PERFORMANCE ASSESSMENT AND ENERGY SAVING MEASURES FOR OUTDOOR LIGHTING IN AN INDUSTRIAL DISTRICT APPLICATION

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ABSTRACT

This paper presents a methodology to assess the performance of an outdoor lighting system in an industrial district through an on-site audit and the subsequent definition of specific Performances Indices. The methodology aims to focus on outdoor area illumination in order to assess the current status of the lighting system and subsequently propose how to optimize the energy efficiency, costs as well as reduce greenhouse gas emissions (GHG).

The results relating to 11 outdoor areas of industrial districts were analysed and presented, focusing on the exterior lighting and comparing their performances. In this perspective, the external lighting system of an industrial district can be regarded as a potential "demonstrator" upon which a numerical/experimental methodology will be developed so as to evaluate the performance of a lighting system from the point of view of its energetic and environmental impact. Finally, appropriate energy efficiency measures are proposed.

Keywords: energy saving, LED, industrial district, exterior lighting

INTRODUCTION

Energy savings can be regarded as "the first renewable source and the fastest, most effective and cost-efficient way to reduce greenhouse gas emissions" [1]. In Europe, it has been recognized that at least 20% of wasted energy is due to the low/poor efficiency of appliances and equipment, with the target of reducing these losses within 2020 having been set [2]. Among the indicators widely reported in current literature, it is worth noting how two-thirds of light sources installed in the European Union are based on a now-obsolete technology (developed prior to 1970) characterized by a low efficiency. Reduction of energy consumption of outdoor area lighting also contributes to the reduction of harmful emissions into the atmosphere as envisaged by the Kyoto Protocol [3].An action plan to improve the energy efficiency of outdoor area lighting characterized by vehicular traffic and internal circulation for goods and services delivery has to involve both technical and economic considerations and has to be compliant with standard and rules to ensure road safety; moreover it requires the optimization and reduction of maintenance and operating costs as well as the control of "dispersed" luminous flux to reduce the light pollution [4,5].

A methodology for the assessment and retrofitting of an outdoor lighting system in an industrial district is presented in this paper. First, the basic survey carried out to describe the present status of outdoor lighting and its main photometric performance by a measurement of both illuminances and luminance levels on road surface is discussed. Then, the procedure for the suitable assessment in terms of lighting performance and energy consumption (also considering present rules and standards) is reported, with the adoption of some key indicators finally leading to retrofitting proposals for the enhancement of energy efficiency, along with a reduction in cost and greenhouse gases emissions.

METHOD

The need to develop a "methodology" and then set up a suitable operating tool can be recognized from the finding that, at a regulatory level, there are no guidelines for analyzing the lighting system performances of the outdoor areas in industrial districts as well as for verifying the efficiency level. On the contrary, within the context of the public lighting of towns and cities, tools and methods for developing suitable guidelines have been already released [6-11] with the aim of identifying and defining key parameters and criteria to be followed for the design and installation of an efficient outdoor lighting system. Thus, the illumination of the outdoor areas of an industrial district can be considered a potential "demonstrator" upon which to develop a numerical/experimental methodology to evaluate the performance of a lighting system from the point of view of energy consumption as well as identify appropriate energy efficiency measures. The proposed procedure is based on two steps [11]:

1) **Audit**: collection and archiving of all data regarding the technical, economic, energetic characteristics as well as all the required measures to evaluate the status and photometric performance of the outdoor lighting system;
2) **Definition of Performance Indices**: definition of the energy, economic and environmental performance assessment of the lighting system using suitable parameters that might be related to statistical data and benchmark values available in current technical literature.

In the assessment of an external lighting installation, the first requirement is to provide for a detailed identification (mapping) of the power panels and luminaires as well as any general information about the site and measurement conditions, road surface characteristics, driving and visual conditions. In this paper, 11 outdoor areas of industrial districts were analysed; their lighting systems differ for the type and the nominal power of the light sources as well as the type and the arrangement of fixtures. The basic on-site measurements taken during this phase are reported in Figure 1. For each road of the 11 industrial areas, pictures of the night-time situation (1a) have been collected as well as measurements on the road surfaces (1b and 1c). Horizontal illuminance values were acquired by a Chroma Meter CL-200 (Konica Minolta with a measuring range from 0.1 lx to 100 klx and accuracy of ±2%), while the luminance values were acquired with a luminance meter Konica Minolta LS110 (acceptance angle of 1/3° and accuracy of ±2%).

The second phase of the methodology consisted of an operating procedure to define appropriate technical indices, from energetic (electrical power supplied and annual electrical energy required), economic (annual operating costs) and environmental (annual equivalent CO_2 tons emitted) points of view as well as identify critical bottlenecks of outdoor lighting systems and thus support measures for energy efficiency. The indices can also be used for the evaluation/comparison of performances between different zones of the outdoor lighting system of an industrial park or different park settlements. The indices used for a general performances description of a lighting system must cover several fields and should be presented as a "dimensionless" value when referring to both the number of fixtures (nf) as well as to the unit of road length (km). The Performance Indices considered in this study are described and listed in Table 1. The CO_2 emission was evaluate from the electric energy consumption using a conversion factor equal to 0.523 $kgCO_2/kWh$ [12], while the operating costs were evaluated considering an unit cost of electricity equal to 0.23 €/kWh. The Performance Indices allow to identify the zones with low efficiency, with it being beneficial to suggest some renewal or retrofit operations that could be applied in order to improve the performance of the outdoor lighting system. On the basis of the road parameters and lighting situations found during the survey, all the roads were considered as secondary roads (C classification) with a speed limit of 50 km/h, therefore matching the reference lighting class ME4b.

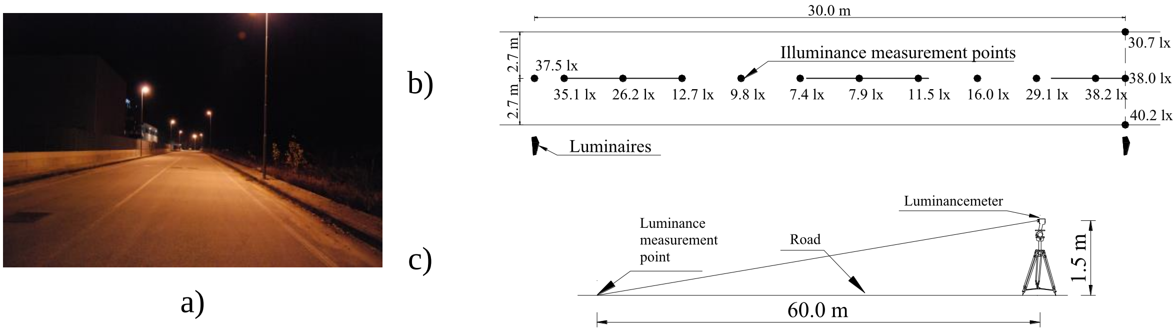

Figure 1: Assessments carried out during the audit, (a) picture of the road during the night, (b) illuminance measurement points and (c) arrangement for road luminance measurements.

Performance Indices proposed	**Description**	**Units**		
Economic impact	Total annual operating cost for electric energy per total road length/number of fixtures	k€/km	€/nf	
Power/Energy supplied	Total electric power or energy supplied per total road length/number of fixtures	kW/km	MWh/km	MWh/nf
Number and distribution of fixture	Total number of fixtures per total road length	nf/km		
Environmental impact	Total annual CO_2 emissions per total road length/number of fixtures	tCO_2/nf	tCO_2/km	

Table 1: Proposed indices.

Taking into account the information obtained during the audit and the limits defined by the current standard [13-16] and the Italian law [17], two different energy efficiency interventions were considered:

- **Scenario #1: optimization with respect to the reference lighting class**. When the measurement and simulation confirm the respect of the lighting requirements, the efficiency of the lighting system can be improved by considering different lighting classes (related to the real traffic flow) during the hours of darkness taking into account that it is possible to reduce the energy consumption by dimming the emitted luminous flux. Traffic flow, related lighting class and luminous flux dimming strategy considered for the different operating period are reported in Figure 2;
- **Scenario #2: optimization in terms of Best Available Technology (BAT)**. This strategy is based on the use of the best available technology in terms of energy savings, thus adopting high efficiency light sources integrated with photovoltaic modules (PV), while respecting the requirements of identified lighting class.

RESULTS AND DISCUSSION

In Figure 3, the values of the Performance Indices referring to the unit of road length (km) calculated for the Industrial Districts under investigation are reported. The figure shows that:

- the average values on the 11 industrial areas of power and energy supplied indices are 9.72 kW/km and about 38.2 MWh/km; the maximum values were observed for settlement #8 (21.9 kW/km and 86.3 MWh/km), while the minimum values for settlement #7 (4.43 kW/km and 17.1 MWh/km);
- the average value on the 11 industrial areas of number and distribution of the fixture index is 37.9 nf/km (ie. a fixture every 26.3 meters); the maximum value was observed for settlement #8 (75.6 nf/km), while the minimum value for settlement #7 (25.2 nf/km);
- the average value on the 11 industrial areas of the economic index is 8.8 k€/km; the maximum value was observed for settlement #8 (19.8 k€/km), while the minimum value for settlement #7 (3.93 k€/km);
- the average value on the 11 industrial areas of the environmental impact index is about 20.0 tCO_2/km; the maximum value was observed for settlement #8 (45.1 tCO_2/km), while the minimum value for settlement #7 (8.94 tCO_2/km).

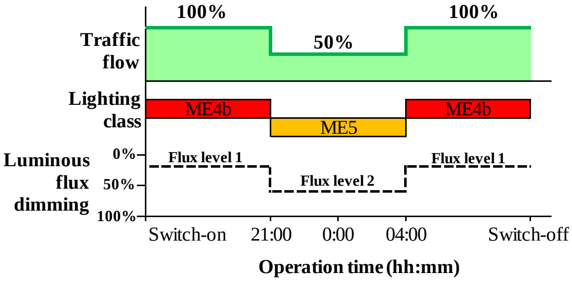

Figure 2: Traffic flow, lighting class considered and flux dimming.

Figure 4 shows the values of the Performance Indices referring to the number of fixtures (nf) for the Districts investigated. Figure 4 highlights an average value of 1.0 MWh/nf for the energy supplied index, 0.23 k€/nf for the economic index and 0.52 tCO_2/nf for the environmental impact index.

Figure 5 shows the results, in terms of both the energy saved and the CO_2 emission avoided, considering the two efficiency actions applied. On the basis of the on-site measurement performed during the audit, the lighting requirements were respected only by the lighting system of the Industrial Districts #1 and #3 therefore, Scenario #1 was analysed only for these two districts. For district #1, the flux was dimmed to 89 % for level 1 and 67 % for level 2, whereas for district #2, the flux was dimmed to 51 % for level 2 only. Scenario #2 allows for a complete self-sufficiency, eliminating the electric energy purchased from the grid and then the related environmental impact considering that the use of a lighting system with integrated PV modules covers all the energy requirements. As reported in Figure 5, the luminous flux control would enable energy savings and a CO_2 emissions reduction of about 25%. The solution, even if relevant for energy saving and environment protection, is, however, expensive in terms of installation costs. This is due to the high price of every single new pole as well as the fact that the luminous flux emitted by the fixture integrated with a photovoltaic module [18] was lower than the existing one and that the number of new poles required was greater than the existing one, which is on the average of about 3.4 times.

CONCLUSIONS

This paper describes a methodology for the analysis and subsequent proposal for renewal operations of an outdoor lighting system within an industrial district. In order to evaluate the effectiveness of the proposed methodology, it was applied to 11 industrial districts. Finally, the benefit achievable through two energy efficiency scenarios were evaluated for each industrial district, in terms of energy saving and CO_2 emission reduction. The methodology started with a detailed audit based on an in-situ survey and measurement and proceeded with the calculation of some Indices required for assessing the economic, environmental and energy system performances. The audit phase showed that the lighting requirements were respected only by the lighting system of the Industrial Districts #1 and #3. For these districts, the application of Scenario #1 allowed to achieve significant energy savings on the average of 25%. The solution proposed in Scenario #2, if on one hand allowed for complete self-sufficiency, eliminating energy consumption and environmental impacts related to the use of lighting system, on the other presented very high installation costs.

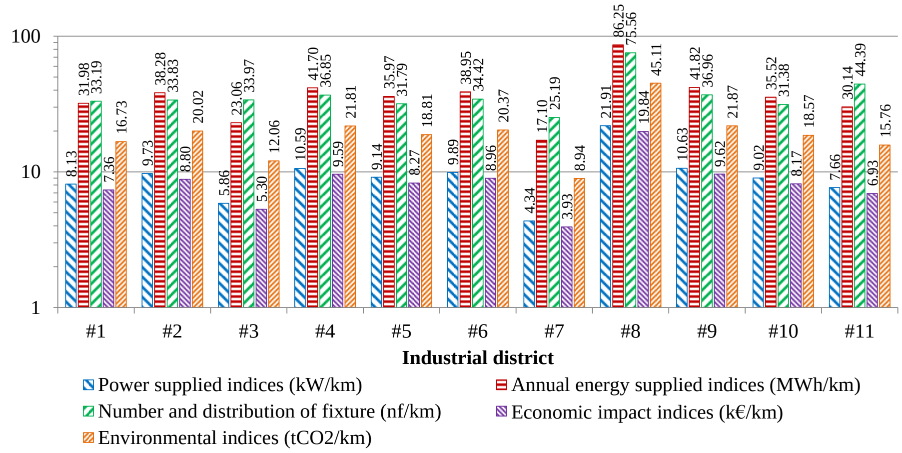

Figure 3: Performance indices referring to the unit of road length (km).

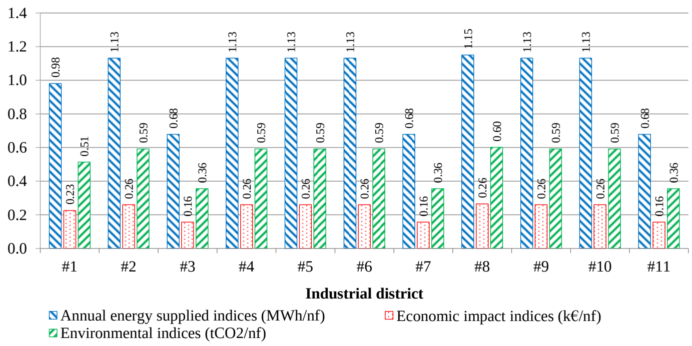

Figure 4: Performance indices referring to the number of fixtures (nf).

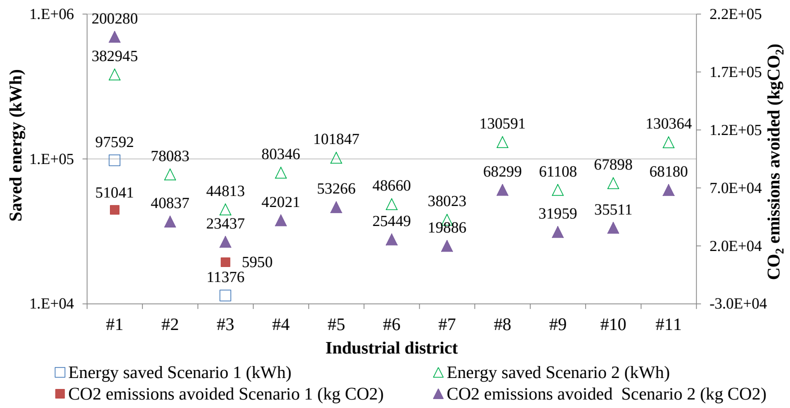

Figure 5: Yearly energy savings and CO_2 emissions avoided for the two different scenarios and different districts.

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