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The daylighting contribution in the electric lighting energy uses: EN standard and alternative method comparison

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Abstract

The standard *EN 15193:2007. Energy performance of Buildings. Energy requirements for lighting* includes a comprehensive method, which takes into account the daylighting contribution in the calculation procedure. Such contribution is obtained through several approximations. An alternative approach is developed, where the daylighting contribution is based on the availability of outdoor illuminance data and an explicit procedure. The methods are tested on a standard office building, whose lighting requirements are calculated for different visual tasks, observation positions and climatic zones. The results show discrepancies among the methods and address the need of a more accurate estimation of the lighting energy service.

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Keywords: Electric lighting in buildings, daylighting contribution, illuminance data

1. Introduction

EU and national energy efficiency strategies recognize the building sector as the most important to reach the respective targets [1, 2, 3]. It is also recognized that the energy performances of building should be addressed to the whole energy services, and not only the space heating as happened in the past decades [4]. Several surveys were carried out in the past years to assess the energy consumption for electric lighting in building application. The figures are relevant for in general but in particular for the not residential buildings: 14% of the total consumption in EU, 26% in US [5,6]. A study carried out recently in Spain set in 31% the share of the electricity consumption for

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lighting in commercial buildings [7]. It is, hence, not surprising that the artificial lighting is seen as one of the most cost-effective energy measures in buildings [8]. A relevant potential hence exist to improve the performance of existing building and optimize that of new construction.

If the issue of the electric lighting is topical in many countries, as reviewed in [9], it has to be noted that is still addressed in terms of limiting the installed power more than in terms of energy performances. In most cases the potentialities of the efficient lighting is seen in terms of reducing the installed power, more than observing the time evolution of this power use. The reference European standard *EN 15193:2007. Energy performance of Buildings. Energy requirements for lighting* provides an operational method and two calculation methods, different in accuracy and complexity [10]. However, the reliability of the prediction methods has to be carefully addressed to fully exploit the potentialities of the electric lighting as effective energy saving measure, since the over/underestimation of the consumption respect to the practice is an obstacle to the technology spread, especially in the nearly zero energy building (nZEB) vision to be adopted in the next years.

This paper addresses the way daylighting contribution is incorporated into the above cited standard and the first analyses, carried out using an alternative method based on additional input data. The study is focused on the energy aspects related to electric and natural lighting in buildings; visual comfort issues are not taken into account.

2. Objective and methods

The standard [10] introduces the LENI as indicator for annual electric energy required to assure the lighting service in buildings and to be determined as follow:

$$\mathrm{LENI} = \mathrm{W}/\mathrm{A}\ [\mathrm{kW}h/\mathrm{m}^2\mathrm{year}] \tag{1}$$

Where: W is the total annual energy used for lighting [kWh/year] and A is the total useful floor area of the building [m^2]. The standard defines several approaches for calculating/assessing the energy use for lighting: a metering method, which is not taken into account in this study; a quick calculation method and a comprehensive calculation method. Reference values are also provided for different building typologies; they are summarised in Table F.1 of the [10].

The two calculation methods are based on the calculation of the energy consumption for the lighting service and the energy uses due to the parasitic energy uses. Being the latter out of the scope of this study, the general equation to determine the energy uses is:

$$\mathrm{W_L} = \sum\{(\mathrm{P_n} \cdot \mathrm{F_c}) \cdot [(\mathrm{t_D} \cdot \mathrm{F_O} \cdot \mathrm{F_D}) + (\mathrm{t_N} \cdot \mathrm{F_O})]\}/1000\ [\mathrm{kW}h/\mathrm{year}] \tag{2}$$

Where:

P_n	[W]	Installed power in the zone;
F_c	[-]	constant illuminance factor;
t_D	[h]	daylight time usage;
F_O	[-]	occupancy dependency factor;
F_D	[-]	daylight dependency factor;
t_N	[h]	non-daylight time usage.

The simplified method is based on the previous equation, using standard pre-calculated values for t_D, t_N, F_D and F_O, provided by [10]; specific data can be used if available. All the parameters of equation (2) are to be calculated when the comprehensive method is applied; however some approximations and limitations apply, e.g. only fixed illuminance values (300 lux, 500 lux, 750 lux) can be assigned as visual tasks.

The study here presented focuses on the daylighting contribution to the determination of the energy uses for lighting in non residential buildings, with a specific application for office building. The standard [10] takes into account the daylighting contribution thanks to the daylight dependency factor F_D in equation (2). Previous analyses however demonstrated that the approach may lead to relevant discrepancies respect to other approached. [11].

The annual lighting energy consumption W_L is determined in two different ways:

1. According the procedure defined in [10];
2. Using an alternative method based on climatic data and on specific conditions for the indoor lighting conditions, with new daylight/non-daylight time usage (t_{sat}) and the same values for P_n, F_C, F_O used for previous method.

The two methods are tested on a reference office building. The results are analysed and discussed.

2.1. The daylighting contribution according to EN 15193:2007

The daylighting contribution is estimated through the F_D parameter, which is in turn function of several additional parameters and whose calculation structure is schematised in Figure 1.

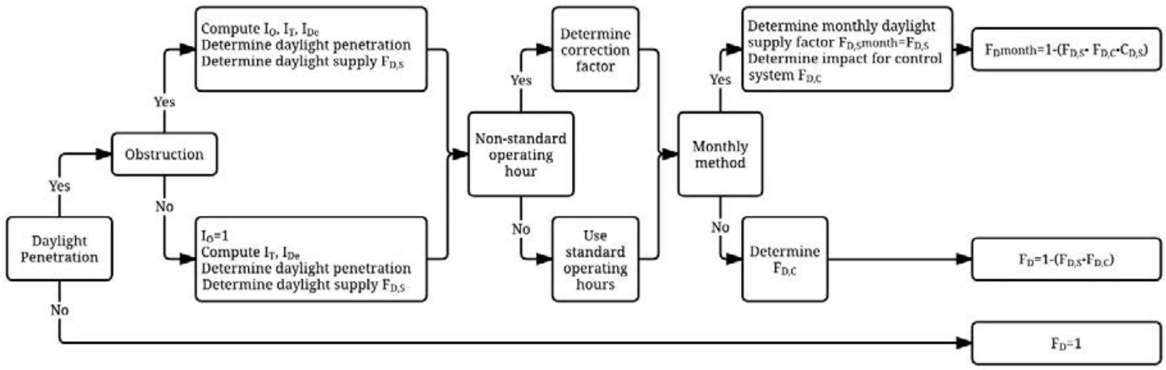

Fig. 1. Determination of the daylighting contribution according to the EN standard.

The parameters which enter into the calculations of F_D are:

- The presence of external obstructions and the self-shading of the window/building components;
- The daylight penetration, function of the height of the windows and the height of the working plane;
- The window and working plane area;
- Characteristics of the glazing unit (transparency, frame factor, dirt, radiation incidence angle).

Being available the above data, the standard provide a calculation procedure to determine F_D. The working periods can be defined by the user or taken by the standard periods. However the method includes some correction coefficients, whose origin is not made explicit in the calculation flux.

2.2. The daylighting contribution according to the alternative method

The implementation of the alternative method starts from the consideration of the natural light contribution in buildings at the southern Europe latitudes and from the anomaly of predicting an Energy service uses getting rid of the climatic conditions. The procedure is based on the following steps for each building zone:

1. Determination of the daylight factor (D). It can be calculated as an average of the working area or in specific observation points. This condition implies an *a priori* determination of the zone layout and the users position in the zone.
2. Determination of the maintained indoor horizontal illuminance on the working area, according to the required visual task.
3. The previous data are used to calculate the minimum external horizontal illuminance, which ensure the indoor illuminance levels for the visual task through daylighting.
4. Calculation of the number of daylight/non-daylight hours through climatic (illuminance) data set respect to the minimum illuminance value defined in the previous point.

Once the occupancy factor is known, the term $[(t_D \cdot F_O \cdot F_D) + (t_N \cdot F_O)]$ in the equation 2 is replaced by the figures calculated with the alternative method. Since the approach is based on the daylight factor, which is determined under the CIE overcast sky condition, the calculations are carried out considering the outdoor diffuse illuminance as input data. In a next research phase other configuration will be tested, as shading systems coupled to the glazing unit and horizontal global illuminances, in order to assess the luminous response of the building under irradiation conditions typical of the Mediterranean climate.

3. Calculation

The calculation exercise is carried out using an office building as reference case. The energy requirements for the electric lighting service are determined according to the two calculation methods defined in [10], as well as using the alternative method.

3.1. The reference building

The building is located in the northern outskirts of Rome (latitude 42°) in the Enea Casaccia Research Center and consists of two floors. It has typical linear development along the east-west axis, it is 48m long and 12m deep, see figure 2. North offices are 3.6m wide and 4m deep; in south offices the depth is 4.9m. Other analyzed zones are the toilet and the corridor. The same layout applies on the two floors. Each office has a window 3.5m wide and 1.4m high, with a clear double glazing unit. The net room height is 2.7m. Internal light reflectance is determined according to bibliography data, according to the furniture present in the office rooms. No obstruction limit the daylight availability.

North offices are equipped with two luminaries, each of them hosting two 36W fluorescent lamps; south offices have three luminaries of the same type. Other lighting power are: 396W in the corridor and 120W in the toilets. All the lighting sources are manually operated and not dimmable.

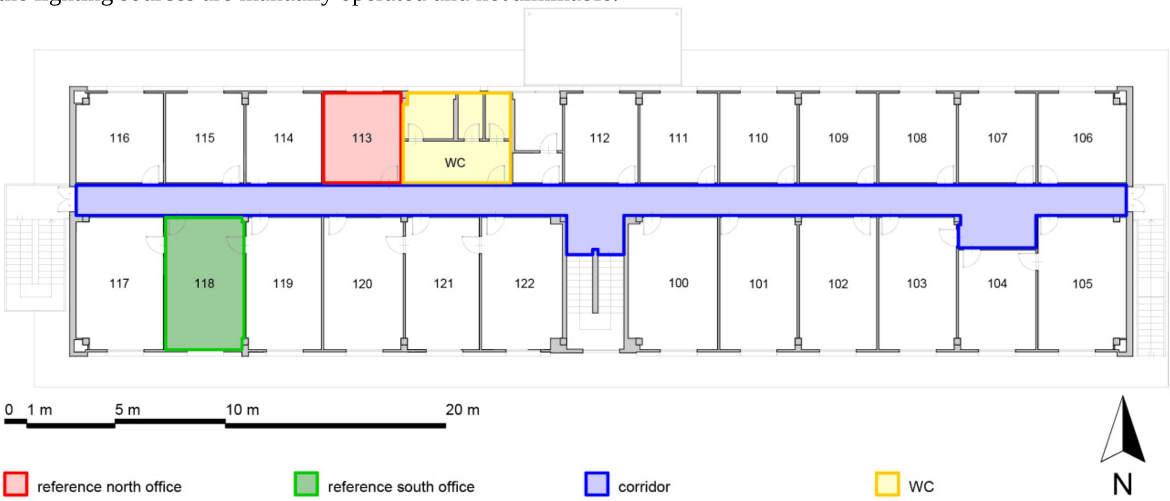

Fig. 2. Reference building first floor.

3.2. Operative and climatic conditions

An occupation profile from 8.00 to 17.00 for five days per week is considered. For the two calculation methods defined in [10], t_D and t_N have been determined according to sunrise and sunset time for Rome.

The visual task on the office horizontal working plan is 500 lux; corridor and toilet visual tasks are set respectively to 100 and 200 lux.

Calculations for the alternative method are based on the daylight factor, determined in different positions: 1, 2, 3 and 4 meters from the window in the middle of the room. Calculation are also carried out for the room average daylight factor.

The climatic data needed for the application of the alternative method are taken from the Satel-Light database [12]. The database provides horizontal, global and diffuse illuminance values. Monthly mean hourly diffuse horizontal illuminances are used as input to estimate daylight availability. The Rome illuminance data are in Table 1. As operative example of the method described in section 2.2, numbers in the red background correspond to the outdoor illuminance levels that do not ensure the visual task in the office zones, respect to the average daylight factor. The procedure is analogously applied for the daylight factor in specific points. The exercise was carried out also for Palermo (latitude 38°) and Milan (latitude 45°) to estimate the impact of the latitude on the lighting energy performances.

Table 1. Monthly mean hourly diffuse illuminance for Rome.

Hour	E_d [klux] Jan.	E_d [klux] Feb.	E_d [klux] Mar.	E_d [klux] Apr.	E_d [klux] May	E_d [klux] Jun.	E_d [klux] Jul.	E_d [klux] Aug.	E_d [klux] Sep.	E_d [klux] Oct.	E_d [klux] Nov.	E_d [klux] Dec.
8-9	5.9	8.8	13.2	13	16.1	16.9	15.4	14.5	11.3	8	8.7	6
9-10	10.6	13.1	17.8	18.8	21	20.9	19.1	19.5	16.2	13.9	12.9	10.2
10-11	13.7	16	20.7	22.8	24.3	22.7	21.9	22.6	20	18.6	15.7	13
11-12	15.3	17.4	22.2	25.7	26.7	24	22.8	25.1	23	21.4	17.5	14.9
12-13	15.3	18.2	23.9	27.7	28.8	25	23.1	26.9	24.7	23.1	18.2	14.9
13-14	14.7	17.6	23.6	28.5	27.6	24.9	23.9	27.1	24.7	22.6	16	13.5
14-15	12.5	16	21.2	27.7	26.2	25.3	22.8	26.2	24.8	21	12.7	10.9
15-16	8.9	12.7	17.6	24.9	23.4	24.2	22	24.2	22.7	17.9	8.1	6.8
16-17	3.7	8	12.5	20.2	20.6	22.1	20	21	18.5	12.6	2.4	1.5

4. Results

Table 2 reports the test building LENI calculated for the different methods taken into account in this study, the alternative method refers to the average daylight factor calculation. It is impressive the difference among the different standard method. Even without considering the F.1 table values, the application of the simplified method implies a LENI overestimation of about 40-50%. Even worse is the comparison between the most accurate approach of the EN standard and the proposed alternative approach, since the difference is close to a factor 3.

Table 2. Monthly mean hourly diffuse illuminance for Rome, 500 lux on working plane.

Manual On/Off Switch	LENI [kWh/m^{2}year]
EN15193 - Table F.1	42.1
EN15193 – Simplified method	25.7
EN 15193 – Comprehensive method with standard utilisation hours	18.7
EN 15193 – Comprehensive method with specific utilisation hours	16.3
Alternative method	5.5

A second task carried out in this study is the LENI comparison of the EN comprehensive method versus the alternative method, being the latter estimated in different observation points. The results are in figure 3 and refers also to the city of Palermo and Milan. It can be noted the overestimation of the standard (constant blue lines) until 2 meters from the windows; at 3 and 4 meters the D value dramatically drops and this implies a close to full time electric lighting switching on.

It is finally interesting noting that the EN results do not show significant differences in the 38-35°C latitude range: LENI varies in the 16.0-16.8 kWh/m^{2}year range, while the alternative method is more latitude dependent in those calculation points where the daylighting contribution is significant.

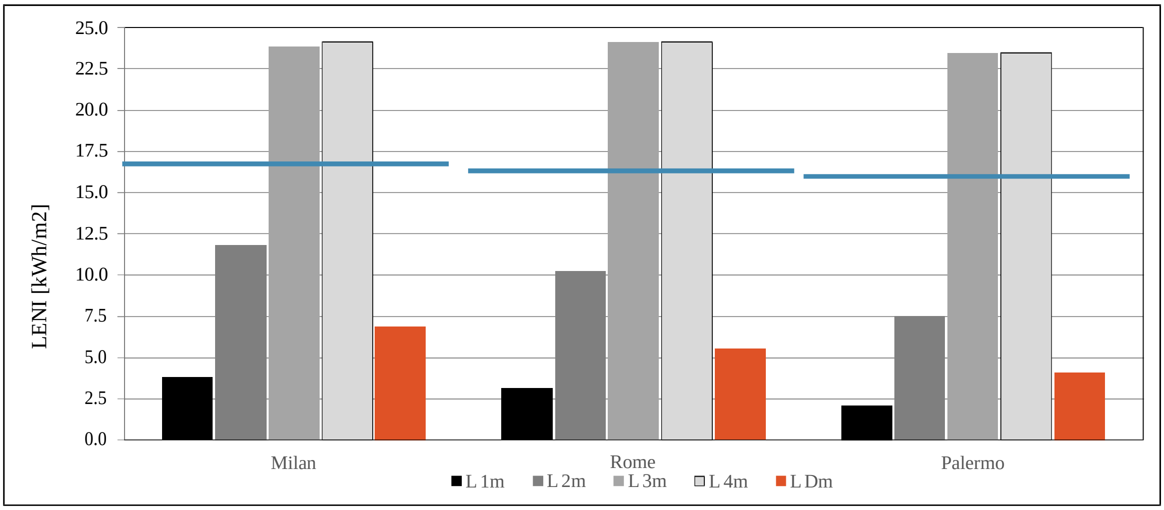

Fig. 3. LENI results for different methods, localities and observation points. Blue lines report the results according to EN 15193:2007

5. Conclusions

This paper was intended to compare the electric lighting uses of an office building determined applying the reference EN standard methods and an alternative approach. The results show that the standard leads to significantly different results among the proposed EN methods. Larger discrepancies are found for the alternative method based on the average daylight factor, up to a factor 3. The alternative method was also tested at different observation points, showing how the EN standard over/underestimates the electricity uses according to the distance from the window. It is also observed a fair latitude dependence of the EN method, conversely the alternative method seems more sensitive to this parameter.

The alternative method has to be further investigated respect other building typologies, being sensitive to the working plane size and position respect to the window. Comparison versus electricity consumptions from field monitoring will be also analyzed and used as a benchmark for model validations.

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