18th International Conference on Renewable Energies and Power Quality (ICREPQ'20)
Granada (Spain), 1th to 2nd April, 2020
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.18 June 2020

Evaluation of Energy Efficiency in Large-Scale Public Lighting. The case of the City of Cuenca, Ecuador.

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Abstract. This paper describes a large-scale energy efficiency assessment of the public lighting system in the city of Cuenca, Ecuador, carried out with the collaboration of the system administrator, the Central South Regional Power Company (CENTROSUR). For the evaluation, the Spanish regulation ITC-EA-02 and the European standard UNE-EN 13201 were used since there are no similar efficiency standards in Ecuador. Three thousand measurement points distributed on about 200 city roads were surveyed. The results allowed to evaluate the levels of average horizontal illuminance on the road and the mean and general uniformities of the arteries as well as the energy efficiency during the years 2014-2015. As a conclusion, and according to the aforementioned European regulation, 81% of the studied roads have excessive levels of illumination; 13% deficient levels and only 6% of the roads complied fully with the standards.

Key words

Public Lighting, Energy Efficiency, Regulation, Energy Rating, Illuminance.

1. Introduction

In the year 2002 the administrator of the public lighting system of the city of Cuenca, Ecuador, the South Central Regional Electricity (CENTROSUR) a governmental company, began a program to improve the public lighting system through the geographical division of 23 areas in the urban area of Cuenca, taking into account objectives such as energy efficiency, environmental protection and traffic safety [1]. To comply with the recommendations of the international standards of road lighting, adjustments were made in the technical parameters such as: distance between posts, mounting height of the luminaires and mercury vapor luminaires were changed with high pressure sodium vapor luminaires, both fixed power and double power level. This greatly improved the levels of lighting and reduced the consumption of electrical energy. The use of better technology brought benefits but did not include the assessment of the efficiency, except for the consideration that sodium lamps were more efficient than those of mercury. At the present, efficiency assessment and energy labeling are spreading all over the world and becoming mandatory. A study of public lighting developed in the Croatian city of Rijeka, which includes the replacement of mercury vapor luminaires as was the case of Cuenca, resulted in lower energy consumption, reduced CO2 emissions and improvements in road lighting [2].

In relation to its performance, the lighting of the city of Cuenca is well accepted by citizens, according to a survey conducted in 63 Distributors in South America and Central America by the Regional Energy Integration Commission (CIER) in the year 2015, thus placing the South Central Regional Electricity Company in the first place about satisfaction in public lighting service [3]. Users satisfaction and lighting performance are important issues although do not means efficiency necessarily.

In Ecuador, as many other developing countries, energy efficiency of public lighting is not mandatory. Would be profitable for the country to adopt such regulation? How much would be cost an assessment? As to respond to these interesting questions, the decision was to replicate in Cuenca procedures of other countries, such as the assessment methodology the one in force in Spain since 2009, hereinafter referred to as "Regulation of Energy Efficiency in outdoor lighting installations and their complementary technical instructions" (Royal Decree No. 1890/2008) [4]. This Regulation offers a complete procedure of assessment and qualification of the different illuminated transit roads.

2. Objectives

The objectives of this study were:

1) To evaluate the public lighting facilities efficiency, considering the case of the city of Cuenca as a prototype.
2) To carry out illuminance measurements in the field to establish preventive maintenance plans.
3) To analyze the effects of adopting a regulation of energy efficiency in Ecuador, measured in terms of energy savings.

3. Current data from the public lighting system

At present, public lighting has become one of the priority services provided by the CENTROSUR to the citizenship, as a key element of the security and well-being.

The canton Cuenca is divided politically in 15 urban parishes, and 21 rural parishes. The urban parishes make up the City of Cuenca, which is located in the inter-Andean region of Ecuador, with a population of 505,585 inhabitants (329,928 in the urban area) and an area of 72.32 km^2; only 2.34% of the total area of the canton, which is 3,086 km^2.

Most of the luminaries that constitute the system of street lighting are installed using the infrastructure of electrical distribution networks, while ornamental lighting systems - sports courts, parks, monuments - are built usually through circuits of their own.

3.1 Demand and energy of public lighting

The technical information on public lighting in the canton Cuenca as of December 2014 was obtained from the cadastre of public lighting developed by the Geographic Information System for the Electrical Distribution Administration -SIGADE- [5] of the CENTROSUR. A summary is shown in Table I.

Table I. Statistical data of public lighting in the canton Cuenca - 2014

Number of luminaires	55,748
Demand (kW)	10,350
Invoiced Energy (kWh)	3,762,582
Billing (USD)	375,129

On the other hand, the power and energy demanded by public lighting to the electrical distribution system during 2014, is presented in Table II.

Table II. Public lighting energy importance, both in energy and power

	Total System	Public Lighting	%
Power	170 MW	10.35 MW	6.08
Energy	80,288,910 kWh	3,762,582 kWh	4.68

The average of international references placed consumption of public lighting in around 3% [6]. In Zagreb, Croatia, the consumption by public lighting represents only 0.79% of the total energy consumption [7]; in Serbia, that percentage is 1.76% [8], in Portugal 3% [9], in Spain the energy consumption in lighting represents 10% [10], for its part in the European Union, the percentage of consumption by lighting compared to the total is around 1.3% [11] [12]. Compared with those figures the values obtained locally (almost 5%) positioned the ecuadorian public lighting among the highest, which supports the work on efficiency that has been proposed here.

3.2 Luminaires installed in the system of public lighting

As of December 2014, the lighting system of the canton Cuenca reached 55,748 luminaires, representing an increase of 8.15% compared to December 2013 (51,545 luminaires), with an average power of 186 W per luminaire and a consumption of 44,510 MWh/year.

The streets and avenues are illuminated by high pressure sodium vapor lamps, both fixed power and dual power level, and in lesser amount with mercury vapor (Hg) lamps, which are in the stage of gradual elimination because they are inefficient and polluting for human beings and ecosystems. For ornamental lighting, halide mercury (MH) and LED luminaires are available. A summary of the luminaires used by type is presented in Table III.

Table III. Luminaires for public lighting in the Cuenca canton

Light source	Quantity	%
Mercury	1,119	2.01
Mercury halide	582	1.04
LED	1,066	1.91
Sodium Double Power Level	28,695	51.47
Sodium Fixed Power	24,286	43.56
TOTAL	**55,748**	**100**

3.3 Urban road public lighting of the city of Cuenca

In accordance with the provisions of Regulation CONELEC 005/14 [13], the distribution companies of the country are responsible for general public lighting; that is to say the illumination of public roads. Below are expossed technical data of the urban road public lighting of the city of Cuenca obtained in the Direction of Planning and Commercialization of the CENTROSUR (December 2014):

- Number of luminaires (Total): 31,627;
- Total installed power: 6,380 kW;
- Electric energy consumption: 28,000 MWh/year;
- Average electrical energy consumption per luminaire: 883.70 kWh/year;
- Average installed power per luminaire: 202 W;
- Average electrical energy consumption of Street lighting per one capita: 85 kWh/year;
- Average installed power per capita: 19.34 W;
- Average price of kWh for street lighting: 9.97 cents;
- Annual average invoicing: USD 2,786,493.37;

- Working hours of Street lighting: 4,380 hours/year;
- Number of urban residential customers: 97,768 customers;
- Residential customers per luminaire: 3.09;
- Power by residential customer (rc): 65.25 W/rc;
- Population in the urban area: 330,000 inhabitants;

Similar information was obtained in the current study and energy audit of public lighting for the city of Siroki Brijeb, located in the south-western region of Bosnia and Herzegovina [14].
The luminaires that make up the road lighting in Cuenca are distributed according to what is indicated in Table IV.

Table IV. Road lighting luminaires in the urban area of Cuenca

Type of luminaire	P(W)	Luminous flux (lumen)	Quantity	Average life (hours)	%
Sodium High Pressure	70	6,600	373	30,000	1.18
Sodium High Pressure	100	10,700	1,758	32,000	5.56
Sodium High Pressure	150	17,500	12,637	32,000	39.96
Sodium High Pressure	250	33,200	15,925	32,000	50.35
Sodium High Pressure	400	56,500	503	32,000	1.59
Mercury High Pressure	125	6,300	28	16,000	0.09
Mercury High Pressure	175	12,700	269	16,000	0.85
Sodium High Pressure Projector	400	56,500	127	24,000	0.40
LED	100	9,570	7	50,000	0.02
TOTAL			**31,627**		**100**

Source: Cadastre of public lighting of CENTROSUR
https://www.osram.es/ls/productos-y-servicios/index.jsp
http://www.industria.denmark.cl/descarga/Denmark_Philips1.pdf

The collection of the costs of the general public lighting service fee is made monthly, through the collection of a fixed value to consumers of the electricity service, that is: residential rate 14%, commercial rate 18.5% and industrial rate 3.5%, as established in Resolution 1002-2506 of the Board of Directors of CENTROSUR dated January 2, 2002. The cost of the monthly energy is valued by multiplying the electricity tariff of public lighting by the total of energy consumed in the month by said lighting.

4. Illuminance measurements

Once the support of CENTROSUR was obtained, providing vehicles and necessary equipment and the allocation of personnel of the Department of Public Lighting, the study and planning of the activities and methodology of work began.

First, the size of the representative sample for each class of lighting (M) was established by means of statistical calculations, determined as a function the speed of circulation and the average intensity of daily traffic on the streets of the city. Then, a schedule for personnel was proposed to carry out lighting measurements and permissions were processed with the municipal authority of transit to suspend the mobilization of vehicles on the road during the time required for the measurements.

4.1 Simplified method of measurement of the average illuminance

Using the method called "nine points" could be determined in a simplified manner, the illuminance (E_m), as well as the average (U_m) and general (U_g) uniformities [4].

4.1.1 General conditions of the test

Prior to the measurements and to ensure it, the following points were considered:

- Perform measurements only in a section of the road, because that will be representative for parameters such as: light source, mounting height, advancement, tilt angle of the luminaire, separation between two points of light, the width of the roadways is constant along the road.
- The measurements were carried out in straight sections of the road and without obstacles that obstruct the light distribution of the luminaires.
- Illuminance was measured in the fifteen points specified as shown in Figure 1.
- The measurements were taken with the luxmeter at floor level.
- Care was taken to keep the staff in charge of the measurement from producing shadows or blocking light before the equipment.
- During the measurement, the value of the voltage of power supply was recorded with the luminaires in normal operation.
- No measurements were carried out when the weather conditions were unfavorable (rain), in the same way, when there was influence of other facilities.

4.1.2 Marking of the road

The staff assigned both in the morning and in the evening, proceeded first to the construction of the measurement grid by placing the points according to the arrangement of the luminaires (Fig. 1.).

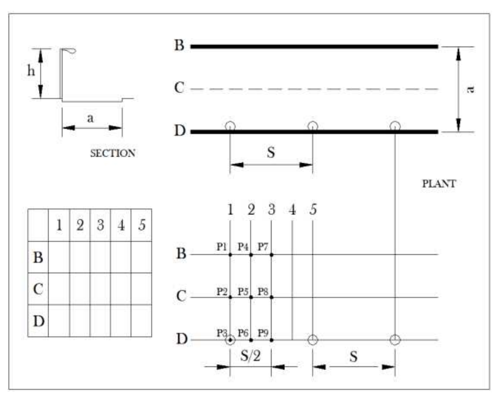

Fig. 1. Nine Points Method
Source: Supplementary Technical Instruction [ITC-EA-07]

4.1.3 Data collection

Once the points in the measurement grid were defined, illuminance levels (E) were measured in the fifteen points resulting from the intersection of the axis B, C, D with the ordered 1, 2, 3, 4 and 5, Figure 1. All the parameters involved in the field were also considered such as: address of place, date, time, supply voltage, transformer number and power, data from the luminaires, type and power of the lamp and ballast, luminaries layout, distance between luminaires, mounting height, width of the roadway, width of sidewalks, luminaire layout advancement, surface type, road safety, lighting type, the measurement personnel, equipment used and the environmental conditions during the measurement. The survey covered a total of 197 areas comprising 2,955 measurements of illuminance, sufficient data for analysis.

The illuminance measurements began at late October 2014 and over successive nights during 62 days, at times from 21h00 until 23h00, since from this time on, vehicle traffic is minimal and additionally there are no cars parked on the way. The horizontal illuminance was measured with a luxmeter brand Gossen Mavolux, model ML 5032B with certificate of calibration by the **Laboratoire Central d'electriciti (L.C.E.)**, with date: 05/03/2013 (Figure 2), while for the measurement of the voltage supply circuit of lighting the power quality analyzer Topas 1000 notebook was used, three-phase energy CL3121, Figure 3.


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Photometry and lighting fixtures

CERTIFICATE OF CALIBRATION

Calibration of	Illuminance meter GOSSEN Mavolux 5032B under CEI standard illuminant A
Delivered to	Schreder Ecuador SA M Gustavo Enriquez Juan de Selis OE1-183 y Galo Plaza Lasso Quito ECUADOR
Performed on	25/02/2013
Delivered on	05/03/2013
CLE task nr.	13EG0113
CLE certificate nr.	LBE02857456 - 1.0
Applicant reference nr.	Order N° 20130074 of 19/02/2013

*This document is fully electronically signed

*Author	*Verification	*Approval
Couvreur Guy Technical Operator Photometry and lighting fixtures	Deswert Jean Michel Technical Expert Photometry and lighting fixtures	Deswert Jean Michel Technology Manager Photometry and lighting fixtures

Fig. 2. Calibration certificate for the Mavolux ML 5032B luxmeter

The group #70 of lighting of CENTROSUR working every day between 08h00 to 10h00 hours, was involved marking the measurement grid, as well as for the measurement of advancement and mounting height of the luminaire, sidewalks width, number and power of each luminaire (Table V).

Table V. Total cost of the Task Group

Group # 70	Cost/Time Average	Quantity	Total cost $
Head of Electrical Group	17.95	1	17.95
Electrician	14.59	1	14.59
			32.54
Shopping Cart basket of AP	31.38	1	31.38
Total time/cost group			**63.92**
Total # of days		62	
# Hours per day		2	
Total hours (morning)		124	
TOTAL 1			**7,926,08**

The total cost for support of the groups of the Company during the night (6 people in rotating shifts), was of USD 7,063.80.

The total number of man-hours invested in this whole field work, is equal to 1,488 man-hours, which meant an approximate cost of USD 15,000 that were afforded by the CENTROSUR.

Fig. 3 Supply voltage readings with the device CL3121 on Heroes de Verdeloma Ave. and Eugenio Espejo street.

4.1.4 Data processing

With the field information obtained (Figure 4), the calculations of the average illuminance (Em) and the illuminance of each point were carried out, as well as the values of average and general uniformity by applying the formulas indicated in the so called "nine points method". Values obtained were compared with standard reference values for the lighting type studied and situations of compliance and non-compliance were defined.

Fig. 4. Performing the illuminance readings at each point of the grid in Araucana street.

4.1.5 Calculates versus field measured lighting levels

In accordance with the Supplementary Technical Instruction ITC-EA-02 of efficiency regulation [4], the average lighting illuminance levels of facilities may not exceed by more than 20% of average reference levels. These levels are based on the European standards of the UNE-EN 13201 series "Lighting of roads" [15]. Likewise, minimum values of uniformity must be guaranteed.

Illuminance ranges of tolerance were defined based on the results obtained (E_m) and the one specified as standard (E_{mr}) according to the following criteria [16]:

- If $E_m < E_{mr}$ → Illuminance level is poor.
- If $E_{mr} \leq E_m \leq 1.2\ E_{mr}$ → Illuminance level is optimal.

- If $E_m > 1.2\ E_{mr}$ → Illuminance level is excessive.

Illumination levels obtained in the field measurements were compared with reference values (E_{mr}) for each of the studied roads, a summary of general results is shown in Table VI.

Table VI. Comparison of lighting levels

Level	Number of Roads	Percentage (%)
EXCESSIVE	160	81
CORRECT	12	6
POOR	25	13
TOTAL	**197**	**100**

5. Calculation of energy efficiency

With the average illuminance data calculated (E_m) and those of uniformities (U_m) and general (U_g) it is possible to assess the installation quality of public lighting and determine the energy efficiency and its corresponding rating of the outdoor lighting network in the studied roads. The energy efficiency of public lighting installations can also be assessed using the energy performance indicators: a) the power density indicator DP and b) the annual energy consumption indicator DE [17].

With the power of a luminaire (P) and the illuminated surface (S) resulting from field measurements, we calculate the value of the energy efficiency ($\mathcal{E}$) [4], as shown below:

$$\mathcal{E} = \frac{S \cdot Em}{P}\left(\frac{m^2 * lx}{W}\right) \qquad (1)$$

Through the use of Table 1 and 3 (EA-01) [4] comparing the values of the average illuminance and the energy efficiency are define the compliance with the requirements of minimum energy efficiency; in the same way the value of reference energy efficiency ($\mathcal{E}_R$) is determined.

The energy efficiency index ($I\varepsilon$) and the rate of energy consumption (ICE), are calculated by applying the following formulas:

$$I\varepsilon = \frac{\varepsilon}{\varepsilon_R} \qquad (2)$$

$$ICE = \frac{1}{I\varepsilon} \qquad (3)$$

Finally, the energy rating of the installation by comparing the values obtained with those listed in Table VII.

Table VII. Energy rating of a lighting installation

Energy Rating	Index of energy consumption	Energy Efficiency Index
A	ICE < 0,91	Iε>1,1
B	0,91 ≤ ICE < 1,09	1,1 ≥ Iε>0,92
C	1,09 ≤ ICE < 1,35	0,92 ≥ Iε>0,74
D	1,35 ≤ ICE < 1,79	0,74 ≥ Iε> 0,56
E	1,79 ≤ ICE < 2,63	0,56 ≥ Iε> 0,38
F	2,63 ≤ ICE < 5,00	0,38 ≥ Iε> 0,20
G	ICE ≥ 5,00	Iε ≤ 0,20

Source: Supplementary Technical Instruction [ITC-EA-01]

The energy calculations of the installation were performed through the application of formulas (1), (2) and (3); the results are indicated in Table VIII.

Table VIII. Results of the energy rating

Type of Lighting	Energy Rating							Total
	A	B	C	D	E	F	G	
M1	9							9
M2	38							38
M3	54	3	2		1			60
M4	56	16	5	1				78
M5	9	2	1					12
Total	**166**	**21**	**8**	**1**	**1**			**197**

6. Conclusions

81% of roads have excessive lighting levels; 13% have deficient levels and only 6% of the roads fully comply with the provisions of the regulation, which has turned Cuenca into an over-illuminated city, according to the study carried out.

The lighting system has an energy rating type "A" on 84% of the roads, however, several roads do not comply with the levels of lighting and uniformity as defined in the Spanish Regulation. There are no roads rated F and G.

To achieve reference levels (standard), it will be necessary to use double power level luminaires for reducing the installed power, measures that will allow a saving of energy in the city of Cuenca of almost 500 MWh/year would mean USD 50,000/year.

At the end of 2014, Ecuador public lighting had 1,249,674 luminaires with a total installed power of 198 MW and a consumption of 1,008 GWh. The fact that public lighting in the country has pass trough similar process of that described for Cuenca, it is consistent to consider the results here exposed can be extrapolate to all Ecuador. If such´s the case, mandatory regulations once in full application would lead to energy saving of about 23,000 MWh/year and USD. 2,300,000, which demonstrates the convenience of having an energy efficiency regulation like the Spanish one.

Perform illuminance measurements over time to develop a permanent up-to-date database, in such a way as to assess and control the degree of lighting installations depreciation.

The results of the energy rating of the surveyed roads, allows us to know the status of various facilities, to learn about roads that have a lower degree of compliance with the regulations and to establish preventive maintenance programs for them.

Acknowledgments

The work was carried out thanks to the support of the concessionaire of the public lighting service in the city of Cuenca, the Regional Electrical Company Centro Sur CA (CENTROSUR), materialized with the allocation of personnel, vehicles and necessary equipment.

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