486: Daylight simulation in buildings

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Abstract

Emphasis on daylight is given to non-domestic buildings because in such buildings the specificity of the activities or the high levels of illumination demand a more careful control on daylighting examined for design purposes. Clearly energy saving in that situation is one of the reasons for that emphasis. This paper deals with light coming into the rooms through the window providing natural light once the window is considered the only system that provides and controls light flux and distribution. Rooms can be classified according to their occupancy and use, and then many different activities requiring different illumination levels can be developed in the same space. Room's classification is the first step to establish the ratio window to the floor area for daylight purposes. Therefore the aim of the present work is to investigate window's characteristics as a mean to assess daylighting. Windows' parameters were taken up to calculate daylighting for 12.00m² rooms. The simulated cases were accessed varying windows position, shape, size and geometry, maintaining in all cases 3.60m² area. This methodology can be applied in architectural education aiming students' comprehension about users' comfort and energy savings. ECOTECT and Radiance softwares were used to simulate the proposed windows' parameters.

Keywords: daylighting, architectural education, computer simulation

1. Introduction

There are two important topics related to daylight use: the first one reffers to pollution caused by energy consumed by artificial lighting and the second one is related to psycologic and physiologic damages caused by the lack in natural lighting (BAKER, 1993). These questions, associated with architectural and aesthetics issues, are the basic fundamentals of daylighting.

The concerning about global warming and sustainable design has increased the importance of planning daylight use in non-residential buildings. This is a strategy to improve energy efficiency by minimizing lighting, heating, and cooling loads (IEA, 2000). Considering that windows are the only elements providing daylight inside environments, its characteristics are closely related to energy savings.

In non-domestic buildings the specificity of activities or the high lighting levels required to develop them, demand a more careful control on daylighting (SILVA, 1996) and energy saving in this situation is one of the main reasons for that emphasis. Nowadays glass building envelope is a synonym of status, and some corporations build these typology trying to show their position and capability. This architectural solution is common in many parts of the world, however these buildings usually do not show any adaptation to local climate.

Artificial lighting demand increased with modern free plan tendencies, where large rooms were common. The large use of artificial lighting during the day is also an important issue related to saving energy needs. In glass wall buildings, deeper environment parts could become dark due to the contrast with visible sky areas (HOPKINSON, 1966). Although lighting levels in these deep areas could be adjusted to reach NBR 5413 values, better results are found when artificial lighting is used as daylighting complementary resource.

During the second half of 20th century, daylighting became a minor architectural issue because of the cheap and abundant electricity and efficient electric light sources (LECHNER, 2001). According to Knijinik (1994), in non-residential buildings, fluorescent lamps represent 50% of lighting energy use. This type of efficient lamps with reflectors can reduce energy use up to 65%, keeping the same lighting level.

Rooms can be classified according to their occupancy and use, and then many different activities requiring different lighting levels can be developed inside the same space. Some authors recommend minimum lighting levels values from daylight according to users' activity, while others refer to space use.

Windows must be considered as the system providing daylight. Then is important to comprehend design's relationship with thermal performance. Main topics are that the larger is the void, more direct solar radiation enters in the space and the closer the void is to the wall, more light will be reflected inside the environment, if its parameters contribute to this.

This paper deals with lighting coming into the rooms through the window providing daylight where it is considered the only system providing and controlling light flux and distribution. Some of the simulations show how different window's shapes, sizes, geometries and positions respond

to lighting distribution.
As a simplified assessing manner, comfort can be qualitatitive verified when related to uniformity quotient and quantitative verified when related to lighting level. These variables depend on fenestration's size, position (on the wall) and shape, and on space geometry (on which wall will window is positioned). Besides that, daylighting systems and environment determine materials, colors, specularity, reflectance and transparency. Figure 1 shows relation between comfort and lighting.

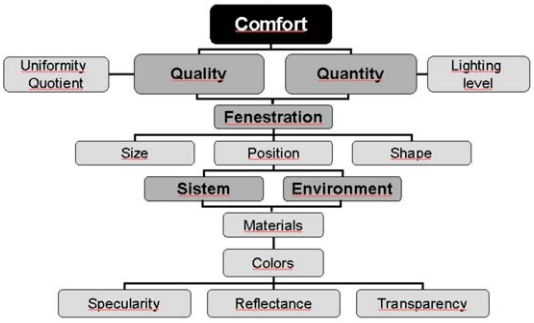


Figure 1 – Relation between comfort and lighting

Buildings' heating, cooling and lighting are accomplished not just by mechanical equipment, but mostly by the building design itself. Then, architects can satisfy the need for aesthetic expression and efficiently heat, cool and light buildings through an environmentally responsible design (LECHNER, 2001). Architectural design is the main resource to assure that buildings will be heated, cooled and lit correctly.
Electric lighting and general daylighting have the same goal: to supply high quality and efficient light while minimizing direct glare, veiling reflections and excessive-brightness ratios. Lechner (2001) established some specific goals related to daylighting due to window's location limitations and daylight variability:

- to get more light deeper into the building to raise the lighting level inside it and to reduce lighting gradient across the room;
- reduce or prevent severe direct glare of unprotected windows and skylights;
- to prevent excessive-brightness ratios, specially those caused by direct sunlight;
- to prevent or minimize veiling reflections, specially from skylights and clerestory windows;
- to diffuse the light providing multiple reflections;
- it is limited to those spaces which have critical visual tasks, and it is related to the use of full daylighting and sunlight aesthetic potential.

To develop an efficient lighting design, it is necessary to know space's specific use and characteristics. In this work, to achieve these goals, basic daylighting strategies are related to:

- space planning
- environment geometry
- windows shape
- windows size
- windows position

Both building's orientation (when designing with direct solar radiation) and shape are critical to a successful daylighting scheme. It must be considered not only the external form, but also internal spaces shape (LECHNER, 2001). This way it is important to observe the relation between shape (of room and window) and daylighting quality.

2. Objective

The objective of the present work is to investigate window's parameters as a mean to assess daylighting using the concept of Daylight Factor (DF).
Windows' light performance was investigated with the intention of assessing lighting distribution inside spaces. This way it is possible to provide students means to comprehend architectural design concerned with comfort and energy saving.

3. Methodology

Lamps are the main artificial lighting resource, and sun is the only daylighting resource. Light from the sun enters inside the environment, direct or indirectly, being diffused by the atmosphere and reflected by natural or artificial enrironment surfaces (Majoros, 1998). This way a luminary filters and distributes light from an electric device, and the sky is the daylighting device that allows sunlight coming into environment, being transmitted, reflected or diffused.
Windows are also daylighting devices, as daylight passes through it to lit the interior environments, but it could not be efficient in the general building structure. Being a transparent part of building envelope, it also causes glare and thermal loads (BAKER, 1993). This work considers diffuse light, so direct light is not being simulated, this way direct glare and thermal loads from sunlight are not the object of this study.
Reffering to interior lighting, PROCEL (2002) defines that efficient design must provide:

- good visibility conditions;
- good colors reproduction;
- electric energy saving;
- facility and low costs maintenance;
- initial compatible price;
- use of local task lighting;
- use of both natural and artificial lighting.

In this work, windows' size, shape and position are assessed to comprehend lighting distribution inside a room provided by a fenestration. Environment geometry is assessed to analyze lighting distribution according to geometry variation. In this case, the main parameter is the comparison between a different geometry and the first one (base environment). In this work, window's light performance is seen, as the only standpoint for window design. This way is possible to contribute to energy saving in buildings and improve light quality inside the environment.
All simulations were developed to Porto Alegre (Brazil), where the latitude is 30,02ºS and the

longitude is 52ºW.
As mentioned before, room's classification is the first step to establish the ratio window to floor area for daylight purposes. Porto Alegre's Building Regulation considers three types of room: rooms to stay at night (e.g. bedrooms), rooms to stay during the day (e.g. living rooms, dining rooms, kitchens, offices) and rooms to stay for a short period (e.g. halls, corridors, toilets, storage rooms). This paper deals with simulations dbased on rooms to stay during the day as non-residential buildings' are considered the stand point of this work.
Simulated cases were generated varying windows position, shape, size and room geometry. In presented simulations where variations were related to window's position, shape and room's geometry, in all cases 3.60m² window area was maintained. Window size simulation was based on wall area, then in the first case a 25% wall area window was simulated and in the second case a 60% wall area window was simulated. It is important to detach that, in all cases, room floor area corresponds to 12.00m². Wall area where windows are located in all window's parametric simulations have 9.00m² (3.0 x 3.0m²), then 40% of wall area, which corresponds to windows' area, is 3.6m².
The following figures shows simulated cases. Figure 2 is the base simulated environment, then varying this interior space (windows' shape, position and size, and room's geometry), daylighting distribution was assessed.

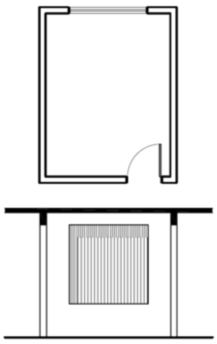
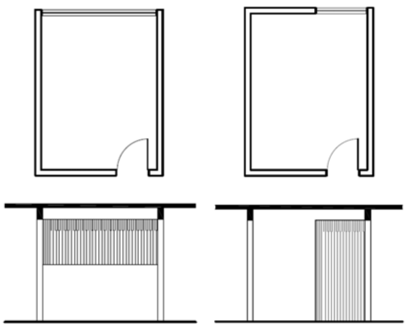


Fig 2. Base environment

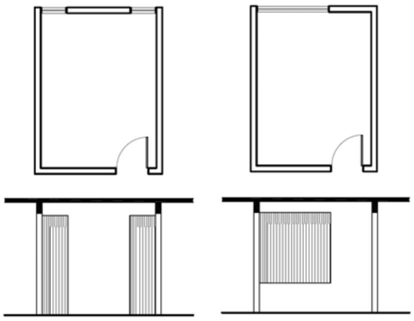
Figure 3 shows window's shape variation, Figure 3a is a 3.60m² horizontal window and Figure 3b is a 3.60m² door shaped window, this way it could also simulate daylighting from a glass door.



(a) (b)

Fig 3. Shape: horizontal (a) and door (b)

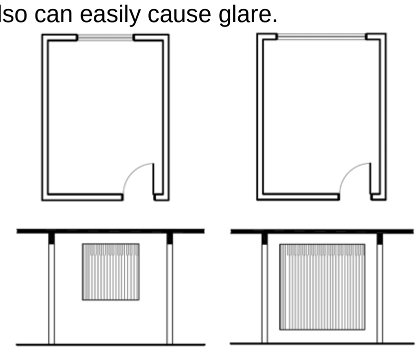
Figure 4 shows window's position variation. The aim is to assess the difference on daylighting distribution and uniformity inside a room due to lighting reflections and distribution. Figure 4a shows the 3.60m² window divided in two 1.80m² window (2x20% wall area) and Figure 4b shows the original 3.60m² window close to a white wall which easily spreads light to all interior environment.



(a) (b)

Fig 5. Position: 2 x 20% (a) and left (b)

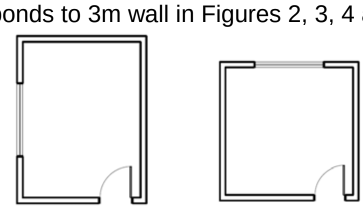
Figure 5 shows a variation on window's size related to wall area. Then Figure 5a shows a 25% wall area window and Figure 5b shows a 60% wall area window. These simulations investigate the distribution uniformity due to a smaller window inside a white environment and a big window that provides more daylight availability but also can easily cause glare.



(a) (b)

Fig 5. Size: 25% of the wall area (a) and 60% of the wall area (b)

Figure 6 shows the assessed environment geometry. In Figure 6a 3.60m² window was located on the larger wall (4m) and Figure 6b shows a square environment where the window is located on the wall in front of the door which corresponds to 3m wall in Figures 2, 3, 4 and 5.



(a) (b)

Fig 6. Geometry: 4m wall (a) and square environmental (b)

This work took the classification of the spaces and the minimum lighting levels required to assess window's performance. These values are

recommended in the NBR 5413). ECOTECT and Radiance softwares were used to simulate the proposed windows' parameters. Simulations are shown in item 3.2.
This methodology can be applied in architectural education aiming students' comprehension about daylighting distribution, users' comfort and energy savings as it shows lighting efficient and deficient rooms. These windows' parameters were investigated to determine a methodology to assess daylighting inside spaces, besides allowing correct daylighting fenestration design. It is important to highlight that these are the first architectural design decisions related to daylighting, as this work aims to set an educational approach to systemize graduate students investigations. Then the main point is to comprehend the parameters and variables involved and be able to analyze them, not just know that they exist but be able to understand. This is the reason why just a little number of parameters were assessed, but also depleted all daylighting characteristics of each of them.

3.1. Parameters

Mentioned 8500lux is due to an uniform sky which according to CIE Daylighting Availabity Graph (Figure 7) corresponds to the lighting levels available in more than 90% of the hours when daylighting is available, to a 30ºS latitude, as Porto Alegre. The correspondent point is marked with a bullet in the Figure bellow.

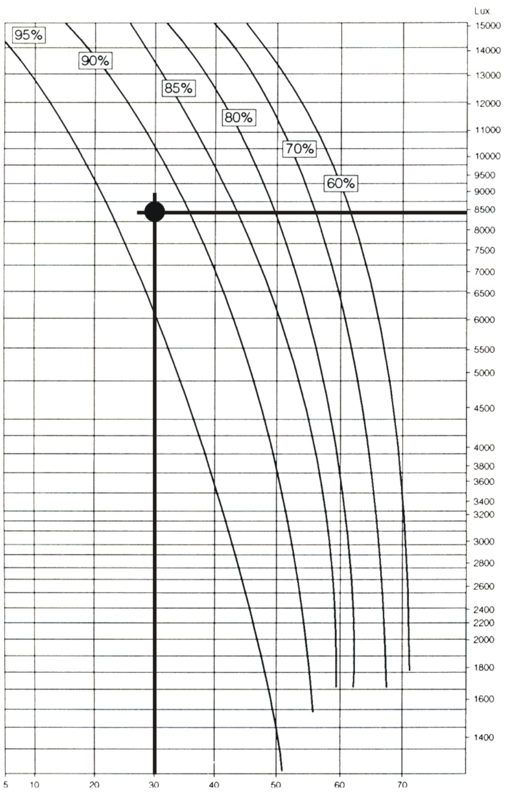


Fig 7. CIE Daylighting Availabity Graph

The following parameters were used to develop the simulations:

- 0.75m high task plan (according to NBR 5413 which also determines minimum levels to internal lighting);
- to internal walls, floor and ceiling were admitted 0.95 reflectance value;
- lighting void composed by a single glass (transparency 0.92);
- calculations were based on the CIE data, with external 8500lux and uniform sky.

The same 0.95 reflectance value was admitted to every wall, floor and ceiling as this work shows a parametric study which has the aim of comparing variations on windows parameters and uniformity quotient. Then the values are not important, but the possibility of assessing differences on daylighting system behavior.
Except geometry variation, where the window was positioned on the larger wall (4m) wich was faced to west, all the other simulations were performed to a north facing environment.
The NBR 5382, suggests that the illuminance in any point of the task plan should not be less than 70% of the average illuminance, stablished by NBR 5413. This way, it should be taken care in cases where the void size increases (as Figure 5b), because depending on the environment characteristics light can cause glare.

3.2. Simulations

The tables bellow show maximum, minimum and average DF values calculated in all simulated cases. Considering these three values, the uniformity quotient (UQ) was also calculated, it must be calculated as showed bellow:

$$u = \frac{m}{\overline{m}}$$

u – uniformity quotient
m – minimum lighting level (DF or lux)
$\overline{m}$ – lighting levels average (DF or lux)

Table 1: Minimum, maximum, average DF and uniformity quotient to the base environment

	Base
Minimum	13.51
Maximum	34.69
Average	18.35
UQ	**0.736**

Table 2: Minimum, maximum, average DF and uniformity quotient to the environments in which varied windows' shape and position

	Shape		**Position**	
	Horiz.	**Door**	**2x20%**	**Left**
Min	13.19	12.17	11.94	13.00
Max	22.26	35.87	31.83	36.33
Average	17.04	15.99	15.33	18.51
UQ	**0.772**	**0.761**	**0.778**	**0.702**

Table 3: Minimum, maximum, average DF and uniformity quotient to the environments in which varied windows' size and environment geometry

	Size		**Geometry**	
	25%	**60%**	**4m wall**	**Square**
Minimum	8.69	18.94	12.16	13.31
Maximum	19.84	38.01	34.48	34.12
Average	12.11	23.85	18.43	18.59
UQ	**0.715**	**0.794**	**0.848**	**0.715**

According to the tables above, the maximum UQ found was 0.848 to the window positioned on the 4m wall (variation on environment geometry) and the minimum UQ value found was 0.702 to the window positioned on the left (variation on windows' position). Figures bellow show the simulation made to the base environment (Figure 8) and the referred extreme cases – "left position" and "geometry 4m wall" (Figures 9 and 10).

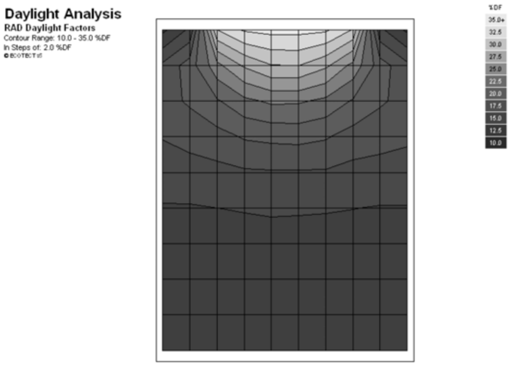


Fig 8. Simulation made to the base environment

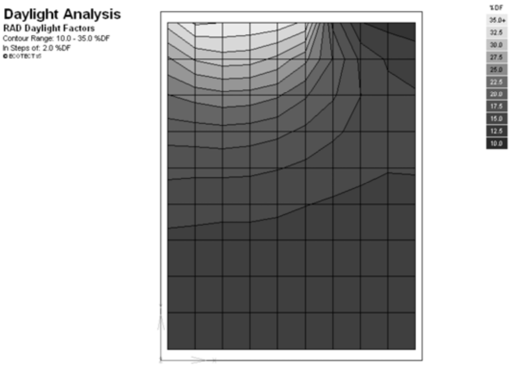


Fig 9. Simulation made to the window positioned on the left (variation on windows' position), situation that corresponds to the minimum UQ found

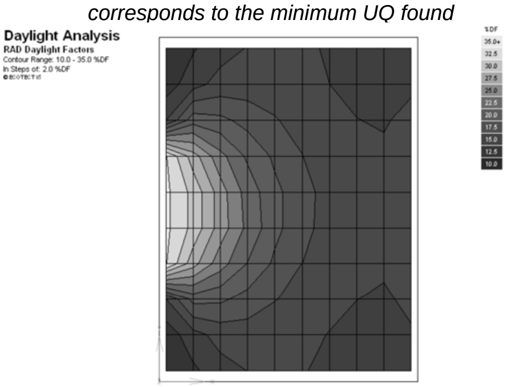


Fig 10. Simulation made to the to the window positioned on the 4m wall (variation on environment geometry), situation that corresponds to the maximum UQ found

4. Results Discussion

The UQ varies from 0 (less uniform situation) to 1 (more uniform situation). Tables 1, 2 and 3 shows that a little variation on UQ results were caused by windows' shape, position and size and by environment geometry variations.

Assessed cases relation between uniformity quotient and parameters are shown on Figure 11.

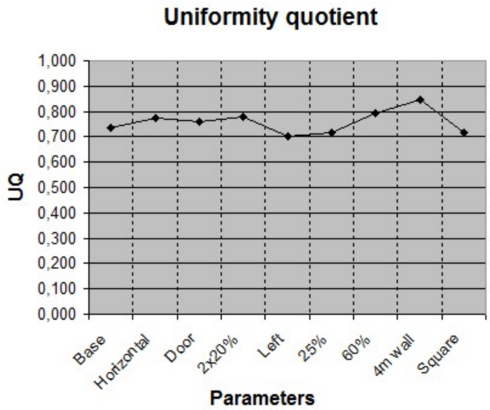


Fig 11. Relation between uniformity quotient and simulated parameters

Considering that UQ values vary from 0 to 1 and extreme calculated values are 0.848 and 0.702, UQ variation is almost 0.15. These values show that analyzed parameters do not cause a very large variation on lighting distribution.

In case of varying windows' size (25%), although minimum and maximum lighting levels are smaller than the other minimums and maximums found, UQ is 0.715 due to space characteristics and to window position.

On windows' shape variation, horizontal window configuration showed a good performance, but to achieve room's deeper parts and a mayor UQ value on work plan, the window providing daylight should have a minor sill, as in this model it is 1.50m and the work plan heigh is 0.75. This relation creates a dark spot close to the wall.

2x20% position simulation is a good design solution, but as the window area was also 3.60m², lighting level is minor between both windows, and mayor in the middle of environment. Considering that non-residential buildings are being analyzed and in these spaces is common to have central space area used, it can be a problematic window design.

Geometry variation shows that positioning fenestration in larger wall, inside a clear environment, uniformity quotient is considerably increased.

These referred cases are the most important of each simulated parameter, other results were presented on tables (see item 3.2) as they showed less significant results referring to UQ.

DF results express relation between external and internal illuminance, and then the internal illumination corresponds to the variation on external light availability.It is important to notice that NBR 5413 stablishes a minimum illuminance level for internal spaces. As these values are 500lux to library reading spaces and 1000lux to drawing offices, most of values shown on simulations can be considered sufficient. Some minimum DF shows that the solution was not successful, but the average shows:

- highest average: 23.85%
- lowest average: 12.11%

Condidering external 8500lux, 12,11% is equivalent to 1020lux, which is sufficient for

suggested activities. Highest average, 23.85%, corresponds to 2030lux.
From this study, is possible to conclude that, in most of simulated cases, lighting level is sufficient as all other options showed higher levels and that daylighting availability to Porto Alegre (RS, Brazil) exceeds 8500lux most of time that we have daylight availability.
This parametric study can be useful to provide energy savings in buildings, as they show most adapted situation to provide more or less lighting levels inside spaces. These simulations are not considering direct solar radiation, so efficiency issues are related to a better use of daylighting to save energy used to artificial lighting. Lighting levels must be carefully verified on NBR 5413 to assure that daylight system will provide needed lighting levels.
It is also useful to help students to make a decision about the consequences of their design decisions, as solutions adopted to daylighting systems intervene on aesthetics solution, comfort conditions and energy savings.

5. Conclusion

This study shows variations between daylighting distribution inside a space due to decisions related to daylighting system. This assessment is based on some parameters variations: windows' shape, size and position and variation on environment geometry.
Assessing this work, students can easily comprehend the importance of a conscious daylighting design on energy efficiency and become more environmentally conscient besides comprehending aesthetics solutions and comfort conditions. This way, this study also shows the importance of developing comfort strategies at the same time of architectural conception.
It is also important to understand architectural spaces as a luminary that spreads, controls and reflects daylighting in interior environments, as the sky does in external spaces. This work shows a high reflective environment which was taken as a parametric base, but is necessary to comprehend that varying these paramets, general lighting availability will also vary.
It is also necessary to keep in mind that the main lighting design goal must be creating an adjusted visual environment. An environment can be considered good in terms of users comfort when it provides visual comfort and allows the development of visual tasks needed by environment function (MAJOROS, 1998). To provide visual comfort, an interior room must have all parts viewed with no difficulty and visual tasks should be developed without tension. Visual comfort with thermal and acoustic issues, are the three parts that complete comfort feeling.
Dynamic nature of daylighting satisfies biological needs to respond to day natural rhythms (LECHNER, 2001). Daylighting design, however, require a careful fenestration design to provide daylighting distribution and quality.
Considering the parameters adopted and results assessed, and aiming a good daylighting distribution, the following rules can be detached as a final conclusion of this work:

- windows should be high on the wall, widely distributed, and optimum area;
- if possible, windows must be placed in more than one wall, or have the area distributed on the same wall;
- windows must be positioned on the larger wall;
- use clear walls to reduce the contrast between windows and walls;
- it became clear that amongst the studied parameters, the environment geometry is the one that mostly affects values for average daylight factors and light distribution;
- for lighting and visual comfort purposes, all simulated cases provided UQ between 0.7 and 0.9, which is a high value. Considering that the more uniform the lighting is, more comfortable people feel and that glare is caused by contrast, we can say that these environmets are functional. It is important to notice at this point that all surfaces have the same reflectance, which helps on providing a satisfying light distribution.

6. References

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