Ingeniería Solidaria

Revision of smart street lighting LED

Revisión del alumbrado público inteligente LED

Revisão da iluminação pública inteligente com LED

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Abstract

Introduction: This Literature Review article is the result of research on the current situation of smart public lighting systems with light-emitting diode (LED) technology in cities around the world.

Problem: How convenient is it to use smart public lighting systems with LED luminaires?

Objective: To review the context of smart public lighting with LED technology.

Methodology: Within this project, a literature review was conducted with more than 50 academic articles found in different databases such as: IEEE Xplore, Scopus, ScienceDirect etc. The selection criteria of the information followed the revision of articles from 2006 to 2018, and also, took into account their installation and performance in different cities and places of the world. Furthermore, articles on polluting and inefficient technologies were excluded.

*Conclusion***:** Considering the current context of LED smart public lighting, it is more likely to be implemented in the future.

Results: Smart LED street lighting systems are more efficient in energy use, leading to savings in medium term costs, and finally, present a lower environmental impact compared to conventional lighting systems.

Limitations: The review focuses on energy efficiency and economic aspects, not on social aspects.

Originality: Smart LED public lighting systems have been researched within the economic and energy efficiency context.

Keywords: Smart LED street lighting, energy efficiency, renewable energies, LED luminaires.

Resumen

Introducción: El artículo de revisión bibliográfica es producto de la investigación sobre la situación actual de los sistemas de alumbrado público inteligente con tecnología de iluminación LED en ciudades del mundo.

Problema: ¿Resulta conveniente la utilización de un sistema de iluminación pública inteligente con luminarias LED?

Objetivo: Revisar el contexto de los alumbrados públicos inteligentes con tecnología de iluminación LED.

Metodología: Se realizó una revisión de más de 50 artículos académicos referentes a alumbrados públicos inteligentes con tecnología LED encontrados en bases de datos como: IEEE Xplore, Scopus, Sciencedirect etc. El criterio de selección de la información se hizo revisando artículos desde el año 2006 hasta el 2018. También teniendo en cuenta su instalación y desempeño en diferentes ciudades y lugares del mundo. Excluyendo artículos sobre tecnologías contaminantes e ineficientes.

Conclusión: El contexto actual en el que se encuentran los alumbrados públicos inteligentes LED los proyecta a ser más implementados a futuro.

Resultados: Los sistemas de alumbrado público inteligente LED son más eficientes en uso de energía, presentan ahorros económicos en el mediano plazo y tienen un menor impacto ambiental en comparación con los sistemas de alumbrado convencional.

Limitaciones: La revisión se centra en aspectos de eficiencia energética y economía, no en aspectos sociales

Originalidad: Los sistemas de alumbrados públicos inteligentes LED han sido investigados en el contexto económico y de eficiencia energética.

Palabras clave: Alumbrado público inteligente LED, eficiencia energética, energías renovables, luminarias LED.

Resumo

Introdução: este artigo de revisão bibliográfica é produto da pesquisa sobre a situação atual dos sistemas de iluminação pública inteligente com tecnologia de iluminação LED em cidades do mundo.

Problema: é conveniente a utilização de um sistema de iluminação pública inteligente com lâmpadas LED?

Objetivo: revisar o contexto das iluminações públicas inteligentes com tecnologia de iluminação LED.

Metodologia: foi realizada uma revisão de mais de 50 artigos acadêmicos referentes a este tema encontrados em bases de dados como: IEEE XPLORE, Scopus, Sciencedirect. O critério de seleção da informação foi com base na revisão de artigos de 2006 a 2018. Também se considerou sua instalação e desempenho em diferentes cidades e lugares do mundo. Excluíram-se artigos sobre tecnologias contaminantes e ineficientes.

Conclusão: o contexto atual em que as iluminações públicas inteligentes LED se encontram as projeta a serem mais implantadas no futuro.

Resultados: os sistemas de iluminação pública inteligente LED são mais eficientes em uso de energia, apresentam economia em médio prazo e têm menor impacto ambiental em comparação com os sistemas convencionais.

Limitações: a revisão se centraliza em aspectos de eficiência energética e economia, não em aspectos sociais

Originalidade: os sistemas de iluminação pública inteligente LED têm sido pesquisados no contexto econômico e de eficiência energética.

Palavras-chave: iluminação pública inteligente LED, eficiência energética, energias renováveis, lâmpadas LED.

1. Introduction

Reviewing the current context of smart public lighting with Light Emitting Diode (LED) luminaires acquires its importance as part of the effort to find energy efficiency and the minimization of operational costs during the functional life of a public lighting system. Concerning the amount of electric energy used to operate public luminaires, which represents approximately 19% of the world's electricity consumption [1], reducing that figure might bring auspicious results for its implementation. The combination of LED efficiency, in terms of the number of lumens it emits per watt [Lm/W] [2], and the management ability that smart lighting has on the luminaires and its intensity control, depending on the number of pedestrians or vehicles [3], gives the users favorable prospects.

The first precedent for smart street lighting took place in Oslo city, Norway in 2003. During that year, the system was operated for the first time along with 117 luminaries; then, by 2006, the system had had 4000 luminaries fitted with a control system connected through the internet to a command center. This system allowed for the variation in intensity of the luminaires on the road depending on vehicular traffic, time of day and environmental conditions [4].

During the initial stage of the Norway project, PBC luminaries, that had been used in public lighting for many years and are considered contaminants for the environment, were replaced [5]. However, the main purpose of the project was to reduce the amount of electricity consumed in public lighting by reducing consumption by 30 to 40 %. By 2005, the luminaires replaced and adapted with smart control saved 52 %. By 2007, the number of smart luminaries in use had reached 6000; this number represented 10 % of all the luminaries in Oslo [4].

Smart LED street lighting is important when evaluating its ability to illuminate streets and roads. In 2009, Fusheng Li, (et al) from the University of Fudan, China, analyzed LED lighting performance in terms of energy consumption and color reproduction, among other characteristics. They concluded that LED public lighting, in its current state, was not very favorable for street and road lighting. However, they predicted that in a few years, with clear technological development and regulation, that LEDs would become more prevalent in the future [6].

In 2011, Mircea Popa and Costin Cepişcă, both from the Polytechnic University of Bucharest, Romania, performed research on energy conservation aspects of smart lighting systems. These authors presented a lighting system control that monitors the luminaires, allowing the adjustment of these based on the place, given by latitude and longitude, which makes them turn on at the correct time, processing and storing information about the bulbs' conditions. They concluded that this system was efficient in electricity consumption [7].

Smart lighting systems are subjected to climatic conditions that can affect their operation. In 2011, Xiaogang Liu, 2011 at Huazhong University of Science and Technology, a second work was carried out on problems related to smart lighting installations, considering that smart lighting systems are susceptible to damage under the environmental conditions of the places where they are installed; wind, water and dust can cause deterioration in the luminaires; in the physical structure, in the sensors, the internal electronics of the system and other components of the system. Liu simulated the behavior of a structure under extreme windy and rainy climatic conditions, and concluded that a structure made of aluminum can withstand the effects of the wind [8].

Recently, Professor Vijay Krishna, from the Institute of Education and Research of Chennai, in India, conducted a research in 2007 and presented a hypothesis on energy efficiency along with smart public lightening. Professor Krishna, observing energy losses in places of low circulation of people and proposed a design to make smart public lighting systems, in which energy consumption would be optimal. This proposed system works with sensors that operate both day and night and which were set to an exact time, sending information by Wi-Fi to turn it on and off, applying the gradual darkening of the luminaires on public roads [9].

This review hypothesizes the usefulness of smart street lighting with LED technology. Throughout the article, we will try to explain why it is necessary to start installing smart LED systems in cities. The proposals for the future are aimed at building Smart Cities. This is where the adaptation of this method of urban lighting is justified. This article takes into account two important reasons for focusing on electricity consumption; the costs associated with investing in the project and the monetary savings obtained. Since 2006, these systems have been implemented more frequently in large cities where pedestrian and vehicle traffic are considerable, and where it is most effective.

2. Current stage of the smart LED public lighting

2.1 Cities, networks and smart lighting

The importance of these concepts lies in building a city adaptable to the modern world, especially to new technology, constructing sustainable ideas that can be implemented in every context of life within the city [10]. Having a reliable and secure city when facing failures in electrical systems will improve the quality of life of its citizens in the future. Smart cities associate different concepts whose purpose is to optimize resources and ensure reliable and safe operation of their systems.

There is no formal definition of Smart Cities, but this term is broadly considered as a city that can manage their resources in a highly efficient way, also it refers to those places where there is significant integration of technology in daily life allowing for the creation of more sustainable environments [11]. Smart Cities are part of the European Union's 2030 sustainability objectives, where agreements were reached to lead the world towards a society with environmental responsibility and sustainable development [12].

Therefore, Smart Cities cluster intelligent and modern concepts aimed at obtaining maximum energy efficiency within an urban area. Within the context of Smart Cities, there are Smart Grids. A brief definition for this term would be an electrical network that can intelligently integrate the actions of consumers and electricity generation, among others, to deliver economical, sustainable and safe electricity [13].

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Smart Grids consist of bi-directional power distribution networks, capable of smartly managing electrical power within a system, through electrical developments and telecommunications. Within a few years, it is expected that the electric power of Smart Grids will have a greater component of non-conventional renewable sources [14]. A future objective for these networks might be that electrical energy for smart lighting must come from independent alternative energy sources, which do not belong to a centralized energy company [15].

The consumption of electric power in the world increases as its population grows and settle down in the cities. In addition, fossil resources to generate electricity are limited and harmful for the environment. That is why the most viable efficient alternative involves the use of Smart Grids, which represent a decentralized concept in power systems, thus providing several alternatives to generate electricity and more efficient forms of consumption [16].

Within the Smart Cities and the Smart Grids, we have Smart Lightings systems, which are systems designed to reduce the costs of public lighting. These systems, placed in Smart Cities, allow for better management of lighting, using sensors and devices that control the luminaries, causing them to decrease the intensity or turn off depending on localized pedestrian or vehicular traffic. Smart Lighting is characterized by energy consumption control, information management, handling of external variables, monitoring, etc. In addition, they must be safe, efficient systems and must be for citizens [17].

Currently, it is considered important to combine Smart Grids with Smart Lighting in terms of renewable energy supply. In urban areas where the population is increasing exponentially, such as in major cities of the world, the main source of electricity commonly comes from a central distribution company. In the future, the urban distribution system is expected to be less centralized with the different sources of generation, whether conventional and non-conventional, being combined and therefore becoming the new source of energy for smart public lighting [18].

The concept of Smart Cities implies ideas that will help change the world in a certain way. Life in cities will be easier and more sustainable, since Smart Cities offer modern and practical solutions to many daily problems faced by citizens, such as public transport, public services and communications. As the concept of Smart Cities gradually evolves, it does so with scientific advances, technological changes, and to a certain extent, with the support of local governments thinking about the welfare of their citizens [19]. Intelligent public LED lighting is an important part of a Smart City, as it offers a controlled and intelligent way to supply lighting at night.

2.2 The architecture of smart LED street lighting systems

Smart LED street lighting systems are composed of intelligent electronic devices; equipment and software that allows them to function to their fullest extent. What follows is a detailed list of the most important modules that are used in this type of lighting.

2.2.1 Composition of a smart LED street lighting

A typical smart system consists mainly of a luminaire pole in which the most important element is the LED luminaire. In the luminaire pole, other equipment is also integrated, giving functionality to intelligent lighting [20], such as:

- Light and movement sensors: The light sensor spots when the night starts, in order to turn on the luminaire. The motion sensor senses activity or movement in the close proximity of the luminaire and will act when it detects a passerby or nearby vehicles, sending a signal to the microcontroller [21].
- The microcontroller: This component is responsible for making decisions such as reducing or increasing the intensity of the luminaire. It is programmed with the necessary algorithms for decision making; it can also act independently or be controlled by a central management module [22].
- Measurement equipment: They are necessary for gathering information about external variables surrounding the luminaire, such as temperature, vehicular flow, average vehicular speed, pedestrian flow, humidity levels, luminaire status and other equipment [23].
- Communication equipment: This equipment is responsible for sending information from one or more luminaires to the management center in order to be interpreted and stored [24].

Apart from the luminaire pole, there is a management center, or central. Its task is to receive the information that comes from a luminaire or a group of luminaries. You can give an interpretation to the information you receive, making a decision upon its value. For example, the importance of reducing the intensity of several luminaires in a specific sector. Storing information is also important for the management center, since you can create historical figures, and even, predict events in upcoming years [25].

2.2.2 Internet of things (IoT) and communication in smart lighting systems

The term, Internet of Things (IoT), is defined as an open and complete network of intelligent objects that have the ability to self-organize, share information, data and resources, reacting and acting in response to situations and changes in an environment. The term was used by Kevin Ashton in the self-ID center of MIT (Massachusetts Institute of Technology) in 1999. The IoT refers to the possibility of connecting devices through the internet. If a device such as a street luminaire is connected to the Internet, it can be managed efficiently and gives the possibility of easy identification if it is damaged or has developed a fault [26].

During the last three decades, to measures the development of electronics, telecommunications and computing technological, many appliances, factories, and also public lighting, etc., were automated. With the arrival of the Internet, it became possible to electronically communicate for all kinds of information, including control over the luminaries based on the circulation of vehicles or people [27]. Currently, most intelligent LED lighting systems communicate wirelessly through the ZigBee communication protocol; in some special cases with low numbers of luminaires and equipment, Wi-Fi is used [26].

ZigBee is a very efficient communication protocol, because it allows data to be exchanged easily by connecting a group of devices, in this case luminaires, thus creating a mesh that is capable of collecting information and creating connections between each device within the net. The information is controlled by a main segment for each mesh created. The segment is responsible for transferring data to the control center, which is where the information is finally received to be manage or stored [28]. The great advantage of this communication protocol is that it can connect up to 65,000 devices, higher than what could be connected by Wi-Fi or Bluetooth, in addition to being a communication protocol made for control.

Many smart lighting systems, with or without LED luminaires, use power lines for the transmission of information. This way of communication was the first used before wireless communication protocols existed. The information is sent as bits, which are sent at a frequency of approximately 80 kHz through filters that work with a microcontroller. This way of transmitting information turned out to be reliable in practice [29], to the point that it is still in use and is also used in new smart lighting projects.

2.3 Energy efficiency

2.3.1 Energy efficiency in the LED luminaire

When LED luminaires started to gain popularity on the market, they began to consider the possibility of using them in public lighting systems to make use of their luminous efficiency [30]. The LED luminaire has important features for smart lighting, such as greater efficiency in lumens per Watt [Lm/W], a long lifespan (between 5 to 8 years), the ability for switching multiple times [ON-OFF] without damaging its lifespan, low attenuation of light intensity and good color reproduction. [31], [32].

LED lighting is suitable for lighting in night environments. Its great capacity to emit light allows color reproduction suitable for night lighting. The angular approach of light is ideal for illuminating highways and streets [33]. The LEDs, depending on their semiconductor material, can acquire a different range of colors, from absolute white to almost fluorescent colors, without increasing their temperature or emitting UV radiation during operation [34].

It is possible to examine the useful life and efficiency [Lm / W] of the LED luminaire and compare it with other types of luminaires that are commonly used in public lighting, such as High-Pressure Sodium (HPS), High Pressure Mercury (HPM) and High Intensity Discharge (HID) solutions [35]. In Table 1, the characteristics between different types of luminaires can be compared:

Table 1. Comparison of characteristics of luminaires used in public lighting.

Parameter	LED	HPS (High pressure sodium)	HPM (High pressure mercury)	HID (High intensity discharge)
Active Power [W]	63	70	80	100
Luminous Efficiency [Lm/W]	52	85	46	80
Useful Life [hours]	>50 000	28 000	16 000	10 000
CRI (chromatic reproduction index)	>80	23	48	70
Luminosity				
[Lm]	3 225	6 000	3 700	80 000

Source: [34], [36].

From Table 1, it is important to see that the HPS and HPM luminaires have a considerable average life and proper luminous efficiency [35]. But, some characteristics like the lack of instantaneous ON-OFF switching and attenuation of intensity, are not appropriate for the correct operation of the smart public lighting, while the LED luminarias are pertinent for this type of lighting [32], [36]. Something similar happens with the HID luminaire. It has a powerful luminosity and great capacity for chromatic reproduction, but it is also not suitable for smart lighting that requires instantaneous ON-OFF switching and low intensity attenuation [34]. In short, LED luminaires have the fundamental characteristics to be used in intelligent lighting, due to their operating characteristics and good chromatic reproduction allowing them to operate fully in this role.

2.3.2 Energy efficiency of intelligent LED lighting

By observing how automation has become popular in different areas, street lighting has not been the exception [37]. The goal of smart LED lighting is to reduce the consumption of electricity that is generated per year and, likewise, the costs that this consumption implies. The intelligent way in which light is dimmed when there is no presence of pedestrians or any vehicles circulating on the road, reduces the consumption of electrical energy. This is precisely what is currently sought; energy efficiency, capable of providing adequate light when necessary and, conjointly, decreasing the price resulting from such consumption [38].

It is possible to compare the energy efficiency between a LED lighting without a control system and one with an intensity control system, through the energy efficiency of each one. This is done by comparing the energy consumption [kWh] of a lighting system in the same interval. Figure 1 presents the results of both lighting systems when tested for 14 days in different places such as an office building, a warehouse and a vehicle parking lot, which are public places [39].

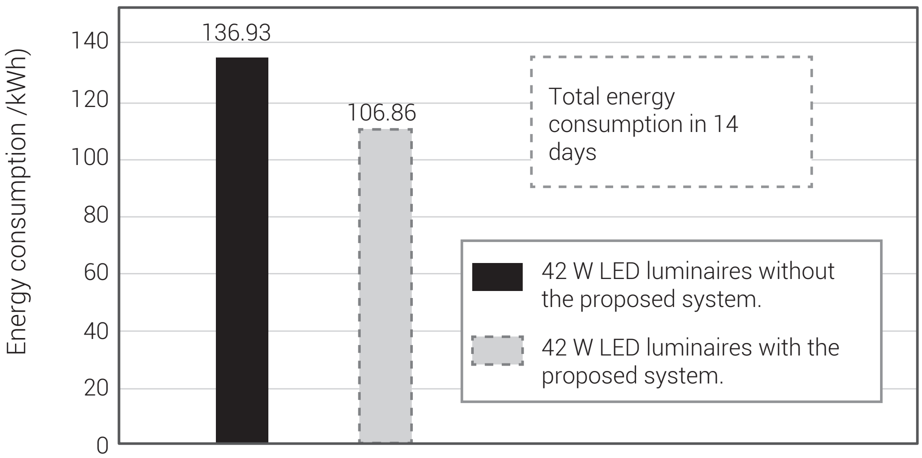

Figure 1. Energy consumption of LED systems with and without control
Source: [39]

Analyzing Figure 1, the LED luminaire system without control had an energy consumption of 136.93 kWh, while the system of LED luminaires with intelligent control had a consumption of 106.86 kWh. According to the results, adding an intensity control system to the LED lighting reduces electric energy consumption by approximately 21.9%. This is logical, since the intelligent system makes the LED luminaires act when necessary and reduce their intensity when lighting is not required [39].

Another research, published in the IEEE Photonics Journal, shows that the public lighting of roads with LED luminaires and control systems for management and maintenance in the city of Washington DC, United States of America, presented energy savings of approximately 66% in places where vehicles circulate [40]. Using variables such as the speed of the vehicles and their flow on the road, an algorithm was made that is capable of modifying the light levels in each LED luminaire. This proposal is appropriate where vehicle traffic is low and less lighting is required.

2.3.3 Urban environment and renewable energies

Intelligent lighting comes to the world to change the concept of night lighting, not only in the form of energy efficiency, but in the effectiveness of its functionality. Current thinking not only focuses on energy and cost savings as the result of intelligent lighting but also on its integration into urban society, in communications, in temperature measurement, in vehicular traffic and others [41] . All this will result in more sustainable city, capable of making citizens' lives more efficient and comfortable.

If the greatest goal is to achieve complete energy efficiency, this means that renewable energies must be used to provide the intelligent LED lighting system with the energy needed to light LED luminaires and operate their entire control system [42].

Most of the current projects that are designed for intelligent LED street lighting, use photovoltaic solar panels as the main renewable resource. This is due to the affordability, ease and relevance that this renewable source has when operating intelligent LED lighting. A photovoltaic park can be installed almost anywhere and can acquire different dimensions depending on its utility in terms of the amount of power required [43]. In most cases, a solar panel can be placed on the pole itself, thus providing an independent power supply for each luminaire in the intelligent LED system. This method implies that the luminaire depends as much as possible on the photovoltaic energy, but it is worth mentioning that there is a control that supplies electric power from the grid, if necessary [44].

Photovoltaic panels are part of the system. They have a battery, or battery bank if necessary, to store energy that is useful for night time operation of the luminaire

[45]. The capacity of the batteries becomes greater over time. It is now possible to maintain a house with all its equipment connected for almost three days in continuous functionality. It is therefore expected that a single battery will serve to maintain several poles with luminaires and their respective equipment.

Considerations have been made regarding other alternative sources of electrical power. Intelligent LED lighting, when associated with the Smart Grid, can also be supplied with electricity from wind, water and geothermal sources, etc. The alternation of sources will make the system much more intelligent and sustainable [46]. A current issue for which the adaptation of public lighting to renewable sources is considered relevant is the reduction of CO2 and polluting gases, since every year the demand for electric power increases in public lighting, and this implies greater supply by power plants' thermal generators [43], [34].

Two notable cases of how energy efficiency can operate are: renewable energy operating near the sea and photovoltaic energy operating in remote places without connection to a transmission system. The first one makes use of the electrical energy of tidal origin, which consists of generating electricity with the movement of the waves of the sea, this method can be very useful in places near the sea [47]. The photovoltaic method in remote places, has optimal performance in places where there is no distribution company, or in small villages where electricity is required for public lighting [48].

2.4 Costs and economic analysis of LED systems for intelligent public lighting

The final price for smart LED lighting systems will change based on the integrated components, the type of sensors and their operation. Smart LED lighting systems have control devices that work by lowering the light intensity of a light bulb depending on the time of day. This decrease in light intensity reduces the consumption of electrical power to one third and consequently savings in expenses. [49]

To perform the economic analysis and find the cost-benefit ratio, equations were used to find the reimbursement period [50] and the IRR (internal rate of return) that will determine whether the project is economically viable or not [51].

The case study to determine the final price was made in the City of Juiz de Fora, Brazil. [36] This city of Brazil was selected because it is a developing country and has shown an interest in the concept of Smart Cities in recent years [52]. It is important to note that it is not easy to determine the exact cost of an intelligent lighting system due to different circumstances, such as the change in the price of the components over time, import costs and taxes on the devices. Table 2 presents a list of the parts and devices (with their prices) that were used in the system of the City of Juiz de Fora.

Table 2. Price of components of a smart lighting system

Component	Units	Unit Cost	Total cost
Microcontroller	1	$12.99	$12.99
Zigbee	1	$37.95	$37.95
Board	1	$2.07	$2.07
Light sensor	1	$2.08	$2.08
Presence sensor	1	$16.04	$16.04
Connectors	10	$0.40	$4.00
Resistances	40	$0.10	$4.00
Capacitors	10	$0.40	$4.00
Boxes	1	$34.56	$34.56
Others	1	$15.00	$15.00
TOTAL			$132.68

Source: [36]

According to Table 2, the approximate final cost of the individual system is $ 133 USD, using similar components to the Brazilian market, without taxes. The first method activates the luminaires at maximum capacity from 6pm to 12am and 50 % dimming from 12am to 6am. The second method uses 50 % of the luminaire's capacity from 6pm to 6am and is only activated when pedestrians are detected. It is important to consider the variation in the number of solar hours; from 10 hours 30 minutes in winter to 13 hours 10 minutes in summer. An approximation was used to determine pedestrian traffic because it is a value that is continuously changing.

An analysis of the return period related to the useful life of the luminaires was performed, applying the economic calculation factors: Return period and an IRR —internal rate of return—. Results found that the investment recovers over time despite the high initial investment. As seen in Table 3.

Table 3. Comparison of investment recovery in different scenarios over time

Stage	IRR (internal rate of return)	Payback period
LED lighting system	5.5%	10.5 years
Replacement of HPS	13.5%	7.2 years
HPM replacement	23.8%	5.0 years

Source: [36]

According to Table 3, the investment in smart lighting systems is recovered in a period of approximately 5 to 10 years. It is important to state that there will be a significant peak in the investment at a certain date in the study period, as it will be necessary to maintain the system. It should also be noted that this system can become more economical depending on the type of sensor and if it works with renewable energy sources.

In areas that are not interconnected and with limited accessibility, greater efficiency with regards to the management of the electric power used for street lighting is required. In Puerto Inírida, Colombia, researcher Yesid Muñoz and other researchers analyzed the possibility of changing all the exisiting luminaires with LED lamps, which would make it possible to reduce energy consumption by 40 %. They concluded that the total investment would be $321,000 USD with an internal rate of return of 42 % in 3 years. This would lower the price of energy to 0.17 USD / kWh [53].

Elsewhere, such as India, researcher Sanjay Kumar of India's RGIPT University investigated the integration of smart public lighting systems in separate modules for isolated areas, such as the village of Bihar, within a period of 20 years. This researcher found that about $1,348.68 USD per year could be saved; money that the village could allocate to food or for adapting a classroom for children [54]. India is interested in greatly expanding the use of solar energy, charting objectives such as increasing solar power capacity from 20 GW to 100 GW by 2022 [55].

2.5 Environmental implications of smart LED lighting systems

The benefits of smart LED lighting systems can also be analyzed with regards to their impact on the environment [56]. Some elements used in the construction of lighting systems contain elements that are harmful to fauna and flora such as mercury or lead.

Smart LED lighting systems that are autonomous, such as those that work with photovoltaic solar panels, require batteries for their operation at night. These batteries have polluting elements such as lead. When the batteries do not have adequate periodic maintenance or when they are not fully charged, sulfurization occurs, generating highly toxic biproducts. [57]

The luminaries that are normally used on public roads use mercury vapor and despite having a long useful life, mercury is highly toxic and when the luminaries are discarded, this element can come into contact with rivers and water sources. They can also cause interference in Smart grid networks [58]. This is why there are international regulations that require reducing the amount of mercury in the construction of luminaires [59].

The consequences of replacing conventional luminaires with LED luminaires on animals are still being researched. Night animals such as bats are sensitive to artificial light, according to the color of the light, whether it is red or white. The researchers Christian Voigt and others from the University of Berlin investigated the phototaxis (orientated reaction of organisms to the light stimulus) of the bats and concluded that migratory bats are attracted by red light but not by warm white LED light. After doing an experiment the results did not find modification on the flight behavior of the animals by this type of luminaire [60].

2.6 Case studies in smart LED street lighting around the world and the outlook in Colombia.

Smart street lighting is increasingly used in different cities around the world. Most cases are focused on intelligent lighting with LED technology, since it is the most optimal technology for this type of lighting model.

2.6.1 Intelligent street lighting in Europe

Europe is the continent in which the greatest growth in the use of of smart LED public lighting has been observed; especially due to the policies promoted by the European Union [14]. All this has led to the emergence of case studies in the European continent along with the multiplying of European examples, regarding energy efficiency and innovation.

In the city of Glasgow, Scotland, in 2013 the British government invested 24 million pounds on the replacement of the luminaires and the modernization of the lighting system, through Internet controlled management. A study of the required light intensity levels in certain specific points of the city was made. It was adjusted to account for pedestrian traffic frequency also to provide tourist hot spots with the best lighting quality. For example, in Riverside Walkway, the luminaires were programmed to provide their lowest intensity of 20% in the case where the motion sensors do not detect the presence of bystanders, and increase to 100% intensity when the sensors detect the presence of people. In another point of the city, Gordon Street, the poles were equipped with sensors capable of measuring the level of noise, air pollution and the presence of passers-by in order to improve the information of the points of high circulation of people in the city. [61]

In Sweden, the lighting replacement and modernization policy began in 2006 and culminated in 2009, within an investment coming from the Klimp climate change program. Since then, Gothenburg has increased its energy savings by more than 60%

and electricity consumption has decreased by 132 MWh per year. Also, CO2 emissions fell 0.16 tons, nitrogen oxide by 85 tons and particulate pollutants by 1.3 tons per year, thanks to the fault detection system, which significantly reduced operational costs. In recent years, new features have been added to the luminaire poles, such as temperature monitoring and systems for detecting illegal parking in areas of the city [62].

Over the years, Turkey has invested a large quantity of money in modernizing the country's infrastructure and public lighting. This country still uses conventional HPS luminaires and some other lighting technologies, which are turned on at full intensity all night. However, this country is currently encouraging the use of LED technology in different areas of big cities, such as Istanbul or Ankara. A plan for the adaptation of intelligent lighting has recently been launched, due to the successful case studies in the European continent and for the satisfactory results that this system offers in monetary and environmental terms [63].

In Portugal, the structuring of a modern intelligent lighting in its capital, Lisbon, is currently being studied. There are currently plans to install LED luminaire systems that can be monitored for maintenance and have light intensity control in historic centers based on the flow of tourists [64].

2.6.2 Intelligent street lighting in North America

The city of San Diego, California, USA, has promoted the initiative of transforming the conventional public lighting that they have, to an intelligent and self-managing one. The idea is to reinforce the use of luminaires as monitoring points for different variables such as temperature, humidity, pressure, noise levels and human traffic. The objective is not only to incorporate an intelligent lighting system, but also variables that can be monitored by other local government agencies, such as the police or the meteorological service, to detect variables at important points in the city [65].

The idea requires the IoT on the luminaire poles, where data and information, necessary for public lighting and other local departments, converge. The project aims to replace 14,000 luminaires out of the 40,000 that the city owns, by LED lighting that fits perfectly with the concept of intelligent lighting [65].

2.6.3 Intelligent street lighting in Asia

The government of South Korea has decided to replace conventional street lighting luminaires with LED technology. An analysis of the countries current system shows that LED technology can save almost 69 % of electrical energy, but it is also found that the reduction of energy can increase up to 77 % when controlling the intensity of the luminaires in certain night hours. The case of South Korea, was based on programming the intensity of the luminaries at certain hours of the night; before 10 pm the luminaries are at 100 % light intensity, between 10 pm until dawn the intensity is reduced by 50 %. The case of South Korea proved to be efficient in terms of savings for intelligent LED lighting systems [66].

When conventional HPS was used all night, the annually electric power consumptions were 1,147.46 kWh. This energy was reduced to 214.46 kWh when the LED luminaires with intensity control were installed. Regarding the environmental issue, the reduction of approximately 990 tons of CO2 emissions, is very useful for a country with serious problems of air pollution, such as South Korea [66].

In Malaysia, projects have been developed to reduce public spending on street lighting by replacing LED incandescent luminaires with large energy savings. [67]

2.6.4 Intelligent street lighting in Australia

In Australia, smart city projects have succeeded because of clear and transparent policies along with encouraging private investment with lower taxes and credit facilities, etc. [68]

An Australian case study on smart street lighting with LED was made in the city of Brisbane, the capital of the state of Queensland, whose government has promoted the development of sustainable projects that reduce the carbon footprint. The researcher Xireng Jiang, developed a project at the University of Queensland, in 2016, to determine the feasibility of replacing the luminaires used on public roads with those using LED technology. The main source of energy for luminaires in smart systems is solar photovoltaic panels which do not emit CO2 and need less periodic maintenance, although, they have a high initial cost. The project was deemed economic viability, reducing polluting gases and generating significant savings in electrical energy, whilst also driving the development and the economy of LED luminaires in Australia [69].

2.6.5 Intelligent street lighting in Colombia

In Colombia, the concept of smart public lighting is beginning to be more interesting, although, there are still places where obsolete luminaires need to be replaced by LED luminaires to make street lighting efficient. In some places, there are obsolete luminaires, which are replaced by technologies such the HID. Intelligent lighting has been structured around very small and limited private projects, such as some public spaces in universities and parks [70].

Some projects demonstrate the convenience of the use of intelligent lighting in cities and public spaces, such as a project to settle luminaires managed by Wi-Fi and ZigBee wireless communication in the city of Bucaramanga. Projects like these, show the potential that intelligent public lighting has [71].

In addition to this, in Colombia, the possibility of making smart cities has been analyzed where different systems work together to improve the services that are used, starting with the improvement of the transportation system [72], and in the future, possibly smart lighting.

Some research on the energy consumption of rural households in the city of Pasto in Colombia shows that 34 % of the energy consumption of these households are invested in lighting. This shows that it is possible to make proper use of energy in some parts of Colombia [73]. If we add to this the studies carried out in the city of Pasto, where the amount of energy produced by monocrystalline or polycrystalline solar panels is observed under the conditions of local irradiation and temperature, it was demonstrated that these perform a good job, especially the monocrystalline panels. This shows that different components of an intelligent public lighting system work satisfactorily [74].

In the city of Medellín, a tree-shaped system with 50W solar panels was designed, equipped with energy backup batteries. It is made of bamboo, proximity sensors and uses white LED light. It has an autonomy of 3 hours and an estimated annual saving of 876 Wh. Lighting sensors turn the LEDs on at night [75]. This project has great energy savings and is one of the few existing in Colombia.

3. Discussion

How convenient is it to use smart public lighting systems with LED luminaires? This article reviews both the current state-of-the-art about intelligent LED public lighting, and the different case studies where this way of illuminating streets and public places is projected or implemented.

The state-of-the-art review shows a set of innovative technologies that come together to form an entire intelligent structure, capable of "dimming" or attenuating LED luminaires. Each element of the intelligent LED system, such as the LED luminaire, wireless communication, motion sensors, internet data, the management center and other additional intelligent technologies, has seen technological progress that has allowed them to develop to the point of being used in public lighting contexts. Any of the technologies that complement the current smart LED system, can be further developed or can be replaced in the future by some superior technology, which is more efficient and effective than its predecessor.

The advancement of technology means that better accessories for intelligent public lighting will emerge. In the case of LED luminaires, these can be replaced by organic LED lights (OLED), or by other superior luminaire technology that may arise in the future. The same can happen with communication systems, that in the future may face a better protocol than ZigBee, or that the information is not handled by the Internet, and thus with all the elements that make up the intelligent lighting. That is why this lighting paradigm can maintain its operating methodology, but with different parts and improvements.

Regarding the review of case studies in different parts of the world, it is assumed that it was carried out between 2006 and 2018. The case studies in this period of time have increased worldwide. At least one country from every continent of the world has implemented this form of public lighting, increasing confidence levels towards this technology in both public and private spheres. As the number of projects related to LED intelligent lighting increases, the understanding of this methodology will be strengthened and, therefore, its functionality will be improved.

One of the drawbacks that comes with smart LED lighting is that they have a costly initial price, that is, a high investment. Although, every year sees an increase in the numbers of this type of project and moreover, the components continue to get cheaper, it does not stop the initial investment from being expensive. Due to the good energy efficiency of intelligent LED lighting, their operation reduces prices for energy consumption and maintenance, causing the initial investment to recover in approximately five years. Another benefit, not related to the economy, has to do with the impact on the environment. This project would promote better storage policies for batteries and other non-functional elements of the LED intelligent system.

As it is well stated, future recommendations have to do with continuing to explore new possibilities helping to create efficiency and effectiveness. Technological advances will allow a better scenario to be created in the future, providing for a highly efficient, reliable and environmentally friendly public lighting system. The challenge for the future is not only to think about the personal well-being of the human being, but also about the well-being of our environment and fauna. Consequently, total sustainability can be achieved with the implementation of new technological approaches.

4. Conclusions

The intelligent public lighting with LED lighting technology is set to be the next step towards energy efficiency in terms of street lighting; mostly because the technologies that make up smart LED lighting have a sufficiently stable level of development to replace conventional public lighting. Given the evidence shown in this review, where intelligent LED lighting consumed approximately 60 % less energy than its predecessor lighting, the hypothesis that this form of lighting should be implemented in more places around the world is strengthened.

Luminaire technology has changed over the years and created a variety of new lighting trends; some more efficient or effective than others. LED technology stands out among others due to its operational characteristics, being the most relevant luminaire to be used in public lighting. The possibility that in upcoming years more lighting technology will have been developed is not ruled out, but it has technological solidity, efficiency and effectiveness that allows it to be the right type of luminaire to be used now, not only in public intelligent lighting, but also in any type of public lighting.

ZigBee communication provides a strong network that interlaces thousands of luminaries, making this a fitting time for the implementation of more intelligent LED lighting projects in public places using this wireless communication protocol. The scope achieved by ZigBee also suggests that its usefulness can be extended, not only in public lighting, but also in other urban areas, thereby allowing a more intelligent environment wherever it is implemented.

The economic, environmental and adaptability challenges to the current demands of public lighting, are something essential in any technological innovation, but the best way to solve this is to further implement its use. It is known that intelligent LED public lighting has obstacles to overcome, but to achieve that, this type of street lighting has to be implemented more and people must get used to these systems. It has shown what this innovative trend is about, thereby opening up more possibilities to make this way of lighting more efficient, more functional and more sustainable. Increasingly, there are proactive articles and projects being developed related to smart LED street lighting, allowing for better public visibility of both the great advantages and some disadvantages of this form of public lighting.

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