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DAYLIGHTING IN COMMERCIAL BUILDINGS: THE USE OF NEW COMPONENTS AND DESIGN SOLUTIONS TO OPTIMIZE VISUAL COMFORT AND ENERGY EFFICIENCY

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ABSTRACT

The use of daylighting in buildings can be an improvement when trying to enhance the environmental quality and the energy efficiency of them. When we talk about commercial buildings, especially shopping centers, daylight has a specific significance, due to the use of the building e the various activities performed inside. This article presents some results of simulations with the software Lightscape®, utilizing different design solutions and components, aiming to improve the existing situation in terms of visual comfort and energy efficiency in a case study building. Some components like light-shelves and a different skylight design are tested and their effects in the light distribution and glare reduction are analyzed.

INTRODUCTION

The concept of environmental quality in buildings is connected to the energy efficiency. In fact, both can contribute to reduce the pollutants emission in the atmosphere and improve the environmental comfort in the buildings. The Environmental Building News proposes some priorities for sustainable buildings, and among these are: energy saving: to design and construct energetically efficient buildings; the construction of health and durable buildings: environmental comfort and safety; recycling buildings: to utilize both existent buildings and infrastructure. (AMORIM, 2001)

Commercial buildings, especially shopping centers, can be adapted to these priorities, because these are buildings with high energy consumption and big demand of environmental comfort. Moreover, there is the possibility of adaptation of existent structures to be used as commercial buildings. This is a trend already in Europe and it is desirable that also in developing countries it happens, due to the reasons mentioned above. The adaptation or the restructuring of a building can then to be object of a real improvement of the existing conditions, both in environmental comfort and energy efficiency.

In this optics, we can say that natural light is a critical point to improve both conditions. This has always had an important role in architecture, and recently some researches have been performed to improve the use of daylighting in buildings (FONTOYNONT, 1998; RIHL, 1998).

COMMERCIAL BUILDINGS AND SHOPPING CENTERS: ARCHITECTURAL CHARACTERISTICS, TRENDS AND ENVIRONMENTAL COMFORT PROBLEMS

Between many typologies of commercial buildings, the shopping centers have a strong presence and an increased growing, especially in the last years. The ICSC defines a shopping center as a building that has a planned localization, parking facilities and the presence of one or more "anchor" shops.

The typology of a shopping center has normally an irregular configuration, and the last trend that we observe is the tendency to create a more natural environment, with plants and natural light. (AMORIM, 2000). In spite of this, we see very similar architectural designs in the entire world, with a few care with the climatic context (figure 1). The Brazilian architect Carlos Dominguez, specialized in shopping center design, mentions that the architectural language used in the projects until today has it's origin in old-fashioned architectural concepts, as the Post Modern (AMORIM, 2001). This can be one of the reasons for this architectural "uniformity" around the world.

Figure 1. The West Oak Mall (U.S.A.) and the Iguatemi Shopping Center, Brazil: similar architectural solutions for different climatic contexts (Source: AMORIM, 2001).

The most common solutions for daylighting are the use of atriums and skylights, normally without solar protection, as we can see also in the figure 1.

Previous studies conducted in Brazil, (CORBELLA and YANNAS, 1998; AMORIM, 2000) have identified some problems in this typology related to the architectural concept, as follows:

- bad distribution of the natural light, due to the absence of shading devices or control elements in atriums and skylights,

- presence of direct sunlight, resulting in strong contrast, that gives to the neighboring areas a darker aspect; as a consequence of this, some areas, as for example the shop windows must compensate these high illuminances with artificial light, increasing the electricity consumption;

- glare and reflections problems due to mentioned questions;

- increase of air conditioning consumption, due to the direct sunlight and artificial lighting.

Figure 2. Direct sunlight in corridors of a shopping center in Brasilia (Photo: author).

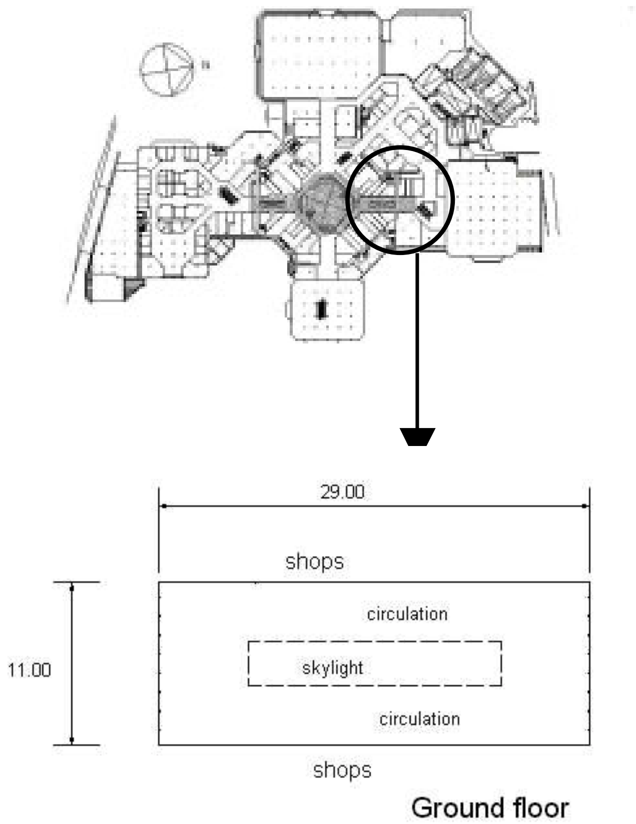
A CASE STUDY: METHODOLOGY

In order to find some components and design solutions for these problems of visual comfort and energy efficiency, a case study was conducted with a representative shopping center in Brasilia, Brazil. The chosen building is the Park Shopping, described in previous work (AMORIM, 2000). This is a building that represents the typical architecture of shopping centers in the 80's, and in the next years will present the necessity of restructuring.

One specific part of the shopping center was chosen to be studied: the area below the skylight (figure 3). This area presents many of the identified visual comfort problems, as the presence of direct sunlight, glare and reflections.

In this area, daylighting simulations were performed, testing different solutions. The purpose of this procedure is to evaluate the present situation in terms of visual comfort only with daylight, and to compare the components and design solutions, proposed to optimize both visual comfort and energy efficiency.

The area illuminated by the skylight is a circulation area (319 m² in the ground floor and 268 m² in the first floor), directly connected with the shops (figure 4).



Figures 3 and 4. Plan of the shopping center and detail of the studied area, illuminated by the skylight

The skylight has an area of 51 m², covered with policarbonate transparent domes (figure 5).

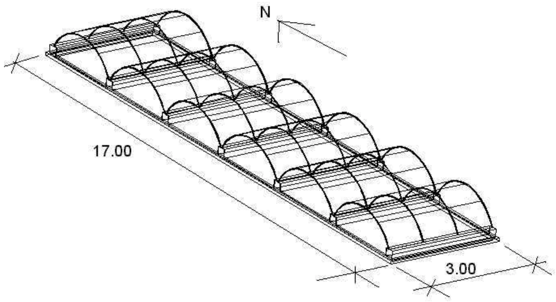


Figure 5. Perspective of the original skylight in a corridor of the shopping

VISUAL COMFORT PARAMETERS

In order to compare the different design and components solutions proposed for this area, some visual comfort parameters were selected. These can evaluate quantitative and qualitative aspects of daylighting, and an optimum result will improve also the energy efficiency of the building, as we mentioned before. The visual comfort parameters that were chosen are:

- **Illuminance values** (optimum average and minimum): a review of the main international norms (AMORIM, 2001) about the advisable values of illuminance for typical tasks in a shopping center gave us the values of optimal average and minimum illuminance. In the evaluated area we have only pedestrian circulation[1], so the values are: minimum illuminance: 100 lux; optimal average illuminance: 400 lux.

- **Analyses of daylight distribution and Illuminance Uniformity:** the first one is done using a grid of illuminance points, stabilised based on an existing norm[2] to evaluate the lighting in internal environments. This evaluation of daylighting distribution is done only in the ground floor, where the zone is extended. The Illuminance Uniformity, calculated for both first and first floors, is defined by the CIE [3] and the italian norm UNI 10380 as the ratio between the minimum and the average illuminance. This ratio must be higher than 0,8. (Minimum illuminance/Average Illuminance >0,8)[4].

- **Glare Analyses:** The glare calculation and analyses in a typical way inside the shopping center is done.

The disability glare producted by the reflected sunlight in the floor, above a skylight (figure 2), is calculated in the ground floor of the building, in an area illuminated by the skylight. We suppose one person doing a typical way in the shopping center, observing the reflected sunlight spot in the floor from 2, 4 and 6 meters of distance. The vision of this spot of sunlight can cause glare . Figure 6 shows a person looking at a reflected spotlight in the floor, at the three different distances, in order to evaluate glare.

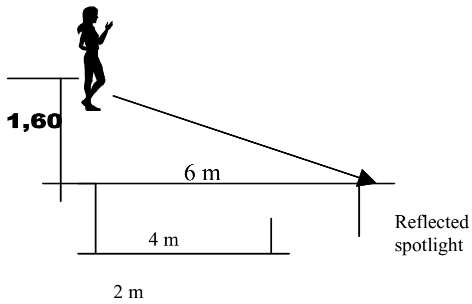


Figure 6. Scheme for the glare calculation in three points of a typical way in the shopping center.

The area of the spot of sunlight is above 51 m²

A quantitative assessment of glare discomfort can be given by the expression of the "glare constant"G(BAKER ET AL, 1993):

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[1] It's also possible to have in this area sales activities and merchandising exposition, but these would require highere illuminance levels or suplementary artificial lighting. In the present case we are evaluatin if the daylighting provided by the existing and proposed design solutions is sufficient to perform the tasks (in this case, only circulation).

[2] UNI. Illuminotecnica. Illuminazione di Interni con luce artificiale, UNI 10380, Ente Nazionale Italiano di Unificazione, 1994.

[3] See: Commission Internationale de L'Eclairage, "Reccomendations on illuminance", in Guide of Interior Lighting, CIE n.29, 1986, part.3.

[4] This parameter normally is used in environments illuminated by artificial light. It is difficult to reach this condition with daylighting, but this was used in this work not in it's absolute values, but to compare some different solutions with an existing one.

$$G = 0{,}478.\ \omega^{0,8}.P.\ Ls^{1,6}/\ Lb$$

ω = is the solid angle subtended by the source

ω = A/d″ where A is the area of the spotlight and d is the distance from the observer to this

P =is a '"Position Factor, depending on the position of the source with respect to the line of sight

Ls = is the luminance of the source, in cd/m″

Lb = is the field luminance

From these calculations we can calculate the Glare Index, suggested from the IES (Illuminating Engineering Society) for artificially lit rooms:

Glare Index = 10 log(10).SUM(1-n).G

where n is the number of glare sources.

And, finally, a Daylight Glare Index can be introduced which is related to the IES Glare Index by the equation:

DGI = 2/3 (GI + 14)

DAYLIGHTING SIMULATIONS: DESCRIPTION AND FIRST RESULTS ANALYSES

The simulations where performed using the software Lightscape® (LIGHTSCAPE, 1999), that can simulate both natural and artificial lighting in internal environments with complex geometry. The input to the software is a file with the geometry of the area, in which is possible to define the materials properties (transparency reflectance and so on), the daylighting characteristics of the region (external illuminance values), and also the artificial lighting system, when this is simulated. In this work the building was simulated only with daylighting. The outputs are: illuminance (lux) and luminance (cd/m²) values and the rendering of the environment.

The simulations were performed in three periods of the year (summer, spring/ autumn, winter). The sky conditions were individuated with the average monthly Nebulosity Index for this region[5]:

[5] Daylight statistics (as the probability of occurrence of each sky type) are not available for this region. For this reason, the average monthly Nebulosity Index was used to define the simulation conditions. This simplification doesn't means that in summer we have only overcast sky, but the predominant condition in this season.

The autumn and spring conditions present very similar results, and for this reason only three conditions were simulated, in the hours from 9 a.m. to 6 p.m. (these are the hours of shopping opening with daylight). The external global illuminances were calculated for these days in this region using the software DLN (SCARAZZATO, 1995). So we have the following days to simulate:

- 22 December, Summer, overcast sky - external illuminances from 3.000 to 20.000 lux;
- 21 June, Winter, clear sky - external illuminances from 8.000 to 96.000 lux;
- 21 march, autumn, partially overcast sky - external illuminances from 3.000 to 95.600 lux.

The first results of simulation for the existing situation were:

- Illuminance Values: The average illuminance value in the first floor is high, especially in the hours from 11 a.m. to 2 p.m.; in the ground floor from 9 a.m. The maximum illuminance values are very high, arriving to 7.000 lux with overcast sky (summer), 24.000 lux with clear sky (winter) and 31.000 lux with partially overcast sky (March). In summer, however, the illuminance values are high in the central hours of the journey, but don't arrive to the minimum requested in the rest of the day. This situation is clearly due to the entrance of direct sunlight without any control elements in both ground and first floors.

- Daylight distribution and Illuminance Uniformity: The daylight distribution in the ground floor present higher illuminances in the center, bellow the skylight, and very low illuminances at the far points of the grid (at 5 meters of distance). This occurs specially with clear or partially overcast sky. The Illuminance Uniformity reflects this situation, and the values are very low compared to the optimal one.

- Glare Analyses: The DGI values calculated are very high, showing that the original solution creates this kind of problem almost in the whole year . In winter, with clear sky we had values of 33 (intolerable[6]), in summer with overcast sky we have from 25 to 28 (uncomfortable to intolerable) and in

[6] Baker et al (1993) presents a scale of sensations due to the the glare defined by the daylight glare index DGI: Below 16 - Imperceptible; from 16 to 20 - Perceptible; from 20 to 24 - Acceptable; from 24 to 28 - Uncomfortable- above 28 - Intolerable.

autumn with partially overcast sky from 25 to 31. This occurs in all the hours were the direct sunlight enters.

PROPOSED COMPONENTS AND DESIGN SOLUTIONS

In order to solve the visual comfort problems identified before, and to improve the use of daylighting, optimizing the energy efficiency of the building, some components and new design solutions were studied. Between the many existing alternatives, we have selected those who present medium/low cost, easy construction and maintenance. From this point of view, light-shelves and a new design for the skylight were proposed as a way to improve the existing situation.

The light-shelf is a component that can be easily added to the existing skylight, optimizing the light distribution, even if it doesn't act as solar protection. Three kinds of internal light-shelves were simulated, and it's design was based on the existing literature (COMPAGNON ET AL, 1992; COMPAGNON ET AL, 1993):

a. curved light-shelf in the first floor

b. flat light-shelf in the first floor

c. curved central light-shelf in the ground floor

The light-shelves a and b are simulated with the light-shelf c, in two possible combinations, as showed in the figures 7 and 8.

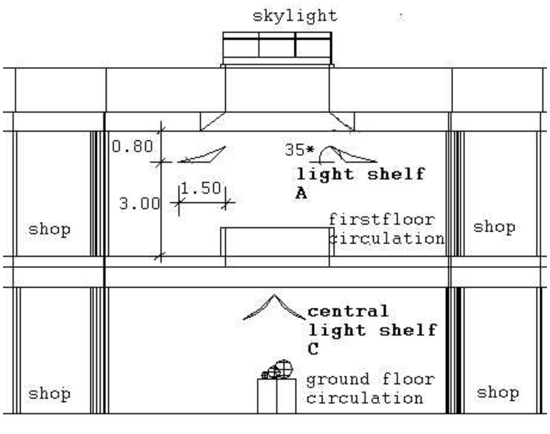

Figure 7. Transversal cross section in the studied area of the building, showing Light Shelf "a" (curved) in the first floor with central light shelf "c" in the ground floor.

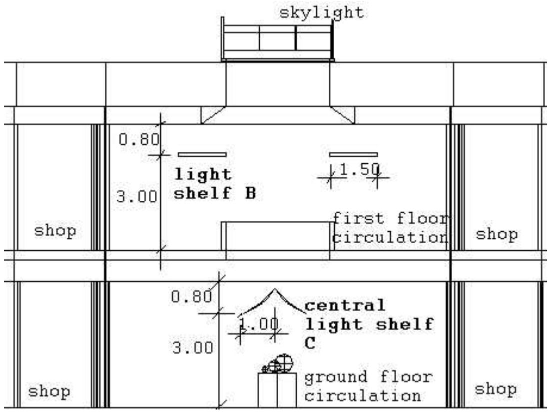

Figure 8. Transversal cross section in the studied area of the building, showing Light shelf "b" (flat) in the first floor

All the light shelves were supposed, in the first simulations, to be made in opaque material painted white (high reflectance). But the opaque material has reduced excessively the illuminances, so we have simulated the light shelves with a perforated material [7], painted white.

The other proposed solution is a new design of the skylight, based in the existing literature (ROGORA, 1998) and in the solar diagram for this region (latitude 16° south).

The new design has the scope to avoid the direct sunlight in the horizontal surface. It is a sequence of 4 monitor skylights, in which the curved shape of the covers, supposed to be made in opaque material painted white, helps to reflect the light below. Only the side facing north is closed with clear glass, and the lateral sides of the skylight were primarily closed with opaque material. However, in the first simulations it was noted that this solution reduces excessively the internal illuminance level; and for this reason the final design of the skylight has the lateral sides also in clear glass. With this design, almost the same amount of transparent area than in the original skylight was maintained (51 m² in the original skylight, 50 m² in the redesign). This is important to compare the two alternatives.

[7] The materials database of Lightscape® presents a kind of perforated material; which was used in the simulations painted white.

The next figures show the new skylight with orientation:

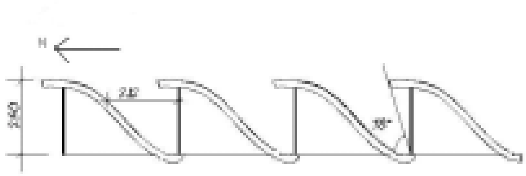

Figure 9. Longitudinal cross section of the new skylight design

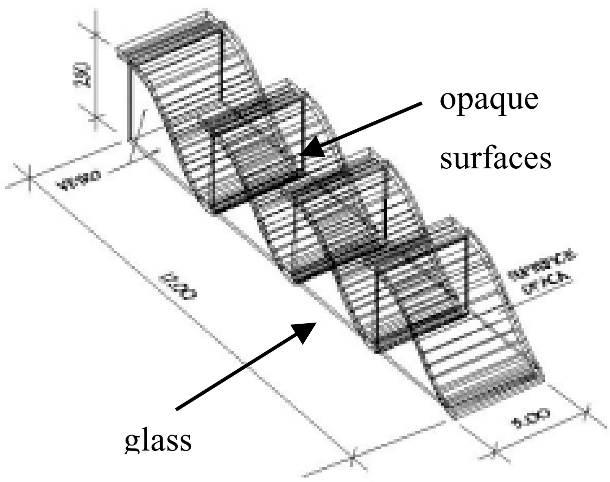

Figure 10. Perspective of the new skylight

DAYLIGHTING SIMULATION RESULTS AND ANALYSES OF THE PROPOSED SOLUTIONS

- **Light Shelf "a" (curved) in the first floor with central Light Shelf "c" in the ground floor**

Illuminance Values: The light shelf "a" in the first floor, in march at 10 a.m., has reduced the average illuminance from 4373 lux to 2114 lux, reducing also the maximum illuminances from 31538 lux to 30988 lux. In June the average illuminance has been reduced from 5356 lux to 193 lux, and the maximum illuminance was reduced from 17889 lux to 283 lux. In December the average illuminance has been reduced from 409 lux to 59 lux; the maximum illuminance was reduced from 5211 lux to 339 lux. This shows an improvement especially in autumn, where adequate levels of average illuminance where maintained, while reducing excess of direct sunlight. Also the illuminance uniformity in the first floor was improved.

In March, at noon, the central light shelf "c" in the ground floor has reduced the maximum illuminance, from 31538 lux to 30988 lux, maintaining an adequate average illuminance (2114 lux) . In winter (June) the maximum was reduced from 17889 lux to 283 lux, maintaining an average illuminance of 193 lux . In summer we can observe an excessive reduction of average illuminance (from 409 lux to 59 lux), below the minimum requested for circulation in some points.

Analyses of daylight distribution and Illuminance Uniformity: The results in the illuminance values with the light shelf "a" show an improvement in the illuminance uniformity, specially in summer/december. In fact, the value of Illuminance Uniformity in the first floor increases from 0,03 to 0,4 at 10 a.m., when the sunlight is directly above the light shelf. Also in winter/june and autunn/march periods we note an improvement (from 0.02 to 0.05 in winter/june and from 0.03 to 0.4 in autunn/march at 10 a.m.) but not so high as in summer. The light shelf has a better performance when the sun angle is almost perpendicular to it, as in summer.

In the ground floor, in summer, with the central light shelf "c", we can observe two spots of higher illuminances, instead of one, as in the original skylight. This improves the daylight distribution, and the Illuminance Uniformity values increase from 0,01 to 0,09 at 10 a.m. and 15 p.m. Although, at noon this solution doesn't performs well, showing the same illuminance uniformity as in the original skylight. In autunn and winter there is also an improvement of the illuminance distribution (from the value of 0.006 to 0.009 in winter and from 0.004 to 0.076 in autunn, at noon), but this solution performs better in summer.

Glare Analyses: The light shelf "a" eliminated glare in the first floor at 10 a.m. in summer, winter and autumn; in other periods of the day, the glare reduction was of 10%. In winter this reduction is of 30%, but the values are still high (more than 26). The number of hours in which we can perceive glare is also reduced.

The central light shelf "c" in the ground floor is also effective to reduce glare; the values in winter are reduced from 33 to 26, in summer from 28 to 24 and in autumn from 31 to 28. Although, this solution can't eliminate completely glare, especially at noon.

- **<u>Light Shelf "b" (flat) in the first floor with central Light Shelf "c" in the ground floor</u>**

Illuminance Values: The flat light shelf "b" in the first floor has a similar performance when compared with the curved one, in the illuminance values.

Analyses of daylight distribution and Illuminance Uniformity: In the Illuminance Uniformity, the flat light shelf "b" has a worse performance when compared with the curved one. In fact, the Illuminance Uniformity value in the first floor has increased when compared with the existent skylight, but not so much as with the curved light shelf.

Glare Analyses: The DGI values in the flat light shelves are similar to those obtained with the curved one.

The central light shelf "c" in the ground floor, of course, have the same performance in the three parameters as in the previous presented combination, with curved light shelf "a".

- **<u>New Skylight Design</u>**:

Illuminance Values: The average illuminance is excessively reduced, specially in the ground floor, where the minimum required illuminance level (100 lux) is not reached. The value of average illuminance in autumn is 82 lux in ground floor at noon and 2397 lux in first floor at 10 a.m.; in winter is 71 lux in ground floor and 6195 lux in first floor; in summer is 36 lux in ground floor and 2397 lux in first floor.

Analyses of daylight distribution and Illuminance Uniformity: Although the minimum illuminance level is not reached, daylight distribution, specially in the ground floor is improved. With this solution it was eliminated the spotlight with very high illuminances. The Illuminance Uniformity values are improved in the ground floor at noon, increasing from a value of 0,05 to 0,14 in the ground floor at noon, from 0.006 to 0.012 in june and from 0.009 to 0.27 in december. In the first floor at 10 a.m. the values increase from 0.004 to 0.04 in march, from 0.03 to 0.12 in december.

Glare Analyses: With this solution the occurrence of glare was almost eliminated, both in first and ground floors. We can see the presence of glare only in the first hours of the morning in the first floor. The values of DGI goes down from 33 to 28 in the first floor at noon in march, from 33 to 25 in the first floor at noon in june. We can see then a good eduction of glare compared with the original solution of skylight.

CONCLUSIONS

From the simulation results and analyses we can take some conclusions:

- The worse problem in the original skylight is daylight distribution and the presence of glare, due to the strong entrance of direct sunlight. In order to solve this problem, a new skylight design and the addition of light shelfs are proposed.
- The simulations with the software were very useful to compare the proposed design and components solutions. Using the software, it was possible to calculate some visual comfort parameters as the Daylight Glare Index and the Illuminance Uniformity, despite these were not automatically calculated in the simulations.
- The new skylight design has improved significantly the illuminace uniformity, with a better distribution of daylight in the spaces. Also the presence of glare was reduced, in both floors and in the hole year; but unfortunatly, this solution has reduced the illuminance below the adeguate level.
- The proposed light shelves globally had a better performance in all the parameters. In the first floor the curved light shelf "a" has performed better than the flat one, maintaining adeguate illuminance and improving the illuminance uniformity. Although the glare was not completely eliminated, it was observed a significant reduction both in the DGI values and in the number of hours in which the glare is observed.
- In the groung floor, the central light shelf "b" eliminates the spotlight with very high illuminance values in the center of the area. creating two spotlights in the area, which improved the daylighting distribution. Better Illuminance Uniformity values were also reached with this solution, maintaining the illuminance in adeguate values. Although this solution can't eliminate completely glare, especially at noon, it was effective in other periods of the day.
- We can see clearly that is necessary to find a compromise between the illuminance levels and

the other visual comfort parameters, in order to obtain a good solution from all points of view. Sometimes is not possible to find a perfect one.

- All the solutions for a better daylighting system utilization must be used togheter with control systems of artificial lighting (e.g. "dimming"), in order to make a good use of the available daylighting. The artificial lighting system will compensate this, when the daylighiting levels are not enough to the performed tasks.
- With these arrangements, a good visual comfort solution will improve also the energy efficiency of the building, reducing the electricity consumption both for artificial lighting and air conditioned, contributing to a better environmental quality of the building.
- Finally, we can say that the adaptation or the restructuring of commercial buildings, utilizing some of the proposed solutions, can be a good opportunity for an improvement of the environmental quality. In the case of the shopping centers, it will also contribute to give a regional character to it's architecture and to eliminate the architectural "uniformity" of this typology, not compatible with the specific climatic conditions and with both visual comfort and energy efficiency goals.

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