An Alternative Method for the Assessment of the Typical Lighting Energy Numeric Indicator for Different Outdoor Illuminance Conditions.

Benedetta Mattoni¹, Alessandro Mangione¹, Laura Pompei¹, Fabio Bisegna¹, Domenico Iatauro²,
Francesco Spinelli², Michele Zinzi²

¹Sapienza University of Rome, Roma, Italy

² ENEA Centro Ricerche Casaccia, Roma, Italy

Abstract

The contribution of daylight plays a key role in the evaluation of the Lighting Energy Numeric Indicator (LENI), which refers to the annual lighting energy consumption per square meter: the higher the contribution, the lower the energy consumption. Calculation of energy need for artificial lighting is defined in European Standard EN 15193-1:2017; the daylight availability is assessed by using the Daylight Factor. This parameter is easy to use and commonly applied by designers and technicians, but it has several limitations. The estimation of daylight contribution proposed in the first version of the EN 15193:2008 was discussed in literature and alternative methodologies and models have been suggested, since it was noticed that it underestimated the daylight contribution. Starting from these considerations, this study will focus on the analysis of a parameter which represents a middle way between static and climate-based variables. This new variable is the Daylight Factor Target, reference parameter of the new EN 17037. The D target will be used in the alternative methodology of LENI calculation developed in previous studies and the results will be compared with the ones obtained by applying the EN 15193-1:2017 procedure. Results showed that the Daylight Factor Target allows to assess in the first building design phase the LENI of any building which complies with the EN 17037, independently from its characteristics, just choosing the operative working hours and the lighting power installed. The LENI target resulted to be 50% lower than the values obtained using EN 15193-1:2017.

Introduction

Role of daylighting in buildings is relevant both for health and comfort of final users and for optimizing energy consumption. Daylight availability allows to reduce artificial lighting and decrease CO₂ emissions and global warming (Jenkins and Newborough, 2007; Aghemo et al., 2014). Calculation of energy need for artificial lighting is defined in European Standard EN 15193-1:2017 (Technical Committee CEN/TC 169 Light and lighting, 2017) which proposes an indicator of energy efficiency of the lighting system called LENI (Fantozzi et al., 2017). The contribution of daylight plays a key role in the evaluation of the LENI: the higher the contribution, the lower the energy consumption. In the EN 15193-1:2017 the Daylight factor (Mardaljevic et al. 2013, Longmore 1975, Johnsen and Christoffersen 2008) is the parameter

which puts in relation daylighting and building. During the years, the estimation of daylight contribution proposed in the EN 15193-1:2017 was discussed in literature and alternative methodologies and models have been suggested. These studies (Zinzi and Mangione 2015, Tian and Yuehong 2014, Lo Verso et al. 2014, Moret et al. 2013, Li and Wong 2007) highlighted that daylight contribution in the first version of the EN 15193:2008 was underestimated, especially in Southern latitudes and the efficiency of Daylight Factor was questioned. Due to this, the first version of the Standard EN 15193 published in 2008 was revised, leading to the publication of a new version in 2107. In the upgrade of the EN 15193-1:2017, many modifications have been made; among them the most relevant are: the use of climate data for daylight contribution of different locations expressed in terms of ratio between direct solar radiation and global solar radiation, the possibility of calculating different values of LENI as building orientation change. The use of D has instead remained the same. In literature, climate-based parameters, such as the Useful Daylight Illuminance (Nabil and Mardaljevic, 2006) or the Daylight Autonomy (Acosta et al. 2018), have been proposed as lighting variables for assessing as realistically as possible, the availability of indoor daylighting. Nevertheless, both in Lighting and Energy standards, they have not been yet accepted nor used as reference parameters. One of the reasons is that calculation would be longer and more complex compared to the evaluation of the Daylight Factor. It is easy-to use parameter but it has limitations due to its low flexibility since it doesn't take into account latitude conditions and building orientation; these two aspects have been included in the new version of the EN 1519-1:2017 as additional aspects, not in the calculation of D. It is a-dimensional and static and is a ratio that represents the illuminance available indoor relative to the illuminance available outdoor at the same time under overcast skies. Despite its limitations, the Daylight Factor maintains undeniable strengths, such as calculation speed and easiness of application. These characteristics cannot be found in the other climate-based parameters used in lighting assessments. However, what slows down the overcoming of the Daylight factor is its spread among the designers and experts, which makes it useful both in design and verification phases. A compromise between the positive aspects of the Daylight factor and the climate-based variables, could represent a valid alternative for the evaluation of the availability of

daylight in buildings. Starting from these considerations, this study will focus on the analysis of a parameter which represents a middle way between static and climate-based variables. This new parameter will be used in the alternative methodology of LENI calculation developed in (Zinzi et al., 2018) and the results will be compared with the ones obtained by applying the procedure provided in the EN 15193-1:2017. The variable chosen for the calculation is a parameter, included in the new proposal of the prEN 17037 (Technical Committee CEN/TC 169 Light and lighting, 2018), which could replace the use of the Daylight Factor. This Standard is going to be approved and defines methods and requirements for the evaluation of daylight availability in buildings, as the EN 12464 (Technical Committee CEN/TC 169 Light and lighting, 2011), does for artificial lighting. This variable was chosen for many reasons, in particular to make technicians aware of this new lighting parameter for the assessment of the typical LENI for different outdoor illuminance conditions.

Methodology

The development of an alternative parameter to the Daylight factor standard for lighting calculation arises from the need to take into account the real availability of daylight and the characteristics of the indoor and outdoor environments. Authors who proposed this new parameter (Mardaljevic and Christoffersen, 2017), belonging to the working group of the CEN TC169/WG11, suggested to move from standard conditions of daylight calculation (CIE overcast Sky) to real sky conditions based on measured climate data. This parameter was defined as Daylight factor target (D_T). In the following subsections the characteristics of this parameter and its application on this analysis will be described.

Description of the Daylight Factor Target

Basing on the definition (Mardaljevic and Christoffersen, 2017), in order to achieve the required condition of natural lighting in the building, a specific level of Target illuminance must be guaranteed for a specific percentage of hours in the year, on a specific percentage of relevant area. The parameter is expressed as ratio between outdoor illuminance and indoor target illuminance, as the Daylight Factor; but the values of outdoor diffuse illuminance are extrapolated from measured climate data. The aim is to define one Daylight Factor target per each location.

The equation is the following:

$$\frac{E_T \times 100}{H_T} = D_T [\%] \quad (1)$$

where

E_T is the indoor Target illuminance;

H_T is the horizontal outdoor diffuse Target illuminance;

D_T is the Daylight Factor Target.

The E_T value is set according to the EN 12464 based on the visual task. In the paper, authors propose to use 300 lx as indoor illuminance target in offices, referring to literature studies (Reinhart and Weissman, 2012; IES LM-83-12, 2012), which demonstrated the efficacy of this value for common visual task. In (Reinhart, 2004) it was pointed out that the switching probability of the artificial system is very high when level of indoor illuminance is lower than 100 lx while it is very small when indoor illuminance is equal or more than 300 lx. Therefore, these two values (100 and 300 lux) have been used in (Mardaljevic and Christoffersen, 2017) as reference target for the calculation: 300 lux for D_T and 100 lx for minimum Daylight Factor Target (D_{Tm}).

For the definition of the cumulative annual value of H_T , four attempts have been made:

1. To consider a fixed period of the year (such as for example operative working hours);
2. To base the calculation on sun position defining a specific altitude as reference value;
3. To take into consideration only the horizontal diffuse illuminances exceeding a certain threshold, (i.e. only daylight values);
4. To define a fixed set of illuminances in the climate dataset.

The last option resulted the more adequate, being able to avoid complications due to discrepancies among different latitudes and locations and/or other uncontrollable boundary effects. According to this, authors decided to consider a fixed set of illuminances common to all countries: the 8760 illuminance values were put in descending order; then, the first 4380 values (the highest ones, excluding night hours and very low daily values) were taken and the median value of this list was chosen as typical H_T of each location. Finally, using equation 1, the D_T of 33 European countries were calculated; among them the only italian one is Rome. The most important aspect of this parameter is that it is location based but it is independent from the geometrical characteristics of the building: it can be considered as the target value for designers and technicians to compare to, in order to evaluate if the building complies with lighting prescriptions. This parameter is a reference value for side-lit buildings. Author also defined the requirements each building should comply with: in a side-lit space, the D_T must be achieved on the 50% of the relevant area for the 50% of the daylight hours in the year (2190 hours), and contemporary the D_{TM} must be guaranteed on the entire area for the 50% of the daylight hours. The new parameter, despite it is not estimated using exactly a climate-based analysis, it is more aligned to real climatic conditions than the Daylight Factor standard. Furthermore, lighting software do require only a little implementation to adapt to this new variable for both lighting and energy calculations. At a first stage, designers could continue calculating the DF of the building with the common procedure and the commercial software (like Dialux) and compare it with the D_T ; lately, when available on commercial software, it would be possible to assess the Daylight Factor of each building

using the climate data. It can be noted that this parameter is from one side simple and intuitive as the Daylight Factor, but on the other side it seems to consider both the spatial distribution and the real climate data as the Daylight Autonomy.

Parameter application to the case study

The application of the D_T to the current study consists of two steps:

- the calculation of the D_T for the 19 main Italian cities, taking into account several level of target illuminances E_T (100, 300, 500 and 750 lux) and using the diffuse illuminance values provided by ENEA for calculating H_T . The annual dataset is based on Typical Meteorological Year.
- Application of the Alternative Method for LENI calculation proposed in (Zinzi et al., 2018) using the D_T for each location and comparison with the results of the EN 15193-1:2017.

The 19 cities are the following: Trento, Aosta, Trieste, Milano, Venezia, Torino, Bologna, Genova, Firenze, Ancona, Perugia, L'Aquila, Roma, Campobasso, Bari, Napoli, Potenza, Catanzaro, Palermo. Calculations have been developed using the tool Grasshopper, plug-in of the modelling software Rhinoceros. This software was not used for performing lighting simulation, but it was applied to automate the H_T calculation for the 19 cities using the ENEA climate dataset. Additionally, the tool was used for building the LENI calculation workflow described in EN 15193-1:2017, modifying some steps of the process according to the Alternative Method.

When D_T for each location is assessed, a $LENI$ value can be calculated which correspond to the typical consumption of buildings in different outdoor illuminance conditions. According to the Alternative Method, the value of H_T for each city is compared with the hourly values of diffuse illuminance E_{dh} provided by ENEA. The working period 08:00-17:00 suggested in EN 15193-1:2017 was chosen: in the hours when the $E_{dh} \geq H_T$, the lighting system is switched off; on the other hand, when $E_{dh} < H_T$, it means that daylight is not enough for reaching the levels of required illuminances, and therefore the lighting system is switched on. The sum of annual hours when the lighting system is on, is the t_{AM} . In Equation 2 the complete formula for $LENI$ calculation is shown:

$$W_L = \sum (P_n \cdot F_C \cdot F_O \cdot t_{AMn}) / 1000 \text{ [kWh/year]} \quad (2)$$

P_n [W] is the power of the lighting systems installed in the zone;

F_C [-] Constant illuminance factor;

F_O [-] Occupancy dependency factor;

t_{AM} [h] the sum annual hours when lighting system is on.

The D_T represents the reference value for a building which complies with the new daylighting Standard EN 17037:2018; the $LENI$ Target, associated to the D_T , represents the lighting energy consumption of a building which, independently from its geometric and physics characteristics, is well-lit by daylight. The $LENI$ Target of three representative locations (Rome, Milan and Palermo) will be compared to the results obtained applying the EN 15193-1:2017.

Case study description

The F51 building, located inside the ENEA Research Centre in Casaccia was chosen as a case study. This building has a rectangular plan of 48 m x 12 m, composed by two floors with an average height of 2.7 m.

Figure 1: F51 building plan in the ENEA Research Center

In this report, the office number 108 (Figure 1) was analysed: dimension and characteristics are summarised in the table below (table 1).

Table 1: Geometrical characteristics of office number 108, inside the F51 building in the ENEA Research Centre

Room characteristics	Width	3.5 m
	Depth	4 m
	Height	2.7 m
Window characteristics	Height	1.3 m
	Width	3.3 m
	Height of the windowsill	1 m
	Distance from the ceiling	0.5 m
	Glass transmittance	0.8 m

Simulations have been performed with Grasshopper, a free plug-in tool of the 3D modelling software Rhinoceros. Average indoor illuminance E_m was measured on a specific surface, located at 0.50 m from the walls and 0.75 above the floor. Variables of equation 2 are the shown in Table 2. Total lighting power P_n depending on the required illuminance values was calculated with DIALux 4.13, a free commercial software. F_c and F_o values were taken from the EN 15193-1:2017.

Table 2: Values of P_n , F_c and F_o

E_T	P_n	F_c	F_o
100 lx	43 W	1	0.8
300 lx	66 W		
500 lx	132 W		
750 lx	198 W		

P_n has been calculated with LED lighting fixtures.

Results

H_T of each location was estimated according to the procedure described in (Mardaljevic and Christoffersen, 2017), using outdoor illuminance values provided by ENEA. Results are shown in table 3.

Table 3: Values of H_T for each location

city	latitude	H_T [lx]
Palermo	38.12	17757
Catanzaro	38.90	17263
Potenza	40.63	17140
Napoli	40.85	16873
Bari	41.12	16882
Campobasso	41.55	16489
Roma	41.90	16010
L'Aquila	42.35	16484
Perugia	43.10	16188
Ancona	43.62	16204
Firenze	43.77	16051
Genova	44.40	16082
Bologna	44.48	15759
Torino	45.05	15866
Venezia	45.43	16148
Milano	45.45	15735
Trieste	45.63	15974
Aosta	45.73	15885
Trento	46.07	14907

In Palermo the highest value was registered (17757 lx), in Milano the lowest (15735 lx). The difference is 2022 lx which corresponds to the 13%. The average H_T value among the 19 locations is 16377 lx.

Analyzing the trend shown in Figure 2 it can be seen that as latitude increase, H_T decreases with a few exceptions:

a few locations with lower latitude have a lower H_T compared with locations with higher latitude (e.g. Campobasso and Rome, Bologna and Venice).

Figure 2: H_T trend as latitude changes

The calculated D_T is shown in table 4 as E_t changes; the D_{T100} value is not influenced by the different latitudes: the average value is 0.61%, with a minimum in Palermo (0.56%), and a maximum in Trento (0.67%) with a difference of 0.11 percentage points. Concerning the D_{T300} values, the average value obtained among the locations is 1.84%, the maximum 2.01% in Trento and the minimum 1.69% in Palermo, with a difference of 0.32 percentage points. These values of D_{T300} are aligned with the target value of DF 2% established in current regulations (Ente Nazionale Italiano di Unificazione, 2007; Ministero dei lavori pubblici, 1975; Ministero dei lavori pubblici, 1967; Ministero della salute, 1975). A difference of 0.54% between maximum and minimum values of D_{T500} can be noticed, with an average value of 3.07%, a minimum value of 2.82% and a maximum of 3.35%, respectively calculated in Palermo and Trento. Finally, the average D_{T750} is 4.61%, with a minimum of 4.22% in Palermo, and a maximum of 5.03% in Trento (difference is about 0.81 percentage points).

It is evident that differences among D_T values of the 19 locations are lower than differences among the corresponding H_T . Comparing the D_T Rome values shown in (Mardaljevic and Christoffersen, 2017) (D_{T100} 0.5%; D_{T300} 1.6%; D_{T500} 2.6%; D_{T750} 3.9%) with the calculated ones it is possible to notice significant differences. This difference is due to the outdoor diffuse illuminance data used for D_T evaluation: in this case data were provided by ENEA (obtained through a measurement campaign), while in the paper (Mardaljevic and Christoffersen, 2017) data were extracted from EPW weather file.

Variations among the D_T calculated in the two studies increase as illuminance target increases: a difference of 20% is registered between the D_{T750} calculated in (Mardaljevic and Christoffersen, 2017) and the one evaluated in this study. The LENI Target, estimated with the Alternative Method, seems to be proportional to P_n , as shown in table of Appendix 1 (shown at the end of the paper).

Table 4: D_T of 19 locations depending on E_T

city	latitude	DT100 [%]	DT300 [%]	DT500 [%]	DT750 [%]
Palermo	38.12	0.56	1.69	2.82	4.22
Catanzaro	38.90	0.58	1.74	2.90	4.34
Potenza	40.63	0.58	1.75	2.92	4.38
Napoli	40.85	0.59	1.78	2.96	4.44
Bari	41.12	0.59	1.78	2.96	4.44
Campobasso	41.55	0.61	1.82	3.03	4.55
Roma	41.90	0.62	1.87	3.12	4.68
L'Aquila	42.35	0.61	1.82	3.03	4.55
Perugia	43.10	0.62	1.85	3.09	4.63
Ancona	43.62	0.62	1.85	3.09	4.63
Firenze	43.77	0.62	1.87	3.12	4.67
Genova	44.40	0.62	1.87	3.11	4.66
Bologna	44.48	0.63	1.90	3.17	4.76
Torino	45.05	0.63	1.89	3.15	4.73
Venezia	45.43	0.62	1.86	3.10	4.64
Milano	45.45	0.64	1.91	3.18	4.77
Trieste	45.63	0.63	1.88	3.13	4.70
Aosta	45.73	0.63	1.89	3.15	4.72
Trento	46.07	0.67	2.01	3.35	5.03

The H_T of each location is the same for a defined operative time as E_T changes and consequently the sum of the annual hours when the lighting system is on (t_{AM}) is unvaried. Despite the target indoor illuminance increases from 100 to 750 lx, the D_T increases proportionally, making the t_{AM} unvaried. The only thing that changes is the artificial lighting power which increases in order to achieve the target level of indoor illuminance.

Concerning the LENI values, it is possible to underline that the scarce variability of D_T has an influence on the variation of the LENI target: for E_T of 100 lx, the average LENI value is 3.08 kWh/m²year, with a maximum of 3.18 kWh/m²year in Trieste and a minimum of 2.97 kWh/m²year in Palermo.

This difference is 0.21 kWh/m²year which corresponds to an increase of 7%. For a E_T of 300 lx, the average LENI value is 4.71 kWh/m²year, with a difference of 0.33 kWh/m²year between maximum and minimum values registered in the same cities. Finally, if E_T is 500 lx and 750 lx, the difference between maximum and minimum are respectively of 0.65 kWh/m²year and 0.98 kWh/m²year.

Comparing those results with the ones obtained with the EN 15193-1:2017 (Table 5) for three cities (Rome, Palermo and Milan), it is possible to highlight that the LENI calculated according to the EN 15193-1:2017 is higher than the LENI target and, additionally, the last one assesses more clearly the climatic differences among locations.

Table 5: Comparison between the LENI calculated with EN 15193-1:2017 and the LENI target

location	latitude	LENI EN 15193- 1:2017 (Davg 4.25%) [kWh/m ² *year]	LENI target 500 (ENEA Edh/working days/DTavg 3.02%) [kWh/m ² *year]
Palermo	38.12	11.51	6.29
Roma	41.90	11.56	6.38
Trieste	45.63	12.02	6.74
$\Delta(max-min)$ [kWh/m ² *year]		0.51	0.45
$\Delta(max-min)$ [%]		4%	7%

The parameter used in the EN 15193-1:2017 for characterizing the different locations is H_{dir}/H_{glob} . The maximum difference of $\frac{H_{dir}}{H_{glob}}$ among the Italian locations is 39%; this percentage has a very low impact (of about 4%) on the LENI difference. As aforementioned, maximum and minimum H_T difference (measured respectively between Palermo e Trieste) is only 13%, but it has a more consistent influence on the LENI difference of those cities, being about 7%.

For energy analysis, H_T seems to better point out the climatic characteristics of the various locations than the parameter H_{dir}/H_{glob} used in the Standard EN15193-1:2017. It is necessary to underline that this LENI target is not exactly the LENI of the building: it is the LENI of a generic building which independently from its geometric characteristics complies with the new EN 17037 lighting requirements.

Conclusions

The Daylight Factor is the reference parameter of the new lighting standard EN 17037, which establishes how to assess the availability of daylight in indoor spaces. This work aims to use this new lighting parameter for LENI calculation applying the Alternative methodology proposed in previous studies, in order to connect and integrate the new parameter of daylight assessment with the energy performance of buildings. The D_T from a lighting point of view, is the minimum threshold of daylight availability in spaces to guarantee visual comfort for the users. The application of this parameter to Italian cities highlighted that:

- The use of measured climatic weather data (as the ones provided by ENEA for this research) in the D_T calculation procedure is easy
- A single outdoor diffuse illuminance value (H_T) could be a rapid and relatively accurate solution for defining the climate condition of each location
- One of the relevant advantages of the D_T is that it is independent from the physical and geometric characteristics of the building and so

it allows to identify target values of energy consumption for artificial lighting for each location. These values are representative of a well-lit building as the level of required indoor illuminance value changes.

The use of D_T will allow to easily calculate in the first building design phase the LENI of any building which complies with the lighting Standard EN 17037, independently from its characteristics, just choosing the operative working hours and the lighting power installed. It has to be noted that the power for emergency lighting and control systems was not considered in this evaluation. One of the weakness related to the potentialities of H_T is that the differences of H_T among cities are not significant enough to influence the D_T and consequently the LENI of each location. The D_T calculation through measured lighting data (median H_T derived from 4380 hours of maximum illuminance) is suitable for overcoming the limitations of the Daylight Factor from the lighting perspective, but it could not be accurate enough for energy analysis. Nevertheless, the LENI target resulted to be 50% lower than the values obtained using the Standard EN 15193-1:2017. The D_T calculation procedure also excludes the evaluation of building orientation, which is instead included in the EN 15193-1:2017. Future developments could include a deeper analysis of the EN 17037 to better understand which aspects can be included in the calculation of the lighting energy needs of the buildings.

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Appendix I

Values of LENI target of each location for different illuminance thresholds

city	latitude [°]	tAM (08-17)	LENI target 100 [kWh/m2*year]	LENI target 300 [kWh/m2*year]	LENI target 500 [kWh/m2*year]	LENI target 750 [kWh/m2*year]
Palermo	38.12	1202	2.97	4.54	9.07	13.61
Catanzaro	38.90	1258	3.11	4.75	9.49	14.24
Potenza	40.63	1264	3.12	4.77	9.54	14.31
Napoli	40.85	1262	3.12	4.76	9.52	14.28
Bari	41.12	1269	3.13	4.79	9.57	14.36
Campobasso	41.55	1250	3.09	4.72	9.43	14.15
Roma	41.90	1220	3.01	4.60	9.20	13.80
L'Aquila	42.35	1244	3.08	4.71	9.41	14.12
Perugia	43.10	1244	3.07	4.69	9.38	14.07
Ancona	43.62	1255	3.10	4.74	9.47	14.21
Firenze	43.77	1250	3.09	4.72	9.43	14.15
Genova	44.40	1233	3.04	4.65	9.30	13.95
Bologna	44.48	1242	3.07	4.69	9.37	14.06
Torino	45.05	1243	3.07	4.70	9.39	14.09
Venezia	45.43	1277	3.15	4.82	9.64	14.46
Milano	45.45	1246	3.07	4.69	9.38	14.07
Trieste	45.63	1289	3.18	4.86	9.72	14.58
Aosta	45.73	1218	3.01	4.60	9.19	13.79
Trento	46.07	1263	3.12	4.77	9.53	14.30
LENI mean value			3.08	4.71	9.42	14.13