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Article

A Study to Improve the Quality of Street Lighting in Spain

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Abstract: Street lighting has a big impact on the energy consumption of Spanish municipalities. To decrease this consumption, the Spanish government has developed two different regulations to improve energy savings and efficiency, and consequently, reduce greenhouse-effect gas emissions. However, after these efforts, they have not obtained the expected results. To improve the effectiveness of these regulations and therefore to optimize energy consumption, a study has been done to analyze the different devices which influence energy consumption with the intention of better understanding their behavior and performance. The devices analyzed were lamps, ballasts, street lamp globes, control systems and dimmable lighting systems. To improve their performance, they have been analyzed from three points of view: changes in technology, use patterns and standards. Thanks to this study, some aspects have been found that could be taken into account if we really wanted to use energy efficiently.

Keywords: lamps; ballasts; dimmable lighting systems; twilight switch; energy efficiency

1. Introduction

Street lighting is an integral part of the municipal environment, promoting comfort, as well as enhancing the safety and security of its users [1]. This kind of lighting has the greatest impact on energy consumption in most Spanish municipalities, and may account for up to 80% of the electricity consumed by municipalities [2]. Furthermore, the average lamp power used in Spain, with an average of 157 W per lamp, is one of the highest in the European Union, well above the United Kingdom (76 W) or The Netherlands (61 W) [3]. This is perhaps due to the fact that 20% of street lighting lamps are based on outdated and inefficient technologies [4]. Table 1 shows the percentage of each kind of lamp in use in 2007.

Table 1. Percentage of each kind of lamp in some European countries in 2007.

Country	HPM (%)	HPS (%)	LPS (%)	MH (%)	FL (%)	LED (%)
Netherlands	4.76	44.76	28.57	2.85	19.04	0
UK	0	41	44	0	15	0
Spain	20	70	0	0	10	0

HPM = high pressure mercury; HPS = high pressure sodium; LPS = low pressure sodium; MH = metal halide; FL = fluorescent; LED= light-emitting diode.

To improve this situation, the Spanish Government put forth the Royal Decree 1890/2008 [5] and its corresponding Complementary Technical Instructions. Its objectives are: (1) to improve energy savings and efficiency, and consequently, reduce greenhouse-effect gas emissions; (2) to limit glare and light pollution; and (3) to reduce intrusive or annoying light levels. Moreover a strategy, known as the Energy Saving and Efficiency Strategy (E4) was also defined [6], which established a series of standard actions aimed at improving the energy system. The target set in this Plan was to achieve a consumption of 75 kWh per inhabitant per year. Its main measures were: (1) to establish a program of replacement of existing external public lighting equipment, based on obsolete technologies, with other more up-to-date and efficient equipment; (2) implementation of energy audits; and (3) to set up and run energy training courses for municipal technicians and the maintenance managers of municipal installations.

Sanchez de Miguel [7], who defined a procedure to estimate the energy consumption in public electric lighting in Spain from 1992 to 2012, came to the conclusion that the most populated provinces appeared to have begun to stabilize the growth of their expenditure on public lighting, but that this had no occurred in the less populated provinces where this expense continued to rise at a similar rate despite the economic crisis. The general trend of Spain during the last eighteen years had been one of nearly constant growth. One of the purposes defined by the strategy was to promote the use of more efficient equipment. Analysing the lighting level control devices installed in the Community of Andalusia, for example, it is possible to observe that 64% of the installations do not have voltage regulators [8]. This sort of devices allows the amount of energy consumed to be reduced when the conditions are appropriate, for example when the number of vehicles does not exceed some predetermined quantity.

Neither of the regulations mentioned before have obtained the expected results. To help with this issue, the aim of this manuscript is to detect any aspects that the previous regulations might have overlooked. These aspects have been analysed form the point of view of energy efficiency and energy consumption. If these new considerations were to be included in future updated versions of the regulations, we are sure that the quality of street lighting would be similar to the standards of other European countries which are doing quite well in this area. The remainder of this paper is organized as follows: Section 2 presents the related work, Section 3 describes the main elements of our study and finally Section 4 contains the conclusions.

2. Related Work

The related work is divided into two parts: the first part analyses the different proposals to measure energy efficiency and the second part shows the strengths of some foreign street lighting standards. There are only a few European countries that have provisions addressing the energy efficiency of the whole street lighting system, among them Spain and The Netherlands [9]. Hence, the first part shows the different methodologies used to measure the energy efficiency. The way proposed by the Slovenian government in 2007 [10] consisted in measuring the annual energy consumption per citizen per year. The main disadvantage of this proposal is that for areas with high population density it is easier to achieve lower level values than for areas with low population density. Another way was presented by Silva [11], who developed a tool which can assess street lighting performance in the context of energy efficiency. This tool uses three indicators: one to evaluate lighting performance and two others to evaluate energy performance, one being luminaire coverage and efficiency and the other lighting control devices. The only shortcoming of this tool is that the score used for lighting control devices has only two values—zero or one—depending on whether the installation has (one) or does not have (zero) this kind of devices. In the research carried out by Pracki [12], a new classification system based on the installed and normalised power densities was proposed. Although he claimed that energy consumption depends on the burning hours, he did not take that into account in his proposal. Different criteria were used in a German road lighting competition [13], where the energy efficiency of the street lighting was defined as the amount of energy consumption per kilometre per year in kWh/(km × Y), and the energy used (kWh) to produce a certain luminous flux over time. Besides, in the research carried out by Kyba [14] the same definition of efficiency in urban street lighting (kilowatt hours per kilometre per year) was also proposed because this measure allows assessment of all the elements that influence energy consumption. For the case of Spain [5], energy efficiency is based on the lit-up surface, average illuminance and the total active power installed.

There are a lot of options to define energy efficiency, but it seems to be impossible to use just one measure to describe the energy efficiency of street lighting systems [15], although all of them have the same goal of reducing the energy consumption without sacrificing the visibility conditions and comfort. This article is focused on the main devices which influence energy consumption with the purpose of improving the energy efficiency considering the current Spanish regulations.

The second part shows the strengths of different street lighting standards compared with the Spanish Regulation already implemented. The Technical Regulation of Lighting and Street Lighting (RETILAP) [16] from Colombia incorporates a section to establish the coexistence between luminaires and trees. The Public Lighting Design Manual from Hong Kong [17] defines the design layout (single-sided, staggered, opposite and twin-central) regarding the mounting height of the luminaire. Another strength of this Manual is that it defines the distance between luminaires and fire hydrants in order to not to block their operation. Minnesota’s Energy Law [18] establishes that a lamp with initial efficiency less than 70 lumens per watt must be replaced when worn out by light sources using lamps with initial efficiency of at least 70 lumens per watt. The Spanish regulations established that the new lamps shall have an initial efficiency of at least 65 lumens per watt.

3. Main Elements

An analysis of the main elements is necessary to understand how each component affects the final energy consumption. These elements are divided as follows: lamps, ballast, street lamp globes, hours of operation, lighting level control devices and renewable energies. To be sure about their involvement in the final energy consumption, each component was studied individually. Then, after studying how each component influences the final energy, different criteria to save energy were established. According to Boyce [19], there are four options to save energy: changes in technology, in patterns of use, standards and basis of design, but from our point of view, changes to the basis of design require a careful reconsideration of what such lighting is for and how it might best be achieved, so each element was studied excluding the fourth option.

3.1. Lamps

There is no doubt that lamps are the most representative component of street lighting. There are several types of lamps on the market which can be used on this kind of installation, including, among others, high pressure mercury (HPM), high pressure sodium (HPS), low pressure sodium (LPS), metal halide (MH) and light-emitting diode (LED) lamps. At present, in street lighting applications, HPS and MH lamps are the most widely used light sources. LEDs are fast developing light sources and are considered a promising light source for general lighting, although this kind of source on the market is not that cheap yet. Currently, HPS lamps are the dominant light source used in road lighting because of the long lamp lifetime and high luminous efficacy. MH lamps offer high luminous efficacy and good color rendering properties [20].

There are two different options to save energy in the case of lamps: changing the standards and changing the technology; for example, the British Standard BS 5489 [21] allows reducing the required lighting class when the color rendering index (CRI) of the lamp is higher than 60 (white light) [22]. On the other hand, the Hong Kong regulations only allow reducing it if the lamp has a CRI equal to or greater than 80 [17]. This reduction is only permitted on subsidiary roads. If the current Spanish standard took into account this reduction, the illuminance level would be reduced by at least 25%. Table 2 shows the reduction of illuminance level.

Analysing Table 2, we notice that there are two more lighting classes in the British standard than in the Spanish standard. These lighting classes are S5 and S6. In this respect, we must agree with the Royal Decree because 40% of night-time street crime occurs when lighting levels are at 5 lux or below [23]. Before recommending the incorporation of this advantage into the Spanish standard, it is necessary to be sure that this change does not decrease the quality of the installations. There are several researches that confirm the benefits of white light. One of them is the study conducted by Godfrey [24], who concluded that driver reactions with cool white light are more efficient than with “warm” coloured light.

Table 2. Illuminance savings by reducing lighting class.

Lighting class (Spain)	Lighting class (BS)	Illuminance level (lux)	New class	New illuminance level (lux)	Illuminance savings (%)
S1	S1	15	S2	10	33%
S2	S2	10	S3	7.5	25%
S3	S3	7.5	S4	5	33%
S4	S4	5	S5	3	40%
-	S5	3	S6	2	33%
-	S6	2	-	-	-

Lewis [25] also reported the results of reaction time tests where detection of a pedestrian was conducted using MH, HPM, HPS and LPS. He found an approximately 50% increase in reaction time for sodium sources *versus* MH, at a luminance level of 0.1 cd/sq.m. At a relatively high lighting level of 1 cd/sq.m, he reported an increase in reaction time of approximately 15% of HPS *versus* MH, and 25% for LPS *versus* MH. In our opinion, there are several evidences that prove the benefits of the white light yet the current Spanish Standard does not include it. This should be incorporated in order to improve the energy efficiency.

Related to changes in the technology, it is necessary to guarantee that these changes do not decrease the amount of light output. The best parameter to compare two kinds of lamps without decreasing the luminous flux is the luminous efficacy of the lamp. This parameter is the quotient luminous flux emitted by the power consumed by the source, unit lumen per Watt [26]. Table 3 shows the main features of the different kinds of lamps.

Table 3. Main features of the different kind of lamps.

Lamp type	Luminous efficacy (lum/W)	Colour rendering index (CRI)
HPM	50	15
HPS	130	25
MH	80–108	75–90
LED	90–130	>80

Luminous efficacy is also used by the Spanish regulations [5], where the minimum values specified is 65 lum/W. As it can be seen in Table 3, HPM lamps do not comply with the requirements, so it does not make sense for this kind of lamp to appear in the Spanish standard. In the case that lighting designers wanted to change the kind of lamp, they may follow this criterion because it is possible to find lamps with the same or higher luminous flux and less power consumption. For example, by simply replacing common bulbs with energy-saving LED lamps one can reduce energy consumption by up to 80% [27].

3.2. Ballast

All kinds of lamps require a ballast to operate correctly. For this reason, the presence of this device in street lighting systems is indispensable to ignite the discharge and control the lamp. Ballast devices can be divided mainly into two types: electromagnetic and electronic. Electronic ballasts are considered more energy efficient than electromagnetic ballasts, and for this reason they have been promoted as replacements the latter, to the point that some countries have changed their regulations to encourage their use. Other advantages are that electronic ballasts produce no flicker effects and provide an instantaneous startup [28]. Due to the fact that electromagnetic ballasts have high power loss from the iron and copper losses in the magnetic choke, they are 10%–15% less efficient than electronic ballasts [29,30]. To verify that the power of electronic ballasts is lower than that of electromagnetic ballasts, different ballasts were studied of Philips [31]. Table 4 shows the power savings for two different LPS lamp powers.

Table 4. Power savings using electronic ballasts with LPS lamps.

Lamp type & power (W)	Electromagnetic ballast power (W)	Electronic ballast power (W)	Power saving
1 × SOX 35 W	11.7	3.7	8
1 × SOX 55 W	19.5	5.5	14

These power savings are under nominal conditions and although they might be considered insignificant, they should be taken into account because the power saving percentage in the case of a 55 W SOX is 18%. To analyze the benefit of this replacement under normal conditions, the research carried out by Omar [32] was studied. They examined the energy consumption of 277 units of 250 W HPS for a month. The energy consumption with electromagnetic ballasts was 30,913.2 kWh and the energy used with electronic ballasts was 20,172.7 kWh. Therefore in this case the energy saving was 34.74%. Besides, there are other researchers that have studied the benefits regarding the supply voltage. A good example is the research done by Dolora [33], who studied the savings for HPS 150 W lamps. This research concluded that the supply voltage bears on in the final energy consumption. Table 5 shows the power variation regarding the supply voltage.

Table 5. Power variation between electronic and electromagnetic ballasts [33].

Supply voltage (Vac)	Electromagnetic ballast		Electronic ballast		Power variation (%)
	Power (W)	Illuminance (lx)	Power (W)	Illuminance (lx)	
200	122.7	161	154.2	256	25.6%
210	136.7	190	156.8	256	14.7%
220	152.3	220	157.1	256	3.1%
230	168.3	255	156.0	256	−7.3%
240	187.1	291	154.8	256	−17.2%
250	204.2	327	154.3	256	−24.4%
260	224.6	367	154.2	256	−31.3%

As it can be seen, when the supply voltage is 250 V, the percentage of power variation is 24.4%, this means that the luminaire power can vary by up to 49.9 W. The problem with the Royal Decree [5] is that it only specifies the maximum power per luminaire, when in our opinion the maximum ballast power should be specified because designers sometimes are not aware if the kind of ballast that satisfies the requirements. Table 6 shows a good example.

Table 6. Luminaire power for different kind of ballasts.

Nominal lamp (W)	Maximum lamp power allowed (R.D 1890) [5]	Lamp power plus electromagnetic ballast (W)	Lamp power plus electronic ballast power (W)
1 × SOX 35 W	42 W	46.7 W	38.7 W
1 × SOX 55 W	65 W	74.5 W	60.5 W

As it can be appreciated, lighting designers must pay attention when choosing the ballast because although the maximum power is defined, the luminaire power must be checked because in the analyzed case the installation of electromagnetic ballasts would not satisfy the minimum requirements.

3.3. Street Lamp Globes

Although people believe that street lamp globes do not influence energy consumption, the choice of this part is very important because it influences the upward reflected light and thereby light pollution. Light pollution is not simply any astronomical or ecological light pollution, because enormous amounts of energy are wasted with light pollution. For example, at the end of the 1990s the amount of sky glow over Sapporo, Japan was equivalent to 15 million kWh of energy, 29 million kWh over London, UK and 38 million kWh over Paris, France [34]. The total amount used for public outdoor lighting in Helsinki, Finland is roughly 170 million kWh, meaning that all Helsinki could be illuminated with just five days of the “waste light” of Paris. The light sent upward is thus estimated to produce economic losses worth billions of euros every year [35]. The best option to save energy regarding the light pollution is by changing standards. The current Croatian regulation establishes lower levels than the Spanish regulations. Table 7 compares the maximum upward light ratio of the installation (ULR) for Croatia [36] and Spain [5].

Table 7. Maximum percentage of ULR for Croatia and Spain.

Croatia standard		**Spanish standard**	
Classification zone	**Maximum ULR (%)**	**Classification zone**	**Maximum ULR (%)**
EO	0%	Not exist	0%
E1	0%	E1	1%
E2	2.5%	E2	5%
E3	5%	E3	15%
E4	15%	E4	25%

As it can be appreciated, the maximum percentage of ULR in Spain is higher than in Croatia. Although Croatia is not the country with the strictest regulations, in our opinion the Spanish regulation should incorporate at least the minimum level established in the Croatian rules.

The Chilean D.S.N °686/98 regulation [37] defines that a lamp with a luminous flux equal to or less than 15,000 Lm cannot emit more than 0.8% of its nominal flux above horizontal level when installed in a luminaire. Lamps with a luminous flux of more than 15,000 Lm should not emit more than 1.8% of their nominal flux above horizontal level when installed in a luminaire.

In 2007 Slovenia adopted a law (Official Gazette of the Republic of Slovenia, No. 81/2007) aimed at tackling light pollution. The law requires that 0% of the output of a luminaire should shine above the horizon (90°) [38].

To analyze how ULR influences this kind of installation, several simulations were done with the DIALux software. The analysis consisted in studying what happens if the luminaire has the same kind of lamp and the street lighting globes are different. The model of the studied luminaire was the CitySpirit Modern (Philips, Amsterdam, The Netherlands), the street lighting globes were four and the kind of lamp was LED. Figure 1 shows the average illuminance regarding the ULR for 22 X XR-E-PE/WW, 22 X XR-E-Q3/NW and 22 X XR-E-Q5/CW lamps.

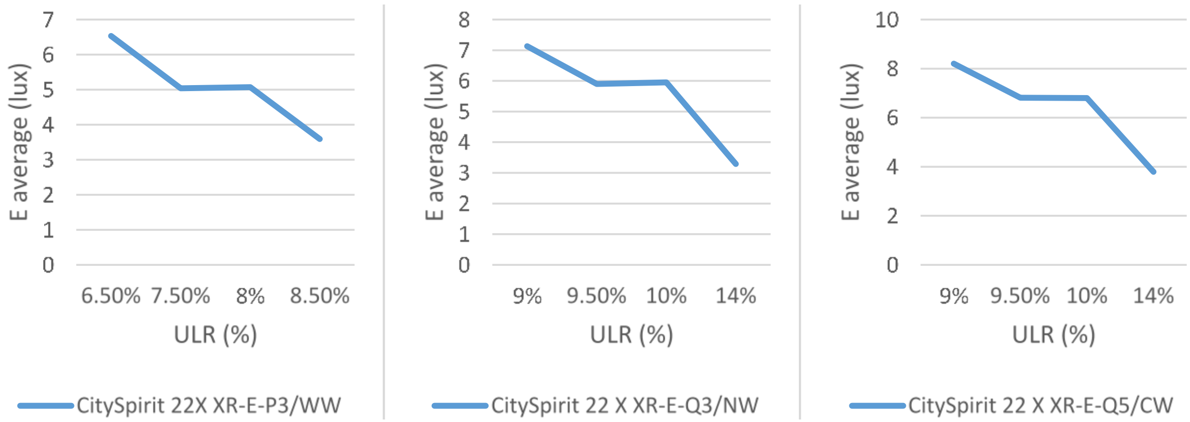


Figure 1. Illuminance regarding the ULR.

As it can be seen for this luminaire model, if the ULR increases, the average illuminance decreases, but the lamp power and the lit-up surface were the same for the three simulations, therefore the energy efficiency bears upon the ULR. Another model of lamp analyzed was the Urbana (Philips) and again ULR was studied and the same performance can be appreciated, the street lighting globes were two in this case and the lamp was an HPL-N80W. Table 8 shows the results.

Table 8. ULR regarding the street lamp globes.

Globes	Total lamp flux	System flux	Luminaire power	Lit-Up surface	E average (Lux)	Overall uniformity	ULR (%)
	3600	684	90	80	5.02	0.2	4.5
	3600	792	90	80	4.74	0.273	16

It is possible to think that as the system flux is higher in the second option than in the first option, the average illuminance would be higher than the first one, but the reality is that as this sort of street lighting globes does not have any device to avoid the light pollution, and thus the average illuminance is lower than in the first case. From our point of view, ULR magnitude should be taken into account for the energy label, because with the current systems only assess the illuminance on the lit-up surface.

3.4. Hours of Operation

The current Spanish standard [5] includes three possible devices for that purpose: astronomic time switches, twilight switches and remote management systems for electrical boards. Astronomic time switches turns lights on and off with a fixed time offset from sunrise and sunset. To estimate the daily hours of sunrise and sunset the latitude and longitude are needed because of the movement of the Sun, as it can be seen on the sunrise sunset calculator program tool [39].

Twilight switches measure the amount of natural light available to turn on and off the lamps regarding this level. As happens with astronomic time switches, it is possible to establish an approximation of the number of burning hours using the latitude and the level of natural light required to turn the system on or off [40]. An option to decrease the hours of operation and therefore to save energy with this kind of device is by changing the use pattern. Angus Council (U.K.) [41] studied the trimming of photocells; the factory setting of the switch on/switch off levels are 70 lux on and 35 lux off (70/35). By reducing the switch ratio to 35/18 they could typically save 92 burning hours per year per luminaire. The Institution of Lighting Professionals (ILP) [42] estimated that if the switching levels were reduced 35/16, a saving of 1%–2% per luminaire could be achieved. This regulation is not recommended for older lamp types such as LPS and HPM operating on conventional ballasts. Such installations should be operated at 70 lux on and 35 lux off as a minimum to allow the lamps to fully run up by the time the lighting is required. The only drawback of the previous studies is that they did not specify the latitude. This lack of information was solved in the study carried out by American Electric Lighting (AEL) [43] because the latitude was taken into account in the results. Table 9 shows the hours of operation at latitude 35° (Los Angeles, California) for various photocell settings.

Table 9. Hours of operation regarding the twilight settings [39].

On (lux)	Off (lux)	Hours of operation
8.6	10.7	4113
10.7	12.9	4130
32.2	19.3	4187
16.1	24.7	4167
27.9	33.3	4204
10.7	32.2	4265
21.5	107.6	4340

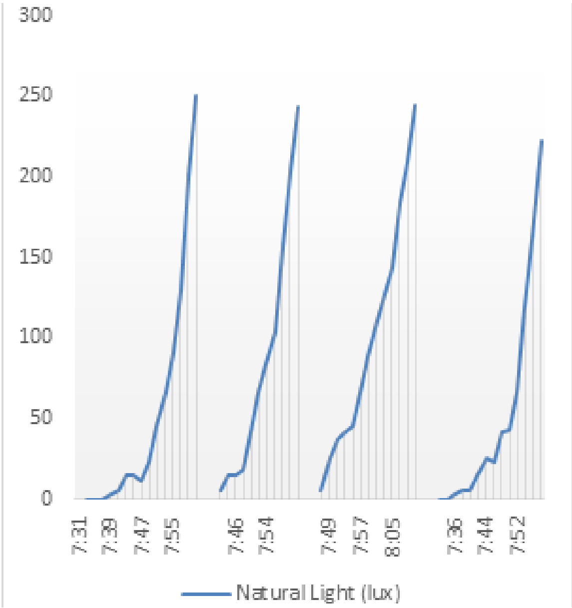
Remote management systems are composed by a server-client architecture system for monitoring, detecting, controlling and communicating problems instantly to a central control room or directly to maintenance technicians [44]. Telemanagement integration in street lighting networks of small cities has hardly been developed both in a conceptual and applicative way, especially due to limited economical resources of local communities which have become responsible for too many new tasks, public illumination being one of them [45].

The hours of operation depend on these devices which also consume energy. Analyzing the data of the manufacturer ORBIS [46], it can be appreciated that the power consumptions are very similar independently of the kind of device. Table 10 shows the power consumption.

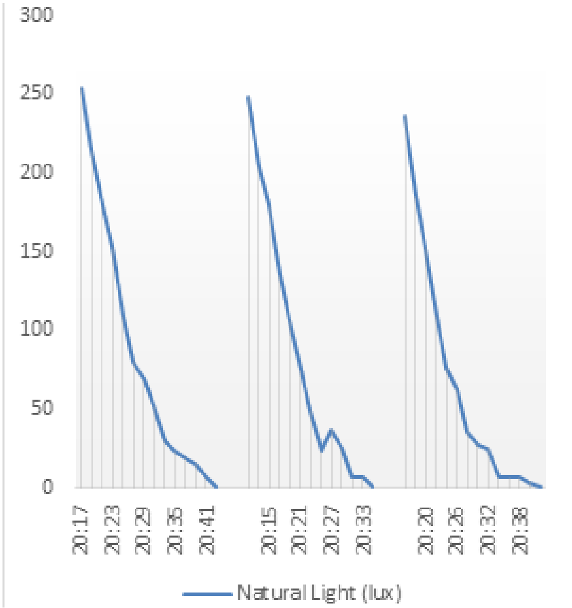
Table 10. Power consumption of street lighting control systems.

Type	Model	Self-Consumption (VA)
Astronomic	DATA ASTRO	5
	ASTRO NOVA CITY	6
	ASTRO UNO	6
Twilight	ORBIFOT	8
	VEGA	8
	ORBILUX	3.4
Remote Management	XEO LUM	4.8

As each device uses different technology and criteria to turn on and off, the hours of operation established for each device will be different. We have measured the natural light level during different days with the purpose of understanding the operation of each device. Figure 2a shows the natural light level several days at sunrise and Figure 2b shows the natural light level of several days at sunset, where the data of both figures were measured in Madrid (Spain) in September 2014. A PCE-174 (ORBIS) digital illuminance meter was used to obtain the data.



(a)



(b)

Figure 2. Natural light level during the sunrise (**a**); and during the sunset (**b**) in Madrid.

As it can be seen, the tendency is different for each day because of the weather conditions are different and therefore climate bears upon the natural light levels. In that aspect we agree with Howell [40] that the weather conditions are even more significant than latitude in determining days. Hence the main drawback of astronomic time switches is that they do not take into account the real level of natural light. Besides, analyzing in detail the data of the previous trimming, Table 11 shows the time when the natural light reached a certain value. It can be seen, trimming the photocells allows decreased the hours of operation, while on the other hand natural light level reached 35 lux twice on 21 September. This issue is the main problem of photocells because undulations in light level can cause erratic operation, but this can be solved with the controller.

Table 11. Time when the natural light reached a certain value.

Day	Sunrise			Sunset		
	18 (lux)	**35 (lux)**	**Savings Minutes**	**70 (lux)**	**35 (lux)**	**Savings Minutes**
19 September 2014	7:46	7:48	2 min	20:29	20:32	3 min
20 September 2014	7:46	7:47	1 min	20:28	20:31	3 min
21 September 2014	7:46	7:48	2 min	20:21	20:24 and 20:27	-------
22 September 2014	7:47	7:48	1 min	20:25	20:28	3 min
23 September 2014	7:41	7:45	4 min	20:24	20:27	3 min

As it can be seen, photocell trimming could save approximately 4 min per day. This means that the amount of burning hours may reduce by 24 per year.

3.5. Lighting Level Control Devices

There are three different types of level control devices contemplated in the Spanish standard [5]: series inductive type ballasts for dual power level, power controlled electronic ballasts and regulators and stabilizers in the head of the line.

The main problem of using ballasts for dual power levels is that these systems act locally, requiring an adjustment device attached to each of the individual charges and also a general control system to control all of them [47]. Regulators and stabilizers are able to control the voltage according to different parameters such as number of vehicles per hour [48], weather conditions or the presence of pedestrians [49]. Their operation consists of hanging the input mains voltage to a variable voltage within the range from 220 to 170 V [50]. Those changes are accompanied by variations of illuminance and lamp power. Figure 3 shows the working of these sort of systems, where it can be seen their potential on energy savings.

The main advantage of stabilizer lighting systems is that they are able to avoid overvoltage situations. The research carried out in China [51] showed how, despite the fact the nominal voltage is established at 230 V like in Spain, it reached values as high as 246 V. This overvoltage situation is the main reason for the shortened lifetime of lamps.

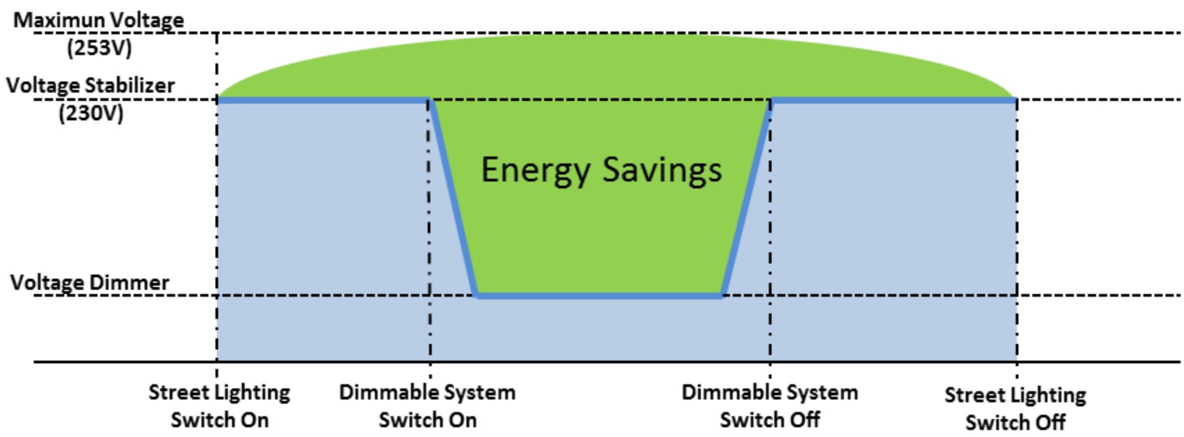


Figure 3. Regulator and stabilizer devices.

Taking into account that the energy savings depend on input voltage, it is necessary to define the input voltage in order to satisfy the minimum luminous flux level allowed. According to Bacelar [52], the minimum luminous flux level should be established at 50%, because it was shown that this dimming does not seem to have a great influence to the visibility of observers nor drivers. Furthermore this minimum level coincides with the current standard [5]. Following the recommendations of General Electric [53], the minimum voltage regarding the kind of lamp is shown in Table 12.

Table 12. Minimum voltage regarding the kind of lamp according to GE [53].

Kind of lamp	Minimum voltage (Vac)
HPM	200
HPS	180
LPS	190
MH	180

Analyzing in detail the research conducted by Yan [50], who studied the characteristics of HPS lamps of 50, 70, 100, 150, 250 and 400 W dimming the voltage. It can be observed that the percentage of light output decreases more than 50% for 180 Vac in the case of HPS and MH. Figure 4 shows the percentage of light output for the case of 50 and 70 W HPS lamps.

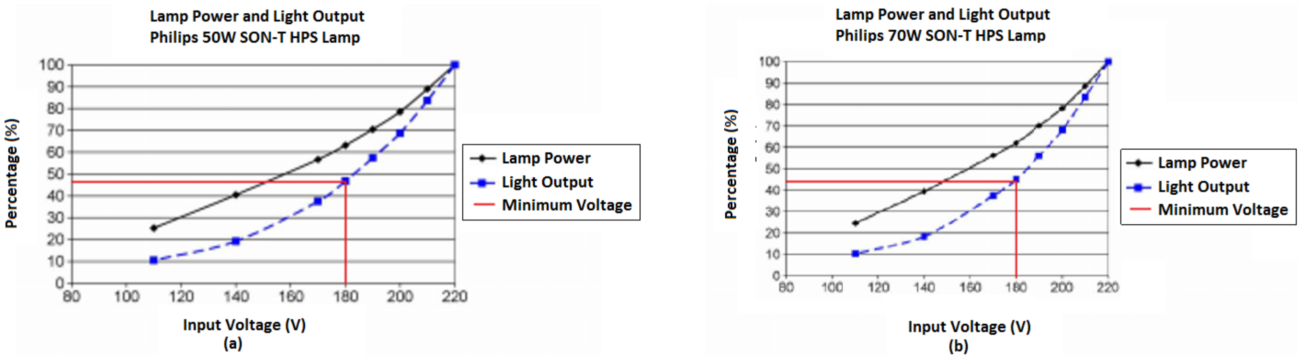


Figure 4. Lamp power, light output and minimum voltage for HPS lamps (50 and 70 W).

Therefore the minimum voltages showed in Table 12 are not completely right because they do not satisfy the minimum requests impose by the current standard. In our opinion the minimum voltage for each kind of lamp should be the values shown in Table 13.

Table 13. Minimum voltage to decrease the light output 50%.

Kind of lamp	Minimum voltage (Vac)	Decrease luminosity flux (%)
HPM	200	30%
HPS	190	50%
LPS	190	10%
MH	190	50%

From our point of view, the unique shortcoming of Spanish standard [5] regarding lighting level control devices is that it does not specify when it can be used. If we followed the recommendations of the Dutch ministry, dimmable road lighting systems could operate at 20% when the density of traffic at night is low, at 100% when the traffic density is high and 200% when there is a combination of high traffic density and exceptional conditions such as fog. The conclusions were that 20% light level has no negative safety effects and is sufficient for low traffic density but 200% light level is not justified because the cost is high and the safety improvements are marginal at best [54]. Another project [55] also investigated the effect of dimming, the lighting level setting were determined as follows; 100% when there are more than 3000 vehicles per hour, 75% when the range of vehicles is 3000–1500 and 50% when the number of vehicles per hour is lower than 1500. Following both projects and observing the behavior of Spanish roads, Figure 5 shows the number of vehicles per hour of a road in the Community of Murcia.

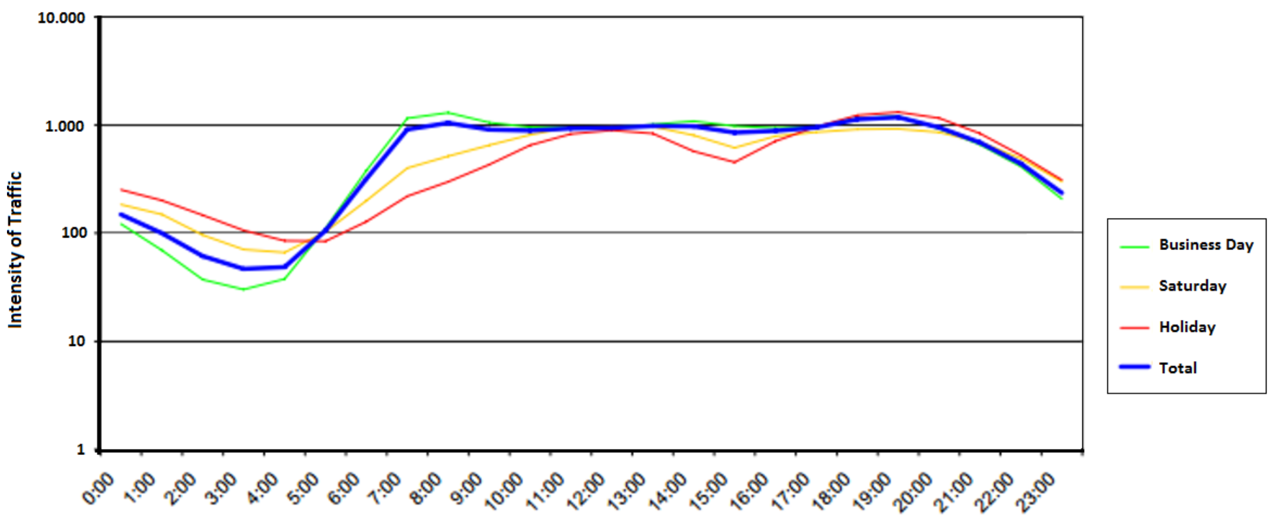


Figure 5. Number of vehicles per hour in a road from the Community of Murcia [56].

As it can be seen, lighting level control devices can operate perfectly from 1:00 am to 5:00 am, because the number of vehicles decreases considerably. In this aspect, the Croatian normative [57] specifies that if the local government does not prescribe a schedule, the street lighting must be turned off or reduced by 50% at least at 1:00 am. In our opinion, it should be mandatory within the Spanish normative that lighting level control devices reduce the light levels at least from 1:00 am, because most of the time the conditions allow it.

3.6. Renewable Energies

The global necessity for energy savings requires the usage of renewable sources in many applications and outdoor lighting installations are no exception. Spain, owing to its location and climate, is one of the countries in Europe with the most abundant solar resources [58]. Global solar irradiation on a horizontal plane is estimated as being between 1.48 and 3.56 kW/m^2 day in Spain.

The solar energy option may be the best solution in the case of an autonomous street lighting system because of the long life time, easy installation and modularity [59]. This sort of renewable energy allows reducing the CO_2 emissions considerably and thus the energy consumption. A good example of the benefits of solar energy in street lighting is the research carried out by Nunoo [60], who achieved energy savings per day of 603 kWh. Analysing in detail the research carried out by Constantinos [61], who optimized a photovoltaic system for street lighting, the total autonomous days of operation may reach up to 315 per year. In other words, in this case the energy savings were about 86%.

On the other hand, maintenance of the photovoltaic panels is very important, because dust effects reduce the performance of solar panels. The research carried out by Al-Almmri [62] shows that the losses of the output power of the fixed solar panel can reach 26% for one month. As well, their orientation can cause a considerable loss of efficiency. Likewise, the slope of the panel should be changed two to four times a year to maximize the solar absorption, since the optimum slope in the summer is not the same as the optimum one in the winter [63]. These drawbacks can be solved with regular maintenance.

Outdoor lighting can be supplied with other kinds of renewable sources or even a combination of several types of renewable sources like the research performed by Al-Fatlawi [64], who combined solar and wind energy. Power systems which include photovoltaic systems and wind turbines typically include energy storage devices so that loads can be operated when solar energy is not available or when wind velocities are too low to generate power [65].

Nowadays, renewable energies are indispensable to satisfy the normative for buildings, however the Royal Decree [5] overlooks this subject in the field of street lighting. Previous research shows that the incorporation of solar energy for street lighting is an incredible opportunity to reduce energy consumption and improve the quality.

4. Conclusions

Following the completion of this paper, this study has shown some aspects that they should be incorporated into the Spanish Standards to improve the quality of street lighting. The related work allows us to know that there are other important aspects that the Spanish normative does not contemplate, such as the minimum distance between luminaires and trees, or the minimum distance between luminaires and fire hydrants. These recommendations could be considered irrelevant but any step forward makes headway.

Regarding lamps, white light is a new concept that benefits when lamps have a color rendering index higher than 60. The incorporation of this subject could reduce the illuminance level at least 25% for subsidiary roads. This advantage has been incorporated within the British Standard and in Hong Kong, now it is the time for Spain. Furthermore, we have noted that the British Standard considers two more lighting classes than the Spanish Standard.

In relation to ballasts has been corroborated that electronic ballasts consume less energy than electromagnetic ones. Although this power saving may be considered insignificant, the example analyzed obtained a power savings of 18% regarding the luminaire power with electromagnetic ballast. The weakness of the Spanish standard is that it only specifies the maximum luminaire power. Hence designers must take into account the choice of the kind of ballast because although the maximum power is defined, it is very easy exceed the maximum luminaire power value.

Concerning light pollution, Spain is not very strict and should be more rigorous. The simulations done with DIALux verify that ULR bears upon the illuminance and therefore if the Spanish regulation were stricter regarding light pollution, street lighting systems would improve in quality.

Related to hours of operation each device works using a different technology and therefore the hours of operation are different in each device. Moreover, it has been corroborated thanks to the measures of natural light using a digital illuminance meter that weather conditions are even more significant than latitude in determining days. The recommended trimmings have been corroborated and photocell trimming may save 24 h per year. This action allows one to decrease the energy consumption while maintaining good service.

Finally, the benefits of lighting level control devices is shown, while on the other hand it is required to be careful with the input voltage value because if the trimming is too low, the illuminance would not satisfy the minimum requirements and could affect the visibility of drivers and observers. Moreover 1:00 am to 5:00 am was defined from as the best period to use them. We wish to highlight that the Spanish normative should encourage the use of renewable energies for street lighting.

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Author Contributions

Alberto Gutierrez-Escolar has contributed to the sections on lamps and renewable energies, Ana Castillo-Martinez has developed the ballast section, Jose Maria Gutierrez-Martinez has developed the hours of operations section and Jose M. Gomez-Pulido has obtained the natural light data and finally Zlatko Stapic has been the person in charge of finding the differences between the Spanish Standard and the rest of the regulations. Jose-Amelio Medina-Merodio has contributed to the section on street lamps globes. All the authors were involved in preparing the manuscript.

Nomenclature

CRI	Color Rendering Index
HPM	High Pressure Mercury
HPS	High Pressure Sodium
LPS	Low Pressure Sodium
LED	Light-Emitting Diode
MH	Metal Halide
R.D.	Royal Decree
ULR	Upward Light Ratio

Conflicts of Interest

The authors declare no conflict of interest.

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