A Urban Lighting Renovation Project to Optimize Environmental Performance and Reduce Energy Consumption: Results of a Measurement Campaign

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***Abstract*— In the last few years, the need to reduce costs and to limit energy consumption, together with the availability of financial and carbon reduction incentives led many public authorities to undertake the renovation of public lighting installations. In the North of Italy, a major program of public lighting renovation is being implemented in Torino since 2015. To verify the effectiveness of the interventions, the performance of the new LED lighting systems compared to the previous installations were assessed through measurement campaigns and computer simulations. The paper presents the main features of the project, the methodology adopted for the performance evaluation campaign and the results obtained in terms of both lighting performance (measured luminances and illuminances over representative areas) and energy performance (calculated Power Density and Annual Energy Consumption Indicators as defined in the EN 13201-5:2015).**

***Index Terms*-- urban lighting, energy efficiency, measurement campaign, energy performance indicators.**

INTRODUCTION

Public lighting is a fundamental service for the security of citizens and for the enhancement of urban spaces; however, it also represents one of the most important item of expenditure in the budget of municipal administrations. The operating costs, for energy consumption and luminaires maintenance, can be greatly reduced, for both new and existing installations, through the adoption of new green technologies, which allow the increase of systems energy efficiency and of light sources lifetime. The need of reducing costs, combined with the urge of limiting energy consumption to decrease the emission of CO_2 in the environment, led many public authorities to undertake the renovation of urban lighting plants, in particular by replacing old lighting technologies with new LED luminaires and/or by introducing lighting control systems.

The Italian situation on public lighting has been recently outlined in a national project named “Progetto Lumiere” launched by the Italian research institute ENEA [1]. The scope was to promote the energy efficiency in the field of public lighting and to create a network linking Municipalities, research centers and other stakeholders to share knowledge and facilitate the technology transfer. The studies carried out in the project showed that the lighting sector in Italy (public, industrial and residential), is responsible for a total energy consumption of approximately 50,8 TWh/year, of which 6,1 TWh/year, corresponding to 12%, are used for public lighting. There are about 11 million of light points with a total installed power of 1.595 MW. Furthermore, considering a sample of 809 Municipalities, representing the 10% of Italian municipalities with a population of between 5.000 and 50.000 inhabitants, it was found that there are three types of lamps mainly used in existing plants: high pressure sodium (50% of total installed power) mercury (42%) and metal halide (6% of the total). The average power of the light points is 145 W and it is possible to estimate that the number of light points with luminous efficiency below 70 lm/W is about 2 million [2].

Furthermore, the lighting plants of the 86% of the Municipalities involved in the project are controlled with a traditional switch ON/OFF system (twilight switch - 55%, clock - 28%, astronomical clock - 13%).

In general, these data demonstrate the high potential that interventions of public lighting renovations have in reducing energy consumption: in Italy, on average, savings of about 30%-40% could be easily achieved [1].

THE TORINO A LED PROJECT

A major program of public lighting plants renovation is being implemented in Torino, in the North of Italy. The project, named TORINO A LED, started in 2015 and entails the replacement of 55.000 luminaires: from high pressure sodium or metal halide technologies to LED luminaires. The project involves different types of areas, mainly traffic roads, but also pedestrian streets, squares and parks. The main objective is energy saving, which has been estimated of 20.000.000 kWh/year, that correspond to 3,5 ton/year of CO_2 not released in the environment. Additional energy savings are expected, thanks to the adoption of a control system designed to dim the light in two steps: from 12:00 a.m. to 01:00 a.m. the power is reduced by 20% and, from 01:00 a.m. to 06:00 a.m. the power is reduced by 30%. Besides energy saving and CO_2 reduction, the project aims to guarantee the lighting performances required for safety and visual comfort (as specified by technical standards), to increase the light flux utilisation factor, to avoid obtrusive light and reduce light pollution.

The luminaires replacement is based on the results of a project carried out by IREN Energia. The project was founded on the indications given by two local directives: the Urban Traffic Plan (PUT) and the Municipal Lighting Regulation Plan (PRIC), which respectively provided the classification of the roads and pedestrian areas and the corresponding general lighting criteria. Afterward, each type of area was associated with a lighting category, as required in the standard UNI 11248 [3], and the lighting requirements specified in accordance to the standard EN13201-2 [4]. The dimensioning of the lighting plants was the result of lighting simulations carried out for each type of area or road included in the project. Luminaire characteristics were defined in order to respect, being close as much as possible, the overall lighting requirements (maintained average luminance/illuminance, uniformity, glare control, etc.).

To verify the effectiveness of the renovation project, a measurement campaign to evaluate on field the lighting performance and energy consumption of the new LED lighting systems (ex-post systems) compared to the previous traditional lighting plants (ex-ante systems) was included as part of the project and carried out by the Politecnico di Torino, which operated as a consultant of the IREN Energia lighting group.

The measurement campaign was carried out on a set of urban streets/areas and lighting systems, which were considered representative of the overall stock of lighting plants and urban contexts in Torino.

THE METHOD TO ASSESS THE LIGHTING AND ENERGY PERFORMANCE

Different approaches were adopted to assess the lighting performance and the energy performance of the selected streets sample: a measurement campaign was carried out to verify, in field, the lighting conditions obtained with the ex-ante lighting installations and, later on, with the ex-post LED lighting systems. Besides, the energy performance was calculated from the results obtained through the lighting simulations. In the following sections, the procedure used for the two type of analysis is described in details.

A. Lighting assessment

For each analysed street, the lighting performance of ex-ante and ex-post lighting plants was assessed by means of in-situ photometric measurements. The measurement campaign was based on luminance and illuminance data acquisition, in accordance to what required in the standard EN 13201-3 [5] and EN 13201-4 [6].

Luminance measurements of the road surface were carried out for motorized traffic reads, whilst horizontal and semi-cylindrical illuminance was measured for pedestrian areas and cycleways.

A videophotometer TechnoTeam “LMK Mobile” (based on Canon EOS digital camera) was used to assess the luminance distribution of the framed carriageway as luminance image. The luminance image was acquired considering the observer position in each traffic lane at 60 m from the relevant measuring area of the carriageway.

A method to analyse the luminance images was adopted based on three steps as shown in Fig. 1: step 1) luminance image acquisition of the relevant area of the carriageway (Fig. 1.a); step 2) rectification of the luminance image and definition of the measuring grid (Fig. 1.b); step 3) luminance data analysis (average value, overall and longitudinal uniformity) (Fig. 1.c).

For pedestrian areas and cycleways, horizontal illuminance was measured by means of a Minolta T-1 luxmeter considering grid points at ground level, whilst semi-cylindrical illuminance was measured with a PRC 106 luxmeter equipped with a specific photometric head used at 1.5 m of height to assess facial recognition.

General information on geometrical data, road surface characteristics, environmental conditions, condition of the installation, etc. were also recorded during the measurement campaign as relevant information for the data analysis.

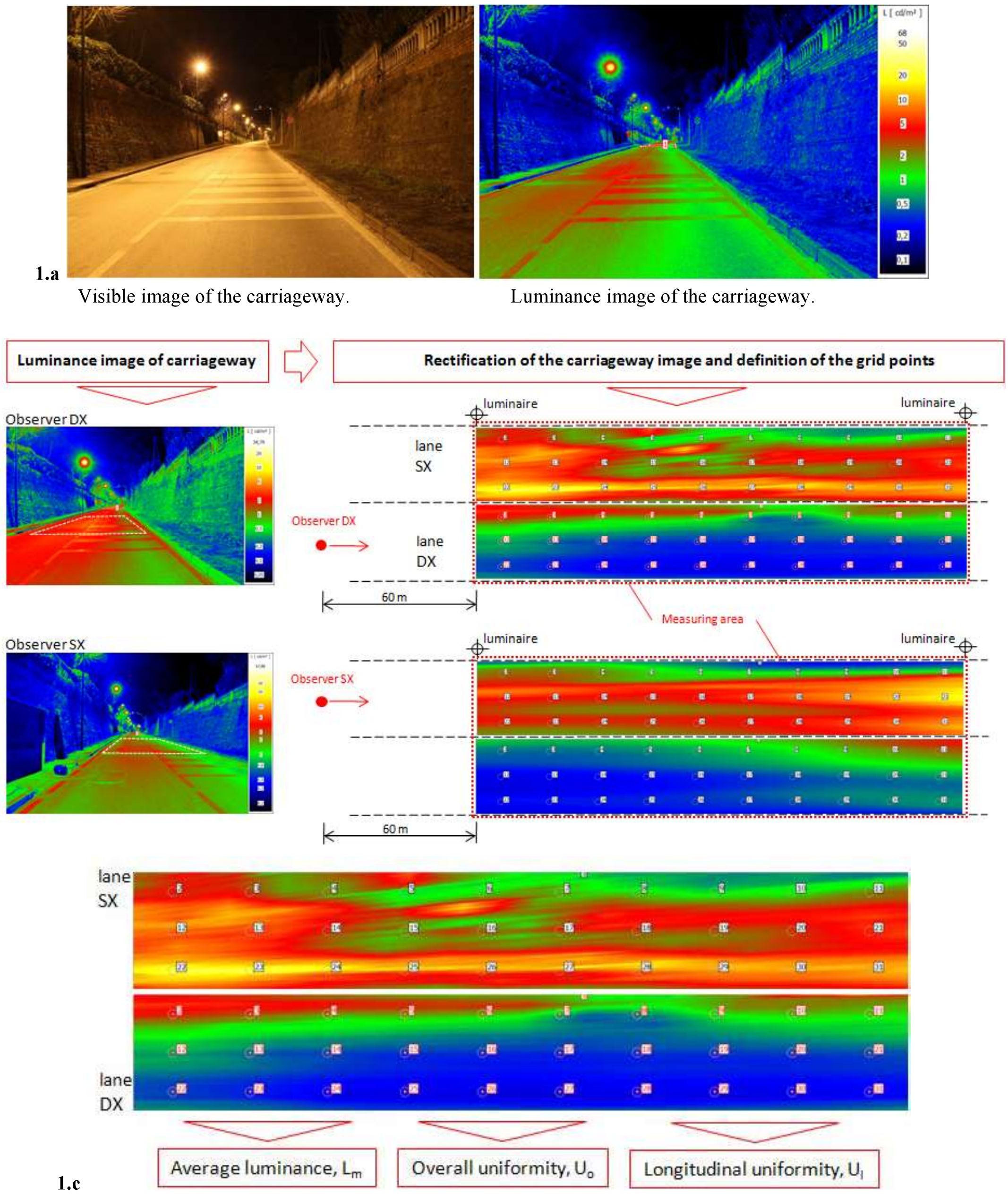

Figure 1. - Example of luminance image analysis for a two lane road with single side luminaire arrangement.

B.Energy assessment

Several factors affect the energy performance and therefore the energy consumption of a lighting system. A major role is played by features of the system components such as the lamps luminous efficiency, the optical efficiency of the luminaires and the ballasts energy losses. The efficacy in exploiting the emitted light flux is another important factor that generally depends on the lighting design choices and finally, the type and features of the lighting control system, designed to manage the on/off switching and/or to dim the light flux, is a further element that affects the public lighting annual energy consumption.

In general, the energy performance of a lighting system can be assessed through parameters that evaluate the energy efficiency of the system or its energy consumption. For public lighting systems, several approaches have been proposed up to now [7] and, finally, two numerical indicators for the assessment of the energy performance have been defined and presented in the standard EN13201-5 [8].

The two numerical indicators are the Power Density Indicator (D_P) and the Annual Energy Consumption Indicator (D_E) and can be calculated with the following formulae:

$$D_P = \frac{P}{\sum_{i=1}^{n} E_{med,i} \cdot A_i} \quad (1)$$

where D_P – power density indicator (W/lx/m^2); P – system power of the lighting installation used to light the relevant areas (W); $E_{med,i}$ – calculated maintained average horizontal illuminance of the sub-areas (lx); A_i – size of the sub-areas lit by the lighting installation (m^2); n – number of sub-areas to be lit.

$$D_E = \frac{\sum_{j=1}^{m}(P_j \cdot t_j)}{A} \tag{2}$$

where D_E – annual energy consumption indicator for a road lighting installation (kWh/m^2); P_j – operational power associated with the jth period of operation (W); t_j – duration of jth period of operation profile over a year (h); A – size of the lit area lit (m^2); m – number of periods with different operational power P_j

Within this study, the two energy performance indicators were calculated for each analyzed street/area and for both the ex-ante and ex-post installations. The aim was to assess the increase of the energy efficiency and the achievable energy savings. The indicators were calculated considering a part of the lighting installation corresponding to the area used for the lighting design and defined in the standard EN 13201-3 and both the ex-ante and ex-post lighting plants of EN 13201-4.

RESULTS

The results presented in this paper are referred to a sample of 11 reference roads and areas: 9 of them with motorized traffic, and 2 pedestrian areas. This is a subset of the overall sample, as the measurement campaign is still in progress.

A. Lighting performance

The data of the measurement campaign are referred to different sates of the luminaires maintenance: the ex-ante installation were close to the end of their life while the ex-post installation were at the beginning of their life. To allow a comparison of the lighting performance of both types of plants the data measured for the new LED installations were multiplied by the maintenance factor adopted in the dimensioning phase (MF = 0,8).

In Fig. 2 the lighting performance of the ex-ante and ex-post installations are compared. The red lines in the graphs correspond to the performance required according to the standards.

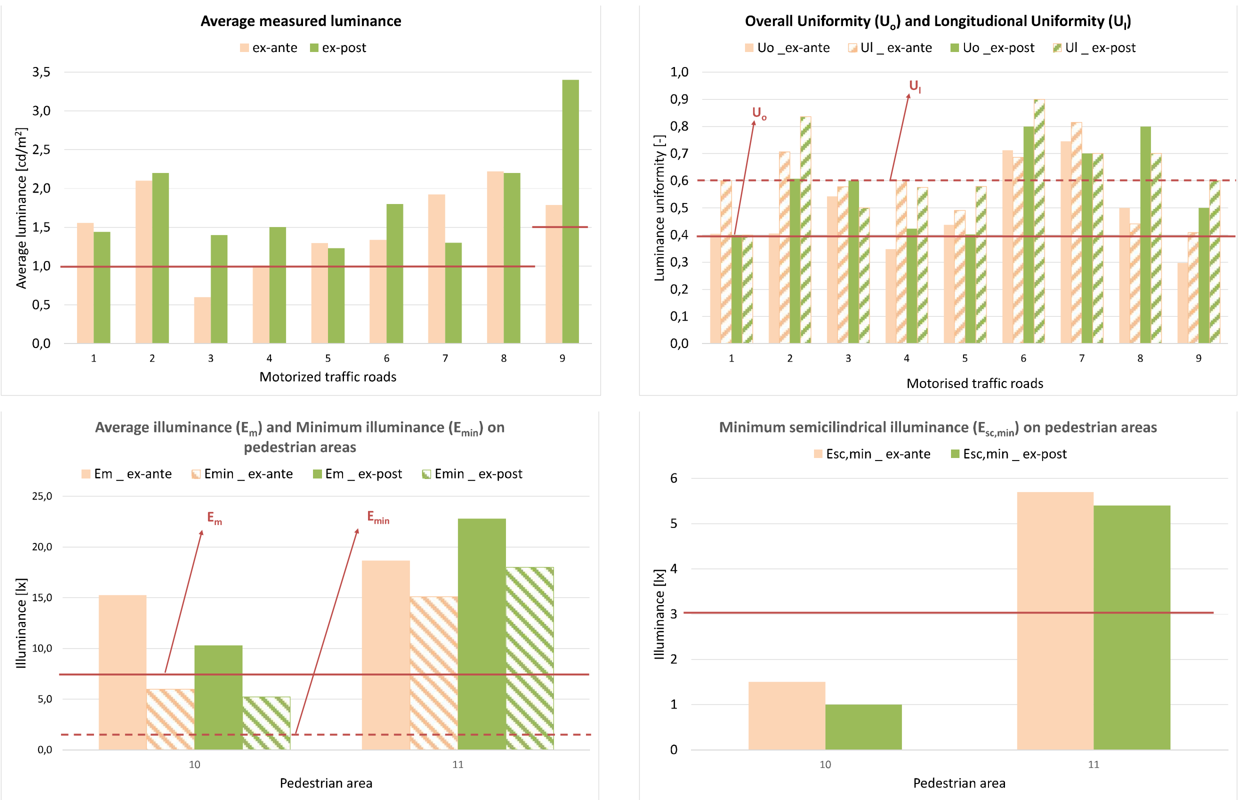

Figure 2. – Lighting performance of the ex-ante and ex-post installations for the motorized traffic roads and the pedestrian areas.

The results of the measuring campaign showed that, for both the ex-ante and ex-post lighting plants of all the selected roads and areas, the minimum required lighting performance is generally achieved. Only the longitudinal uniformity (U_l) and the minimum semi-cylindrical illuminance are, in a few cases, below the required value. The data also demonstrate that, in field, the lighting quantity provided by some installations is significantly greater than the required and simulated value. In the subset of data presented in this paper, the 44% of roads exceeded the required lighting level of the next higher lighting class and the same occurs for 50% of the pedestrian areas. On the other hand, 4 out of 9 motorized roads showed a decrease of the lighting quantity with the transition to LED plants.

B. Energy performance

The results obtained from the calculation of the energy performance indicators are presented in Fig. 3. The D_P of some ex-ante installations were not calculated because the photometric data of the luminaires were not available.

In general the results demonstrate the significant increase of the energy efficiency of the ex-post lighting systems: the average value of the Power Density Indicator (D_P) is 57,2 mW/lx·m^2 for the ex-ante installations and 23,7 mW/lx·m^2 for the LED plants, with a percentage reduction of 42%. The increase in the energy performance is even greater if the Annual Energy Consumption Indicator is considered (D_E): in this case the average values for the ex-ante and ex-post analysed installations are respectively 4,86 kWh/m^2 and 1,58 kWh/m^2, with an average percentage reduction of 64%.

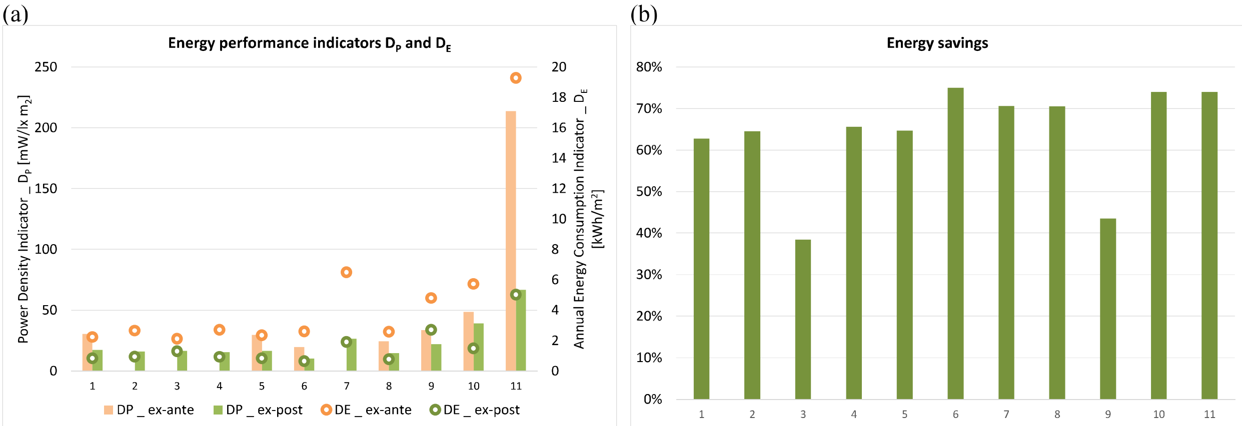

Figure 3. Energy performance indicators for the ex-ante and ex-post installations (a) and energy savings (b)

CONCLUSIONS

The renovation of public lighting systems is among the measures municipal administrations more frequently adopt to reduce their expenditure budget and increase the city's environmental sustainability by reducing CO_2 emissions in the atmosphere. Nevertheless, the renovation of existing installations implies the luminaires substitution on existing poles and bearings and it therefore requires a careful design to ensure that appropriate lighting conditions are achieved in addition to energy savings.

Within this study a specific case study, the TORINO A LED project, was analysed. The study involved the assessment of the lighting and the energy performance of a sample of installations, which were selected to be representative of the overall lighting system typologies in Torino. The analysis was carried out by measuring the lighting performance in field and calculating the energy performance. The results demonstrated that the substitution of traditional high pressure sodium or metal halide lamps with LED luminaires and the implementation of a stepped dimming control system allowed to obtain substantial energy savings (64% on average for the subset of the installations sample considered in this paper). Furthermore, the careful design of the retrofit interventions also ensured the respect of the lighting requirements.

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