312: Analysis of Urban Occupation X Daylighting Availability Using the Preferable Sky Window Parameter

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Abstract

The lack of an urban planning that takes into account bioclimatic issues has produced dense urban areas with few possibilities for the use of natural resources. Insolation and daylight in the built environment depend on surrounding conditions: very dense urban areas covered with tall buildings usually result in spaces with restricted solar radiation and daylight access. However, still there are no worldwide accepted criteria parameters or patterns in order to control and ensure the democratic access to natural resources, such as natural ventilation, solar radiation, daylight, etc. The present proposal consists in analyzing the illumination behavior in a naturally illuminated indoor environment, which is exposed to different patterns of occupation and configuration of the urban land. The applied method presents an innovative parameter used to characterize the sky vault daylighting potential denominated Preferable Sky Window (PSW). The PSW area was divided in 9 parts and each one was analyzed separately, according to the illuminances it produced in the internal room. Afterwards, several hypothetical scenarios were simulated. These combined different urban occupation and obstruction contexts. The data regarding the illumination levels was obtained through computer simulations using the Apolux software, specially adapted for this study. The most favorable scenarios regarding daylight admission and distribution were those which the PSW was visible through vertical strips, that is, in terms of the built mass, they are associated to the gaps between buildings instead of their heights. The results particularly showed a possible verticalization of the cities by controlling the density of the constructions, lateral and frontal distances between buildings combined with the variation of the building heights. One of the major contributions of this study is the use of urban land occupation pattern indicators, based on objective criteria of daylighting availability.

Keywords: daylight availability, urban obstruction, urban legislation.

1. Introduction

There is a concern about the daylight access in an urban environment ever since the ancient roman laws. In many countries this concern is translated in regulations that define building heights and street widths. In Brazil, the urban occupation is regulated by land usage laws, which define the occupation percentage, building heights and easements. However, this may not assure daylight access.

Researches have been made in order to efficiently relate the daylight phenomenon in the urban context to specific land occupation scenarios. Studies like the ones from Ng (2004, 2004, 2005) for the city of Hong Kong brought new alternatives in order to provide access to daylight in the context of a vertical urban environment.

This paper is based on the application of an innovative characterization parameter of the illumination potential of the sky vault in the urban environment, called "Preferential Sky Window" (PSW). According to Pereira et al (2007) and Leder (2007), this parameter may be characterized by three aspects: i) the relative light contribution of each sky patch, ii) the reduction effect of the incidence angle cosine, iii) the percentage of visual access to the dome from the room. Defining the parameter resulted in the identification a sky section, which is responsible for most of the illumination on the working plan (see Fig. 1). The evaluation was made considering the city of Florianópolis – 27º 30'S 48º30'W – at 12:00 pm, with an overcast sky, a pattern established by the Commision Internationale de l'Eclairage (CIE, 1996).

The development of this research is based on this conceptual basis and it aims to apply it as a tool in analysing the urban land occupation.

2. Objectives

Assuming that the assumption that the PSW can be used for defining the sky obstruction limits in order to assure the availability of daylight in indoor environments, this study's objective consists in analysing land occupation patterns in order to provide the indoor environments, exposed to these scenarios, the access to reasonable daylight levels.

Therefore, two stages were accomplished: 1) division of the Preferable Sky Window in 9 sections and the identification of the amount of light coming from each one (see Fig. 1); 2) generation of hypothetical scenarios through the combination of different urban obstruction and occupation contexts, and simulation of daylight conditions in an indoor environment which is exposed to these scenarios.

3. Methodology

3.1 Individual study of the sections

3.1.1 Typologies used for indoor environment

Three variables were considered for studying the environments – geometry, opening and its use – because these have a great influence in the amount of available light in the working plan, as well as in the average illuminance value needed to undertake different visual tasks. Four different environments were defined; two bedrooms and two offices, because of their different visual tasks, different illumination levels are required.

The environments do not have any furniture and the internal surfaces reflection factor follow the recommendations from the DIN 5034 (DIN, 1985): 70% for the ceiling, 50% for the walls, 20% for the floor (see Table 1).

The indoor height is 3,0 meters. The analysis plan is a horizontal surface located 1 m from the floor, the same as the window-sill height.

Table 1: Systematization of the typology variations

Tipologies		Geometry	Opening	E_m
BdRoom_1/6		4 x 4m	1/6 floor area	100 lux
BdRoom_50%		4 x 4m	50% of facade	
Office_4x4		4 x 4m		300 lux
Office_4x8		4 x 8m		

3.1.2 Sky obstruction models

This study 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 plan located in the indoor environment. This zone is limited: horizontally (azimuth) – 45º to the left and right sides from a line perpendicular to the façade; vertically (height angle from the horizon line) – between 15º and 60º, measured from the centre of the opening at a window-sill height (Pereira et al, 2007).

The sky obstruction models consisted of: 1) a completely unobstructed sky; 2) an unobstructed PSW region, and 3) each one of the nine PSW were unobstructed. The first model simulates an opening exposed to all the light coming from the sky; while the second one considers only the light coming from the angular zone corresponding to the PSW. The third sky obstruction model unfolds into nine models, which results in the division of the PSW in nine parts, horizontally limited every 30º and vertically limited every 15º (see Fig. 1(b)).

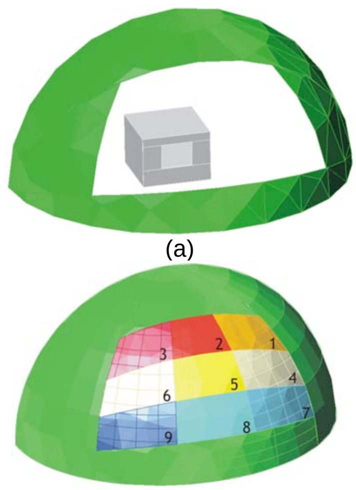


Fig 1. Sky Obstruction Models: Prefencial Sky Window (a) and the division of the PSW in 9 sections (b)

3.1.3 Computer Simulation of the models

The models were produced with AutoCAD and exported to the Apolux software (Claro, 1998), which was used as the daylight simulation tool. This software was developed by the Laboratory of Environmental Comfort of Federal University of Santa Catarina and uses the radiosity algorithm to determine the daylight behaviour. It provides values for illuminance, luminance and Daylight Factor (DF) for any surface in any day of the year and at any time.

Using this software, simulations were conducted on four internal environment typologies for each one of the eleven sky obstruction conditions. The illuminance values were collect in a grid of points evenly distributed on the horizontal analysis plan.

The Apolux software has two modules: Fractal and Fóton. The first one is for the models preparation, allowing several operations in order ensure the models be correctly processed in the Fóton module. After loading a DXF archive, Fractal creates a file (*.PJT* extension) that is imported into Fóton for running the simulations.

The simulations were made considering the city of Florianópolis – 27º 30'S 48º30'W – at 12:00 pm. The chosen period was the winter solstice, for this is the less favourable daylighting availability. The opening orientation is irrelevant because of the adopted overcast sky condition.

The external illuminances used in the simulation, for ajusting the illuminances and calculating the DF, were defined according to the graphic of frequency of occurrence of external diffuse illuminances (klux) developed by Souza (2004), presented in Figure 2. According to the author, when analysing daylight systems performance, the direct incidence of sunlight is usually not considered, only the diffuse component, light coming from the sky. The graphic allows for evaluating the percentage of the time we can count on illumination levels above a certain value. The adopted external illuminance values correspond to an occurrence probability of 60%, in the winter during working hour's period. The choice for the winter season implies studying the less favourable condition, because there is less daylight available. The cross-analysis of this data indicates that in 60% of the analysed period the 10.000 lux external illuminance value (Ed) is exceeded (see Fig. 2). It should be considered that the overcast sky condition presents variations during the day, being that many variables may interfere in the quantity of available daylight, such as, the presence of clouds and the surrounding obstruction.

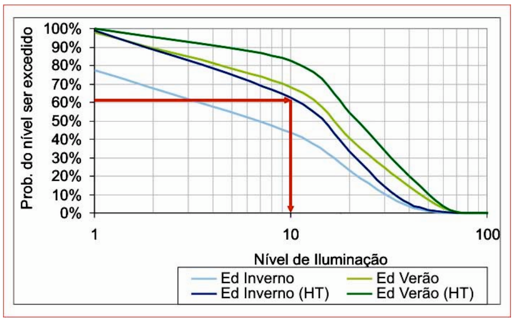


Fig 2. Diffuse illuminance occurrence probability (%) in Florianópolis (SOUZA, 2004)

3.1.4 Analysis variables

The daylight performance that resulted from the three sky obstruction conditions in the indoor environment is analysed according to two variables: a) horizontal illuminance over the working plane; and, b) Average Daylight Factor (DF) on the vertical plane (exterior face of the opening).

3.2 Data processing

3.2.1 Required illuminance levels

In Brazil, the available reference that establishes the minimum average illuminances for interior lighting is the NBR 5413 of ABNT (ABNT, 1991). This regulates the required illuminance levels for each class of visual task, from which is obtained the recommended minimum average illuminance values (E_m) used for bedroom and office spaces, 100 lux and 300 lux accordingly. These values defined by the ABNT, generated the illuminance intervals used in the analysis, as shown in Table 2. The definition of these illuminance intervals refers to the recommendation which states that illuminance levels at any point of the working area should not be under 70% of the E_m. Based on these definitions some illuminance interval classifications have been proposed, such as the one made by Cabus (1997) and Kramer (2002). The present study uses the classification defined below (Table 2), based on the ABNT, and considering all the previous considerations.

Therefore, the classification adopts 70% E_m as the top limit for the interval classified as *inferior bad*, the interval classified as *acceptable* comprehends illuminance levels that go from 70%E_m to 130% E_m (sufficient light zone) and from 130% E_m to 1000 (superior transition zone). According to the NBR-5413 most of the visual activities undertaken in buildings need from 500 lux to 1000 lux. Therefore, illuminance levels that above 100 lux can be considered excessive due to the increasing probability of glare effects or other adverse situations, such as, overheating and increase of energy consumption.

The computer simulation produced illuminance distribution data that was represented by iso-illuminance mapping. Several graphics were made allowing the visualization of light distribution according to the classification presented in Table 2.

3.2.2 Urban scenarios hypothesis

For this stage, the studies developed by Ng (2003), on illumination percentages and user satisfaction were used as reference. Through his research with a sample of users, the author concluded that satisfaction with the lighting conditions was, in 80% of the interviewed, achieved when the average DF on the vertical plane of the opening achieved 8%.

The present study verifies that the possibilities of achieving the vertical DF of 8% correspond to the contribution of at least four of the nine sky sections of the PSW, according to values shown in Table 3. With four sections visible it is possible to combine five different types of obstruction models that can be related to real situations in the urban environment.

Table 2: Classification of illuminance intervals

Classification	Illuminance intervals		Zones
	Bedroom	*Office*	
Inferior bad	< 20 lux	< 160 lux	Insufficient
	20 lux - 70 lux	160 lux - 210 lux	Inferior transition
Acceptable	70 lux - 130 lux	210 lux - 390 lux	Sufficient
	130 lux - 1000 lux	390 lux - 1000 lux	Superior transition
Superior bad	> 1000 lux	> 1000 lux	Excessive

4. RESULT ANALYSIS

4.1 PSW luminous potential analysis

At this moment, the Preferable Sky Window (PSW) takes over the role of a "control parameter of the access to daylight in the urban context that may assure the use of daylight as a source of illumination in indoor environments."(PEREIRA et al, 2007). The PSW corresponds to only 32% of a half sky and produces around 98% of the average illuminance obtained with that half sky with no obstructions. However, this contribution is not uniform, since even within the PSW area there are sectors that contribute more than others. Therefore, the sections are simulated individually, obtaining the lighting potential of each one of them. For the analysis, the DF values were verified in the vertical plane and the distribution of illuminances in a horizontal working plane.

Table 3 shows the vertical DF values obtained, for each ambient; the section 5 presents the highest average of vertical DF, followed by the section number 8.

Table 3: Average DLF (%) in the vertical analysis plane (external face of the opening) obtained in each environment.

Section	BdRoom 1/6	BdRoom 50%	Office 4x4	Office 4x8
1	2,05	2,03	2,03	2,03
2	2,07	2,01	2,01	2,02
3	2,05	2,03	2,03	2,03
4	2,32	2,31	2,31	2,32
5	**2,77**	**2,67**	**2,67**	**2,69**
6	2,32	2,31	2,31	2,32
7	2,05	2,05	2,05	2,06
8	**2,68**	**2,64**	**2,64**	**2,63**
9	2,05	2,05	2,05	2,06

According to the graphics presented in figure 3, it is seen that the sections 1, 2 and 3 present maximum values of illuminance – approximately 243 lux – higher than the other sections, however, when the mapping of the isolux curves was made, it is verified that the distribution is not homogenous. At the same time, the sections 7, 8 e 9 present lower values of illuminance – with the maximum in approximately 94 lux – in relation to the other sections, however more homogenous in the working plane, what can be proved by the existence of almost 50% of the working plan of the section 8 comprehended only by a zone defined as acceptable. The mapping of the sections 4, 5 e 6 presents a more homogenous distribution and higher illuminance values comprehended in the acceptable zone. It is observed, in this case, that the homogeneity in the distribution of the illuminance in the working plane is inversely proportional to high illuminance levels. Therefore, the previous observations show that a good lighting performance cannot be achieved through the removal of obstructions only from one of the PSW sections, but from a combination that includes removing obstructions from some inferior sections as well as from some superior sections of the PSW.

Therefore, it is considered that a section has a good lighting performance when it produces illuminance values within the *acceptable* zone, with good distribution homogeneity. The achieved results show that there is a relationship between the good performance of the section and the vertical DF on aperture plane. Section 5 is a good example; it produced the highest average vertical DF (see Table 3) and the best performance over the working plane (see figure 3). Section 8 produces the second highest average vertical DF (see Table 3) and shows the best performance when analysed under the distribution homogeneity aspect. Therefore, the best performance of the central section 5, points out that a favourable urban scenario should keep it without obstructions.

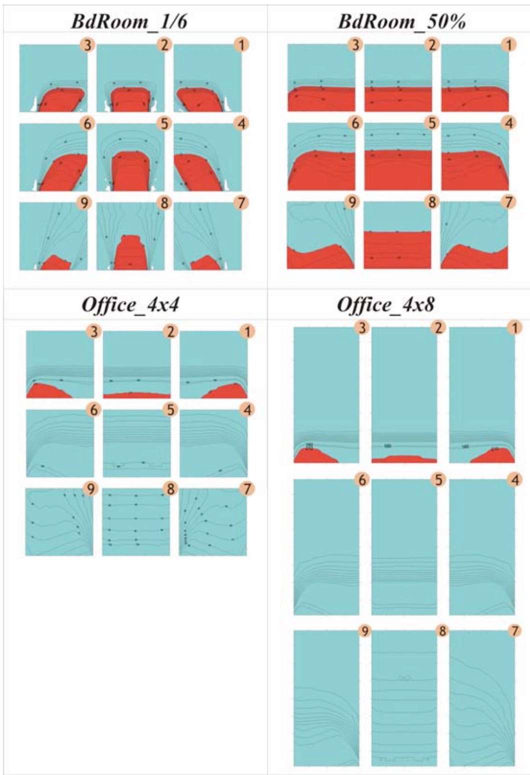
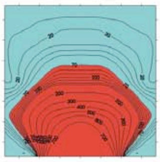
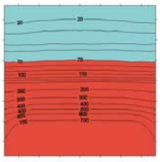
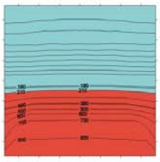
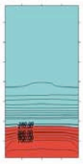
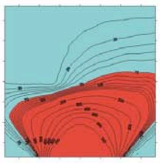
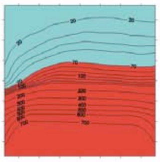
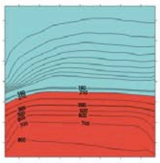
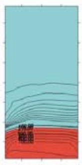
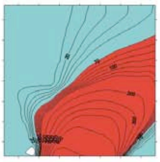
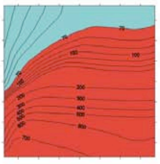
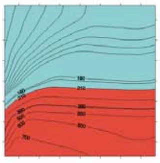
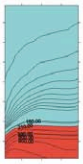
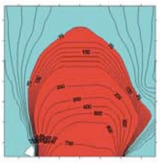
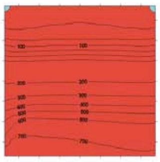
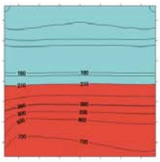
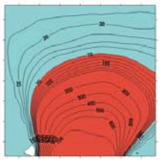
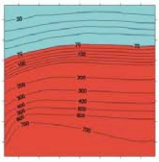
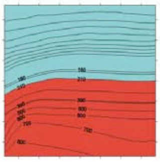
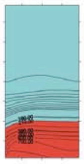


Fig. 3 Illuminance distribution on the working plane produced by each one of the PSW sections. The red colour indicates the acceptable illuminated zones; the blue colour indicates the insufficient illumination zones

4.2 Scenario hypothesis analysis

The criteria used for the composition of the scenario hypothesis – 8% of average vertical DF – correspond to the keep clear (unobstructed) at least four sections of the PSW. This is equivalent to about 40% of the PSW area. However, it is not this absolute value that determines a good performance for the scenario, but which of the sections compose the unobstructed 40%. Therefore, the results indicate the preference for keeping clear the vertical pattern, that corresponds, in a real scenario, to the lateral distance between buildings, instead of unblocking with a horizontal pattern, that correspond to the building height limit.

Table 4: Comparative table of the scenario hypothesis X versus different indoor environment typologies. In the *scenario hypothesis* column the yellow sections are unobstructed sections of PSW and the gray/black ones are obstructed. The *Acceptable%* column corresponds to the average percentage of the area characterized as *acceptable lighting zone* (red region) for each scenario.

Scenario hypothesis	*BdRoom_1/6*	*BdRoom_50%*	*Office_4x4*	*Office_4x8*	% Aceptable
A 					45,21%
B 					42,80%
C 					48,25%
D 					58,75%
E 					50,31%

The scenario D (see Table 4) presented the greatest percentage of working area within the *acceptable* interval, 58,75 %. The combination that results in this hypothesis is the composition of sections 2, 3, 5 and 8, which correspond to the three central sections in the vertical axis added to a superior side section. In a real scenario, this situation would be equivalent to having buildings with different heights and with some distance between them.

The scenario C (Table 4) is the combination of sections 2, 3, 6 and 9. Same as the D scenario, it consists on three vertical sections; however, these sections are not central, but lateral ones. In this hypothesis, the resulting average was 48,25 %, and it is equivalent to the same possible scenario as hypothesis D.

The scenario E (Table 4) presents an reasonable average percentage of 50,32 %, however it is not compose by a section group that forms a vertical strip. It is the combination of sections 2, 3, 5 and 6. It does not correspond to an unblocked vertical strip, however it includes the section that most contributes, section 5. This one has proved to be the second best performance.

The scenario A (Table 4) has the fourth higher *acceptable* percentage grade, being 45,21 %. It is the combination of a horizontal strip (sections 1, 2 and 3) added to section 5. The scenario B, combining the sections 1, 2, 3 and 6, presents the lowest acceptable zone percentage of 42,8 %.

From the results, it can be noted that unblocking about 40% of the PSW presents little difference in the lighting performance when different combinations of sections are unobstructed. Maintaining the same percentage of unblocked PSW, we find a 16% difference between the best performance (hypothesis D) and the worst performance (hypothesis B). When the unblocking proposals are applied to real scenarios, two distinct land occupation patterns are found: 1) distance between buildings, such as scenarios D and C; 2) low building heights, such as scenarios A and B.

5. Conclusion

This research presented a methodology that applies an innovative parameter for characterizing the illumination potential of the sky vault in an urban environment - Preferable Sky Window (PSW). Proceedings based on computational simulations allowed the identification of sections of the PSW that most contribute to daylit indoor environments. Simulation with hypothetical scenarios showed that the central section (section 5) of the PSW presents the greatest potential to illuminate working plans through vertical apertures.

Analysing two different uses for the indoor environments, bedroom and office, allowed to verify that the criteria proposed by Ng (2003), related to the minimum of 8% of vertical DF, is only reasonable for bedroom environment. This difference occurs because of the distinct required illuminance levels; for the demands of a bedroom, the 8% vertical DF criteria has proved reasonable; for the office, though, illumination levels were very low, with low percentages of the working plane within the *acceptable* illumination zone.

The analysis of hypothetical scenarios indicates two distinct land occupation patterns that characterize the lack of obstruction of the Preferable Sky Window and, therefore, improve the daylight performance. Unblocking the PSW in a vertical pattern presents better performances, followed by unblocking the PSW in a horizontal pattern. In terms of built volumes, they are associated to: 1) distance between buildings and 2) low building heights. The performance difference between these two patterns was around 16%, firstly considering the distances between buildings, and secondly, where the low buildings prevail. However, the urban density, which is getting bigger every day, tends to get more vertical.

In this particular study, considering the daylight demands, the results point to a possibility of vertical growth of the cities and this can be achieved by controlling the frontal and side distances between buildings in combination with their heights.

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