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The new prEN 15193-1 to calculate the energy requirements for lighting in buildings: comparison to the previous standard and sensitivity analysis on the new influencing factors

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Abstract

The differences included in the new version of the standard prEN15193-1 to calculate the LENI were analyzed, especially focusing on the approach to calculate the daylight supply factor ($F_{D,S}$). The estimation of the daylight availability does not only rely on the calculation of the daylight factor but it also accounts for the climate, the orientation of openings, and the presence of mobile sun shades for glare and thermal control. A sensitivity analysis on these factors was carried out, complemented by a set of case-studies (simple reference rooms with different site and architectural features) for which the LENI was calculated.

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Keywords: prEN 15193-1:2015, LENI, daylight supply factor; sensitivity analysis, parametric study.

1. Background

The standard EN 15193 [1] is part of a set of standards which were developed to support the implementation of EPBD directives. In the standard, the LENI (Lighting Energy Numeric Indicator) was introduced as a metric to quantify the energy performance for lighting in a building, also in the perspective of providing an input for the

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heating and cooling load estimations for the determination of the combined total energy performance of a building. The method to calculate the LENI considers, with different levels of detail, the main factors affecting the buildings' energy consumption for electric lighting: the power of the lighting systems, including the parasitic power of control systems and the power for recharging the emergency lamps; the type of control system (manual or automatically controlled according to daylight availability or spaces' occupancy); the daylight penetration into the indoor spaces through both vertical glazing and roof lighting systems; the building usage and the corresponding lighting requirements; the occupancy profile (occupancy time and probability).

The standard, originally released in 2007, has recently gone through a revision during the years 2013-14. As a result of the revision, a new version was drafted [2], that is currently under evaluation and is due out by early 2017.

Within this context, the paper describes the differences that were introduced in the new version of the standard to calculate the LENI, compared to the previous version. The differences are mainly concerned with the approach to calculate the daylight supply factor ($F_{D,S}$), which is the parameter that takes into account the daylight availability, with respect to the lighting requirement, of the building zones.

In this study, a comparison between the original and the new version of the Standard and a sensitivity analysis on the most important factors influencing the $F_{D,S}$ were carried out. These were complemented by a set of simple reference rooms in different sites and with different architectural features, for which the LENI value was calculated. The goal of the study was to outline the strengths and weaknesses of the new method for the calculation of LENI (prEN15193-1:2015) with respect to the previous one (EN 15193:2008).

2. Comparison of the new standard to the previous version

The standard EN15193:2007 defines the methods for estimating or measuring the amount of energy required or used for lighting in buildings. The calculation methods rely on the following formulae:

$$LENI = \frac{W}{A} = \frac{W_{L,t} + W_{P,t}}{A} \qquad \left[\frac{kWh}{m^2 year}\right]$$

$$W_{L,t} = \sum \frac{(P_n \times F_c) \times [(t_D \times F_O \times F_D) + (t_N \times F_O)]}{1000} \qquad [kWh/t_s]$$

$$W_{P,t} = \sum \frac{P_{pc} \times [t_y - (t_D + t_N)] + (P_{em} \times t_{em})}{1000} \qquad [kWh/t_s]$$

W = total annual energy required for lighting
$W_{L,t}$ = total energy for illumination
$W_{P,t}$= total energy for standby
A = total useful area of the building
P_n; P_{pc}; P_{em} = total powe,r for luminaire, and for controls and emergency standby respectively
F_C = constant illuminance factor
F_D = daylight dependency factor
F_O = occupancy dependency factor
t_D; t_N; t_y; t_{em}= daylight time; daylight absence time; number of hours in a standard year; battery charge time.

More information on the original standard and the calculation method were presented by Aghemo et al. in a previous paper [3]. The calculation method was also critically analyzed by other Authors: Tian et al. [4] developed a quadratic relationship to expand the range of latitudes, valid for different daylight penetration classes, maintained illuminance levels and control types. Zinzi et al. [5] proposed an alternative approach, where the daylighting contribution is determined based on the availability of outdoor illuminance data, and applied it to a standard office building, showing differences with the results from the EN 15193:2007.

By comparing the new and the previous document, it emerges that the main difference in the calculation method concerns the definition of a more detailed approach to estimate the daylight contribution to the energy performance of lighting. The factor that takes this contribution into account is F_D, which in turn depends on two other factors: $F_{D,S}$, or daylight supply factor and $F_{D,C}$, or lighting control factor. The first one is the factor that estimates the "daylight autonomy" of the zone under consideration, the second one accounts for the effect of the type of daylight-responsive control system of the zone (effectiveness in exploiting daylight based on the type of lighting control).

Substantial changes were introduced in the method to calculate both $F_{D,S}$ and $F_{D,C}$. In the previous version of the standard, the $F_{D,S}$ was determined from a table as a function of the latitude, of the daylight penetration class (and therefore of the Daylight Factor) and of the maintained illuminance requirement. In the new version, the $F_{D,S}$ is calculated with a formula that considers two different façade states, i.e. with activated and de-activated solar and/or glare protection. The formula accounts for the time during which shadings are activated or de-activated as well as for the corresponding relative daylight supply factor:

$$F_{D,S} = t_{rel,D,SNA} \times F_{D,S,SNA} + t_{rel,D,SA} \times F_{D,S,SA}$$

$t_{rel,D,S,SNA}$ = relative portion of the total operating time during which shading system is not activated
$F_{D,S,SNA}$ = daylight supply factor evaluated at times when the shading system is not activated
$t_{rel,D,S,SA}$ = relative portion of the total operating time during which shading system is activated (1 - $t_{rel,D,S,SNA}$)
$F_{D,S,SA}$ = daylight supply factor evaluated at times when the shading system is activated.

The relative time during which the shading system is de-activated is determined as a function of the site location (latitude), the climate condition (defined through the 'luminous exposure', that is the ratio of direct to global illuminance - H_{dir}/H_{glob}) and the façade orientation. Similarly, the $F_{D,S,SNA}$ is provided as a function of the site (latitude), the climate (H_{dir}/H_{glob}), the façade orientation, the daylight availability without shading (Daylight Factor - D) and the target maintained illuminance E_m. Instead, the $F_{D,S,SA}$ is determined as a function of the type of shading and the daylight availability class (D_{class}), that in turn depends on the daylight factor of the carcass opening (D_{CA}).

As for the lighting control factor $F_{D,C}$, in both versions of the standard this is determined as a function of the D_{class} and of the type of control system, this latter being considerably expanded in the new version. Furthermore the new $F_{D,C}$ also depends on the maintained illuminance required for the zone.

Fig. 1 shows the flowcharts to determine the effect of daylight in the previous and new standards.

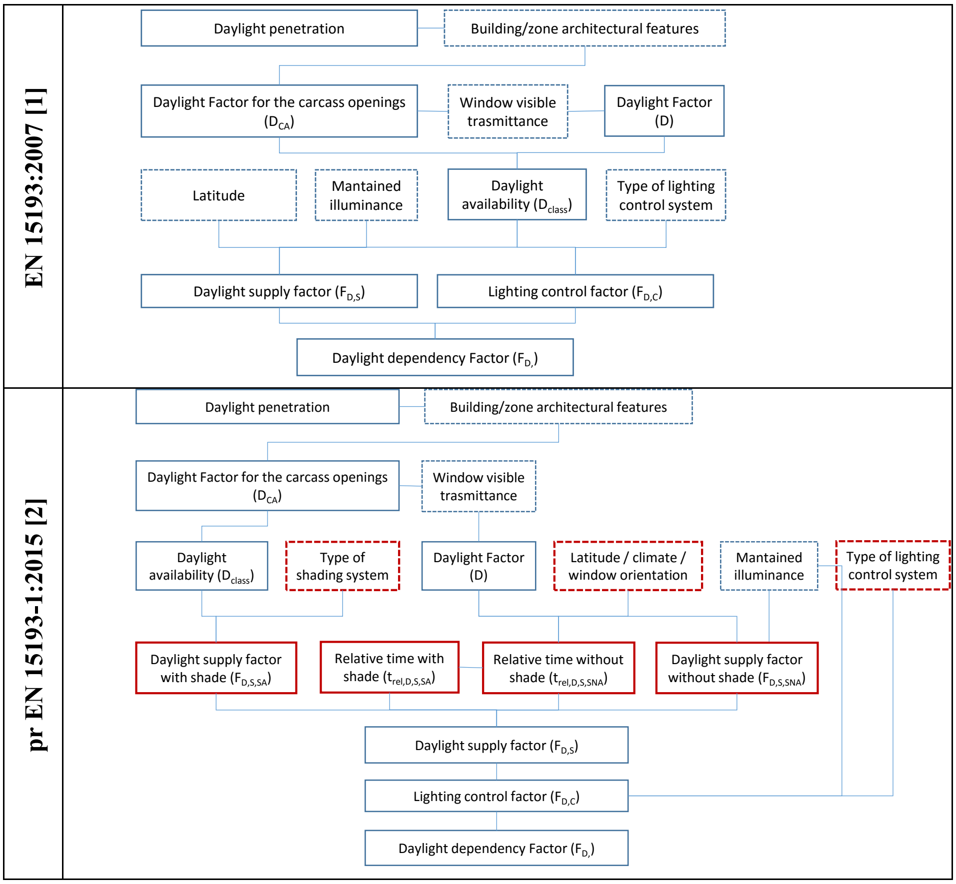

Fig. 1. Flowcharts for the determination of the daylight dependency factor F_D according to the prEN 15193-1:2015 and to the EN 15193:2007.

As a consequence of the new approach, the $F_{D,S,SNA}$ for a building at a specific latitude varies depending on the climate condition, on the façade orientation and on the type of movable shading system. Using the previous method yields to obtain the same $F_{D,S,SNA}$ value for any climate and orientation, regardless of the presence of a shading system.

The $F_{D,S,SNA}$ values are drawn from a set of three tables (one for each orientation – south, north and east/west), in which D varies from 0.125% to 18% and the latitude from 0°N to 75°N (five ranges of north latitude: 0°-15°; 15°-30°; 30°-45°; 45°-60°; 60°-75°). For each latitude range, two values of H_{dir}/H_{glob} are provided. On the whole, H_{dir}/H_{glob} ranges from 0.34 to 0.71, but specific, different H_{dir}/H_{glob} ranges are provided for each latitude range. Furthermore, five levels of maintained illuminance are considered (100; 300; 500; 750; 1000 lx).

For the estimation of the $F_{D,S,SA}$, three main categories of shading solutions are considered:

- glare protection only (manually operated)
- automatically operated protection against solar radiation and glare (moved in relation to the amount of daylight)
- light guiding systems (considered as shading systems with additional light-guiding/redirecting functions).

A fourth type of shading system is included in the $F_{D,S,SA}$ table. This corresponds to a system that is not relevant for solar or glare shielded windows, but that was introduced to remind people that if a Display Screen Equipment is in use, some shielding will be required.

The review of the simplified method to estimate the daylight dependency factor is the most substantial variation between the two versions of the standard, as it deeply affects the calculation procedure and the LENI results.

Several other differences and implementations can be pointed out: the new standard applies also to residential buildings; it introduces the concept of the "expenditure factor", useful to carry out a quick analysis of the energy flows in an electric lighting system; it provides equations to calculate the daytime and night time hours (t_D and t_N); it implements the informative parts for the definition of the input data. Furthermore, a technical report was developed to assist practitioners in the application of the LENI calculation method according to the new standard.

3. Sensitivity analysis on the factors influencing the daylight supply factor $F_{D,S}$

As mentioned earlier, the daylight supply factor $F_{D,S}$ was greatly expanded in the new standard by introducing new factors, such as the climate characteristics of the site, the orientation of the building and the presence of mobile shades. A sensitivity analysis of these factors was therefore carried out, so as to show the variation of the $F_{D,S}$ values in response to the variation of each factor. The approach is similar to the one adopted by some of the Authors in a previous study, which was focused on the old version of the standard [6].

The analysis was based on a parametric study, using a sample office room as a case-study and changing its architectural and climatic characteristics. The office was 3.5 m large, 5.4 m deep and 3 m high. The following parameters were changed to calculate the $F_{D,S}$:

- *latitude*: five locations were chosen, with latitudes of 7.5°, 22.5°, 37.5°, 52.5°, 67.5°, so as to have one location at the centre of each latitude interval introduced in the new standard
- H_{dir}/H_{glob}: three to six values for each latitude. For instance, for the latitude range 30°-45°, the H_{dir}/H_{glob} ranges from 0.45 to 0.71: for this latitude, the $F_{D,S}$ values were calculated for H_{dir}/H_{glob} values of 0.45, 0.50, 0.55, 0.60, 0.65, 0.71, through a linear interpolation of the values supplied for the two lower and upper extremes (0.45 and 0.71)
- *orientation*: south, west and north
- *mobile shades*: the room was first assumed without a mobile shade and then compared to cases having each type of the shades introduced in the standards: 'glare protection'; 'automatic sun and glare control'; 'light guiding'
- *window area*; this was set in such a way to determine 4 values of the Daylight Factor D: 5%, 3%, 1.5% and 1%.

The following parameters were kept constant: the window was assumed as totally unobstructed and equipped with a double pane glazing with a visible transmittance of 74%; a reduction factor for frames k_1 of 0.8; a reduction factor for pollution k_2 of 0.9 and a reduction factor for non-normal light incidence k_3 of 0.85.

Combining the possible variables assumed in the parametric study yielded a database of 1200 cases. For each case, a $F_{D,S}$ value was also calculated using the equations of the old version of the standard, so as to allow a comparison between the two versions to be carried out.

3.1. Effect of latitude and climate (H_{dir}/H_{glob})

Fig. 2 shows the variation of $F_{D,S}$ values for the five latitudes analyzed and, for each latitude, for different H_{dir}/H_{glob} values. The results that were obtained for cases in the absence of mobile shades are reported, so as to allow a comparison with the results found using the old EN 15193:2007. It is worth stressing that if the old standard is used, one single value is found for a given latitude in the range 38°-60°, while with the new standard a set of $F_{D,S}$ value is found for the same latitude, as a function of the luminous exposure.

In the graph, the average $F_{D,S}$ values which were obtained for each H_{dir}/H_{glob} according to the new standard are reported, together with the minimum and maximum value (to show the amplitude of the variation - dotted lines). Besides, three $F_{D,S}$ values according to the old standard are also plotted: L=38° (to be compared to the values from the new standard for a latitude of 37.5°), L=52.5°; L=60° (to be compared with a latitude of 67.5°).

Observing the trends shown in the figure allows the two main following considerations to be drawn:

- as far as the new standard is concerned, for each latitude, $F_{D,S}$ values decrease as the H_{dir}/H_{glob} values increase (that is for climates with an increasing presence of the direct illuminances), even though with a different slope. The latitude value of 52.5° (representing the latitude range 45°-60°) shows a peculiar trend, with a very little difference of $F_{D,S}$ values for the different H_{dir}/H_{glob} values.
  In general, for the same H_{dir}/H_{glob} value, $F_{D,S}$ values decrease as the latitude increases. Nevertheless, it is worth stressing that two pairs of lines (for L=7.5° and L=22.5° and for L=37.5° and L=52.5°) intersect. This means, for instance, that a location with a latitude of 52.5° and H_{dir}/H_{glob} values greater than around 0.53 has higher $F_{D,S}$ values than a location with same H_{dir}/H_{glob} values but at a latitude of 37.5°
- as far as the comparison to the previous version of the standard is concerned, the results show a good fit for the latitude of 52.5° and of 60°, while for the latitude of 38° the approach of EN 15193:2007 yielded $F_{D,S}$ values greater than what found using the approach of prEN 15193-1:2015.

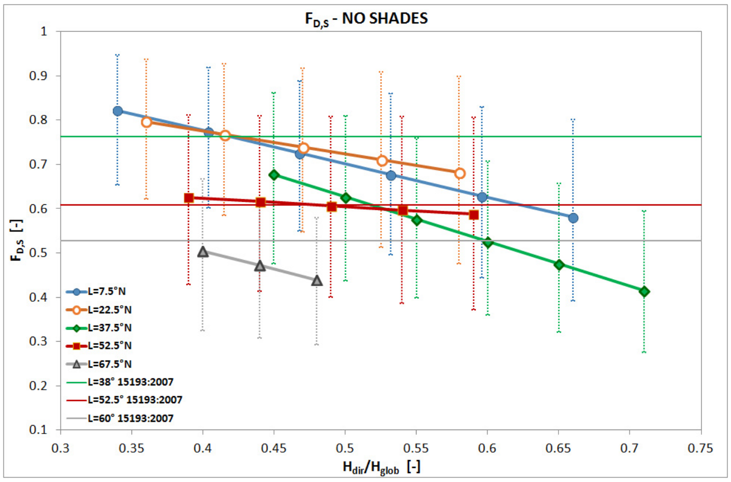

Fig. 2. Variation of $F_{D,S}$ for different latitudes and luminous exposure values according to the prEN 15193-1:2015 and to the EN 15193:2007.

3.2. Effect of the orientation

Fig. 3 shows the variation of $F_{D,S}$ values for the three orientations analyzed. A dedicated graph was plotted for each mobile shade, as well as for the case of absence of shade. The $F_{D,S}$ results were shown as average of all the $F_{D,S}$ values which were found for each latitude, so as to synthetically represent the trends according to the orientation.

The trends in the graphs show that:

- for the case of absence of mobile shade, the $F_{D,S}$ values observed for south-facing rooms are higher than what found for west-facing and, to an even more extent, for north-facing rooms

- in the presence of a shade manually operated to control glare phenomena, the trend is the opposite: $F_{D,S}$ values are higher for north-facing rooms than for west-facing and south-facing rooms, as a consequence of a different frequency of utilization of the shade (much more frequent for south–facing spaces than for the other orientations)
- for an automatic sun and glare shade, the $F_{D,S}$ show the same trend, independently of the orientation
- the use of a light guiding system results in higher $F_{D,S}$ values for south-facing spaces, as this system allows an increased exploitation of the available daylight which is admitted into a space.

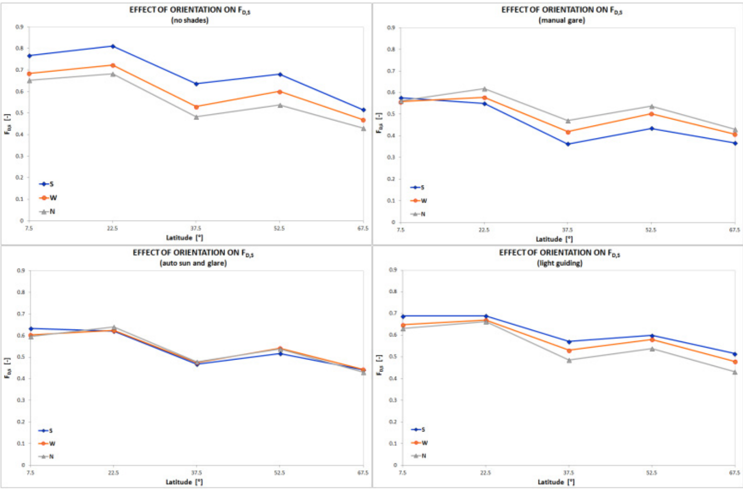

Fig. 3. Variation of $F_{D,S}$ for different orientations according to the prEN 15193-1:2015.

3.3. Influence of the sun shading systems activated

Fig. 4 shows the variation of $F_{D,S}$ values focusing on the three mobile shades, in comparison with the case of absence of shade. The $F_{D,S}$ results are reported as average of the $F_{D,S}$ values which were found for each H_{dir}/H_{glob}.

From the graphs, it emerges a constant trend, independently of the latitude: $F_{D,S}$ values are higher when the window has no mobile shade (as expected), and, when a shade is installed, for a light-guiding system, followed by the automated sun and glare control system and by the manual glare shade. It appears clear that the manual glare is the least favorable shade, while the light guiding system, which is conceived to be a re-directing system, allows more daylight into the room, still maintaining a shading effect.

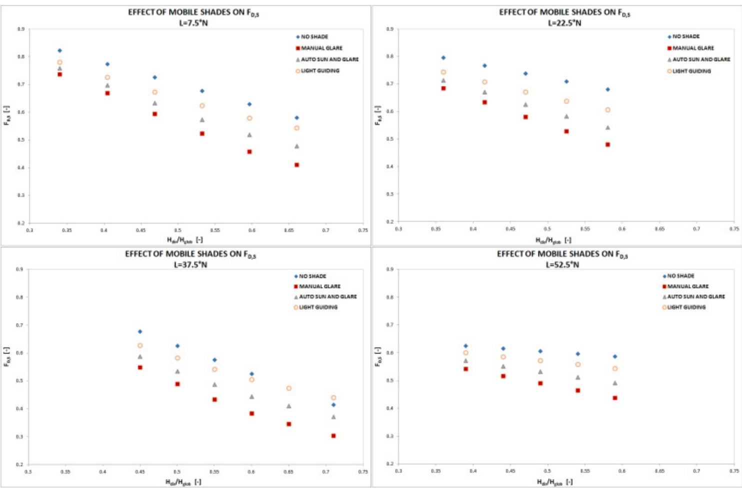

Fig. 4. Variation of $F_{D,S}$ for different mobile shades according to the prEN 15193-1:2015.

4. Calculation of LENI values for a sample office with different features (using the new and the old versions of the standard)

As a further step, the energy demand for electric lighting, in terms of LENI value, was calculated for some of the cases of the previous analysis. For this analysis, two lighting control systems were selected to proceed to the calculation of the LENI value: a manual control and a dimming control with stand-by losses and switch on. These control types are among the ones proposed by both versions of the standard. A Maintenance Factor MF = 1 and = 0.8 was set for the manual control and for the dimming control, respectively, while an absence factor F_A of 0.5 was assumed for all cases (typical value for offices). The analysis had two aims: i) to allow a comparison between the LENI values which are obtained for the same case using the two versions of the standard (for this purpose, cases without mobile shades were assumed); ii) to show the variation of LENI values in response to the variation of the factors that influence the $F_{D,S}$ and that were analyzed in the first part of the study (for this purpose, a same room facing south and north, with and without mobile shades, was assumed).

Fig. 5 reports the LENI values for two European sites, different for latitude and climate (luminous exposure value): Athens (L=37.9°, H_{dir}/H_{glob}=0.39) and London (L=51.2°, H_{dir}/H_{glob}=0.56). the LENI values are referred to a room with a Daylight Factor of 1.5%. The following consideration can be drawn from the data shown in the figure:

- for both sites, the LENI values calculated according to the old standard are higher than the corresponding values calculated according to the new version
- furthermore, it can be observed that in the presence of a manual light control the LENI according to the old standard tends to be higher than the corresponding values according to the new version, while the opposite trend applies in the presence of a dimming control. This means that the potential saving due to a dimming control with respect to a manual control is lower if the approach of the new standard is used
- among the different mobile shades introduced in the new standard, the highest LENI values were observed in the presence of a manual shade (and the lowest ones in the absence of a mobile shade, as one could expect); this is consistent with the relative differences observed for the daylight supply factor $F_{D,S}$.

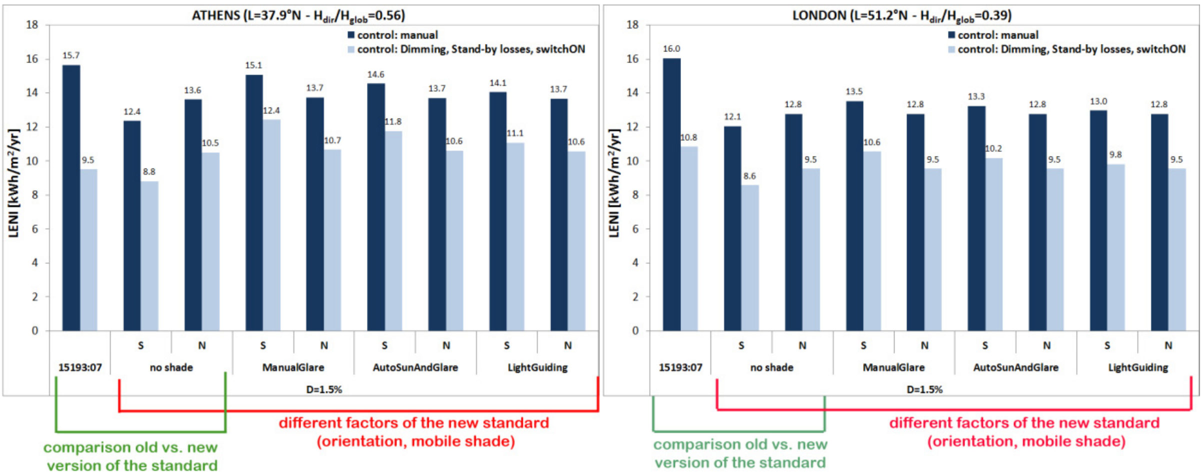

Fig. 5. Variation of LENI values according to the EN 15193:2007 and to the prEN 15193:2015 for two different European sites.

For a different analysis, the LENI values were also calculated for the site of Turin, Italy. Turin has a latitude of 45°, which raises the problem of which latitude range to refer to for the calculation of $F_{D,S}$ and LENI values: actually, two latitude ranges can be used indifferently, 30°-45° and 45°-60°. No information is provided in the standard on how to deal with threshold latitudes of 15°, 30°, 45°, and 60°. However, the results in the figure show that the LENI values do not differ significantly, as the maximum relative difference was found to be 10.4%.

5. Conclusions

The paper analyzed the main differences included in the new version of the standard prEN15193-1 to calculate the LENI, with a special focus on the approach proposed to calculate the daylight supply factor ($F_{D,S}$). Compared to the original version of the standard, more factors were introduced for the estimation of the daylight availability to be used for the calculation of the LENI, so as not to limit the analysis to the influence of the Daylight Factor, but to also account for the climate, the orientation of openings, and the presence of mobile sun shades.

A sensitivity analysis on the influence played by these factors was carried out through a parametric study. This relied on a dataset of $F_{D,S}$ values for 1200 cases, that is a sample office room with 5 latitudes, 5 H_{dir}/H_{glob} values, 4 window areas (determining a Daylight Factor of 5%, 3%, 1.5%, 1%), 3 orientations and 4 types of mobile shades.

In short, the following general trends were observed for the influencing factors analyzed:

- latitude and climate (H_{dir}/H_{glob}): for each latitude, the $F_{D,S}$ values decrease as the H_{dir}/H_{glob} values increase, even though with a different slope. For the same H_{dir}/H_{glob} value, $F_{D,S}$ values decrease as the latitude increases. However, there are few exceptions to these trends: for higher H_{dir}/H_{glob} values, $F_{D,S}$ values for a latitude of 22.5° are higher than the corresponding values for 7.5° and the same applies for the two latitudes of 37.5° and 52.5°
- orientation: this plays a role on the daylight supply in a room, in combination with the absence/ presence of a mobile shade. $F_{D,S}$ values were higher for rooms with south-facing windows in the absence of shade and in the presence of a light guiding system. The opposite applies with shades based on a manual control of glare, as north-facing rooms showed the highest $F_{D,S}$ values (and south-facing rooms the lowest ones). With a shade based on an automated solar and thermal control, the $F_{D,S}$ are substantially the same independently of the orientation
- mobile shades: for each latitude, when a shade is installed, the highest $F_{D,S}$ values were observed for a light-guiding system, followed by the automated sun and glare control system and by a manual glare shade
- comparing the new and the original version of the standards, the results show a good fit for the latitude of 52.5° and of 60°, while for the latitude of 38° the approach of EN 15193:2007 yielded $F_{D,S}$ values greater than what found using the approach of prEN 15193-1:2015
- the LENI values calculated for Athens and London were higher when the old standard is used; furthermore, in the presence of a manual light control the LENI according to the old standard was higher than what found using the new version, while the opposite applies for a dimming control. This means that the potential saving due to a dimming control with respect to a manual control is lower if the approach of the new standard is used.

In conclusion, it is worth stressing that the new version of the standard expanded the possible cases that influence the daylight availability in a room, compared to the previous version. The effect of important factors, such as latitude, climate, orientation and presence of mobile shades, was taken into consideration for daylighting and energy analyses in the new standard. This is useful for the design team to predict, since the earliest design phases onwards, both the daylight amount in each space of a building and the corresponding energy demand for lighting. This in turns allows determining the global energy consumption of the considered building.

As shown in the paper, the new approach to determine the $F_{D,S}$ and the LENI is more complex than the original method, as it involves an incremented number of factors. For this reason, applying the method can be difficult for non-expert users and the development of a software to support them to calculate the LENI appears worthwhile.

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