Sky Obstruction and Daylight:
Using the preferable sky window to urban daylight analyses

FERNANDO O. R. PEREIRA[1], SOLANGE M. LEDER[2], LETICIA N. MORAES[1], CECILIA LENZI[1]

[1] Federal University of Santa Catarina, Florianópolis, Brazil
[2] Federal University of Paraíba, João Pessoa, Brazil

ABSTRACT: The urban environment can cause obstruction of the sky thereby affecting sunlight and daylight availability on the building fenestration and also further inside the building. This study uses the Preferable Sky Window (PSW) parameter to analyze daylighting availability in different urban scenarios with the objective to obtain some basic guidelines for daylighting access in urban environments. The PSW consists of a sky zone which identifies the sky section that has the greatest daylight potential in a horizontal plan located in the indoor environment. The scenarios with the most unobstructed PWS parameter were assumed to have the most daylight availability. The urban scenarios tested consisted of a fixed volume of buildings located in a pre-determined plot area. A computational daylighting simulation was also performed to correlate the PSW obstruction with the indoor daylighting performance. Daylighting simulation and PSW analyses were performed using Apolux code. According to this work, guidelines can be developed restricting building height and spacing in order to provide minimum standards of daylight availability. However, the same rules cannot be directly applied when the occupation pattern is not the same.
Keywords: daylight availability, daylight urban planning, urban sustainability

INTRODUCTION
Daylight use in buildings has a positive impact on the users comfort, well being, and productivity. Replacing artificial lighting with daylighting is energy-efficient and also has a positive impact on peak loads and HVAC consumption. However, besides the structure itself, the urban environment in which the building is located has an influence on energy performance. The urban environment can cause obstruction of the sky thereby affecting sunlight and daylight availability on the building fenestration and also further inside the building. For Ünver et al. [1] the sky obstruction is characterized as one of the main influences on the natural light in an interior space.

Legislation should guarantee a certain amount of daylighting access for each building. In many countries there are land usage laws, which define the occupation percentage, building heights and easements. However, this may not assure daylight access. Hopkinson [2] proposed a graphic method based on the geometric relationship between building height and spacing. The objective of this method is an acceptable level of daylighting in indoor environments, while controlling the amount of sky obstruction. Ng [3,4,5] has conducted studies of the city of Hong Kong using different urban scenarios in order to introduce new alternatives that would provide access to daylight in the context of a high-rise urban environment.

Trying to maximize the indoor daylight use in urban contexts, Leder [6] proposed the Preferable Sky Window (PSW) parameter. The PSW has been applied to provide design constraints that would guarantee certain levels of daylight availability in the urban environment. The PSW parameter consists of a sky zone, see Fig. 1, which identifies the sky section that has the greatest daylight potential in a horizontal plan located in the indoor environment. The zone is defined by horizontal limits of 45° to the left and 45° to the right, and vertical limits from 15° to 60° from the horizon line. The characterization of this parameter takes into account three aspects: the relative contribution of different sky hemisphere patches, the light incidence angle and the indoor sky visibility. After these considerations, was possible to determine the sky area that presents greater daylight contribution to an interior environment.

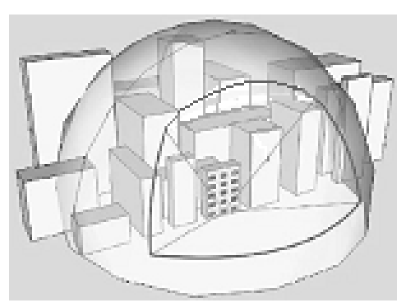


Figure 1: The concept of the Preferable Sky Window zone

The PSW sky portion has a visible sky factor of 32%, while the remaining area, or the sky outside the PSW zone, has a visible sky factor of 68%. Analyses were conducted isolating the illumination reached from the two sky area: PSW zone and the remaining sky area, comparing the resulted daylight performance in a indoor environment. The comparison showed that the sky portion corresponding to the PSW showed a daylight availability impact on interior rooms much greater (1.5 to 2 times) than the remaining sky area [7]. This confirms that the sky portion just in front of the window, defined by the angles mentioned in the former paragraph, has a great potential for illuminating an internal space.

In the context of an increasing urban density, a parameter such as the PSW offers a great potential to analyze and ensure a more sustainable urban environment. A previous study of daylight demands using the PSW parameter had suggested that daylight availability could be controlled with vertical growth of the city as long as certain frontal and side spacing restrictions between buildings were followed [8].
This study uses the Preferable Sky Window (PSW) parameter to analyze daylight availability in different urban scenarios, to point out which urban configuration has the most favourable daylight conditions. A computational daylighting simulation was also performed to correlate the PSW obstruction with the indoor daylighting performance. The objective is to produce basic information in order to establish guidelines for daylighting access in urban environments.

METHODOLOGY

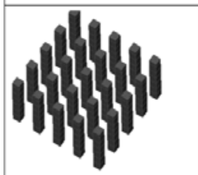
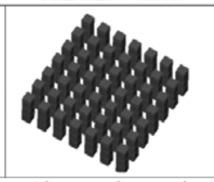
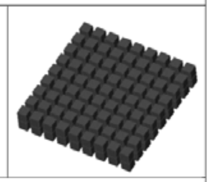
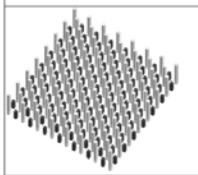
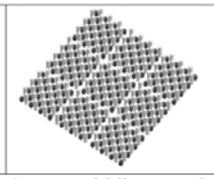
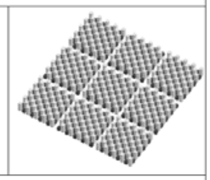
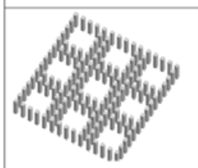
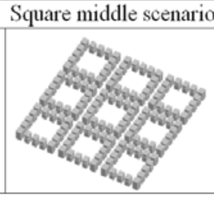
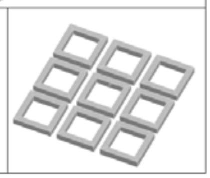
The study consisted of daylighting simulation and PSW analyses all performed using Apolux code [9]. The models were produced with AutoCAD and exported to the Apolux software. The simulations were made reproducing the conditions found in the city of Florianópolis – Brazil, latitude of 27° 30' S and longitude 48° 30' W, at 12:00 pm with cloudy sky condition, CIE overcast sky. The time point of minimum daylight availability, the winter solstice, was chosen for the time of simulation.

The urban scenarios tested consisted of a fixed volume of buildings located in a pre-determined plot area. This was done in order to be able to perform a direct comparison between the different scenarios. Three different levels of plot occupation ratio were studied: 15%, 30% and 50%. The plot land has an area of 16,900 m^2. The buildings have a fixed volume of 162.50 m^3. Three different levels of plot occupation ratio were studied: 15%, 30% and 50%. The plot occupation expresses the ratio between the surface built on the soil and surface of the land considered. Three different building geometries were used: Uniform, Alternated and Square Middle. Each of these was then combined with the three different plot occupation levels. Nine different building scenarios were tested, see Table 1. The building heights in the uniform scenario are 65, 33 and 20 meters, respectively to 15%, 30% and 50% plot occupation. In the alternated scenario the buildings heights are 97.5 and 32.5, 49.5 and 16.5, 30 and 10 to the 15%, 30% and 50% plot occupation respectively. The Square Middle scenario has building heights of 63, 30.88 and 20 meters to the plot occupation of 15%, 30% and 50%.

A sky obstruction analysis using the PSW parameter was then performed. The unobstructed percentage of the PSW is calculated using the equidistant projection method, as a sky view factor. The analysis point is located in the center of the scenario, 2 meter high from the outside level and on the façade middle. Those configurations that allowed the most unobstructed PWS parameter and consequentially the largest daylight availability were then identified. For these scenario configurations, additional and detailed studies, with indoor daylighting analysis were performed. Based on the results from this analysis a separate scenario was also constructed. This scenario attempted to optimize the positive features of each of the previous configurations. We named this the Mixed scenario and an indoor daylighting analysis was also performed on this configuration.

To analyze the indoor daylighting performance, a room model was used. The room geometry was 4.0 meters x 4.0 meters x 3.0 meters (length, width, height). For this analysis the rooms were assumed empty. The internal surface reflectance, following the recommendations from the DIN 5034 [10], are: 70% for the ceiling, 50% for the walls, and 20% for the floor. The analysis plan was placed horizontally and located 1 meter above the floor, at window-sill height. The window area was 1/6 the area of the floor.
The daylighting performance was analyzed according to the horizontal illuminance over the working plane and its distribution within the room.

Table 1: The scenarios models

P.O. 15%	P.O. 30%	P.O. 50%
Uniform scenario		
		
Alternated scenario		
		
Square middle scenario		
		

Daylighting analysis parameters The sky obstruction analysis was based on the application of the Preferable Sky Window parameter, which identifies the sky section that has the greatest daylight potential in a horizontal plane located in the indoor environment. This PSW sky zone is limited: horizontally – 45º to the left and right sides from a line perpendicular to the façade; vertically – between 15º and 60º, above the horizon line, measured from the centre of the opening at window-sill height [7]. From a specific analysis point, located in the middle of each urban scenario, a sky projection was constructed. The sky projection shows the building and the sky overlapped within the PSW projection. It was then possible to calculate the amount of the PSW that was not obstructed by the surrounding buildings. The scenarios with the most unobstructed PWS parameter were assumed to have the most daylight availability.

For the indoor daylight analysis the Brazilian interior lighting standard [11] was used, with the minimum average illuminance level for a house, specified as 100 lux. Illuminance intervals, see Table 2, were constructed using the minimum average illuminance (Em) as a reference. An interval of 70% to 130% of Em was assumed to provide adequate illuminance (sufficient lighting interval), under 70% of Em was considered insufficient; 130% of Em to 1000 lux was also considered as acceptable (superior transition interval), and above 1000 lux was considered excessive lighting.

Table 2: Daylight analysis illuminance intervals

Classification	Illuminance intervals Room	Zones
Inferior	< 20 lux	Insufficient
	20 lux - 70 lux	Inferior transition
Acceptable	70 lux - 130 lux	Sufficient
	130 lux - 1000 lux	Superior transition
Over	> 1000 lux	Excessive

A computer simulation was used to produce illuminance distribution data that were represented by iso-illuminance mapping allowing the visualization of daylight distribution. The external illuminances used in the simulation, for calculating the indoor illuminances, were determined according to the graphic of frequency of occurrence of external diffuse illuminances (klux) developed by Souza [12], presented in Fig. 2. This graph predicts the probability of illumination levels at a certain value. The chosen external illuminance value of 10 klux corresponds to an occurrence probability of 60% during winter working hours (Wh).

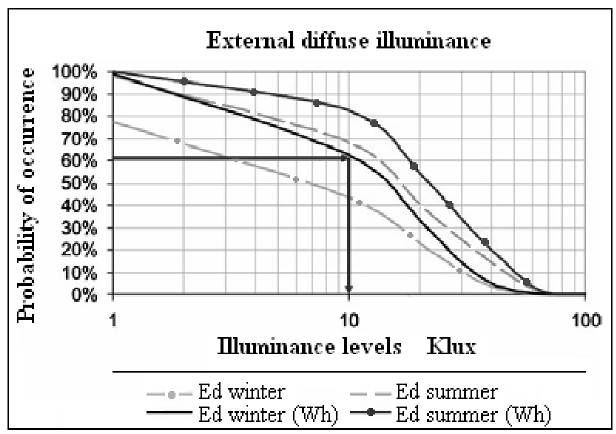
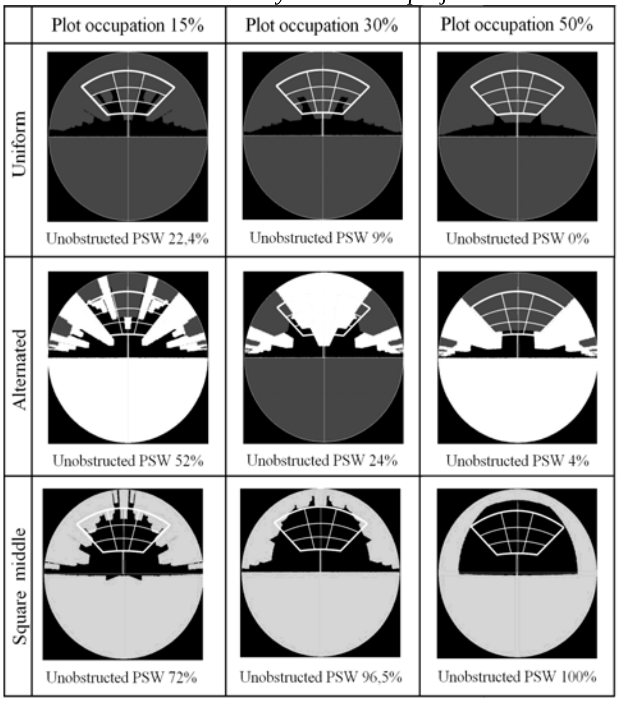


Figure 2: Diffuse illuminance occurrence in Florianópolis [12]

RESULTS ANALYSIS

The sky obstruction analyses are showed in Table 3. The nine scenarios: Uniform, Alternated and Square Middle with the three plot occupations: 15%, 30% and 50% were analysed considering the PSW parameter. Each urban scenario has a specific analysis point, located in a central building and on the middle of the façade. From this analysis point a sky projection was carried out, showing the buildings and the sky overlapped within the PSW projection, see Table 3, making possible to identify the unobstructed portion of the PSW. This unobstructed PSW percentage is shown below each picture.

Table 3: Urban scenarios sky obstruction projection



The urban scenarios with the most unobstructed percentage were the Square Middle ones. The unobstructed PSW percentage versus plot occupation was 72%, 96,5% and 100%, for plot occupations of 15%, 30% and 50% respectively. After the Square Middle scenario, the next most favourable scenarios were the Alternated ones. The unobstructed PSW percentage for this scenario was 52%, 24% and 4% for the plot occupations of 15%, 30% and 50%. The Uniform scenario was the least favourable. This configuration resulted in unobstructed PSW percentages of 22.4%, 9%, and 0%.

It is important to reiterate that each scenario that was compared has the same volume of buildings and the same land area, varying the plot area occupation. These combinations showed a different correlation between PSW obstruction and plot occupation. For example, to the Alternated scenario a higher plot area occupation resulted in a higher PSW obstruction. At the same time, for the Square Middle scenario a higher plot occupation showed a lower PSW obstruction. In order to accurately predict daylight availability, one must characterize the urban configuration.

The Uniform urban configuration showed the worst daylight obstruction, suggesting that an urban configuration which variation is desirable. Furthermore, with the Alternated scenario building high variations, and with the Square Middle scenario varying plot occupation concentration were also more desirable. The analysis was repeated with the analysis point moved from the middle of the façade to a building corner, in an attempt to verify the impact of this condition on the previous results. These results are depicted in Fig. 3. The middle façade point is the more sensitive point in detecting obstruction as using the corner façade point revealed a higher percentage of unobstruction than the middle point.

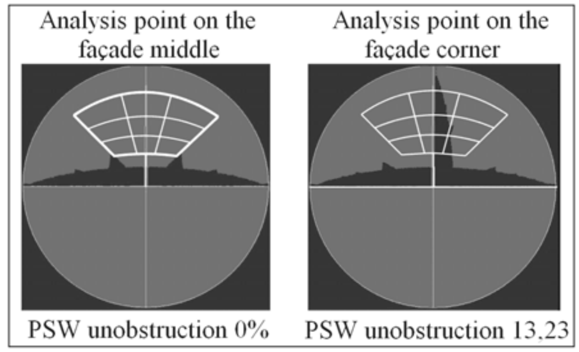


Figure 3: Uniform scenario sky obstruction projection with the point analysis on the façade middle and façade corner

After these results determined the most favourable scenarios in terms of daylight availability, Square Middle and Alternated ones, were used to create a new scenario, the Mixed scenario, see Fig. 4. This was created in an effort to produce a scenario with an improved daylight performance. The Mixed scenario has as twice the volume as the other two scenarios. The buildings heights are 94.5 and 31.5, 48 and 16, 28.68 and 9.56 to the 15%, 30% and 50% plot occupation respectively

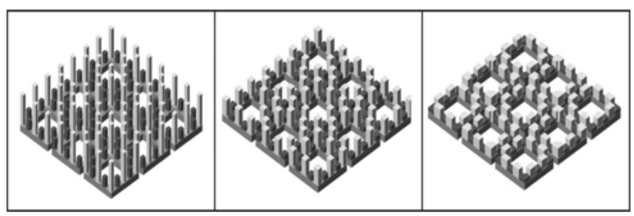


Figure 4: Mixed scenario with the plot occupation of 15%, 30% and 50%

Finally these scenarios: Mixed, Alternated and Square Middle, were used in an indoor daylight analysis. The indoor analysis points were located 1 meter above floor level. A grid of points was used for the indoor analysis. The illuminance analysis was carried out using the illuminance intervals shown in Table 2. The grey colour refers to an illuminance classified as inferior, red colour to an acceptable illuminance and the blue colour refers to an over- illuminance.

The Square Middle scenario demonstrated the best indoor daylighting performance and is depicted in Fig. 5. The area receiving acceptable illuminance levels for plot area occupations of 15%, 30% and 50% was 74.6%, 85.7% and 77.8% respectively. For this Square Middle configuration, there was a correlation between the indoor daylighting results and the PSW obstruction results. The most obstructed PSW situation, plot occupation of 15%, had the lowest daylight performance. The most unobstructed PSW situation, plot occupation of 50%, resulted in the highest illuminances, with 77.78% of the area with acceptable illuminance and 22.22% as over-illuminance.

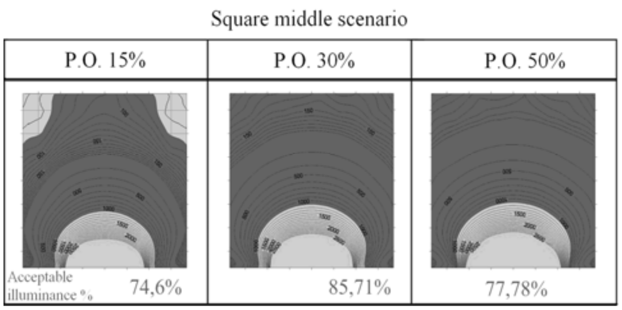


Figure 5: Square Middle scenario indoor illuminance

The Mixed scenario had the second best daylighting performance, as depicted in Fig. 6. Acceptable illuminance levels were achieved in 60.3%, 66.7%, and 69.8% of the area for plot occupations of 15%, 30 %, and 50% respectively. It is important to point out that the Mixed scenario has twice the volume when compared to the Square Middle and Alternated ones. This might suggest a better daylighting performance to the Mixed scenario.

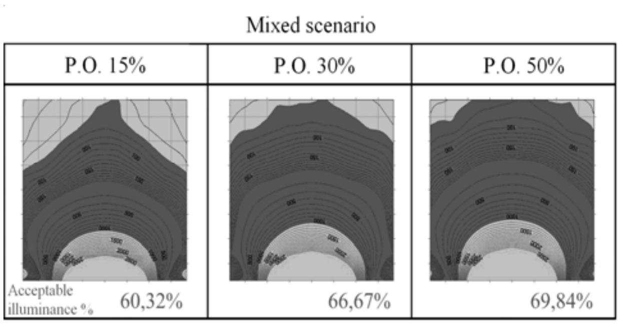


Figure 6: Mixed scenario indoor illuminance

The Alternated scenario presented the worst indoor daylighting performance, see Fig. 7, with a different tendency compared to the other scenarios, with the lower plot area occupation showing better results than in the other occupations. The acceptable illuminance for the plot occupation of 15%, 30% and 50% was 37.37%, 36.51% and 20.63%, respectively. In this scenario, a correlation with the PSW obstruction can be also observed. The most PSW unobstructed situation, the plot occupation of 15%, resulted in the highest daylight performance, and the most PSW obstructed situation, the plot occupation of 50%, resulted in the lowest daylighting performance.

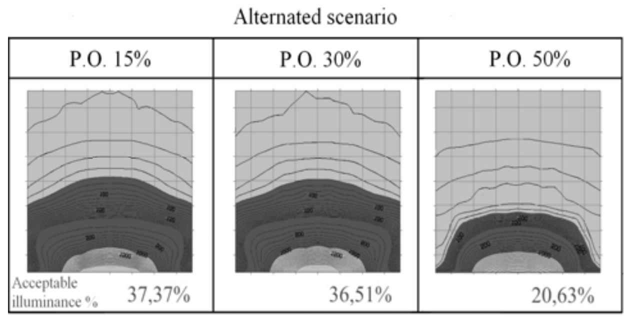


Figure 7: Alternated scenario indoor illuminance

To the Alternated scenario, as also to the Uniform scenario, the higher plot occupation the lower is the daylighting performance. These scenarios have a plot area occupation uniformly distributed, that means to a same volume, increasing the plot area occupation results in decreasing the building spacing. So, in this case, the study showed that a lower spacing between buildings is mores impacting over daylight availability than the building height. Otherwise, to the Mixed and Square Middle scenarios, a higher plot area occupation showed a higher daylighting performance. For these scenarios with concentrated plot occupations, increasing the plot occupation results in reduction of building heights. One can conclude, to this urban configuration, the building height is more impacting over the daylight availability. It is important to point out that the Mixed and Square Middle scenarios have a non uniform building distribution, as the alternated and uniform scenarios. Using the analyses point in the midle of the scenario is not enough to analyse the whole scenario. A second analysis point should be used in the façade oriented to the road, beside that one in the court. Otherwise, this scenario is also caracterized with low building heights, resulting in a probably low PSW obstruction.

CONCLUSION

As urban density continues to increase so does sky obstruction. This negatively affects sunlight and daylight availability both on the building façade and also within the structure. Currently there are no urban design constraints in place that could guarantee adequate levels of daylight availability. This study has applied the Preferable Sky Window (PSW) to analyze daylight availability in different urban scenarios. The objective is to produce basic information in order to establish guidelines for daylighting access in urban environments. The PSW can be used to identify a section of sky that has the greatest daylight potential for a horizontal plan inside of a structure. The scenarios with the least obstructed PWS parameters were assumed to provide the most daylight availability. The urban scenarios tested consisted of a fixed volume of buildings located in a predetermined plot area. Plot occupation levels studied were 15%, 30% and 50%.

PSW obstruction and indoor daylighting performance were correlated by computer simulation. Daylighting simulation and PSW projection mask were performed using Apolux code. Our results show how building height and spacing affect light availability in certain urban configurations. For uniformly distributed plot area occupations of similar volumes of buildings, the larger the plot occupation the closer will be the spacing between buildings. To this urban configuration the results show that reduced spacing between buildings has a more significant affect on daylight availability than building height. For scenarios with concentrated plot occupations, increasing the plot occupation resulted in reduction of building heights. Higher daylight availability observed in this situation was driven by the reduction in building heights.

Complex urban environments with random occupation patterns will require more detailed analysis. According to this work, guidelines can be developed controlling building height and spacing in order to provide minimum standards of daylight availability. However, the same rules cannot be directly applied when the occupation pattern is not the same. A complex urban environment, with an undefined occupation pattern, may need more in depth studies.

REFERENCES

1. Ünver, R., Öztürk, L., Adigüzel, S., Çelik, Ö., (2003). Effect of the facade alternatives on the daylight illuminance in offices. *Energy and building*, 35: p. 737-746.

2. Hopkinson, R., Petherbridge, P., Longmore, J., (1966). *Iluminação Natural*, 776p.

3. Ng, E.; Wong, N., (2004). Better daylight and natural ventilation by design. In *PLEA International Conference.* Eindhoven, Netherlands, September 19-22.

4. Ng, E., (2005). Studies on Daylight Design of High Density Residential Housing in Hong Kong, *International Journal of Lighting Research and Technology* , 35: p.127-140.

5. Ng, E., (2005). A study of the relationship between daylight performance and height difference of buildings in high density cities using computational simulation. *In IBPSA International Conference*. Montreal, Canadá, August 15-18.

6. Leder, S., (2007). *Urban occupation and daylight: a proposal for controlling sky obstruction to ensure daylight availability*. Ph. D. Florianópolis: Federal University of Santa Catarina, Brazil. (in Portuguese)

7. Leder, S., Pereira, F., Claro, A., (2007). Preferable sky window: a new parameter to correlate sky obstruction and indoor daylighting performance. In *PLEA International Conference*, Singapore, November 22-24.

8. Pereira, F., Leder, S., Leticia, M., Cecilia, L., (2008). Analysis of urban occupation x daylighting availability using the preferable sky window parameter. In *PLEA International Conference*. Dublin, Ireland, October 22-24.

9. Claro, A., Pereira, F., (2001). Luz solar: prototype for the study of daylight in architecture and urbanism. In *PLEA International* Conference. Florianopolis, Brazil, November 7-9.

10. German Institute for Standardization. (1983). *DIN 5034: Daylight in interiors*. Berlin: DIN.

11. Brazilian National Standards Organization. (1991). NBR 5413: Illuminance in Interiors. Rio de Janeiro: NBR.

12. Souza, R., (2004). *Development of empirical models for internal illumination phenomena*. Ph. D. Florianópolis: Federal University of Santa Catarina, Brazil. (in Portuguese).