A new simplified daylight evaluation tool, description and validation against the standard method of EN 17037

Bertrand DEROISY*[1], Nicolas DUPIN[2], Sabine PAUQUAY[3] and Jens CHRISTOFFERSEN[2]

[1] Belgian Building Research Institute, Brussels, Belgium
[2] Velux A/S, Hørsholm, Denmark
[3] Velux Belgium, Belgium

** Corresponding author: bdr@bbri.be*

ABSTRACT

A new daylight evaluation tool using a simplified assessment method to determine the daylight quantity provided to a typical room was developed. Its calculation method is based on a set of formulas integrating the main factors characterizing the indoor space and the outdoor context. The results are expressed as a corrected Glass-to-Floor ratio (GFR*) which is used as a proxy for the daylight provision. This value can then be used to attribute a rating or "Daylight score" to each space. The main finding is that the simplified method is an easy and relatively reliable estimation for daylight provision. A comparison of the tool with detailed daylight simulations according to the daylight factor method of EN 17037:2018 shows that a high correlation is obtained. The tool is applicable for any case which has conditions matching closely to the models and situations defined. Due to its easy implementation and the limited number of input parameters this evaluation method could be well suited for building passport schemes.

INTRODUCTION

Objective

Daylight provision is an important quality feature of a space and has many beneficial effects on the occupants. Well daylit spaces provide significant amounts of light indoors varying through the day and the seasons. Daylight openings provide direct views and connection to the outside. We also know that daylight affects our physiological and psychological health (Veitch 2013, Knoop, 2019). Growing evidence confirms that the intensity, spectral, spatial and temporal dynamics of daylight are essential for our well-being and health. Since the beginning of human evolution, our circadian rhythm has relied on daylight as the primary environmental stimulus. (Houser, 2020, Webler 2019). This leads to a renewed emphasis on daylighting in buildings, but new techniques are required to assess daylight exposure and interdisciplinary exchange is the key to integrating findings into architectural practice (Münch 2020). Daylight can be characterized in different ways either by calculations either by measurements or sometimes even with a combination of both methods. An accurate characterization of daylight provision can be rather complex and time-consuming, especially for any spaces with special building geometries or specific features, such as solar shadings or window reveals with specular finishes. This complexity can be a barrier for better evaluation of daylighting qualities, and more specifically in smaller residential projects. A review of current daylight metric (Dogan, 2019) identified, for residential applications, the main shortcomings. It highlights for example the difficulty to establish an occupancy schedules because of the diversity of residential activities and personal preferences. A new simplified daylight calculation method was developed to allow quick and easy estimation of the daylight provision for most typical situations in terms of room shapes and daylight openings. It is inspired on the methodological approach in the Danish Building Regulation which allows an assessment of glass-to-floor ratio as an indicator for daylight provision. As this new tool is intended to be used by persons with no specific knowledge in daylight calculations methods its results are expressed in a more easy-to-grasp notion of Glass-to-Floor ratio (GFR) rather than a physical photometric value. Glass-to-Floor ratios (GFR) or Window-to Floor ratio (WFR) are often used in building regulations as the parameter to set the criteria for daylight requirements, but it is only a simple indicator, and future criteria in legislation should target more precise daylight metrics.

The main purpose of this study is to describe the evaluation method and to verify its reliability for a set of representative cases. A comparison using the simplified daylight evaluation tool and the results obtained through a detailed calculation of target daylight factors, according to the recommendations in EN 17037:2018 (CEN 2018) was done. This standard specifies an evaluation method for daylight provision, either based on daylight factor or illuminance levels, in a space to ensure sufficient levels of daylight throughout the year. To demonstrate compliance with the standard, it is necessary to show that a target daylight factor, depending on the geographical location, is achieved across 50% of a reference plane for at least half of the yearly daylight hours.

METHODS

The 'Daylight Evaluation' tool uses a concept of corrected glazing surface (A_g*). This method aims at integrating all dominant factors that impact the daylight supply to the room. It is calculated for each daylight opening by multiplying the real glazing area (A_g) with a set of eight correction factors (1):

$$A_g^* = \sum_{i=1}^{8} C_i \times A_g \qquad (1)$$

The determination of the correction factors is based on equations and several input parameters as shown in Table 2. For the correction factor related to the room depth (C7), the distance to be considered for the calculation can vary when daylight openings are placed in different facades. The room depth is always measured in a direction perpendicular to the plane of the daylight opening and projected in a horizontal plane at floor level.

The resulting corrected Glass-to-Floor ratio (GFR*) determined at room level is defined as the sum of the corrected glass-to-floor ratio of each individual window in relation to the total floor area. The formula for determining GFR* is given below (2).

$$GFR^* = \frac{\sum_{n=1}^{p} A_g^*}{A_f} \qquad (2)$$

A_g is the area of the glazed or transparent parts of the building envelope, A_f is the total area of floor surface (m^2) and p is the number of daylight openings in the considered space.

The input parameters to be identified for each daylight opening in the room are:

- α : Average obstruction angle, determined at the center point of the glazing between a horizontal line and the upper point of any obstruction elements located within 45° of the vertical normal plane on the plane of the glazing (unit: degrees)
- φ : Slope of building envelope where daylight openings are located. A vertical façade plane has a slope of 0°, while a horizontal plane has a slope of 90° (unit: degrees)
- ϖ_v : Obstruction angle in a vertical plane between the outer edge of the masking element and the center point of the glazing (unit: degrees)
- ϖ_h : Obstruction angle in a horizontal plane between the outer edge of the masking element and the center point of the glazing (unit: degrees)
- τ_v : Light transmittance of the glazing determined according to EN 410:2011 (-)
- d : Wall thickness at window opening or average dimension of the building envelope if the wall thickness is not constant (unit: mm)
- D : Average room depth measured from glazing plane (unit: m)

Knowing the simplified daylight evaluation method uses a modified ratio of the glazing surface the results are not directly comparable to the assessment method of the daylight standard which determines daylight factors on a horizontal reference plane. However, the relative classification of different configurations should be equivalent when assessed with both methods. The verification of daylight provision was assessed for a selection of 124 cases which are considered representative for residential buildings. First the median daylight factor on the reference plane and the minimal daylight factor, excluding the 5% lowest values, have been determined with the daylight factor method (method 1 in Annex B of the European standard EN 17037:2018). The advanced raytracing software LightTools (Synopsys 2021) was used for the simulations of daylight illuminances levels across the reference plane. Precise geometrical models, detailed optical characteristics of surfaces and physically modelled material properties are essential to correctly evaluate the impact of different parameters. The variable parameter settings were meant to study the sensitivity on the simulation results and to identify their effect. The analysis of the main parameters on daylight provision in an indoor space allowed to extract the correction factors determination formulas. Finally, the corrected Glazing-to-Floor ratios (GFR*) were calculated according to equations (1) and (2) and the correction factors formulas given in Table 2.

Geometrical configurations and materials

The daylight simulations are carried out for typical rooms with a rectangular floor plan. Three basic types for the geometry have been taken. These typologies should cover the most common situations for dwellings in the European context (Figure 1).

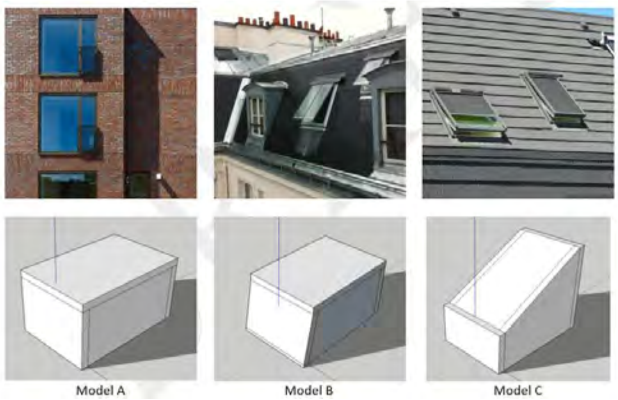

Figure 1. Geometrical models for the testcases

- **Model A**: A simple parallelepiped volume with vertical façades, which is the most typical case for spaces in apartments as well as for many individual houses,
- **Model B**: A volume with a 10° inward sloping façade, which is often encountered in "mansard" type of rooms at the upper level of buildings,
- **Model C**: A volume with a 30° to horizontal sloping roof, which is a frequent condition for rooms on the upper level in detached or semi-detached housing, but also in urban houses.

The depth of the room is made variable, but some other geometrical features were fixed to limit the number of possible configurations. The width of the basic room was fixed at 3,60 m and the height between internal finishes was 2,80 m, except for the model C with the sloping roof where the minimum height was set to 2,00 m. The daylight openings were always placed in the (nearly) vertical shortest wall for models A et B and in an approximately central position in the roof plane for model C.

All the surfaces in the model were assumed achromatic and with a diffuse reflection pattern. The light reflectance was chosen at 20%/50%/70% for respectively the floor, the walls, and the ceiling. The window reveal surfaces, including the sill, stiles and head, all have diffuse reflecting properties and a reflectance value of 50%. Although room surface reflectance is an important factor influencing the distribution of daylight into a real space it is often very difficult to obtain reliable data. In preliminary design phases where the final fit-out is not defined yet designers need to work with realistic reflectance values and therefore recommended default values of the standard EN 17037 were used. The general strategy should always be to fix relatively unfavourable reflectance values in the preliminary phases of the design in order to on the safe side for daylight provision and to allow for multiple types of interior finishing in the final project.

Sky model and climate data

The sky condition for the verification is a standard Overcast Sky (Type 1) as specified in the international standard ISO 15469:2004 (ISO 2004). The sky is modelled for the daylight simulations as a continuous sky with a resolution of 5° for the reference points. Intermediate sky luminance values are calculated by interpolation. The selection of rotational symmetric sky luminance distribution pattern means that the orientation of the test room is not relevant, and so the position of the façade does not have an impact on the results. The outdoor horizontal illuminance level considered is taken according to the table A.3 in the Annex A of the standard EN 17037. The yearly median external diffuse illuminance for Brussels is 15000 lx and it is 16000 lx for Luxemburg.

VARIABLE PARAMETERS

This study examined daylight provision in a typical room and the main factors impacting daylight access. Six variable parameters were selected for analyzing the sensitivity on daylight provision. A reference value and a limited number of other representative values are proposed for each identified variable.

Site conditions

Obstructions to the sky vault can be caused by artificial elements (buildings, infrastructure, etc.) or natural elements (vegetation, mountains, etc.) in the direct environment. To simulate the effect of external site conditions different average obstruction angles were defined. These site conditions represent situations ranging from open landscapes or unobstructed positions in urban areas (high buildings or buildings along large avenues and open spaces) to more enclosed situations in a denser built environment. The geometrical obstructions are modelled in the simulation tool with a cylindrical masking surface of a constant height and diameter around the model.

Masking elements

Masks are nearby obstructions such as overhangs, balconies, or any other permanent construction elements in the field of view. To simplify, the masking effects are divided into two categories, horizontal or vertical elements. Besides a reference configuration free of masking effects we consider a situation with a continuous vertical mask, representing, for example, a condition with side fins or an L-shaped building and a situation with a continuous horizontal mask, representing, for example, an overhead balcony, cantilevered upper stories or any other projecting elements. 19 out of the 124 testcases were assessed with vertical or horizontal masking elements. Masking elements are characterized by their obstruction angles in a vertical or horizontal plane.

Room depth

The dimensions of a space, and more specifically the depth relative to the façade plane, is obviously important when trying to ensure uniform daylight levels. Because it is the proportion of the room depth to height that matters most when bringing daylight to areas further away from openings, a fixed room height (2,80m) is taken. This means that spaces with atypical internal dimensions, such as very high rooms, are not considered. Three situations are considered for the depth of the space, resulting in three depth-to-width ratios. The reference case is a room where the depth equals the width, this is called the "Small" room. For the next cases the room depth is increased to a depth of 1,4 and finally 1,8 times the width. These conditions represent respectively a "Medium" room and a "Deep" room.

Windows area

A typical two-window side-by-side configuration was assessed because this represents probably one of the most common cases in residential spaces. For a same glazing area, the more the surface is split into smaller windows the more the daylight provision is affected. Windows are always placed in the shortest wall of the room and no double exposure was tested. Four distinct window sizes are evaluated labelled "Minimum", "Small", "Medium" or "Large" depending on the geometrical case is with (nearly) vertical windows or if rooflights are included (Table 1). The models with daylight openings in the roof plane (Model C) also contain a set of cases with a combination of a roof light and a window in the vertical façade plane.

Table 1. Window properties, GWR, and uncorrected GFR

Models A /B	Small windows	Medium windows	Large windows
Window size	0,6 m x 2,1 m	0,9 m x 2,1 m	1,2 m x 2,1 m
	Glazing-to-Wall ratio (GWR)		
	25,0 %	37,5 %	50,0 %
Room depth	Glazing-to-Floor ratio (GFR)		
Small	19,4 %	29,2 %	38,9 %
Medium	13,9 %	20,8 %	27,8 %
Deep	10,8 %	16,2 %	21,6 %

Models C	Minimum windows	Small windows	Medium windows
Window size	0,6 m x 1,2 m	0,9 m x 2,1 m	0,9 m x 2,1 m 1,0 m x 1,0 m*
	Glazing-to-Wall ratio (GWR)		
	14,3 %	25,0 %	37,0 %
	Glazing-to-Floor ratio (GFR)		
Small	11,1 %	19,4 %	23,0 %
Medium	7,9 %	13,9 %	16,5 %
Deep	6,2 %	10,8 %	12,8 %

* Window placed in a vertical plane

Glazing properties

The light transmittance is also an important factor for reaching the required illuminance levels in a room. High glazing transmittance is necessary, in particular for achieving minimum illuminances in deeper areas of the rooms. Typical glazing types for buildings are spectrally neutral in the visual range and clear (no diffusion of light). Optical properties of glazing are measured in laboratories and communicated on the specification sheets of window glazing units. It should be noted that no window framing is considered for this study. Three generic values of light transmittance were used in the considered cases, 60%, 70% and 80%. The angular variations of transmittance are calculated in the simulations using the physical properties of glass (refraction index n equals 1,52 and a constant extinction coefficient k).

Wall thickness

The wall thickness at the daylight opening impacts the amount of direct light coming in from sky elements in many positions inside the room. It also has an effect on the reflected light on window reveals that reaches the interior volume, because multiple reflections reduce drastically the power of a light ray. The effect of wall thickness is related to the window size, but since good agreement is reached these parameters can be considered independently for most typical window sizes. The window openings all have right angles except for the cases with a slightly sloping façade (Models B) where the window-sill and head remain horizontal while the façade is inclined. The reference wall thickness is fixed at 400 mm, which is a common value for recent residential constructions. The values taken for the calculations increase with steps of 100 mm up to a wall thickness of 1000 mm.

RESULTS

The target daylight factor in relation to the uncorrected GFR are given in Figure 2 for each testcase without masking elements. The thick horizontal red line, D_T = 2,0 %, represent the target daylight factor to be reached for a minimum performance level in the climate for Belgium according to the standard EN 17037:2018. For different climates, other daylight targets are recommended in the standard. A total of 41 out of the 105 cases, which represent 39% of the defined cases, do not meet the minimum target level of the standard. For all cases of this study with (nearly) vertical daylight openings (Models A and B) it is impossible to reach the median daylight target level of 2% if the uncorrected glazing-to-floor ratio is below a value of 21%. In particular, when site obstructions correspond to a higher class (class D), the median daylight factor could never reach the target daylight factor of 2%, even if highly reflective surfaces are used. Meanwhile, all models with daylight openings in the roof plane show median daylight factors which easily pass above 2%, except for one case with minimal windows in a large room under very obstructed site conditions. The main reasons are that daylight openings that are close to horizontal receive more daylight than vertical openings under an overcast sky model and also that the resulting distribution of illuminances on a horizontal reference plane is more uniform.

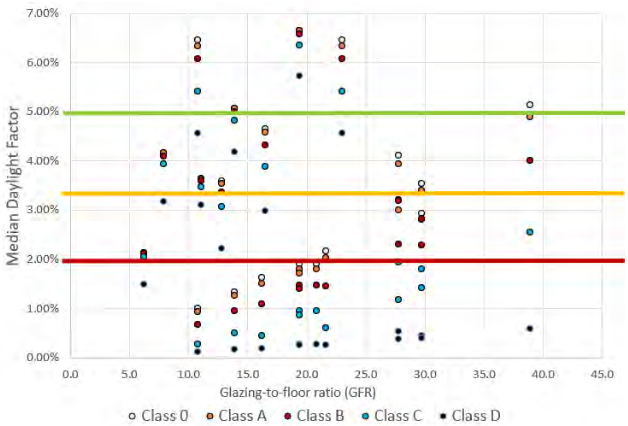

Figure 2. Median daylight Factors in relation to the uncorrected Glazing-to-Floor ratio for the 105 case without obstruction.

One of the main findings of the study for the sensitivity of the results is that some parameters have significantly more impact than others. The total area of daylight openings, the light transmittance of glazing, and the room depth are important factors. But external obstruction due to site conditions is certainly essential and frequently overlooked. On the other hand, masking elements, except for unusual situations such as extreme protruding elements in relation to the size of the daylight openings, have limited impact on daylight provision. Masking elements, with obstruction angles below 12°, reduce daylight provision by less than 5%.

The effect of changing the glazing transmittance was only demonstrated on one geometrical configuration as this effect is close to a linear function when varying the light transmittance values. This is mainly because in an overcast sky condition the light rays are reaching the glazing relatively equally from all directions and all opaque surfaces are perfectly diffuse reflecting in the model. With higher site obstruction levels daylight provision starts to diverge from this perfect linear relation. The effect of glazing transmittance is much more complex to assess with non-diffuse materials and under clear sky.

In Figure 3 a comparison of the results from simple assessment method implementing the evaluation with correction factors and the normative method given in EN 17037:2018 is shown. The cases are ranked according to their median daylight factor calculated with the simulations. The median daylight factor values are shown with the full line on the left-hand scale and the corrected glazing-to-floor ratio GFR* with individual points on the righthand scale. The dotted line represents the linear trendline for the simplified method results. It follows the curve of median daylight factors determined with the simulations.

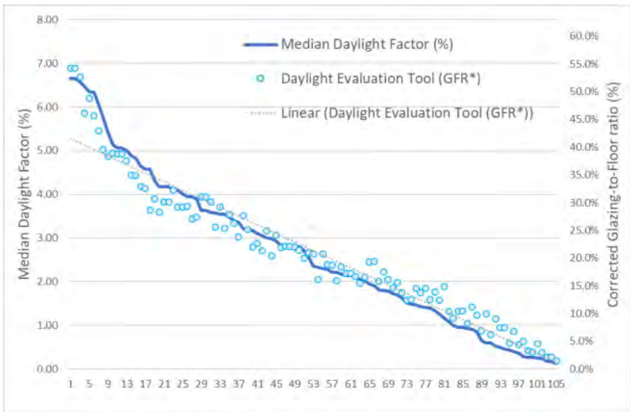

Figure 3. Comparison between simplified method (GFR) on right Y-axis and daylight provision calculation according to EN 17037:2018 (Median Daylight Factor) on left Y-axis*

Excluding the cases with the highest daylight provision the GFR* values are close to the linear trendline of the results with the detailed simulation method. The cases ranked from 1 to 9 are all cases with larger daylight openings in the roof and do not match the trendline, but the GFR* value still match well with the target daylight factor. The maximal deviation between the calculated GFR* and the expected value based on the trendline is in the order of 5 units and on the average difference is 0,5 units. The resulting R^2 value is 0,93. In general, the cases with a combination of rooflights and a vertical window (Model C with medium windows) are the most difficult to predict with a simple method and therefore they are diverging the most from the simulation results.

CLASSIFICATION

The modified glazing-to-floor ratio (GFR*) obtained with the simplified daylight evaluation method could be used for classification purposes. A daylight performance rating or score could be attributed based on the GFR* values for a space and this would represent a step forward from most of the actual building regulation schemes which are blind for the contextual parameters. This rating could be presented in as a graphical scale, frequently used in energy rating schemes, which requires that cases are sorted out into separated categories. For the daylight provision criteria the proposed classes could be defined from A to G with the class A representing the highest performance. This rating could be established so that the scales C and higher comply at least with a minimum performance level according to the European standard for the given geographical locations. The threshold values between classes C and D would then be set at a GFR* value of 17% for an equivalent target daylight factor of 2,0%. If we focus strictly on this threshold only 6 cases would be classified in the wrong class for Brussels when using the simplified tool compared to the standard assessment method. An example of visualization of the classification in given in Figure 4

Room Name	Room Area (m²)	Corrected Glass Area (m²)	Room Score (%)	Room Ranking
Case 1	23.3	6.1	26.2	B

Figure 4. Example of Daylight score and classification

DISCUSSION

A simple assessment is useful to help determine quickly the quantitative aspects of daylight in buildings in which more sophisticated daylight simulations are not used, e.g. single-family housing or existing dwellings that will be renovated. The daylight evaluation method proposed here is also particularly interesting for preliminary design or building rating purposes. However, it is important to remind that the European standard EN 17037:2018 also defines methods and recommended values for three other criteria which are more about the qualitative aspect of daylight (Deroisy 2017). These extra criteria are view out, exposure to sunlight, and glare. In further design stages, these should be considered and evaluated. In a broader perspective daylighting should also strive to integrate both visual and non-visual effects, producing physiological and/or psychological benefits upon humans. Due to benefits and risks that can occur it is recommended that both are considered in the lighting design process.

The other main advantage of the 'Daylight Evaluation' tool is that all the essential parameters are made explicitly visible for the users. This could help them to appreciate the impact of each parameter setting and enable them to adjust iteratively when possible to reach a desired or requested final target level. When integrated into a software tool the calculation speed could be much higher than with detailed raytracing simulations.

The limitations of this simplified approach are related to the methodology used and the reduced set of test cases verified, which does not allow to generalize to every possible case. More cases should be assessed to confirm the reliability of this method and to extend its applicability. A particular issue is related to the complex interactions of the different parameters when combined in a case. For example, the impact of masking effects is not independent of the exposure condition and the chosen site obstructions. Other parameters also have an effect on daylight provision and could also be included. For example, mobile solar shading solutions are neglected but have a significant impact on daylight provision. The daylight performance with solar shading systems is highly dependent on the product type and its installation mode and is probably too complex to integrate for the objectives we pursued. Furthermore, the selection of a standard overcast sky as model as reference also restrains the application of the method to building sites where sky luminance conditions are predominantly overcast. For a more detailed evaluation of daylight provision, the calculation of daylight illuminance should focus on a set of various representative sky conditions for each geographical location, including at least clear and intermediate skies. Calculating daylight provision with a selection of representative exposure conditions could help to account for the orientation of the facade and give value the possible beneficial effects.

CONCLUSIONS

The main outcome of this study is that a simplified method for assessing daylight provision as proposed in the 'Daylight Evaluation' tool gives a reliable estimation for daylight provision in a typical individual space. The method is limited to situations that have comparable characteristics as defined for this study. The cases for which the method is appropriate are essentially restricted to: square or rectangular floor plans, symmetric and centrally placed windows and room surfaces with typical diffuse reflectance properties. Knowing these restrictions, the simple assessment offers a relatively good indication of illuminance levels by daylight in a space.

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Table 2. Correction factors determination formulas, input parameters and reference values.

Factor	Description	Input parameter(s)	Reference value	Correction factor
C1	Glazing type	τ_v : light transmittance	$\tau_v = 0,80$	$C1 = \tau_v / 0,80$
C2	Wall thickness	d : wall thickness with $d \leq 1000$ mm	d = 400 mm	$C2 = -0,0003d + 1,12$
C3	Site obstruction	α : Average obstruction angle with $0° <= \alpha <= 45°$ φ : Slope with $0° <= \varphi <= 90°$	No obstructions ($\alpha = 0°$) Vertical façade ($\varphi = 0°$)	$C3(\varphi = 0°) = -0,00029\alpha^2 - 0.005\alpha + 1$ $C3(\varphi = 10°) = -0,00023\alpha^2 - 0,005\alpha + 1$ $C3(\varphi = 30°) = -0,00021\alpha^2 + 0,0015\alpha + 1$ $C3(\varphi = 60°) = -0,00018\alpha^2 + 0,0025\alpha + 1$ $C3(\varphi = 90°) = -0,00012\alpha^2 + 0,0018\alpha + 1$
C4	Overhangs	ϖ_v : Vertical obstruction angle with $0° \leq \varpi_v \leq 70°$	$\varpi_v = 0°$	$C4 = -0,0003\varpi_v^2 + 0,0066\varpi_v + 1$ $C4 = 0,46$ if $\varpi_v \geq 55°$
C5	Side masks	ϖ_h : Horizontal obstruction angle with $0° \leq \varpi_h \leq 90°$	$\varpi_h = 12°$	$C5 = -0,0045\varpi_h + 1$ $C5 = 0,75$ if $\varpi_h \geq 55°$
C6	Solar shading	Not considered		$C6 = 1$
C7	Room depth	D : room depth with $D < 10$ m φ : Slope	D = 5 m	$C7 = 1$ if $D < 5$ m or if $\varphi \geq 30°$ $C7 = -0,1D + 1,5$ if $D \geq 5$ m and $\varphi < 30°$
C8	Slope	φ : Slope	Vertical façade ($\varphi = 0°$)	$C8 = 1$ if $\varphi \leq 10°$ $C8 = -0,00032\,\varphi^2 + 0,055\,\varphi + 0,64$ if $\varphi > 10°$