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Validation of the EN 15193:2017 calculation method to estimate the daylight supply in a building: comparison with dynamic climate-based simulations

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ABSTRACT
This paper compares a simplified method to calculate the daylight factor and the annual daylight contribution in a space to the output of dynamic daylighting simulations. The simplified calculation method is the one implemented in the European Standard EN 15193 for the calculation of the energy demand for lighting in buildings, while the tool for dynamic simulations is Daysim (managed through DIVA-for-Rhino). The analysis was carried out by applying the two approaches to a reference office room, which was assumed to be located in different sites and having different window areas, with different orientations, both in the absence and in the presence of a mobile shade. The presence of an obstructing building was also considered. A total number of 108 cases was considered for the comparison.
The results showed a very good correlation between the analytical method and the Daysim simulations to calculate the daylight factor (R^2 =0.99, with an absolute average difference of 11%). The correlation was lower for the calculation of the annual daylight contribution (R^2 =0.86, with an absolute average difference of 35%), due to the complexity of variables included (climate, orientation, presence of a moveable shade). Among the variables, the higher differences between the analytical and simulation results were observed for the climate and the absence/presence of a shade.

KEYWORDS
Daylight supply estimation, simplified calculation method, Daylight Factor, DIVA-for-Rhino simulations, EN15193-1 standard.

INTRODUCTION
The standard EN 15193-1 (2017) belongs to a set of standards that were developed to support the implementation of the Energy Performance of Buildings Directives. In the standard, the metric LENI (Lighting Energy Numeric Indicator) was introduced to quantify the energy demand for lighting for a building. Consistently, an analytical calculation method was also supplied. This includes all the main factors that affect the energy consumption for electric lighting: power of the lighting systems, daylight contribution into an indoor space, type of lighting control and building usage. The "core" of the calculation method is the estimation of the daylight contribution through the daylight dependency factor (F_D). This depends on other two factors: the *daylight supply factor*, $F_{D,S}$, to estimate the "daylight autonomy" of the space under consideration; the *lighting control factor*, $F_{D,C}$, to account for the effectiveness of the type of lighting control system in exploiting daylight. To calculate F_D, the building is divided into 'Daylit Areas - A_D', which receive daylight, and 'Non-Daylit Areas - A_{ND}' for which F_D is assumed equal to 1 (no significant daylight contribution).
The calculation method introduced in the original standard (2007) was deeply revised in the present version (2017), with regard to both $F_{D,S}$ and $F_{D,C}$. The analytical procedure adopted in the new version of the standard relies on a parametric study, whose basic principles are described in the EN 15193-2 (2017) and in the ISO 10916 (2014).

Focusing on $F_{D,S}$, this is the result of a two-step calculation. Firstly the daylight factor for the opening (D) is calculated as a function of external obstructions, room sizes and characteristics of the apertures (such as window size, glazing visible transmittance and maintenance, and frame factor). Secondly, the annual daylight supply factor of the considered space ($F_{D,S}$) is determined as a function of D, of the climate, of the orientation of the windows, of the absence/presence of a shading system for thermal and/or glare control, and of the target illuminance. Except for the illuminance, the other factors of step *two* of the calculation method were not included in the original version of the standard (2007). In the new standard, the climate is taken into account through the *luminous exposure* H_{dir}/H_{glob}, i.e. the ratio of the direct horizontal illuminance to the global horizontal illuminance, each being calculated by summing up the illuminances in the hour range 8-17 throughout a year. To account for the presence of mobile shading systems, $F_{D,S}$ is determined with reference to two different façade states, i.e. with systems activated ($F_{D,S,SA}$) and with systems non-activated ($F_{D,S,SNA}$). $F_{D,S}$ is calculated as a weighted average of $F_{D,S,SA}$ and $F_{D,S,SNA}$, using the annual relative time of usage or non-usage of the shading system as weighting factors.
Figure 1 shows a schematic representation of the flow chart to calculate F_D and of the space segmentation into Daylit and Non-Daylit Areas.
More information about the calculation method of the EN15193 standard can be found in Tian and Su (2014), Zinzi and Mangione (2015), and in Aghemo et al. (2016).

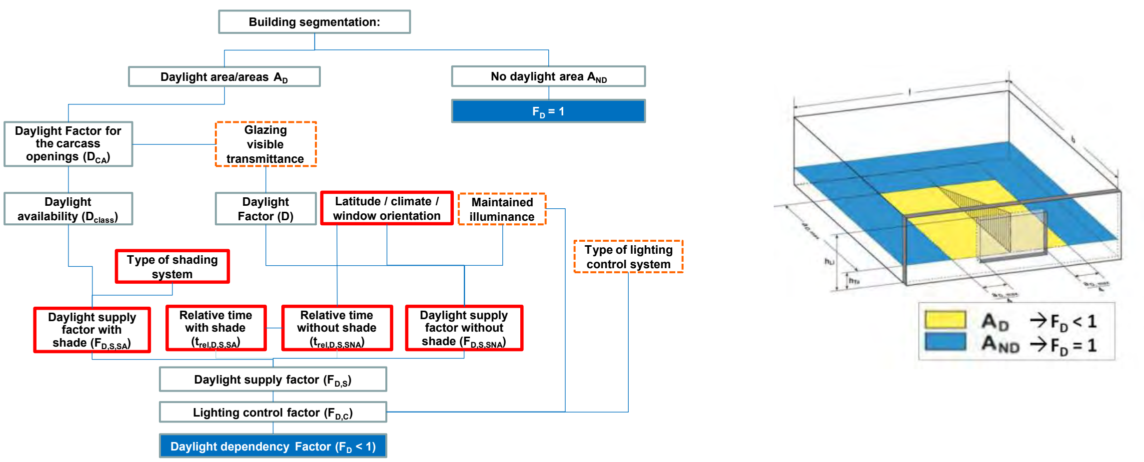

Figure 1. Flow chart to calculate the daylight dependency factor F_D for A_D and A_{ND}.

With the new standard, building practitioners are supplied with an analytical method, which accounts also for climate conditions, orientations and movable shadings, to calculate the daylight contribution in a space and therefore the LENI, without any simulations. The method is tabular, and the influencing factors are considered in a simplified way through discrete ranges. Compared to a dynamic simulation, the analytical method has a lower level of detail.
Within this frame, this paper presents a comparison of the daylight contribution in a space as calculated through the analytical method of the standard and through a dynamic simulation tool. The validated Radiance-based daylight simulation method DAYSIM was used for this purpose (Reinhart and Walkenhorst, 2001). This combines the concept of the daylight coefficients and the Perez sky model to run annual simulations to determine the daylighting and the energy demand for lighting in a space.

METHODS

A set of case studies was defined for the analysis of the daylight supplied in a room, calculated both through the analytical method and advanced simulation. The analytical

method was carried out in accordance with the Standard EN 15193-1 through a purpose-developed Excel spreadsheet, while the program DIVA-for-Rhino was used to manage Daysim annual daylighting simulations (a time-step of 1h was used). The Energy Plus climate files were used, both as input for the Daysim simulations and to calculated the *luminous exposure* H_{dir}/H_{glob}, which in turn was then used as input for the analytical calculation of $F_{D,S}$.
A reference room was chosen, whose plan sizes are 6 m x 6 m, with a floor-to-ceiling distance of 3 m. The room has a single vertical opening (with a lintel height of 2.70 m and a sill height of 1 m above the floor), equipped with a glazing with a visible transmittance of 0.70. The room was meant to be used as a cellular office, with a target illuminance of 500 lx and with an occupancy profile 8:00 through 17:00, Monday through Friday, as specified in Standard EN 15193-1. A series of variables were parametrically modified to obtain a meaningful number of cases for which to compare the daylight contribution determined analytically and from simulations. The cases were defined so as to determine different daylight amounts in the room (poor, medium, high) under different climates to test the two methods.
For each case, D and $F_{D,S}$ values were calculated analytically following the standard, while through the Daysim simulations two climate-based daylight metrics were determined: the continuous Daylight Autonomy DA_{con} and the Daylight Autonomy DA. Conceptually, the DA_{con} appears as the most consistent metric to be compared to $F_{D,S}$, based on how $F_{D,S}$ is defined and calculated in the EN 15193-2 (2017). Considering that the DA is a more widely used metric to calculate the daylighting in a space, this was also determined and compared to the $F_{D,S}$. For the simulations, a grid of sensors was positioned over the workplane (0.8 m above the floor), with a spacing of 50 cm, covering the whole room area except a peripheral stripe of 50 cm. Annual DA and DA_{con} values were calculated for each point of the grid, then computing their average value to be compared to $F_{D,S}$.
The parameters that were modified were: site (3), size of the openings (3), type of shading (2), presence of a building ahead that produces a frontal obstruction (obstruction angle of 45°) (2), and orientation (3) (see Table 1). Each variable was parametrically combined with all the other variables, resulting in a database of 108 cases for the comparative analyses.

Table 1. Variables of the reference room that were changed for the comparative analysis.

Position (3)	London - L = 52.3°N (H_{dir}/H_{glob} = 0.37)	Turin - L = 51.5°N (H_{dir}/H_{glob} = 0.43)	Palermo - L = 38.1°N (H_{dir}/H_{glob} = 0.50)
Window area (3)	1 m x 1.7 m (WWR = 0.09) (carcass area 1.70 m^2)	6 m x 1.7 m (WWR = 0.57) (carcass area 10.2 m^2)	6 m x 3 m (WWR = 1) (carcass area 18 m^2)
Shading (2)	No glare protection	Blind for glare protection	
Obstruction angle (2)	0°	45° (Building with a visible reflectance of 25%)	
Orientation (3)	South	West	North

RESULTS

Comparison of the *daylight factor* calculated analytically and through simulations

Figure 2 shows the daylight factor results (analytical and from simulations) for the entire database. For the analytical method, the D value is the area weighted average value of the two D values for A_D and A_{ND}. Plotting the analytical D values (standard) versus the DF values from Daysim simulations (Fig. 2a) shows a robust correlation (R^2=0.99). In spite of this, a difference in the estimate is observed: the relative difference between the daylight factor values through the two approaches for all the cases analyzed is in the range -18.7% ÷ +9.9%, with an average difference of -5.2% (Fig. 2b). It seems therefore that the analytical method on average tends to underestimate the daylight amount compared to the simulation results.

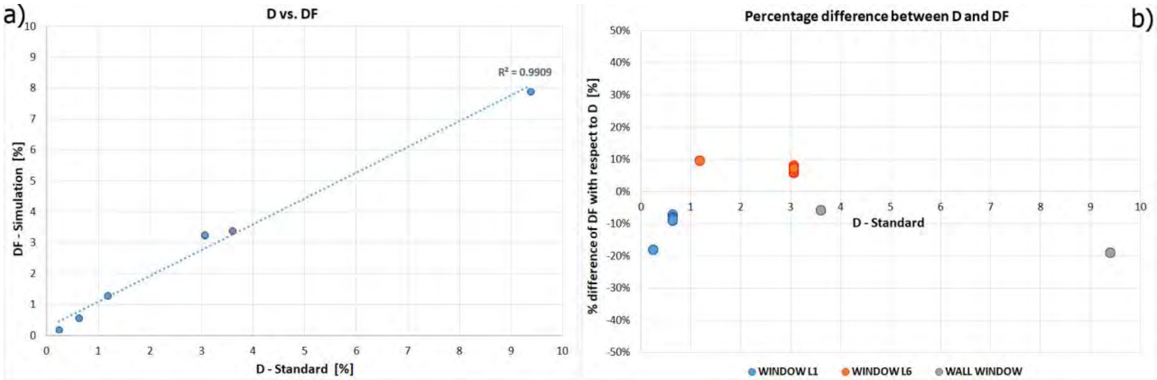

Figure 2. D values (analytical method of the standard) versus DF values from simulations: a) absolute values, b) relative percent difference.

Comparison of the *daylight supply* calculated analytically and through simulations

The daylight contribution in the spaces analyzed through the analytical method ($F_{D,S}$) was compared to two climate-based daylight metrics from DIVA simulations (Fig. 3): the continuous Daylight Autonomy DA_{con} (Fig. 3a) and the Daylight Autonomy DA (Fig. 3b). $F_{D,S}$ is calculated as area weighted average value of the two $F_{D,S}$ values for A_D and A_{ND}.

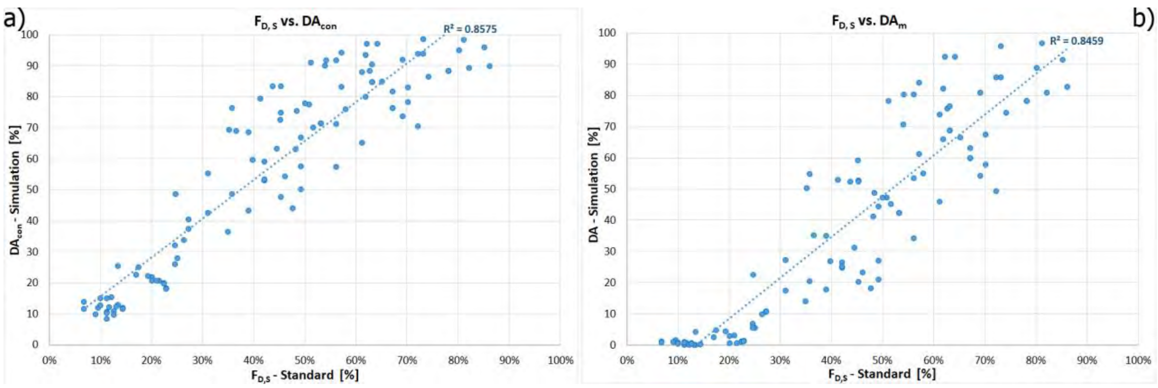

Figure 3. Comparison of the daylight supply: a) $F_{D.S}$ vs. DA_{con}, b) $F_{D.S}$ vs. DA.

The correlation between analytical and simulation results is similar when using the DA_{con} metric (R^2=0.86) or the DA metric (R^2=0.85). In spite of this, the comparison $F_{D,S}$-DA shows a gap for the lower values, in a way that $F_{D,S}$ values in the range 7%-23% correspond to a DA of around 0% (such gap was not observed using the DA_{con}).

Figure 4 shows the relative percent differences between analytical and simulation results.

Based on the results shown in Figure 4, the following considerations can be drawn:

- *range of relative differences*: the range was -115% ÷ +22%, with an average difference of -32.4%. Consistently with what observed for the daylight factor but to a greater extent, the comparison between DA_{con} and $F_{D,S}$ values shows that the analytical method on average tends to underestimate the daylight supply in a room compared to Daysim simulations
- *effect of climate*: the highest differences between analytical and simulation results were observed for Palermo, then for Turin and for London (average difference: -60%, -29%, and -17%, respectively). The way the climate is taken into consideration in the standard approach and in simulations plays therefore a crucial role on the final result: the standard accounts for the climate through the *luminous exposure* H_{dir}/H_{glob}, which synthetizes the climatic variation during the course of a year through a single value that expresses the annual presence of direct radiation compared to the global radiation. Differently, an annual

simulation calculates the daylighting into a space with a time-step of 1 hour, i.e. accounting for a specific sky condition that takes place every hour

- *effect of obstruction*: the relative difference values between the analytical and the simulations results for cases without and cases with obstruction were found to be of the same magnitude (average difference: -35.4% and -28.8%, respectively)
- *effect of orientation*: the three orientations considered showed differences between analytical and simulations results of the same magnitude (average difference: -37.2% for South, -29.1% for West, and -30.1% for North; again, the analytical results tend to underestimate the simulation results). Another aspect to mention is that the analytical approach assumes the same tabular coefficients for East and West orientations, which means that the same D and $F_{D,S}$ values are obtained for the same space facing East or West. Besides, in the presence of the blinds, the DA_{con} values obtained with DIVA for the same space with the window West and East oriented were quite different: the relative differences of DA_{con_W} and DA_{con_E} values were in the range -56% ÷ +8%. These differences are due to the calculation algorithm implemented in Daysim to model the blinds: once glare is detected, the blind is pulled down and left in that position for the rest of day, so an East-facing space remains shaded for longer periods compared to the same space facing West.

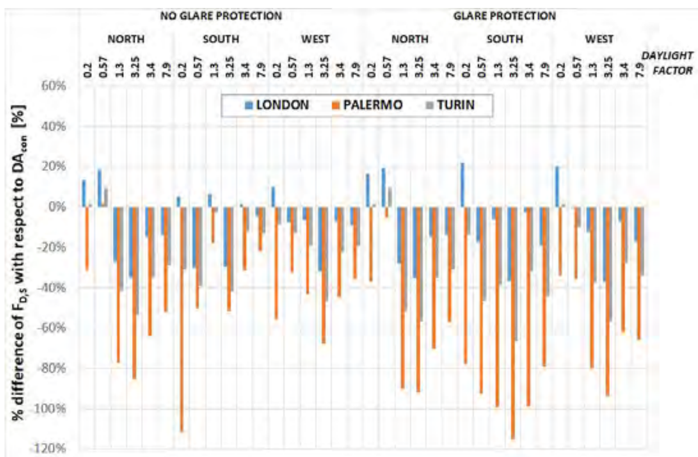

Figure 4. Relative percent differences of the results for the daylight supply.

DISCUSSIONS

The paper presented the results of a study on the effectiveness of a simplified analytical method, adopted in the European standard EN 15193-1, to calculate the daylight supply in buildings, compared to the results from dynamic simulations with a commercially available tool (DIVA-for-Rhino, which uses Daysim). The study was focused on the analysis of two of the parameters included in the simplified calculation procedure: the daylight factor (D) and the daylight supply factor ($F_{D,S}$). The first one is representative of the daylight provision under an overcast sky condition and in the absence of shading devices; the second one is descriptive of the daylight supply calculated taking into account the actual climate conditions, the window orientation, the presence of movable shadings and the required target illuminance.

The results of the study demonstrated that there is a very good correlation between the analytical method and the dynamic simulations with Daysim for what concerns the calculation of D (R^2 =0.99, with an absolute average percent difference of 11%), while the correlation is lower when $F_{D,S}$ is considered (R^2 =0.86). The daylight supply factor $F_{D,S}$ was compared to the DA_{con}, as these two parameters have the same conceptual meaning. The results showed an average difference of -32.4%, ranging between -115% and +22%. Such lower correspondence for the global daylight supply ($F_{D,S}$ and DA_{con}) with respect to the daylight factors is in line

with the greater complexity of the factors affecting $F_{D,S}$ and DA_{con}. The way the climate and movable shading systems are considered in the two estimation approaches particularly seem to be responsible for the greatest gaps observed between the results: the average difference is higher for Palermo (-60%), intermediate for Torino (-29%) and lower for London (-17%), and it is higher for cases with moveable shading devices than without shadings (-41% vs. -29%).
The great difference between $F_{D,S}$ and DA_{con} for Palermo is probably due to the very simplified approach used in the standard to account for climate conditions. Very few climate conditions (expressed in terms of H_{dir}/H_{glob}) are reported in the tables of the standard and, while Torino and London show a H_{dir}/H_{glob} very close to the values used in the tables, the H_{dir}/H_{glob} for Palermo is almost halfway through the values reported in the standard. A linear interpolation was used to calculate the daylight supply factor to overcome this problem.

CONCLUSIONS

The evaluation of the daylight contribution to indoor lighting is a key factor for the estimation of the energy performance of buildings. The availability of simplified calculation methods could be of help to take this aspect into account since the beginning of the design process.
The results of this study confirmed a good correlation between the parameters to estimate the daylight supply in buildings used in the simplified calculation method proposed by the European standard EN 15193 and in the dynamic simulation software DIVA-for-Rhino (which uses Daysim). Nonetheless, the differences between the results, especially for what concerns the $F_{D,S}$ compared to the DA_{con}, are sometimes relevant, particularly for climate conditions that deviate from the data reported in the standard.
As a future work, the database will be expanded (new weather conditions and types of shading) and the energy demand for lighting will be calculated. The study shall provide useful information and data to optimize and implement the standard, particularly for what concerns the impact of climate and movable shading devices.

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REFERENCES

Aghemo C., Blaso L., Fumagalli S., Lo Verso V.R.M., Pellegrino A. 2016. 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. *Energy Procedia*, 101, 232 – 239.

CEN. 2017. EN 15193-1:2017, Energy performance of buildings - Energy requirements for lighting - Part 1: Specifications. Brussels: Comité Européen de Normalisation.

CEN. 2017. EN 15193-2:2017. Energy performance of buildings - Energy requirements for lighting - Part 2: Explanation and justification of EN 15193-1, Module M9. Brussels: Comité Européen de Normalisation.

ISO. 2014. ISO 10916:2014. Calculation of the impact of daylight utilization on the net and final energy demand for lighting. Geneva: International Standard Organization

Reinhart C.F., Walkenhorst O. 2001. Validation of dynamic RADIANCE-based daylight simulations for a test office of external blinds. *Energy and Buildings* 33, 683-697.

Tian M, Su Y. 2014. An Improvement to calculation of lighting energy requirement in the European Standard EN 15193:2007. *Journal of Daylighting* 1, 16–28.

Zinzi M, Mangione A. 2015. The daylighting contribution in the electric lighting energy uses: EN standard and alternative method comparison. *Energy Procedia*, 78, 2663 – 2668.