and lead to their products' diffusion and consumption.

In our case, the analysis of the different types of control arises not only from the study of the existing available documentation but also from the teaching experience developed in this field since 2017 in the Department of Electrical Engineering of the Higher Polytechnic School in the University of Cordoba.

Methodologically, a first step is proposed by an objective analysis of the variables that configure the different types of lighting control [7]. These variables have been divided into four groups—systems, methods, and functionalities of the autonomous and networked systems—whose conjugation generates the different types of control. This offers a global vision that allows us to frame and know which ones are acquiring special prominence in architectural lighting.

Next, we will focus on the DMX method, as the most developed in this particular field, analyzing its characteristics and the elements that make up its installation, based on graphics associated with our teaching experience: Lighting Faculty of Philosophy of University of Córdoba, year 2017, and Center of Experimental Culture (CEUX Building) in Plaza de la Corredera, year 2018.

Finally, we will analyze a practical case, specifically the lighting project of the facade of the Hospital de Santiago in Úbeda, which is a tool that allows us to customize the image of the building through the regulation, adjustment, timing, and programming of different scenes of light and color.

3. Types of control systems: ornamental lighting applied to the architectural and monumental heritage

3.1 Generalities

The attached table (**Figure 1**) includes the variables that may participate in the configuration of the different types of control in the case of interior, exterior, and ornamental outdoor lighting applied to the architectural and monumental heritage.

Control systems are classified as autonomous and network, depending on whether there is interconnection between devices. Network systems are the most used in architectural lighting, since they involve greater savings and flexibility to combine different strategies. They can be classified into a network by groups, point-to-point and interactive in case of interaction with the user (**Figure 2**).

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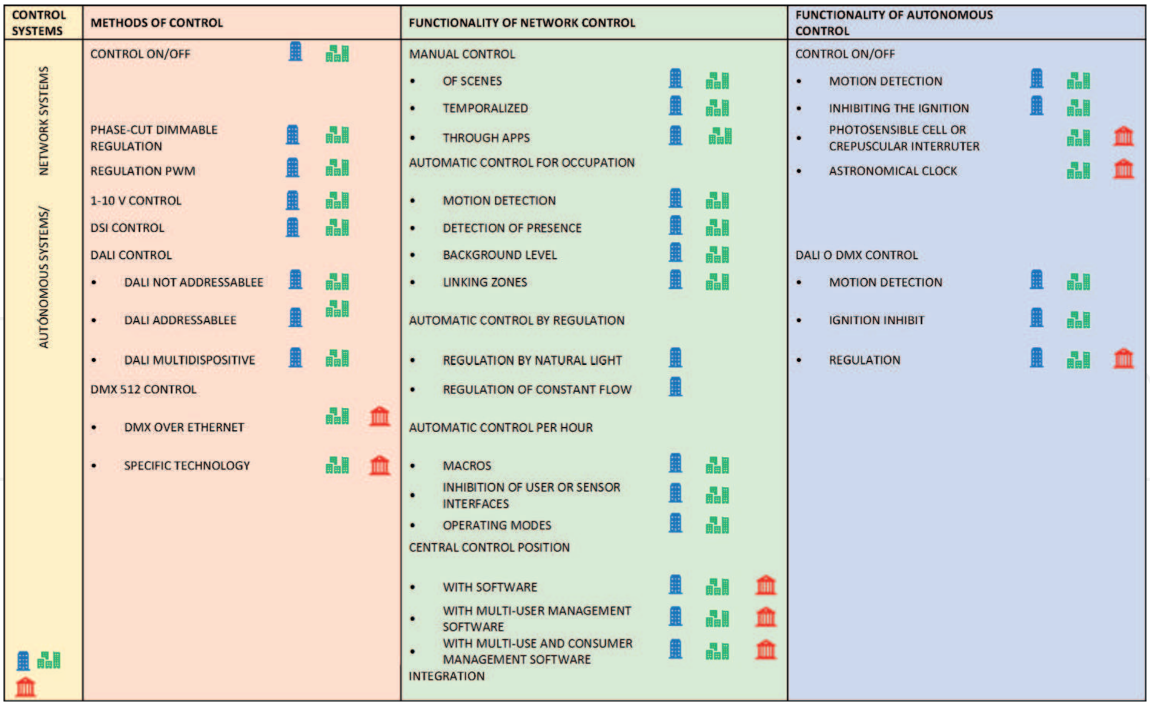

CONTROL SYSTEMS	METHODS OF CONTROL	FUNCTIONALITY OF NETWORK CONTROL	FUNCTIONALITY OF AUTONOMOUS CONTROL
AUTONOMOUS SYSTEMS/ NETWORK SYSTEMS	CONTROL ON/OFF	MANUAL CONTROL	CONTROL ON/OFF
		• OF SCENES	• MOTION DETECTION
		• TEMPORALIZED	• INHIBITING THE IGNITION
	PHASE-CUT DIMMABLE REGULATION	• THROUGH APPS	• PHOTOSENSIBLE CELL OR CREPUSCULAR INTERRUTER
	REGULATION PWM	AUTOMATIC CONTROL FOR OCCUPATION	• ASTRONOMICAL CLOCK
	1-10 V CONTROL	• MOTION DETECTION	
	DSI CONTROL	• DETECTION OF PRESENCE	
	DALI CONTROL	• BACKGROUND LEVEL	DALI O DMX CONTROL
	• DALI NOT ADDRESSABLEE	• LINKING ZONES	• MOTION DETECTION
	• DALI ADDRESSABLEE	AUTOMATIC CONTROL BY REGULATION	• IGNITION INHIBIT
	• DALI MULTIDISPOSITIVE	• REGULATION BY NATURAL LIGHT	• REGULATION
	DMX 512 CONTROL	• REGULATION OF CONSTANT FLOW	
	• DMX OVER ETHERNET	AUTOMATIC CONTROL PER HOUR	
	• SPECIFIC TECHNOLOGY	• MACROS	
		• INHIBITION OF USER OR SENSOR INTERFACES	
		• OPERATING MODES	
		CENTRAL CONTROL POSITION	
		• WITH SOFTWARE	
		• WITH MULTI-USER MANAGEMENT SOFTWARE	
		• WITH MULTI-USE AND CONSUMER MANAGEMENT SOFTWARE INTEGRATION	

Figure 1.
Summary table of control systems and methods and the functionality of control systems. Source: own elaboration. Preferential use: interior lighting, exterior lighting, and ornamental exterior lighting applied to the architectural and monumental heritage.

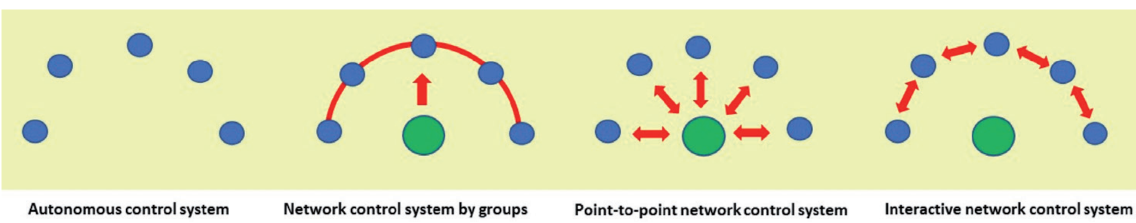

Figure 2.
Types of network control systems. Source: own elaboration.

In the first case, one can control a group of light points, while in the second, one can control and supervise individually every points of light. The latter is the most used in architectural lighting.

The methods of control must be compatible with the luminaire's driver. There are methods, such as phase-cut dimmable regulation or PWM, in which the regulation is carried out in the voltage line itself, with distance being the most limiting factor when working with direct electric current.

Other methods rely on a unidirectional signal, such as 1–10 V or DSI, since the information flows in a single direction, from the controller to the lighting equipment. In the first case, the signal is analogical on two wires sensitive to polarity, while in the second, the system is digital, lacking the polarity cable and its topology is free except for the ring or closed loop.

The Digital Addressable Lighting Interface (DALI) control is not exactly a control method, but rather a bidirectional communication standard (IEC 62386). It is independent of the manufacturer and only the logo guarantees compatibility between the equipment. It provides 256 lighting levels that translate into power levels between 0 and 100% [8]. The advantage of this technology is the bidirectionality of the system that allows receiving feedback on the status of the luminaire. Being a digital system, the data cable lacks polarity and its topology is free except for the ring or closed loop. This greatly helps the installation, making the system flexible and scalable. It can be point-to-point addressable, or be associated with other devices; such as sensors or push buttons. It is a method widely used in both indoor and outdoor lighting.

In front of DALI comes the DMX Control (Digital Multiple X) as a high-speed control protocol (250 kb/s), which is highly developed in the field of stage lighting. In case of high channel density, DMX over Ethernet can be used, which allows speeds of 10–100 Mb/s. Some trading houses have developed specific technology in order to optimize and facilitate the installation and promotion of this method of control.

The functionality of the autonomous control is related to incorporation of sensors or other devices in the ON/OFF and DALI or DMX control. The functionalities of network control can be carried out by means of manual control and automatic control by occupation or regulation, by time, and by control post, the latter being the most used in architectural lighting.

The central control station allows, through a processor and a specific software package, to control, monitor, manage, and maintain the lighting system optimally. There may be different levels of development, from a simple software to a multi-user management and consumption tool, which provides total system information (control, visualization, maintenance, individual consumption, reports, and alarms, among others). These functionalities open a wide range of possibilities in the field of architectural lighting [4].

Thus, there are multiple types of control, each one made by the addition of a system and a control method, affected by different functionalities according to the chosen option. In this scenario, with multiple options of control types for indoor and outdoor lighting, we can frame the control systems associated with architectural lighting. The most used control system is point to point network with DMX method-over Ethernet or not-, and central control functionality [9]. This type of control is based on a high-speed control protocol, which is adapted to the requirements of architectural lighting, since it allows dynamic lighting installations and also the traditional static lighting to which we are used today [10].

3.2 Control systems for LED lighting associated with ornamental lighting applied to architectural and monumental heritage

3.2.1 DMX protocol (digital multiplex)

Control by DMX (Digital Multiple X) technology is a protocol, according to the DMX512 standard, high speed (250 kb/s) or digital signal control system developed by the USITT for the lighting of scenarios and shows. It is currently used increasingly in the field of architectural lighting.

The DMX512 [11] is based on the international EIA RS485 standard. The RS485 transfers the information by a differential line made up of two conductors. It has a high immunity to electrical and electromagnetic disturbances, due to the intrinsic characteristics of the differential amplifiers, which, in both analogical and digital applications, remove all unwanted same polarity signals, amplifying the opposite differential ones [12].

DMX requires a routing process for each luminaire. A DMX universe has 512 channels, each with a regulation capacity between 0 and 255. A monochromatic light source controlled by DMX generally uses a channel to regulate the light intensity, while an RGB projector will use three independent channels [13]. So, a DMX universe can control up to 170 independent RGB luminaires.

In projects with high channel density, DMX is used through Ethernet, which transfers information at the speed of 10 or 100 Mb/s. The Ethernet network uses a single connection cable for all the devices of the system, which allows great flexibility and a notable reduction of control cables [14].

3.2.2 Elements that make up the installation with DMX control method

3.2.2.1 Principles of operation

The DMX512 transmits sequentially the data to the channels in asynchronous mode, at 250 Kb/s. When the transmitter has sent the information to all 512 channels, it informs that the transmission will be made to channel 1 soon and the next cycle begins. The time spent in a cycle is about 22 ms, so short that you cannot perceive its delay [15].

3.2.2.2 Luminaires

In order to control luminaires through DMX, they must have a driver [9]. As a general rule, the number of luminaires in each control module is limited and a DMX signal amplifier must be added to the network in case of exceeding it.

3.2.2.3 Bypass and amplification boxes

The DMX bus only supports the online topology, and the Y-type branches are forbidden, since they significantly degrade the quality of the signal and make transmission unsteady [5]. In case of derivations, or when certain lengths are exceeded (usually 300 m) or more than 30 nodes, it will be necessary to use bypass and/or amplification boxes, which recondition the signal allowing to extend the distance of use (**Figure 3**). These boxes can be isolated to solve eventual malfunctions caused by rings to ground. In projects with a high density of DMX channels, DMX over Ethernet can be used, which allows the use of optical fiber and TCP/IP topology.

Some trading houses use specific technology to optimize the installation. In the case of Philips®, it uses equipment called DataEnablers that, as a bypass box, allow the connection of data and power in order to simplify and guarantee the operation of the installation [16].

3.2.2.4 Cabling

DMX512 uses a cable with two conductors according to the characteristics indicated by the EIA RS485 standard. It consists of a twisted pair (Data (+), Data (−), and GND) and shielded with a characteristic resistance of 120 ohm (**Figure 4**).

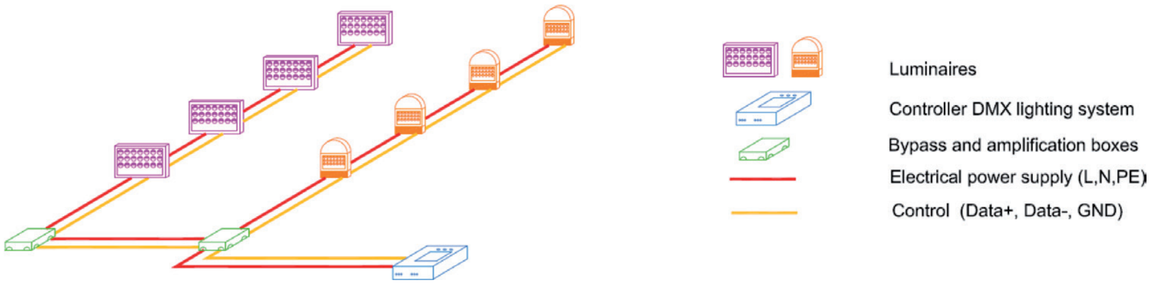

Figure 3.
Diagram of the DMX control scheme principles. Source: own elaboration.

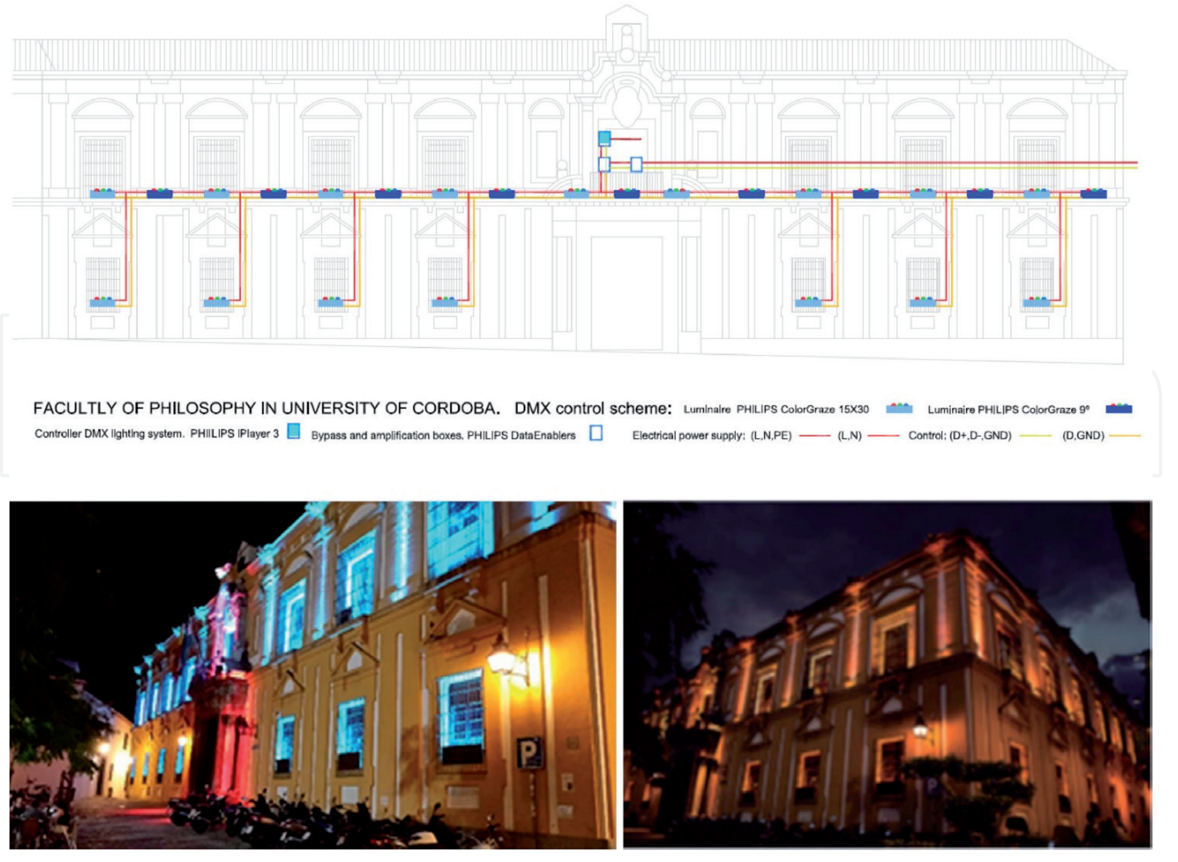

Figure 4.
Lighting and sound show Faculty of Philosophy in University of Córdoba, year 2017. Linear installation scheme formed by Color Grace luminaires of 9° and 15 × 30°, three DataEnablers, iPlayer controller, and wiring between supply (L,N) and data (D,GND) luminaires. As a temporary installation, a bypass box was not placed. Source: own elaboration.

The maximum permissible length of the cable is about 300 m, because losses are a limiting factor when using direct current [17].

A DMX terminator line with a 120 ohm resistor is used to remove a lot of noise and flickering on the DMX line with fixtures since the transmission may be unstable and can cause problems [18].

DMX via Ethernet uses a single connection cable for all the devices of the system; this allows a great flexibility and a remarkable reduction of control cables [14].

3.2.2.5 Controller DMX lighting system

This device consists of a DMX controller, usually from 512 to 1024 channels, which stores a series of sequences or prerecorded scenes. It allows the adjustment of color, brightness, and intensity depending on different types of transitions [19]. It can be controlled manually or remotely, and it includes an astronomical clock for programming according to the day and time of the week (**Figure 5**).

There are higher performance controllers on the market, controlling up to 20 universes or 10,240 channels to 200 universes or 102,400 channels that use DMX over Ethernet [14]. They may contain, in addition to an astronomical clock, a Web user interface for remote management and the ability to be integrated in the same network with other controllers.

3.2.2.6 SaaS software

There are controllers that use software as a service (SaaS) hosted in the cloud that allows the monitoring, administration, and remote maintenance of the lighting

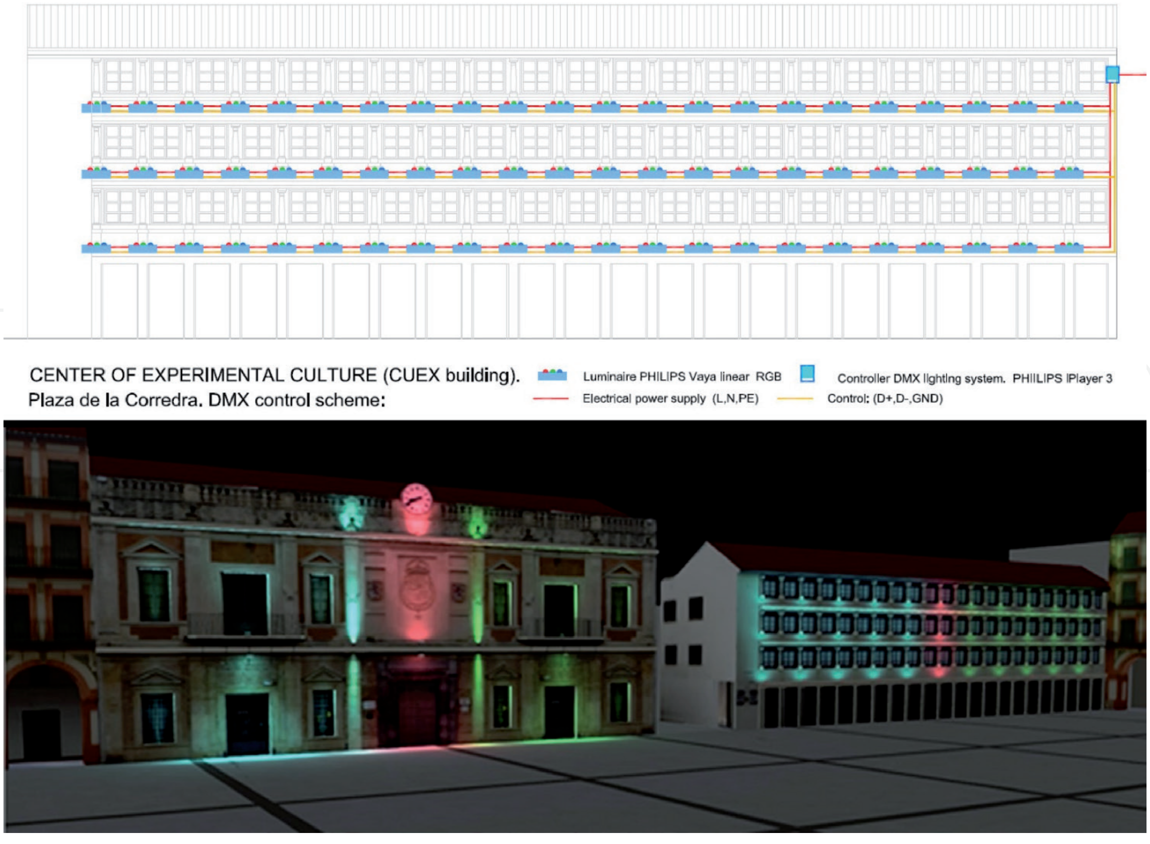

Figure 5.
CEUX building in Plaza de la Corredera, Student Lighting Competition, year 2018. Linear installation scheme was formed by Vaya Linear luminaires, which does not need DataEnablers, iPlayer controller, and wiring between power supply (L,N,PE) and data (D+, D−, GND). Source: own elaboration.

installations. This solution is likely to acquire a great development in the near future, since it allows administrators and designers to perform their functions in the installation quickly and easily, monitor the performance of the system, and instantly update the software and installation. It also allows the storage of data for analysis (Big Data), diagnosis and remote solving problems, and long-term maintenance and installation costs decrease [20].

4. Discussion

Traditionally, the control systems associated with architectural lighting were considered as exterior lighting, being oriented in most cases to a simple time control, and limiting its study to the analysis of uniformity coefficients and levels of illuminance of facades.

Thanks to the evolution of the control systems used in the field of cinematography, together with the possibilities offered by LED technology, the implementation and development of the DMX protocol as a control system applied to the field of architectural lighting is a credible fact. This control system offers the opportunity for a new understanding of lighting based on the promotion of qualitative, dynamic, and versatile aspects [21, 22].

This new conception of architectural lighting has not yet permeated deeply in our society. This type of control makes possible that any installation can be configured as a daily lighting, as a singular, or be part of any show; hence it is dynamic, with changing nature and with personalization capacity [23].

Its implementation is increasingly simple and is associated with the type of luminaire used. It only has the peculiarity that it responds to a differential wiring, which, although it reduces the formation of noise, makes its connections very difficult. This aspect is solved when the DMX system is developed over Ethernet, achieving greater speed and wiring without the above requirements. Obviously, the development of these DMX systems also generates, as in the case of other control systems, significant energy savings and reduction of CO_2 emissions [4].

The installation of the DMX control system requires the addressing of each luminaire and the need for a specialized maintenance staff which may be a problem. The new trend, based on the use of software (SaaS) with cloud service, can be a long-term solution, since the updating and maintenance of the system is continuous and instantaneous [24].

5. Conclusions

Color and light influence our emotions, mood, perception and performance; hence, architectural lighting is a vital tool to enhance and revitalize our cities through of the exterior lighting of its unique buildings [25].

The DMX control system is probably the type of control that best meets the demands of current architectural lighting although scarcely widespread in our society. This solution allows a personalized, creative, and dynamic control, which allows heritage beautification, and daily lighting adaptation through its programming to different events or singular shows [26].

Sector's professionalization through dynamic and intelligent lighting systems requires a highly trained staff. The replacement of an integrated luminaire in a DMX control system, in case of failure, requires its addressing in addition to its replacement, aspects for which the sector is not prepared. In this regard, there are solutions based on DMX control over Ethernet or in the use of SaaS that would facilitate remote monitoring, maintenance, and updating of the installation.

As alternatives, we must emphasize that the development of new technologies applied to LED semiconductors can enable the design and spectral control of lighting. The use of the Internet of Things (IoT) and Big Data could allow the establishment of a predictive model that helps to spectrally design light sources from the consideration of daytime lighting which may result in a way to art and science confluence [27].

6. Practical case of the illumination of the facade of the Hospital de Santiago in Úbeda (Jaén)

6.1 Actual state

6.1.1 General description

The Hospital de Santiago de Úbeda was declared a national monument in 1917. After the closure of the Hospital in 1975, it was used as a cultural center for exhibitions and congresses and a library. The building was designed by Pedro de Vandelvira in 1562, although completed by his son Andrés. It was built between 1562 and 1575, and must be allocated, as stated in the founding statutes in 1562 established by Don Diego de los Cobos y Molina, to a hospital for patients with "buboes" (afterward, the assistance to other diseases was extended), chapel for divine worship, and place of burial [28].

This hospital, in relation to many others built in the sixteenth century in Spain, stands out for its enormous monumentality. Built by Andrés de Vandelvira, it is one

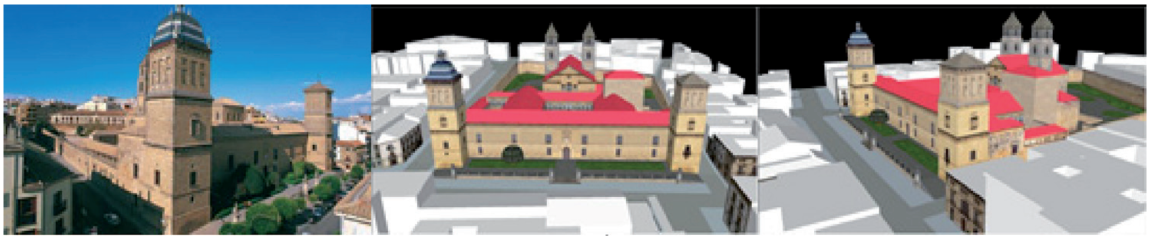

Figure 6.
External view and modeling Hospital de Santiago de Úbeda through DiaLux. Source: own elaboration.

of his most outstanding works and one of the best examples of Spanish hospital architecture of the sixteenth century.

The floor plan is symmetrical and consists of a quadrangular central courtyard chaired by the chapel, on whose corner is a monumental staircase. The main facade was destined to sick rooms. The facade is preceded by a podium that rises above the road (**Figure 6**). It has an important stone arch in the entrance door and two large towers at the ends. The front windows, which were smaller in size, were enlarged in the nineteenth century for hygienic reasons. The towers that delimit the facade have more a symbolic than a functional value. They were covered by glazed tiles and spires that were replaced from 1915 to 1965 by gable roofs, attaching a spire of concrete tiles and pinnacles to the North. Due to its shape, it has sometimes been called as *the Andalusian Escorial*.

6.1.2 Current description of the lighting installation

6.1.2.1 General characteristics of the installation

The measurement equipment is located in the outer box that is located at the foot of the tower. It includes the luminaires that illuminate the main facade of the hospital and those of the surrounding area. It has a 160 A circuit breaker, five three-phase circuits, and one single phase for control and plug.

In the outer frame, there is an astronomical clock in the four circuits for the control. The total installed power is 24,890 W, of which 8080 W correspond to the illumination of the facade of the Hospital de Santiago.

6.1.2.2 Types of existing luminaires and current lighting criteria of the facade of the Hospital de Santiago in Úbeda

The characteristics of the existing luminaires are the following:

- Metal-halide floor projectors and power 250 W.
- Metal-halide projectors in columns and power 250 W.
- Metal-halide projectors at the roofs and terraces and power 400 W.

The analysis of the illuminance and spectrum levels was carried out using a UPRtek MK350S spectrometer. In the images, the difference in illuminance in % of the different areas of the facade can be seen. There are very bright areas that contrast with imperceptible ones; as in the fronts and pilasters giving access to the podium or the towers that contrast with the front of the main facade (**Figure 7**).

The spectral distribution shows a metal-halide lamp with a clearly reproducible 61.6 chromatic reproduction index (**Figure 8**).

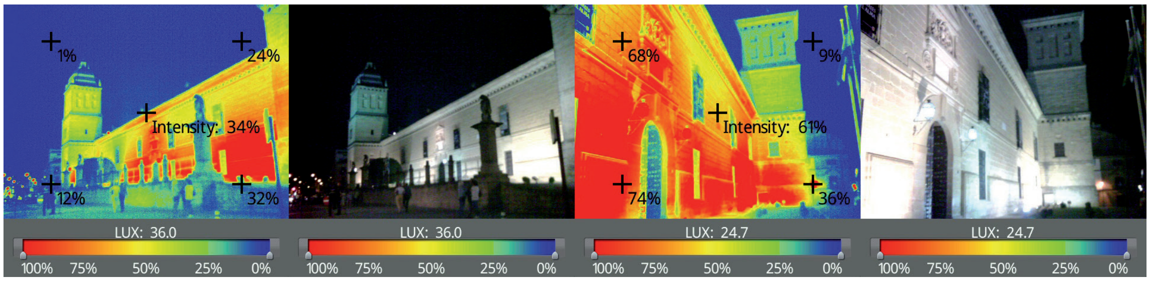

Figure 7.
Analysis of the level of illuminance in %. Source: own elaboration.

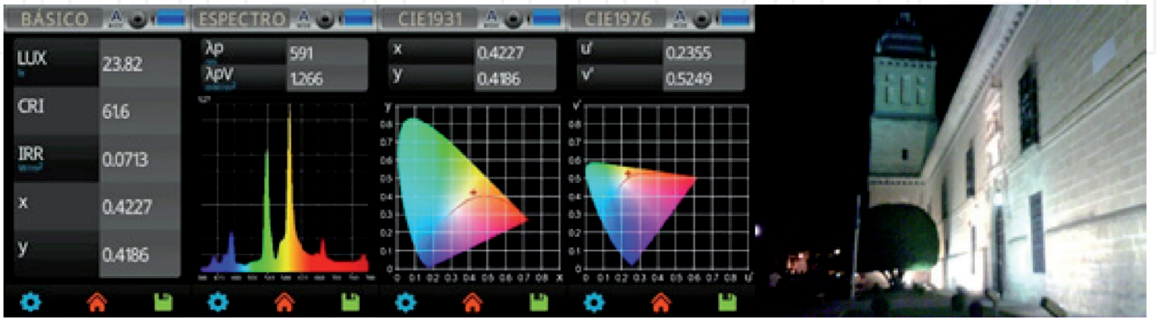

Figure 8.
Analysis of the facade illumination of the Hospital de Santiago. Source: own elaboration.

There are luminaires whose position and location are especially aggressive with the building, like projectors located in the lions of the access pilasters.

6.2 Installation characteristics and lighting proposal

6.2.1 General criteria

The general criteria followed in the lighting proposal for the facade of the Hospital de Santiago are:

a. Incorporation of a new value—illumination—to the existing reality that will enhance the presence, manifestation, and reading of this building, being one of the most relevant and representative of the Renaissance in Úbeda.

b. Energetic optimization through the implementation of control equipment that allows:

- Energetic monitoring of its operation.

- Management and robust monitoring of energy consumption through the use of information and communication technologies (ICT) including control and remote management facilities, connectivity functions, and regulation of intensity.

c. Energy improvement with an annual reduction of energy consumption and greenhouse gas emissions.

d. Control system implementation for compliance with the proposal and to combine daily lighting with creative manifestations associated with singular events.

6.2.2 Proposed luminaires

At the main facade, we propose the replacement of the existing 250 W halogen lamps by other LED technologies with asymmetric optics and 53 W power. In addition, we will substitute the existing projectors in the access pillars to the podium—at a visible position—for four 32 W LED projectors [29] (**Figure 9**).

East and West towers will be illuminated by the nearest luminaires location and the minimum number of projectors with long-distance lighting capacity—just two in the East Tower and four in the West—to minimize the consumption and cost of the installation. In this way, in the East tower, we pretend to arrange an asymmetric projector on the roof, another on the facade, and two on a column; and in the West one, an asymmetrical projector on the roof and two on each column.

6.2.3 Lighting analysis

The lighting calculations of the planned installation have been made by Dialux, considering the determinations of mandatory compliance according to the application of current legislation.

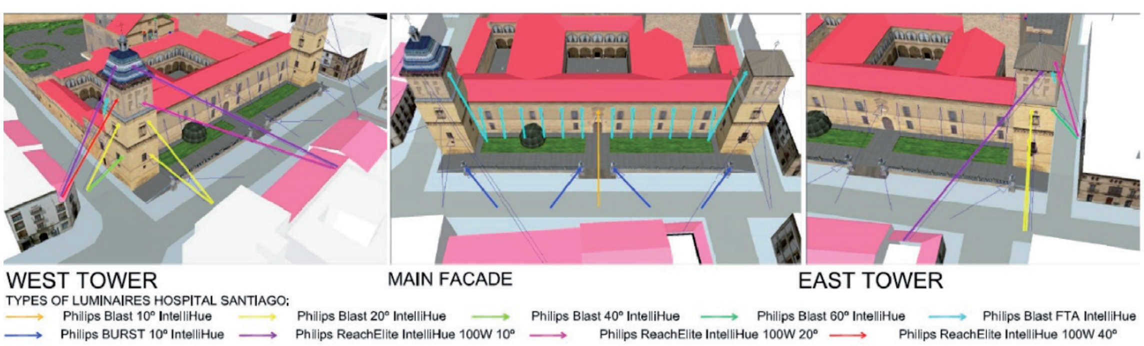

Figure 9.
Types of luminaires and lighting scheme for Hospital de Santiago. Source: own elaboration.

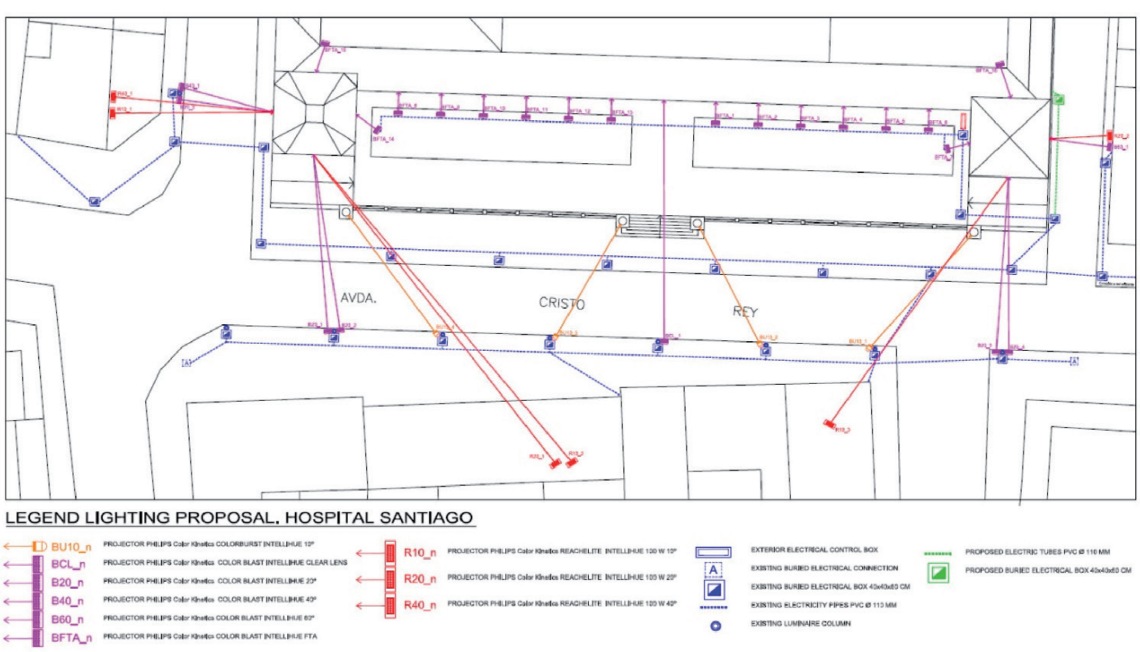

Figure 10.
Lighting proposal—Hospital of Santiago. Source: own elaboration.

In our case, the average illuminance levels exceed 20 lux established in case of ornamental flood lighting [30], as it is the main facade. There are no reference values by accent lighting, as in the lighting of the lateral towers and access pilasters to the podium lighting (**Figure 10**).

The proposal gives a greater uniformity to the lighting of the towers and access podium lighting (**Figure 11**), as well as improves the chromatic reproduction index to values higher than 90.

6.2.4 Control system installation

The projected control team is a point-to-point network system, which will allow the remote management and monitoring of energy consumption through the use of

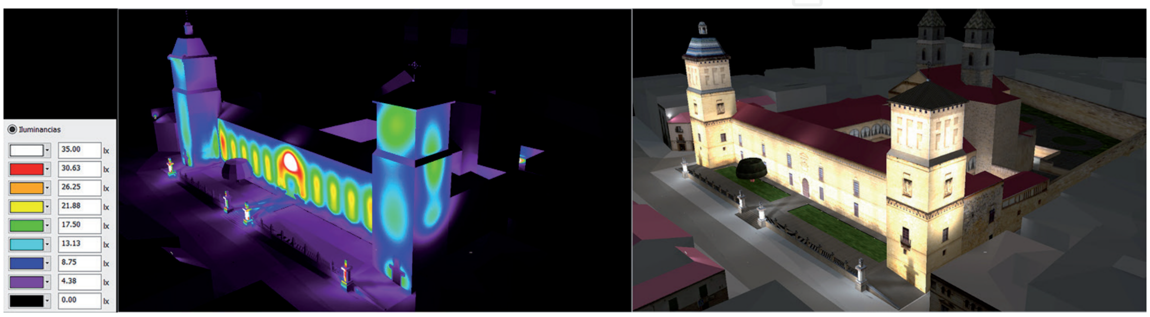

Figure 11.
Illuminance levels according to DiaLux for Hospital de Santiago. Source: own elaboration.

Figure 12.
Control scheme. Project of facade illumination Hospital of Santiago Úbeda. Linear installation scheme consisting of Philips Color Kinetics luminaires, 8 DataEnablers, Pharos controller, SaaS, and wiring between power supply (FNP) and data (+, -, G) luminaires. Source: own elaboration.

	ACTUAL STATE	REFORMED STATE	DIFFERENCE	
	Luminaires on the facade Hospital de Santiago	Luminaires on the facade Hospital de Santiago		
Contracted Power (kW)	8,080	2,000		
Type Rate	3,0 A	3,0 A		
Time discrimination	No	No		
Billing Mode	Monthly	Monthly		
Annual consumption Active Energy (kWh)	33.128	8.200	24.928	0,75
Operating hours	4.100	4.100		
Annual Cost (€)	6.957	1.722		
Average price (€ / kWh)	0,21	0,21		
Number of luminaries	32,00	34,00		
Facade surface	2085,00	2085,00		
Ratio watt per m2 (W / m2)	3,88	0,96		
Ratio light points per m2 (pl / m2)	0,02	0,02		

Figure 13.
Table relating to the balance of installed power, CO_2 emission, and annual balance. Source: own elaboration.

information and communication technologies (ICT), including control and connectivity functions, and intensity regulation.

We propose a network control system with service (SaaS) hosted in the cloud. It is made of a DMX installation connected by a device to the Internet. This solution creates a daylight that can be transformed through its programming into a singular illumination capable of creative manifestations that turn the building into a symbol of singular events (**Figure 12**).

6.2.5 Installed power, CO_2 emission, and annual balance

The proposed intervention will reduce CO_2 emissions and current electricity expenditure, will carry a better illumination of the facade of the Hospital de Santiago in Úbeda, and will provide, through the proposed control system, a dynamic nature to the color and intensity of the installation, enabling the change in the expressiveness of the building.

As shown in **Figure 13**, the proposed installation supposes the decrease of the installed power from 8080 to 2000 W, reducing the annual consumption proportionally by 24,928 kWh/year. The consumption of energy and greenhouse gas emissions are reduced annually by 75.25% compared to the existing one; and the annual balance in energy and economic terms supposes an annual saving of 5.235 €/year [31].

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References

[1] Su K, Li J, Fu H. Smart city and the applications. In: Proceedings of the 2011 International Conference on Electronics, Communications and Control Engineering (ICECC 2011); 2011. pp. 1028-1031

[2] England H. External lighting for historic buildings. 2017 [Online]. Available from: https://historicengland.org.uk/images-books/publications/external-lighting-for-historic-buildings/external-lighting2/ [Accessed: 01 June 2019]

[3] Giordano E. Outdoor lighting design as a tool for tourist development: The case of Valladolid. European Planning Studies. 2018;**26**(1):55-74

[4] Hu W. Effects of Resolution of Lighting Control Systems. Sydney School of Architecture, Design and Planning. The University of Sydney; 2018

[5] Hung NM, Lee C-H. Design of bi-directional RDM-DMX512 converter for LED lighting control. The International Journal of Fuzzy Logic and Intelligent Systems. 2013;**13**(2):106-115

[6] Carrino F, Mugellini E, Khaled OA, Ouerhani N, Ehrensberger J. iNUIT: Internet of things for urban innovation. Future Internet. 2016;**8**(2):1-21

[7] Lighting P. Dynalite controls. Technology overview controls. 2014 [Online]. Available from: https://cdn.dynalite.org/public-download/2947/bd40c4247432c0917b35dda8c1e3bf05 [Accessed: 01 June 2019]

[8] Domingo-Pérez F, Gil-De-Castro A, Flores-Arias JM, Bellido-Outeiriño FJ, Moreno-Muñoz A. Lighting control system based on DALI and wireless sensor networks. In: 2012 IEEE PES Innovative Smart Grid Technologies (ISGT 2012); 2012. pp. 1-6

[9] Patel M, Mukherjee S. Lighting Control Protocols and Standards. In: RK et al. editor. Handbook of Advanced Lighting Technology. Switzerland: Springer International Publishing; 2017. pp. 1-24

[10] Yoowattana S, Nantajiwakornchai C, Sangworasil M. A design of embedded DMX512 controller using FPGA and XILKernel. In: 2009 IEEE Symposium on Industrial Electronics & Applications (ISIEA 2009); Vol. 1; 2009. pp. 73-77

[11] Trejo-Macotela FR, Garcia-barrientos A. Controlador Digital Mediante el Protocolo DMX-512. In 2013 Simposio Iberoamericano Multidisciplinar Ciencias e Ingenierias. Sept 2013. pp. 281-286

[12] Varghese SG, Kurian CP, George VI. A study of communication protocols and wireless networking systems for lighting control application. In: 2015 International Conference on Renewable Energy Research and Applications (ICRERA 2015); Vol. 5; 2015. pp. 1301-1306

[13] Piromalis DD, Arvanitis KG, Papageorgas PG, Tseles DI, Psomopoulos CS. Sensors & transducers LEDWIRE: A versatile networking platform for smart LED lighting applications using LIN-Bus and WSNs. Sensors & Transducers Journal. 2016;**200**(5):50-59

[14] Newton S. Art-Net and wireless routers. In: 2005 Asia-Pacific Conference on Communications; 2005;**2005**:857-861

[15] Yang H, Ahmad AW, Shahzad G, Lee C. Real time bidirectional wireless digital multiplexer (WiDMX512). In: International Conference on Advanced Communication Technology (ICACT); Vol. 2015; 2015. pp. 109-114

[16] Lighting P. Catalogo sistemas de Control. 2013 [Online]. Available from:

http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/Spain/ODLI20160203_001-UPD-es_ES-Philips_Lighting_catalogo_de_sistemas_de_control.pdf [Accessed: 01 June 2019]

[17] Cassera M. DMX Desmystified [Online]. 2018. Available from: https://www.theatreartlife.com/staying-still/dmx-demystified/ [Accessed: 22 July 2019]

[18] Cadena R. Automated Lighting The Art and Science of Moving and Color-Changing Lights. New York: Routledge; 2017

[19] López C, Doval J, Pereira M, Pérez S, Dios J, López O. DMX512 controller for high brightness RGB LED matrix. In: IEEE International Symposium on Industrial Electronics; Vol. 01; 2007. pp. 3025-3029

[20] Philips ActiveSite Specification Sheet. Philips ActiveSite Controller. Remotely monitor and manage dynamic cloud-hosted connected lighting software. 2019 [Online]. Available from: https://www.docs.colorkinetics.com/ActiveSite/Philips-ActiveSite-SpecSheet.pdf [Accessed: 01 June 2019]

[21] Talebian K. Day for Night: The Role of Artificial Lighting in Returning People to Urban Public Spaces. Gazimağusa, North Cyprus: Eastern Mediterranean University; 2012

[22] Besenecker UC, Krueger T. Luminous color in architecture: Exploring methodologies for design-relevant research. ENQUIRY: The ARCC Journal. 2015;**12**(1):35-46

[23] Seitinger S, Perry DS, Mitchell WJ. Urban pixels: Painting the city with light. In: Proceedings of the CHI'09; 2009. pp. 839-848

[24] Zotos N et al. Case study of a dimmable outdoor lighting system with intelligent management and remote control. In: 2012 International Conference on Telecommunications and Multimedia (TEMU 2012); Vol. i; 2012. pp. 43-48

[25] Valdez MT, Ferreira CM, Barbosa FPM. Electrical Engineering course using PBL – the lighting of historical buildings. In: IEEE Global Engineering Education Conference (EDUCON). 2018. pp. 351-355

[26] Boring S, Gehring S, Wiethoff A, Blöckner AM, Schöning J, Butz A. Multi-user interaction on media facades through live video on mobile devices. In CHI 2011 Session Interaction on Mobile Devices. Vancouver, BC, Canada. 2011. pp. 2721-2724

[27] Tokuç A, Köktürk G. The science and art of architectural lighting using smart materials. In: 46th International HVAC&R Congress and Exhibition; 2018. pp. 109-114

[28] Lorite Cruz PJ. Una aproximación a la distribución de la Capilla del Hospital de Santiago de Úbeda antes de su desacralización, así como un estudio de sus ternos conservados en las cajoneras del Santuario del Gavellar. ARGENTARIA, Rev. Hist. Cult y Costumbrista las Cuatro Villas. Jaén y sus pueblos. 2019;**21**:55-72

[29] Kyba CCM, Mohar A, Pintar G, Stare J. Reducing the environmental footprint of church lighting: Matching façade shape and lowering luminance with the EcoSky LED. International Journal of Sustainable Lighting. 2017;**19**(2):132-141

[30] España Ministerio de Industria turismo y comercio, Real decreto 1890/2008, de 14 de noviembre, por el que se aprueba el Reglamento de eficiencia energética en instalaciones de alumbrado exterior y sus Instrucciones técnicas complementarias EA-01 a EA-07. Boletín Oficial del Estado; 2008. pp. 45988-46057

[31] Hermoso-Orzáez MJ, Gago-Calderón A, Rojas-Sola JI. Power quality and energy efficiency in the pre-evaluation of an outdoor lighting renewal with light-emitting diode technology: Experimental study and amortization analysis. Energies. 2017;**10**(7):1-13