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SIMPLIFIED METHOD BASED ON THE DIFFUSE LIGHT AVAILABILITY TO ESTIMATE THE BUILDINGS DAYLIGHT HARVESTING POTENTIAL

ABSTRACT

This work verified the potential of using the temporal Daylight Factor to estimate the lighting energy consumption of environments with different volumetries, types of openings and distribution of photosensors. Such potential was verified against the annual computer simulation based on climate, through a case study for Florianopolis. Six parametric scenarios were evaluated, whose variations included the depth of the environment, the size of the opening and the operation area of the photosensors. The method assumes that a single point of analysis, associated with the control zone of the photosensor and located in the portion of the zone furthest from the opening, is adopted to estimate lighting energy consumption. The choice of this point proved to be valid, depending on the depth of the sensor's coverage area and the window size. In general, the results underestimated the daylight use. It was concluded that the method has the potential to be applied with errors of ~10%, defining a minimum opening area and limiting the depth of the zones to ~1.5 X the height of the lintel. Thus, it is recommended as future work to validate it based on a greater number of variables.

KEYWORDS

Daylighting. Simplified method. Diffuse daylight illuminance. Lighting energy consumption.

[1] In this work, the term photosensor was used to characterize control devices of the lighting system as a function of natural light.

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MÉTODO SIMPLIFICADO BASEADO NA DISPONIBILIDADE DE LUZ DIFUSA PARA ESTIMAR O POTENCIAL ENERGÉTICO DO APROVEITAMENTO DA LUZ NATURAL EM EDIFICAÇÕES

Este trabalho verificou o potencial da utilização do Fator de Luz Diurna temporal para a estimativa do consumo de iluminação de ambientes com diferentes volumetrias, tipos de aberturas e distribuição de fotosensores[1]. Tal potencial foi verificado frente à simulação computacional anual baseada no clima, por meio de um estudo de caso para Florianópolis. Avaliaram-se seis cenários paramétricos cujas variações contemplaram a profundidade do ambiente, o tamanho da abertura e a área de atuação dos fotosensores. O método assume a premissa de que um único ponto de análise, associado à zona de controle do fotosensor e localizado na parcela da zona mais distante da abertura, é adotado para estimar o consumo de iluminação. A escolha desse ponto mostrou-se válida, dependendo da profundidade da área de abrangência do sensor e do tamanho da janela. Em geral, os resultados subestimaram o aproveitamento da luz natural. Concluiu-se que o método tem potencial para ser aplicado com erros de ~10%, definindo-se uma área mínima de abertura e limitando-se a profundidade das zonas em ~1,5 X a altura da verga. Assim, recomenda-se como trabalhos futuros a sua validação com base em um maior número de variáveis.

Palavras-chave

Iluminação natural. Método simplificado. Componente difusa. Consumo de iluminação.

1. Introduction

Day lighting stands out for its qualitative and energetic potential. As for the qualitative aspect, good lighting conditions can increase the productivity and comfort of users of buildings, which have a proven preference for naturally lit environments (EDWARDS; TORCELLINI, 2002; MAYHOUB; CARTER, 2011). Its impact on occupants' health is added due to the non-visual effects of light on the circadian cycle, which regulates a wide range of behavioral and physiological functions (KONIS, 2019).

The energy potential of taking advantage of day lighting by reducing the use of the lighting and air conditioning system is a consolidated theme. The 21st century was marked by the diffusion of LEDs, consisting of an important advance for the energy efficiency of buildings. However, there are still uncertainties regarding the quality of these systems, both in relation to the light offered, as to their durability, and consequently, of their real efficiency. Thus, the use of natural lighting should not be wasted, especially due to its potential to reduce peak demand. Even the most advanced countries in regulating the quality of LED systems, encourage the use of natural light (TITLE 24, 2019). This is because the lighting system is still responsible for about 1/3 of the energy consumption of commercial buildings and varies between 1/3 and 1/8 in residential, depending on the type of water heating (CEC, 2019).

To optimize the energy use of natural light, factors related to the implementation of the building must be considered, such as climatic conditions and surrounding obstructions, those inherent to the architecture itself and to the lighting project. As for the lighting project, the sectorization of the lighting system according to the availability of day light itself, already has great potential for energy savings, allowing the user to operate such system in line with the supply of natural light. The use of photosensitive control systems reduces the time of use or the activated power, based on data measured in real time. Regardless of the type of control, manual or automatic, the integration between both natural and artificial lighting systems is essential. Thus, it becomes necessary to know the behavior of natural light in the environment and define the areas with potential for integration (ROCHA, 2012). One of the reasons why control systems are not considered effective is their inadequate application, with little criterion for the definition of how and where they should be installed (ROCHA, 2012).

Parise et al. (2016) showed a variation of up to 50% in lighting consumption when experimenting with different lighting scenarios for the same internal space, varying only the mode of activation and the arrangements of the photosensors. In the same context, Moraes (2012) obtained an energy saving potential of 46% due to the integration between the systems, while Rocha obtained 62%.

The characterization of the luminous performance of buildings is complex, since the interaction between climate and architecture involves dynamic phenomena. Currently, climate-based daylight modelling (CBDM) is the most used method to evaluate such performance. CBDM is the prediction of any luminous quantity, using realistic sun and sky conditions, derived from standardized climatic data (MARDALJEVIC, 2000, REINHART and HERKEL, 2000). Assessments using CBDM are generally carried out for an entire year, in a time interval of one hour or less, to capture the daily and seasonal dynamics of daylight (MARDALJEVIC E CHRISTOFFERSEN, 2017). Such assessments are made only by computer simulation and require programs with specific capabilities, a high degree of detail and are limited to specialized professionals.

To circumvent such specificities and enable the assessment of the luminous performance of buildings, the European standard prEN 17037:2018 (CEN, 2018) offers an alternative to this type of simulation (Method 2 of the standard), a provision calculation method of natural light for indoor environments based on the temporal daylight factor (DF) (Method 1 of the standard). The method uses diffused external illuminance climatic information to determine the DF values that will be needed to reach a target illuminance for a certain period of the year (MARDALJEVIC, 2000). It was understood that, despite its limitations, DF is a widely used parameter, easily obtainable, with a wide range of free computational tools and easy operation (ex: Dynamic Daylighting (MARSH, 2016) and Daylight Visualizer (VELUX, 2009) The inclusion of the temporal dimension to the DF broadens its scope, bringing information about the availability of light from the building's implantation site. The method was presented as a more accessible way to estimate the performance of buildings, which can be used by a greater number of professionals, enabling the dissemination of the standard.

Based on this concept, AUTHORS (2019) proposed an alternative application for temporal DF, aiming to estimate consumption reduction due to the use of the daylight. The proposal was tested against a single volume, considering three different cities and two types of lighting sensors, dimmable and motion sensors, as well as the influence of the zoning discretization of the areas controlled by the sensors. The results obtained by applying the method underestimated the use of natural light. The precision obtained for estimates of the primary natural light zone resulted in errors of less than 7% for all cities and orientations, being considered adequate for a simplified method. In this sense, the present work aims to deepen the proposal by investigating the potential application of the temporal daylight factor to estimate the lighting consumption of environments with different volumetries, types of openings and distribution of lighting sensors.

2. Objective

To verify the potential of using the temporal Daylight Factor to estimate the lighting consumption of environments with different volumetries, types of openings and distribution of photosensors.

3. Method

To achieve the proposed objective, the potential of the simplified method based on the temporal DF was verified through a case study, comparing its results with those obtained by the annual computational simulation CBDM. The method of this work was divided into three stages: the presentation of the case study; the conceptualization of the simplified method; and the evaluation of its potential.

3.1 Case study

The case study consisted of a regular geometry environment, located in the city of Florianópolis. It is an environment with a ceiling height of 3m and a single centralized opening horizontally, located 1.1m from the floor, with lintel at 2.10m. For the definition of the project illuminance, the classroom activity was attributed to the space, whose illuminance corresponds to 300 lux (ABNT, 2013). An occupation period of 10 hours was established, from 8 am to 6 pm, throughout the year. The Lighting Power Density (LPD) adopted was 15.5 W/m², corresponding to class D for schools using the INI-C complete building method (INMETRO, 2018). The use of daylight was computed by means of photosensors of ideal dimerization. The power controlled by the sensors varied between scenarios.

For the creation of parametric scenarios, the size of the opening, the depth of the environment and the area of operation of the photosensors were varied. All scenarios were evaluated in the four cardinal orientations, totalizing 24 analyses. The three-dimensional modeling was done using the Rhinoceros software.

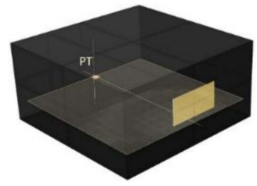
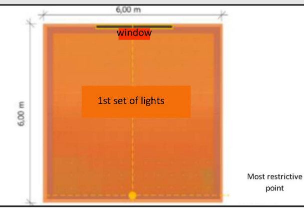
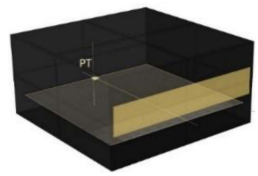
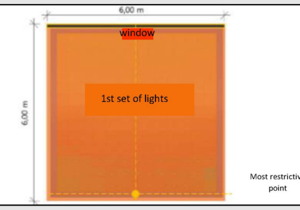
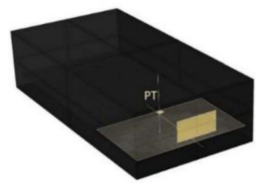
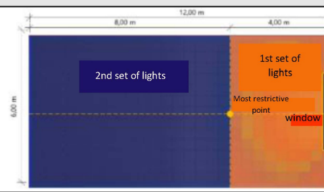
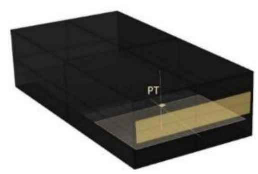
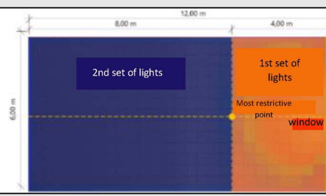
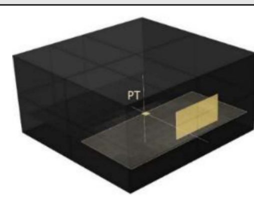
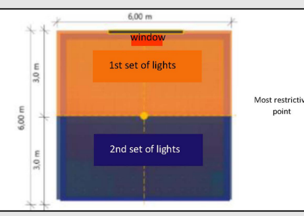
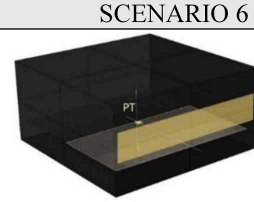
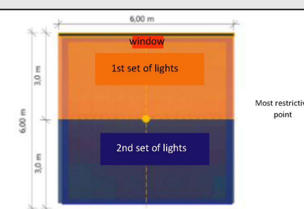
The variation in the opening area aimed to assess the impact of increasing the size of the light source. The height of the lintel and the sill were fixed, increasing its dimension to the sides, extending to the maximum limit of the lateral ends of the facade. The opening of the base case corresponded to 1/3 of the width of the facade, making it possible to verify how much the natural light zone expands to the sides of the opening.

The depth variation aimed to test different geometries, making it possible to compare a 1:1 and 1:2 environment (width:depth). The variation in the operation area of the photosensor aimed to assess the impact of the criterion of its definition on the lighting energy consumption.

Scenario 1 consists of the base case (Table 1). Scenario 2 addresses the variation in the size of the opening; scenario 3, the variation in depth and distribution of sensors in relation to case 1; scenario 4 is similar to scenario 3, including the variation in the size of the opening; scenario 5, only the distribution of sensors varies in relation to case 1; and scenario 6 is similar to scenario 5, adding the variation of the opening size. The following is a summary of the 6 scenarios depending on the area of operation of the photosensors:

Scenario 1 and Scenario 2: The isometric plan models, with the two variations of opening, were evaluated with all the installed power controlled. Therefore, for these cases, the total area of the environment corresponds to the zone controlled by the photosensors (Z_{ILN}).

Table 1. Characteristics of the Scenarios

SCENARIO 1		
Dimensions(m): 6,0 x 6,0 Area (m²): 36,0 Opening (m²): 2,0 x 1,0 POF*(%) :11,1 POFO*(%): 5,5		
SCENARIO 2		
Dimensions (m): 6,0 x 6,0 Area (m²): 36,0 Opening (m²): 5,8 x 1,0 POF*(%): 32,2 POFO*(%): 16,1		
SCENARIO 3		
Dimensions (m): 6,0 x 12,0 Area (m²): 72,0 Opening (m²): 2,0 x 1,0 POF*(%): 11,1 POFO*(%): 2,8		
SCENARIO 4		
Dimensions (m): 6,0 x 12,0 Area (m²): 72,0 Opening (m²): 5,8 x 1,0 POF*(%): 32,2 POFO*(%): 8,1		
SCENARIO 5		
Dimensions (m): 6,0 x 6,0 Area (m²): 36,0 Opening (m²): 2,0 x 1,0 POF*(%): 11,1 POFO*(%): 5,5		
SCENARIO 6		
Dimensions (m): 6,0 x 6,0 Area (m²): 36,0 Opening (m²): 5,8 x 1,0 POF*(%): 32,2 POFO*(%): 16,1		

*POF- Percentage of opening area by facade area
*POFO- Percentage of opening area per floor area

Scenario 3 and Scenario 4: The rectangular floor plan models, with the two variations of opening, were evaluated with one-third (?) of the controlled installed power. That is, one third of the area of the environment close to the opening corresponds to the zone controlled by the photosensors (Z_{ILN}), while the remaining two thirds (?) do not have controls (Z_{IA}). In these cases, the area of natural light corresponds to approximately 2x the height of the lintel, a value disseminated as a rule of thumb (REINHART and LOVERSO, 2010, CALIFORNIA ENERGY COMISSION, 2016).

Scenario 5 and Scenario 6: The isometric plant models, with the two variations of opening, were evaluated with half (½) of the controlled installed power. That is, half the area of the environment close to the opening corresponds to the zone controlled by the photosensors (Z_{ILN}), while the remaining half (½) has no control. In these cases, the area of natural light corresponds to approximately 1.5x the height of the lintel, a value also disseminated as a rule of thumb (CIBSE, 1999, REINHART and LOVERSO, 2010).

3.2. Concept of the simplified method

The proposed method will be presented in comparison to the concept adopted by the European directive prEN 17037:2018 – European Standard for Daylight of Buildings (CEN, 2018). For this standard, an environment provides adequate natural lighting if target illuminance and minimum illuminance are achieved in a fraction of the analysis plan, in at least a fraction of the daytime hours. In this way, the spatial and temporal dimensions of natural lighting are assessed. Two methods are offered to verify the light supply and both apply the annual occurrence of an absolute value for internal illuminance, calculated from the availability of external horizontal illuminance, determined from climatic data at the evaluation site. Method 1 will be presented below and Method 2 deals with the computational simulation of CBDM illuminances.

Method 1, used in this work, estimates the percentage of the area of the environment in which a target DF ($DF_{50\%}$), associated with a target illuminance (E_{alvo}), here 300lux, is exceeded in at least 50% of the analysis period. The temporal dimension is accessed by the median diffuse external horizontal illuminance ($E_{EXT,50\%}$). $E_{ext,50\%}$ is defined by that illuminance that occurs in a

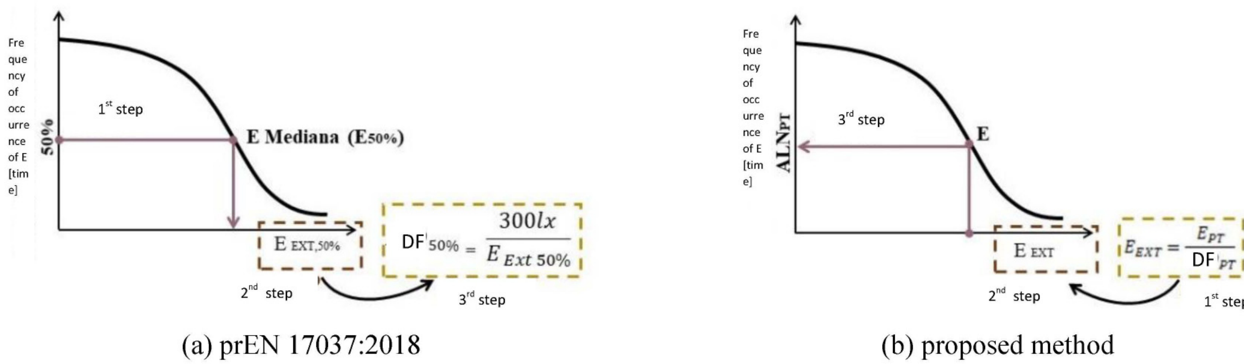


Figure 1 - Comparison between the European standard and the proposed method

location in at least 50% of the hours when natural light is available throughout the year (Figure 1a). To determine the value of $DF_{50\%}$ that must be reached to meet the standard, E_{alvo} is divided by $E_{EXT,50\%}$ of the site. The verification of the attendance of the $DF_{50\%}$ is done in a mesh of points of the analysis plan. The calculation can be done by graphic, analytical or computational methods, as long as it considers all the components of the luminous flux.

The purpose of this work assumes that the temporal dimension related to the provision of daylight could be associated with the operation of the photosensors. It was assumed that the artificial lighting system would only need to be activated during hours when E_{alvo} could not be guaranteed by E_{EXT} according to the DF of a point in the environment (DF_{PT}).

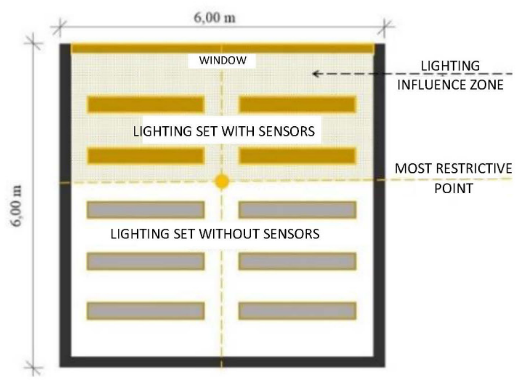
Considering that the reduction in the use of installed power, due to the use of natural light, can be done by controlling the power intensity or by its activation time, the use of E_{EXT} was adapted. Instead of adopting the $E_{EXT,50\%}$ as a reference value for calculating the $DF_{50\%}$ regarding E_{alvo}, it was used to estimate the time that the DF_{PT}, associated with a project illuminance (E_{PT}), is overcome (Figure 1b). The temporal dimension is accessed by the frequency curve of occurrence of the diffuse external horizontal illuminance. E_{PT} is obtained in the luminotechnical project, consisting of the illuminance adopted for the activation of the predicted photosensors.

Unlike the European standard, which assesses the spatial dimension of lighting, this proposal addresses the DF for one point. This point must be located in the region that receives less direct light from the openings, in the area where the photosensor operates. The area of operation of the sensors is obtained in the luminotechnical project, previously chosen by the designer. To characterize this point, is adopted the point furthest from the opening, which provides natural lighting to the sensor, be it lateral or zenith. The simplified method is restricted to environments of regular geometry with a single opening.

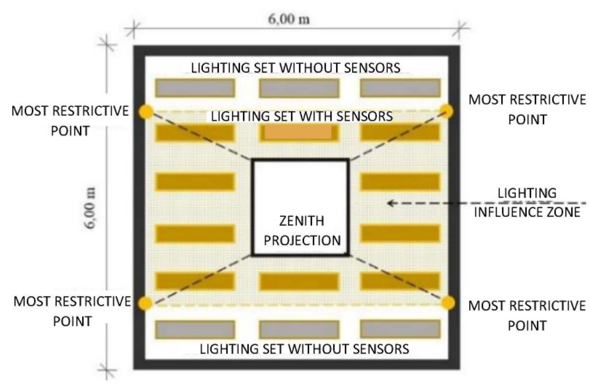
The frequency of occurrence of external illuminance that guarantees the DF calculated for the reference point, given in percentage, was called point's daylight autonomy (DA_{PT}). The complement of its value, corresponds to the percentage of the controlled power actually used. The installed power controlled by the photosensors was called lighting power in use (LPU) and its respective power density, power density in use (PDU). While the density of installed power (DIP) is associated with 100% of the power applied throughout the occupation period, PDU corresponds to the time or intensity of the power applied during the occupation period, depending on the use of natural lighting. The sequence for applying the proposed method is presented below. The Method consists of six steps and will be applied to each of the case study scenarios.

1st step: Identify the light availability checkpoint (PT) in the areas controlled by photosensors (Z_{ILN})

The point must be located on a horizontal reference plane, elevated 0.75m from the finished floor. For lateral lighting, the point furthest from the opening, measured perpendicular to the window that provides natural lighting to this set of photosensors, must be identified. For zeniths, the point of perimeter of the zone furthest from the limits of the zenith opening, seen in projection, must be considered.



(a) PT for lateral opening



(b) PT for zenith opening

Figure 2 - Example of PT location for lateral and zenith opening

2nd step: Calculate the daylight factor for the identified point (DF_{PT})

For this work, the DF_{PT} calculation at the verification points of each scenario was performed using the DIVA-for-Rhino plug-in. The DF_{PT} could have been obtained by simpler tools, especially since it is only a point of analysis. However, due to the work context involving computer simulation in the verification stage, it was decided to use the same program, since the modeling in the scenarios program would already be done for the following steps of the work.

3rd step: Calculate the external diffuse horizontal illuminance (E_{EXT}), necessary to guarantee the required illuminance inside the environment, according to the calculated DF_{PT}

From the obtained DF_{PT} value, the external diffuse horizontal illuminance (E_{EXT}) necessary to guarantee the illuminance at the point (E_{PT}) is calculated, according to Equation 1. The illuminance required at the point (E_{PT}) must be obtained in the luminotechnical project, in the case of this study, it was 300lux.

$$E_{EXT} = \frac{E_{PT}}{DF_{PT}} \qquad \text{Equation 1}$$

Where:

E_{EXT} – External diffuse horizontal illuminance (lx)

E_{PT} – Illuminance at the point (lx)

DF_{PT} – Daylight factor at point (%)

4th step: Check the daylight autonomy for the point (DA_{PT})

DA_{PT} corresponds to the percentage of hours of occupation of the environment attended only by daylight throughout the year. It is obtained through the frequency curve of occurrence of the E_{EXT} of the locality. This curve is made using E_{EXT} data from the city's climate file, based on the occupation hours in question. In the abscissa axis, the diffuse horizontal illuminance intervals are plotted and in the ordinate axis, the percentage of occurrence. For this study it will correspond to the Florianópolis curve, obtained by the climate file EPW-INMET (LABEEE, 2018), considering the occupancy period of 10h (8am – 6pm).

5th step: Calculation of Installed Power Density in Use of the Environment (PDU)

The calculation of the installed power density in use of the environment (PDU_E) is performed by weighting the installed power densities of the lighting zones by their respective area of influence, according to Equation 2. For this study, the DIP of the case study, 15.5 W/m² was adopted. PDU_E was calculated for each scenario.

$$PDU_E = \frac{[(A_{ZD} * DIP) + \sum_{i=0}^{n}(A_{ZDL} * (1 - DA_{PT})]}{A_A} \qquad \text{Equation 2}$$

Where:

PDU_E – Installed power density in use of the environment (W/m²)

A_{ZD}– Area of the zone devoid of daylight sensors (m²)

DIP – Original density of installed power (W/m²)

A_{ZDL} – Area of the zone with daylight sensors (m²)

DA_{PT} – Daylight autonomy for the point

A_A – Area of the entire thermal zone or portion of the building under evaluation (m²)

6th step: Calculation of Lighting Consumption

The lighting consumption, including the savings generated by the photosensors, consists of the product area of the environment by PDU_E, calculated in the previous item, by the number of hours of the occupation period, according to Equation 3. The occupation period adopted was that of the case study, 10h on 365 days of the year, and the area varied according to the evaluated scenario.

$$Consumption_{total} = \frac{(A_A * PDU_E * h)}{1000} \qquad \text{Equation 3}$$

Where:

Total consumption - Annual consumption (kWh)

PDU_E – Installed power density in use of the environment (W/m²)

h – Number of hours of occupation in a year

A_A – Area of the entire lighting zone or portion of the building under evaluation.

3.3. Evaluation of the method potential

The evaluation of the potential of the simplified method was made in comparison to the complete annual climate-based simulation. The autonomy of daylight and the annual consumption of lighting were simulated for the six scenarios, for the four cardinal orientations. The potential of the method was evaluated in two moments: to estimate the autonomy of the natural light of the point, the 4th step of the sequence of the method application; and to estimate the lighting consumption of the environment, 6th step. As the simplified method is not sensitive to variations in the orientation of the building, the influence of this variable was only considered in the computer simulation.

The simulations were performed using the DIVA-for-Rhino plug-in (SOLEMMA LLC, 2014) from the Rhinoceros program (MCNEEL; ASSOCIATES, 2014). The same climate files used to generate the frequency curve for the occurrence of diffuse external horizontal illuminance in the city of Florianópolis were adopted. The Radiance Parameters adopted for the computer simulation were: diffuse inter-reflections of the environment, 7; division of the environment, 1000; sampling of the environment, 256; accuracy of the environment, 0.1; resolution of the environment, 300; direct threshold, 0; and direct sampling, 0. The analysis plan was located at 0.75 m in relation to the floor, with a mesh of points distributed over the entire area, with 0.5 m spacing.

For the analysis of the results of the simulated natural light autonomy, the value obtained at the point corresponding to the one adopted for the verification of the simplified method (DA_{PT}) was sought in the mesh. The comparison between the results of both methods was made through the analysis of errors, considering the percentage error of the period and the error of the period.

The consumption values obtained by the simulation were compared to those obtained by the simplified method, generated from equation 3, presented in item 3.2. It is noteworthy that the Diva-for-Rhino program admits as the reference for calculating the ideal dimerization, the point of least illuminance of a luminous zone. In the case of this work, the point with the lowest illuminance of the set of points controlled by the sensor. The verification of the accuracy of the simplified method was performed by graphical analysis of simple correlation, individualized by orientation of the models of the case studies.

4. Analysis of results

4.1 Application of the simplified method to the case study

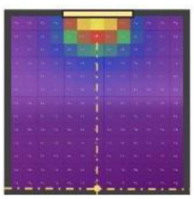
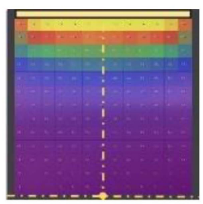
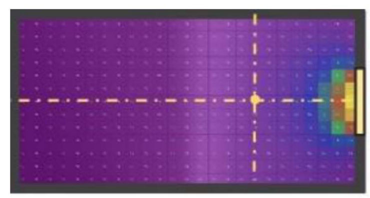
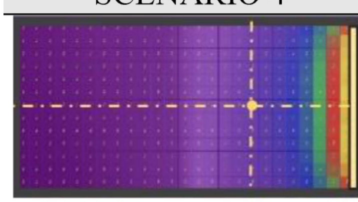
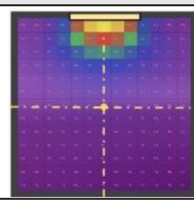
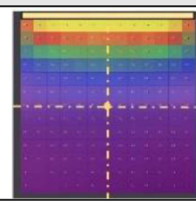
The results of applying the simplified method to the 6 scenarios will be presented in parallel for each of the 6 steps of the sequence established in item 3.2.

1st step: Identify the light availability checkpoint (PT) in the areas controlled by photosensors (Z_{ILN})

The most restrictive point for natural lighting in each zone controlled by sensors in the 6 case studies was identified, according to the criteria established in item 3 (1st step). The points were identified in Table 1 of item 3.1.

2nd step: Calculate the daylight factor for the identified point (DF_{PT})

Table 2 shows the values found at each checkpoint in the 6 scenarios presented.

SCENARIO 1	SCENARIO 2	SCENARIO 3
		
0,5%	1,1%	0,8%
SCENARIO 4	**SCENARIO 5**	**SCENARIO 6**
		
1,9%	1,2%	2,8%

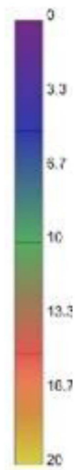


Table 2. Daylight factors at checkpoints

3rd step: Calculate the external diffuse horizontal illuminance (E_{EXT}), necessary to guarantee the required illuminance inside the environment, according to the calculated DF_{PT}

E_{EXT} was calculated by Equation 1. The target illuminance adopted was 300 lx and the DF_{PT} for each case were presented in Table 2. The results will be shown in Table 3.

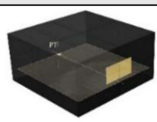
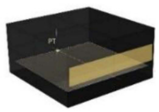
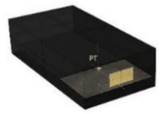
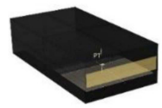
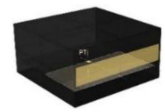
SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
					
60.000 lx	27.272 lx	37.500 lx	15.989 lx	25.000 lx	10.714 lx

Table 3. Diffuse horizontal illuminance values required in each PT

4th step: Check the daylight autonomy for the point (DA_{PT})

Figure 3 shows the frequency curve for the occurrence of external diffuse horizontal illuminance for Florianópolis. The processes for obtaining the graphic were described in item 3.2. The values of external diffuse horizontal illuminance (E_{EXT}), found in the previous step (Table 3), were located on the abscissa of figure 3, to determine the daylight autonomy for the point (DA_{PT}) on the ordinate axis.

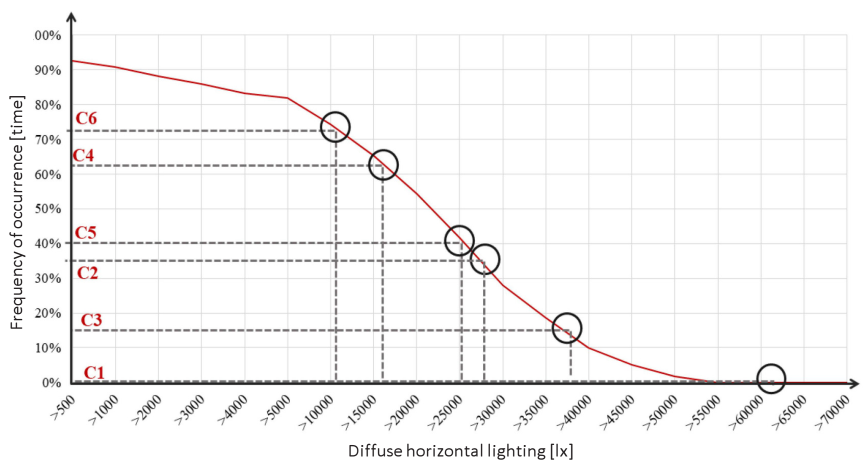


Figure 3. Daylight Autonomy - Florianópolis - occupation period 8 am - 6 pm

The DA_{PT} values found in the graphic, for each of the 6 scenarios, were highlighted in Table 4.

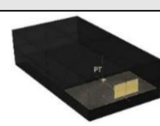
SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
					
0%	35%	15%	61%	40%	71%

Table 4. Daylight Autonomy, DA_{PT}, at the models checkpoint

5th step: Calculation of Installed Power Density in Use of the Environment (PDU_E)

For the calculation of PDU_E, Equation 2 was used. The values adopted for the input variables of the equation, as well as the results obtained, were presented in table 4.

6th step: Calculation of Lighting Consumption

The consumption calculation was made based on equation 3. Table 4 shows all the values adopted for the independent variables of the equation, for all scenarios. The results obtained were presented accompanied by consumption if there were no daylight sensors

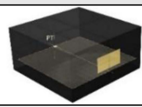
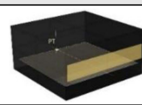
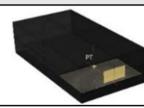
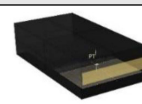
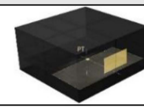
	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
						
A_{ZD}*	36 m²	36 m²	24 m²	24 m²	18 m²	18 m²
DIP*	15,5 W/m²					
A_{ZDL}*	0 m²	0 m²	48 m²	48 m²	18 m²	18 m²
DA_{PT} *	0%	35%	15%	61%	40%	71%
A_A*	36 m²	36 m²	72 m²	72 m²	36 m²	36 m²
PDU_E	15,50 W/m²	10,10 W/m²	14,73 W/m²	12,35 W/m²	12,40 W/m²	9,99 W/m²
Consumption with Lighting sensors	2036,70 KWh/year	1323,86 KWh/year	3869,73 KWh/year	3245,14 KWh/year	1629,39 KWh/year	1313,67 KWh/year
Total Consumption	2036,70 KWh/year	2036,70 KWh/year	4073,40 KWh/year	4073,40 KWh/year	2036,70 KWh/year	2036,70 KWh/year

Table 5. PDU_E and consumption values obtained for the analyzed models

PDU_E – Installed power density in use of the environment (W/m²)

A_{ZD}– Area of the zone devoid of daylight sensors (m²)

DIP – Original density of the installed power (W/m²)

A_{ZDL} – Area of the zone with daylight sensors (m²)

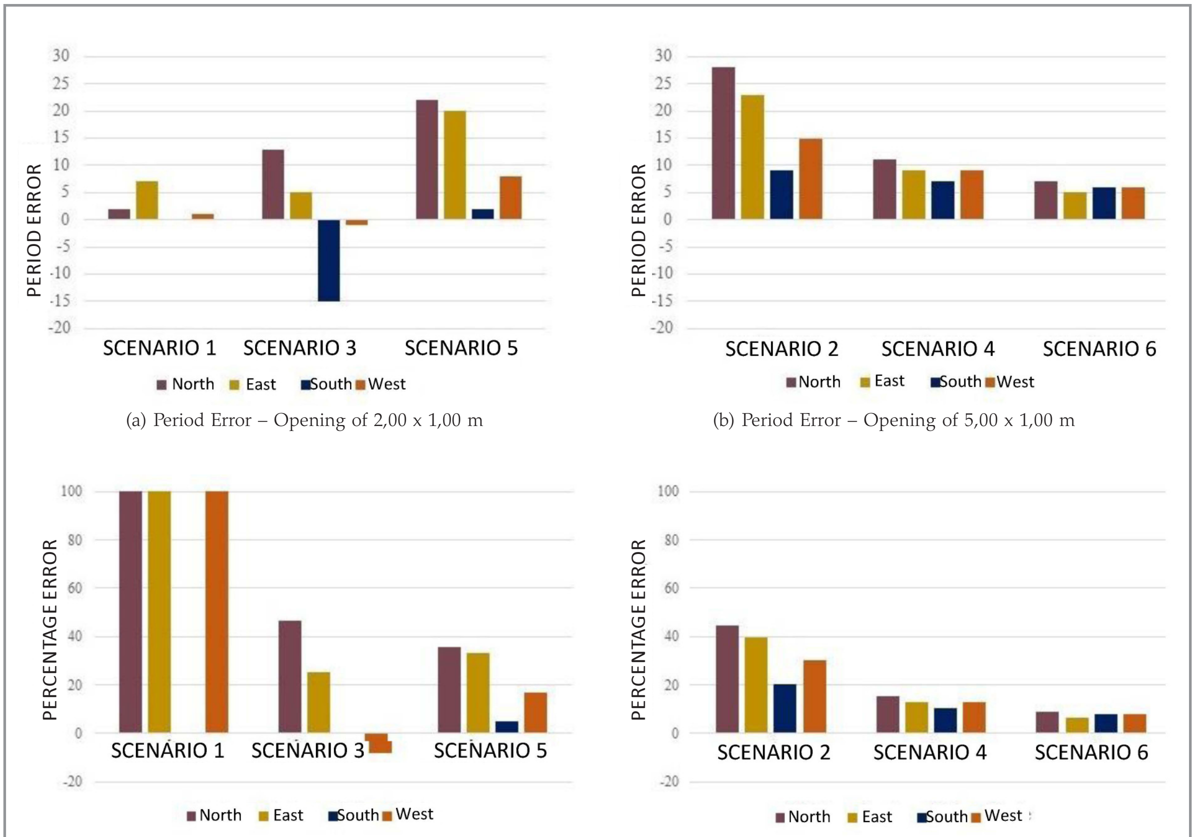
DA_{PT} – Daylight autonomy for the point

A_A – Area of the entire thermal zone or portion of the building under evaluation (m²)

4.2. Evaluation of the accuracy of the method in relation to computational simulation

4.2.1 Daylight Autonomy

In the graphics of Figure 4, a and b, the errors of the period attributed to the comparison of the daylight autonomy obtained by the simplified method and by simulation are presented. In Figure 4, c and d, the percentage errors for the same comparison are presented. It is worth mentioning that, in cases where the value of the DA obtained by simulation was zero, it was not possible to calculate the percentage error, since it uses the result of the simulations as a divisor. The results were separated according to the size of the opening of the analyzed cases. This differentiation was made to evaluate the method against the variation of the opening size, for similar cases.



(a) Period Error – Opening of 2,00 x 1,00 m

(b) Period Error – Opening of 5,00 x 1,00 m

(c) Period Percentage Error - Opening of 2,00 x 1,00 m

(d) Period Percentage Error - Opening of 5,00 x 1,00 m

Figure 4 - Error analysis of the Daylight Autonomy

The results presented in Figure 4 a and b show that the method had lower DA_{PT} values than those obtained by simulation, except for the south and west orientations of scenario 3. The underestimation of the DA_{PT} estimate by the simplified method was expected, since the method considers only the diffuse component of the light, while the simulation considers it in a global way. As it does not consider the different solar orientations, the method tends to generalize the results, which can affect its accuracy in relation to orientations that have very high or very low autonomy values for daylight, as occurred in case 3.

Looking at Figures 4 c and d, in general, there is a decrease in the percentage error of scenario 1, for scenario 3 and for scenario 5 (Figure 4c), and from scenario

2, for scenario 4 and for scenario 6 (Figure 4d). It is noteworthy that the distance from the analysis point in relation to the window is 6m, for scenarios 1 and 2; 4m, for scenarios 3 and 4; and 3m for scenarios 5 and 6. These results indicate that the precision of the method is inversely proportional to the distance that the point of analysis is from the opening, since the more distant the point was from the opening, the lower the precision of the method, regardless of the geometry of the environment. Small variations may occur, depending on the orientation, as occurred for scenarios 3 and 5, for the east and west facades. Such scenarios have identical facades, the difference of which lies in the depth of the environments, 12m for scenario 3 and 6m for scenario 5, and in the distance from the window analysis point, 4m for scenario 3 and 3m for scenario 5. This variation does not repeat when the opening is greater, as can be seen in the results of scenarios 4 and 6, for the same facades.

It was also observed that, in general, for similar scenarios, when the opening is greater, the errors are smaller. See the percentage errors, analyzed by facade, of scenario 1 compared to 2, scenario 3 compared to 4 and scenario 5 compared to 6. The western orientation of scenario 4 and the southern orientation of scenario 6 were exceptions of this observed trend, presenting percentage errors greater than its peers. In view of the findings presented, it appears that the method is less accurate for points with low light, regardless of the reason why it occurs.

4.2.2 Lighting Consumption

Figure 5 shows the correlation graphs between the lighting consumption results obtained by the simplified method and by the annual simulation. The graph points correspond to all the studied scenarios. The orientation that showed the strongest correlation between the results was to the west, with a coefficient of determination (R^2) of 0.9665 and the weakest, the east, with 0.884. These results indicate that the method has the potential to be applied to different orientations with similar performance. However, this potential must be confirmed by a representative statistical sample for the validation of the method.

The west and south orientations, which obtained the strongest correlation, consist of the orientations for which the simplified method overestimated the values of DA_{PT}, or presented smaller errors compared to the other orientations, as illustrated in the error graphs of the period in Figure 5a and 5b. The north and east orientations, on the other hand, with the lowest determination coefficient, presented the lowest consumption values, due to the greater daylight autonomy at the sensors reference point.

The method proved to be less precise for these orientations, precisely because it is the orientation in which direct radiation is most influential for Florianópolis. Again, it is justified, as the method considers only the diffuse portion of the light, while the simulations, consider it in its entirety. The consumption values of the environments obtained by weighting the lighting systems, using the 6th step of the simplified method and by the simulations, are shown in Figure 6.

6. Conclusion

This work verified the applicability of a simplified method, based on diffuse lighting, for estimating lighting consumption, through a case study. The validity of the choice of a single point, located in the portion with the lowest availability of daylight in the area of influence of a group of sensors, was tested, to verify the potential of the method regarding the estimation of daylight autonomy as well as the consumption of lighting. The method was evaluated against the results obtained by the simulation for two volumetries, two types of openings and three types of distribution of lighting sensors.

The results shows that the simplified method, in general, underestimates the use of natural light. They also showed that the way the sensors are distributed affects their performance. The method showed more accurate results for cases with larger openings and with sensors located close to them.

As for the pertinence of choosing the most restrictive point, it was judged that the precision obtained for sensors close to the openings (~ 1.5x the height of the lintel), combined with the larger openings was acceptable for a simplified method, with errors of ~10%. It is recommended that more tests be carried out to determine an application limit of the method, according to the distance from the reference point in relation to the facade, with the size of the opening and considering more locations with different climates and latitudes.

Regarding the potential of the method to estimate lighting consumption, it was concluded that the divergence between its results and those of the simulations was acceptable, with R^2 close to 0.9 for the 4 orientations and without any overestimation by the method in relation to the simulation. As it is a simplification, it has limitations regarding orientations and the direct component of light. Further studies are recommended, with a representative statistical sample for the validation of the method.

The choice of the case studies proved to be adequate, as it allowed verifying some limitations of the method related to the light source, geometry and sectorization of the sensors. For the dissemination of the method, curves can be generated for several cities, just using the data from the climate file and making a histogram, or climate zones whose characteristics are similar, and make them available to the public on a digital platform.

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