Evaluation of Daylighting and Thermo-Energetic Performance in Administrative Building in the South of Brazil

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Abstract: Daylight is a fundamental element to obtain built environments that promote environmental comfort and energy efficiency. However, strategies that enhance the building daylight performance can affect its thermal energetic performance. In this sense, research that addresses these aspects at the same time is considered essential. The objective of this paper was to evaluate the daylighting and thermal-energetic performance of administrative environments in a public institution, and to propose strategies that will enhance the use of daylight and lower energy consumption. Therefore, for future projects, and considering new buildings, and retrofit, this research will be an important reference. The research was developed through a case study of an administrative building model, in which the characteristics of solar orientation, light shelf use, glass type, and light and dark colors in walls were modified and combined, deriving it into models proposed. The daylighting performance evaluations were performed through dynamic simulation with the Rhinoceros for Diva software, and the thermal-energetic performance evaluations with the EnergyPlus software. The results of the work showed that a suitable solar orientation has a great impact on the automation of daylight and the energy consumption of the evaluated models, followed by the type of glass and the use of the light colors in internal walls, and that the use of artificial lighting with dimerization is fundamental as a complement to the daylight autonomy. For the boundary conditions of the study, the use of light shelves modified neither the daylight performance nor the thermal-energetic performance of the evaluated models.

Key words: Daylighting, daylight performance, thermal-energetic performance, administrative environments.

1. Introduction

In prolonged use environments where intense visual activities are performed, the correct use of daylight is essential, not only resulting in energy savings, but also contributing to the thermal-energetic performance of the building.

According to Ref. [1], all light, whether natural or artificial, is radiant and eventually absorbed and transformed into heat. In temperate climate in the south of Brazil, in winter, this heat is desirable only in the winter.

In the same vein, Freewan [2] relates that office buildings spend a large amount of energy for equipment, lighting, cooling and heating. Large windows and highly glazed facades have been increasingly used in new buildings, allowing access to daylight, outdoor viewing and heat gain. The first steps in the architectural design impact the energy consumption of buildings, being 22% of this consumption linked to the quality of the envelope and 6% to the geometry [3]. In this context, opaque envelope has a significant contribution to the building thermal energy performance. Azari [4] defines that the facade has significant influence on the energy consumption of buildings. Heat gain across large glazed areas represents a significant component of cooling load and consequently increased energy consumption. Solar radiation that penetrates through unprotected openings increases summer air temperatures and affects both the users’ thermal...
comfort and the thermal performance of the building, increasing the cooling load. Using glass with low solar factor values can reduce the demand for HVAC energy for office buildings [5]. On the other hand, too much solar protection can cause the use of artificial lighting, which can also impact the performance of the building. In this sense, the combined use of glass with adequate solar factor and the reduction of the thermal transmission of the facade can lead to a reduction of up to 40% in energy consumption in buildings [6].

In this context, it is relevant to evaluate the luminic and thermal performance of buildings, in parallel. In this sense, research that addresses these issues at the same time is considered essential.

The Federal University of Rio Grande, the case study of this paper, adopted a model of the administrative building. The university already built four administrative buildings considering this model.

This building model features large openings without solar device protection. Although the buildings have the same envelope, they are located in different solar orientations, since their implementation has obeyed the criteria of access to the entrance from the existing roads on campus.

Although large windows are interesting, the resulting excess daylight can cause glare in the administrative environments, increasing the thermal load in summer and producing thermal losses in winter. Within the context of the large glazed plans [7], in a study for Belgrade, characterized that a glazed façade can provide double solar gains compared to a Traditional Façade. From these considerations arose the research questions that this article sought to answer: Is the model used in the Federal University of Rio Grande for the new administrative buildings adequate considering the thermal-energetic performance, even though located in different orientations? Which architectural strategies would be necessary to improve its luminic and thermal behavior?

Thus, the general objective of this article was to evaluate the luminic and thermal performance of the administrative environments of a public institution, and to propose strategies that enhance the use of daylighting and decrease the consumption. Its specific objectives were: (i) to evaluate the luminic performance of administrative environments in a standard building model; (ii) to investigate, suggest and identify strategies that could be decisive for the best use of natural lighting and for the improvement of the building thermal performance; (iii) to evaluate the thermal performance in the administrative environments (standard model and proposed models) in the solar orientations with the best luminic performance; (iv) to identify the combinations of strategies that presented good performance for luminic and thermal aspects.

This work seeks to contribute to the dissemination of strategies that enhance the use of natural lighting with good thermal energy performance in administrative buildings so that future projects, both new buildings and retrofit, can rely on references and parameters analyzed.

2. References

The energy crisis that society is going through today requires the rational use of energy. Lighting systems, which account for much of the energy consumed, become one of the main targets in the pursuit of energy efficiency, and integration with daylight is one of the factors that most contribute to achieving an efficient energy system.

In this sense, Fathoni et al. [8] investigated the energy performance of daylight in office buildings in Thailand, and reported that in certain cases the heat dissipated by lamps accounted for 20% of the building cooling load noting that these numbers are significant and deserve attention.

Office buildings often generate a large amount of indoor heat due to high occupancy rates and significant use of equipment and lighting. Office workers depend on the thermal comfort conditions provided in the building to perform their activities. Thus, its
productivity depends directly on the level of thermal comfort provided within the building. The International Energy Agency has indicated that in a typical office building, artificial lighting congests most of the energy, followed by cooling and heating operations [9]. Lamberts et al. [10] characterize that energy consumption by lighting is high in the public sector, ranging from 40% in air-conditioned buildings to 90% of final use in buildings without air conditioning, which shows the high savings potential to be generated in the sector.

The study performed by Huang and Niu [11] reports that the openings are indispensable elements in contemporary architecture. On the other hand, due to their transparency and relatively low thermal resistance, the openings are always associated with a large amount of solar radiation heat gain which results in problems in the light and thermal performance of buildings.

According to Lechner [1], to understand daylighting strategies, it is worth examining lighting from a window first. The lighting level is higher just near the window and quickly drops to levels unsuitable for most visual tasks. Sky vision is often a source of direct brightness, and direct sunlight entering the window creates excessive brightness ratios (sun spots and overheating during the summer).

Good natural lighting is not necessarily proportional to large areas of glass. Excessive glass can cause glare and overheating, and because of the high thermal transmittance of glass, it is the reason for the largest thermal exchange between external and internal environment. Therefore, the choice of material of an aperture, solar orientation and area not only determine the lighting levels, but are also responsible for the internal heat gains.

It is common for buildings with large openings, or glazed panels, not to be able to make efficient use of natural light, spending several hours of the day with closed windows and using artificial light [12].

However, natural light can be used to reduce energy consumption with lighting. To make this possible, it must be explored in an integrated manner with artificial lighting systems. Within this idea, whenever natural light is appropriate to the lighting needs of the environment, artificial lighting should be disabled or reduced.

In short, a building lit with natural light can save a significant amount of electricity if its artificial light stays off when there is enough natural light.

The climate of southern Rio Grande do Sul requires solutions that take into account the correct ratio between openings and thermal gains, so that the best living conditions in buildings can be achieved. Therefore, it is important that lighting and thermal comfort strategies are worked together to emphasize the language of architecture, so that it is based on concrete principles dictated by social, economic, climatic and technological reality [13].

However, it is not very common to find studies that address the luminous and thermo-energetic aspects simultaneously. According to the study [14] on environmental comfort inside offices in China, environmental factors such as lighting and thermal comfort are addressed separately, although they have remarkable combined effects on occupants’ work performance.

3. Method and Materials

For this research, a case study was adopted, the Federal University of Rio Grande administrative building model. The following methodological steps were developed (Fig. 1): (i) literature review on the subject; (ii) survey and data collection, through the analysis of the design plans and documents and technical visits to the sites where the models were built; (iii) experimental design and lighting performance evaluation of the administrative building model (standard model) through dynamic simulation (Rhinoceros for Diva software); (iv) evaluation of lighting simulation results of the standard model and definition of altered characteristics for better performance (proposed models); (v) lighting performance
evaluation of the proposed models through dynamic simulation (Rhinoceros for Diva software); (vi) thermo-energetic performance evaluation of the standard and proposed models, through dynamic simulation (Energy Plus software); (vii) comparative evaluation of daylighting and thermo-energetic performance of the standard and proposed models, in a parallel way, for the improvement of the building performance; (viii) qualitative evaluation of daylighting, through static simulation, on characteristic winter and summer days, of the proposed models that presented the best daylighting and thermo-energetic performance; (ix) verification of the economic viability of the altered characteristics that improve the performance of the studied models.

3.1 Study Object: Survey and Data Collection

The case study was carried out at the Federal University of Rio Grande, municipality of Rio Grande, RS. This campus features three administrative buildings built as the standard model. The standard model of the administrative building has a compact form of two floors (Fig. 2). It was built with a reinforced concrete structure (pillars, beams and slabs). The vertical opaque part of the envelope consists of 20 cm thick plastered brick masonry walls in some parts, and double walls with 33 cm thick solid exposed brick in other parts. The vertical transparent envelope is formed by windows composed of white aluminum frames with 6 mm green absorbent glass (laminated,
The roof is composed by a mineral fiber lining, concrete slab and metal thermoacoustic tile roof, with 40 mm expanded polystyrene filling and white paint finish. The interior wall coverings are light cream and dark red paintings, light cream vinyl floors and white linings. The interior doors are semi-hollow wood, painted white and they have flags. Figs. 3 and 4 show the floor plans of the administrative building model adopted by the Federal University of Rio Grande.

This standard model of administrative building has large openings without sun protection in the various façades, and it was located in different solar orientations, mainly obeying criteria of access to the entrance porch from the existing roads on the campus. Table 1 shows the Window Wall Ratio (WWR) of each façade.

3.2 Experimental Design for Daylighting Performance Evaluation

The cases to be simulated were defined through the following steps: (i) determination of the most relevant interior environments of the building: prolonged daytime use and largest number of users, which resulted in the administrative halls, overlap on the floor plans, with lateral openings in different façades; (ii) definition of the most relevant façade: the largest lateral opening area, which was the reference for the solar orientations, with 37% WWR.

3.3 Daylighting Performance Evaluation of the Standard Model

In order to obtain the necessary data for the daylighting performance evaluation, verification was made in the design plans and documents of the administrative building model (standard model). Visits were also done to the administrative buildings. According to the standard model, the input data in the simulation software were solar orientation, overall dimensions, used materials, surface reflection (sashes, interior doors and ceilings—white = 80%; vinyl flooring and some interior walls—light cream = 75%, some inner walls—dark red = 15% [15]), and the light or visible transmissivity of the glass (6 mm green absorbent glass = 75%). The modeling of the standard model was performed through the SketchUp software, and the file was imported to the Rhinoceros for Diva software to the daylighting performance simulation.
Fig. 3  Ground floor plan—standard administrative building model.
Source: Author, 2011.

Fig. 4  Upper floor plan—standard administrative building model.
Source: Author, 2011.
Table 1  WWR façades (Authors, 2017).

| Façade     | WWR wall ratio (%) | Total/ WWR |
|------------|--------------------|------------|
| Front      | 37%                |            |
| Right side | 23%                |            |
| Left side  | 22%                |            |
| Back       | 16%                | 25%        |

**Fig. 5  Lighting simulation results of the standard model in different orientations.**
Source: Authors, 2017.

3.4 Definition of Proposed Models

Through the simulations of the daylighting performance of the standard model in different solar orientations, it was observed that the best orientation, regarding the daylight autonomy (DA) and the useful daylight illuminance (UDI), with values between 300 and 3,000 lux, was northeast-northwest. The worst results were observed in the south and southwest-southeast orientations, as shown in Fig. 5. The average of the results presented was weighted by the area of the interior environments.

The next step was to evaluate the three best orientations (northeast-northwest, east-west and north), discarding the orientations with the worst results (south and southwest-southeast) in the subsequent simulations, as shown in Fig. 5. From the simulation results of the lighting performance in the standard model, it was proposed to change some constructive characteristics with the intention of improving the lighting and thermo-energetic performance of the administrative building model.

There was a need for greater penetration of daylight into the inner part of some environments, and it was decided to improve the daylighting performance of these spaces using light shelves. Another proposed building feature was the use of light colors (80% of reflection coefficient) in the walls of the back part of the interior environments, since the areas that presented the lowest DA had dark colors (15% of reflection coefficient) on the walls. The replacement of the glasses was also proposed, in order to improve DA, they were changed into two cases: a simple transparent glass and, concerning overheating in the environment, a low-e glass. Therefore, the altered characteristics suggested with the intention of improving the daylighting and thermo-energetic performance of the standard model were: (i) light shelves; (ii) light colors...
throughout the environment; (iii) simple glass; (iv) low-e glass.

In order to define the best position of the light shelf regarding the opening, the daylighting performance of the standard model was simulated, in the best solar orientation (northeast - northwest), on the ground floor, for a central position of the light shelf (30 cm to the outside of the building + 20 cm from the wall + 30 cm to the inner side of the building), for an external position (80 cm) and internal position (80 cm), as shown in Fig. 6. The shelves were in the center of the window, 2 m high from the floor, not being an obstacle in sight through the opening. It was considered as aluminum light shelves, white, with a thickness of 5 mm.

Following the result of the type of light shelf being used, tests were performed to find out the most efficient depth of light shelf for the administrative building model. Six sizes of light shelves were simulated: 40 cm, 50 cm, 60 cm, 70 cm, 80 cm and 1 m. The 60 cm deep light shelf was the one which presented the best DA.

Subsequently, another checking was carried out regarding the height of the light shelf, in this case, located in the upper third of the window, 2.30 m above the floor. The best DA performance was for height of 2 meters above the floor, in the middle of the window.

3.5 Lighting Performance Evaluation of the Proposed Models

The lighting performance evaluation of the proposed models was performed by 72 simulations, which resulted in 36 evaluated models. The experimental design is presented on Table 2.

3.6 Thermo-Energetic Performance Evaluation of the Standard Model and Proposed Models

The thermo-energetic performance evaluation of the standard and proposed models was performed through simulation with the Energy Plus 8.7 software, modeled in the Sketchup 2017 software and Euclid plugin. The software generated the energy use intensity (EUI) consumption in kWh/year of the models by analyzing the energy end uses of heating and cooling, artificial lighting and equipment. The climate data file used was of the city of Porto Alegre-RS, located in the same Brazilian Bioclimatic Zone, ZB3, since the city of Rio Grande does not have a climate data file yet.

3.7 Experimental Design for Thermo-Energetic Evaluation

For the thermo-energetic performance, the models with the solar orientations that presented the best...
daylighting performance were simulated, in this case, north, east, west, northeast and northwest. Firstly, 60 cases were simulated, among them the standard model (variable solar orientation, without light shelves, green absorbent glass and some dark-colored inner walls), and the models proposed, with some altered characteristics (Table 3).

The 60 scheduled cases were evaluated under three different conditions: (i) without artificial lighting (to compare energy consumption with adequate daylighting, i.e. 100% DA); (ii) with artificial lighting on (to know how much savings could be achieved if the daylighting was appropriated); (iii) integrated lighting design, with dimerization (artificial lighting would only be turned on when the illuminance level of 500 lux was not reached by daylighting [16]). As a result of these three conditions, 180 cases were simulated.

3.8 Daylighting Qualitative Assessment

The qualitative daylighting evaluation was developed through static simulation (Rhinoceros software and Diva plugin), on characteristic winter and summer days, for the proposed models that presented the best daylighting and thermo-energetic performance, in a parallel analysis, and for the model which presented the best DA. It was also evaluated the model that presented the best daylighting performance with light shelves, which could promote greater uniformity and less possibility of glare. The parameters of light uniformity and possibility of glare were evaluated at 10 a.m., 12 p.m., 2 p.m. and 4 p.m., on winter solstice (June 21st) and summer solstice (December 21st), under partly cloudy and clear skies conditions, with radiation data provided by the Rhinoceros for Diva software. The illuminance uniformity in the task can not be less than 0.7 [16]. However, when in a lighting system the precise location of the visual task can not be defined due to the location being unknown and/or the activity performed involves a number of different visual tasks, it is recommended that the various task areas are combined to form a larger area (referred to as the workspace). If the illuminance distribution in these larger areas has a uniformity ≥ 0.6, it can be assumed that the uniformity is ≥ 0.7, which is required to meet individual task areas. In this article, it was adopted as adequate illuminance uniformity values ≥ 0.7. As for the possibility of glare, according to Gonçalves et al. [13], Nabil and Mardaljevic [17], Illuminating Engineering Society of North America (IESNA) [18], environments with illuminances above 2,000 lux are subject to produce visual, thermal discomfort and possibility of glare. Therefore, it was defined that values above 2,000 lux would be considered, in this paper, as likely to cause glare.

3.9 Financial Viability Verification

The financial viability of the proposed modifications to the standard model, which allowed the optimization of their daylighting and thermo-energetic performances, was carried out through an analysis that aimed to verify the financial impact of the implementation of the different suggested building characteristics, as well as the return time of investment. The financial verification was based on the simple payback calculation. Payback
is an indicator of the return on investment time in years. Simple payback is obtained from the fraction of the investment made over the annual cost of energy saved. This stage of the research was important to know the viability of the proposed characteristics in a public building, which usually has restricted budgets, in bioclimatic zone 03, to potentialize a better daylighting and thermo-energetic performance.

4. Results

4.1 Lighting Performance Evaluation

The first results presented refer to the evaluation of the standard model in different solar orientations. A higher DA was obtained in the NE and NW oriented models (DA = 64.26%), followed by the E and W orientations (DA = 63.83%). The worst DA percentages were found in the SE and SO (DA = 55.87%) and S (DA = 56.78%) orientations. The difference between the best daylighting performance (NE and NO orientations) and the worst (SO and SE orientations) corresponds to a percentage of 8.37% representing 306 h/year of DA, i.e., more than one month of DA in the study building opening hours. The use of light shelves decreased 1 to 2% of DA, although the literature points to its benefits in the quality of daylighting by reducing the risk of glare and the greater uniformity in daylight distribution throughout the room, reaching deeper spaces and increasing the participation of ceiling reflection [1, 13, 18, 19]. The use of light colors on the walls did not considerably changed the results. However, it is good to point out that, for this case study, few walls were considered with low reflection coefficient (15%). If the models would have larger amounts of dark walls, it would probably have a greater impact on the results. The proposed model which obtained the best daylighting performance regarding the DA was NE-NW_XX_2_B (northeast-northwest orientation, without light shelf, clear glass and light colors). Through the lighting performance results presented, the most relevant altered building characteristics for this administrative building model were solar orientation and glass. Fig. 7 shows an image of the results of the lighting performance evaluation extracted from the program.

Fig. 7  DA of the best lighting performance model.
Source: Authors, 2017.
4.2 Thermo-Energetic Performance Evaluation

It is presented a synthesis of the results of the thermo-energetic performance evaluations of the models, considering the boundary condition and different solar orientations.

4.3 Results Considering Models without Artificial Lighting

Regarding the solar-oriented consumption, it was observed that the northwest-oriented NW_XX_1_B model presented the best performance, and that the west-oriented W_XX_2_B model presented the worst performance. However, it is verified that the economy in the total consumption of the best case to the worst case is approximately 2%. Through these results, it was observed that the altered characteristics that had the greatest impact on the consumption of the simulated models were the solar orientation and the glass type, followed by light shelves use. The choice of solar orientation and the type of glass installed saved 2% of the total consumption of the standard model. It was also observed that, from the thermo-energetic point of view, the solar orientation which model presented the best performance was in the northwest, and the glasses that provided the best performance were the low-e followed by the absorber. Regarding the use of light shelves, it was observed that these devices reduced the consumption of models when oriented to the north, east and northeast, by approximately 0.3%, but increased consumption in the west and northwest orientations by approximately 1%. The use of light colors on all interior walls of the simulated environments increased the total building consumption by up to 0.4%, i.e., it was the least relevant feature in the total consumption of the model.

4.4 Results Considering Models with Artificial Lighting

Comparing the situation that considered artificial lighting always on with the situation without artificial lighting, it was noted that the consumption by refrigeration remained practically the same, but the consumption by heating was lower in the situation that considered artificial lighting always on, due to the heat generated by the lighting. However, it was noted that the total consumption of models, without considering artificial lighting, would save 36% when compared to the cases that considered the use of artificial lighting always on at times when the building would be operating, which attests the importance of proper use of an integrated lighting design.

4.5 Results Considering Models with Dimerized Artificial Lighting

Comparing a condition that considers always-on artificial lighting to dimmable controllers does not qualify for cooling consumption, it remains the same. On the other hand, heating consumption is lower in the case that considers always-on artificial lighting due to heat generated by enlightenment. However, it was observed that the total consumption of the models, considering the artificial lighting system with dimmer controllers, would generate the savings of 21 to 23% when compared to the cases that considered the use of artificial lighting always on (Fig. 8).

4.6 Daylighting Performance vs. Thermo-Energetic Performance

Fig. 9 presents the synthesized results of lighting and thermo-energetic performance, using the results that considered models without artificial lighting; since one of the objectives of this work was to know the impact that some modified characteristics could bring to the daylighting and thermo-energetic performance of the proposed models. Through the joint analysis of the presented results, it was observed that all the altered building characteristics in the proposed models had some impact on the daylighting and thermo-energetic performance of the standard model. However, the most relevant characteristics were the solar orientation and the type of glass. Solar orientation, regarding lighting
performance, increased by up to 8.37% the DA (306 hours/year), and for thermo-energetic performance reduced by 2% the total consumption. The use of light shelves for lighting performance decreased by 1 to 2% DA and for thermo-energetic performance increased consumption by up to 1.1%, but also decreased consumption by up to 0.3%, depending on solar orientation of the simulated model.

Although most results regarding the use of the light shelf point to a decrease in DA, this reduction seemed of little relevance. On the other hand, light shelves are known to provide deeper and more uniform natural illumination while eliminating the glare that usually accompanies the use of large openings. Light shelves also reduce the energy consumption of buildings, in certain orientations [1, 18]. For the types of glass, the best daylighting performance was for a simple transparent ordinary glass, followed by absorbent glass.

The difference between the DA percentage values between transparent and absorbent glass was 5% in all orientations analyzed. Now the difference of DA for transparent glass and low-e, was 14%, i.e. almost two months of DA, in the building opening hours. For thermo-energetic performance, the best results were for absorbent glass, followed by low-e. The reduction was 2% of the total consumption of the studied model, between low-e and transparent common glass; and a maximum of 0.9% between low-e and absorbent. The use of simple transparent common glass should be avoided to eliminate the possibility of glare [1].
However, the best type of glass stood out for the studied models, the absorbent glass that presented results corresponding to low consumption and good DA. Another factor to consider, when choosing glass for the model under analysis, was the higher energy requirement for heating (16 to 18% of total consumption) than for cooling (2 to 5% of total consumption), for low-e type glass. In addition to reducing light transmissivity compared to absorbent glass and transparent common glass, it also reduces the radiation that penetrates the internal environment, increasing the possibility of thermal discomfort by cold. The use of light colors (80% reflection) on all internal walls, for lighting performance, increased by 1% in DA and for thermo-energetic performance, increased consumption by 0.4%, i.e., light colors improved performance, but the dark colors improved the thermo-energetic performance of the models. Another important aspect observed is that dark colors were applied to the deepest walls of the standard model, where the light loses intensity, so it would be feasible to use walls with higher reflections, to promote the efficiency of daylighting and to allow the sensation of a well-lit space using the least amount of light [1]. On the other hand, large color variations can be problematic. Office interiors should be illuminated to provide good visibility without distracting colors; however it is important to provide enough variation in luminance or color to make for a stimulating and attractive environment. Where there are no prolonged visual tasks, such as in lobby, hallways, and receptions, color variations are encouraged, using eye-catching colors and appropriate high illuminance focal points to draw attention [18]. From these analyses, it was sought to determine the model with the best daylighting and thermo-energetic performance. In this study, the best results are found in the NW XX I B model (northwest solar orientation, no light shelves, with absorbent glass and all light-colored inner walls); and NW XX I D (northwest solar orientation, no light shelves, with absorbent glass and some dark colored inner walls). These two models presented a balance between DA and energy consumption values. Fig. 10 presents synthesized results of lighting and thermo-energetic performance analyzed in parallel, using the results that considered the models with dimerized artificial lighting. Through the joint analysis of the presented results, it was observed that all the altered building characteristics in the proposed models had some impact on the lighting and thermo-energetic performance of the standard model. However, for the models under the condition without artificial lighting system, the most relevant characteristics were the solar orientation and the type of glass. Considering the

![Fig. 10 DA × Energy consumption of simulated models with dimerization.](source: Authors, 2017)
dimerized artificial lighting system, the solar orientation model that presented the best thermo-energetic performance was the northwest and that for the lighting performance was the northeast and northwest ones. These results were like those corresponding to the models evaluated under the condition without artificial lighting. It is believed that the best performance, which corresponds to the lowest consumption, occurred in the northwest orientation, because, according to the distribution of consumptions, the model presented greater need for heating than cooling, and as it had the highest percentage of openings facing northwest (WWR = 37%), eventually allowing for greater heat gain as a consequence of sun-air temperature, which as a concept considers the combined effects of solar radiation and air temperature, thereby decreasing consumption for heating.

The use of light shelves, for lighting performance, decreased by 1 to 2% at DA, because, when a shading object is inserted in the windows, obviously the amount of light that enters the environment decreases. However, this reduction of DA seemed unimportant. For thermo-energetic performance, consumption decreased when oriented north, east, and northeast, up to 0.7% (in the east orientation). On the other hand, light shelves also increased consumption in the west and northwest orientation by a maximum of 0.7% (northwest) on some models. As for the types of glass, the best lighting performance corresponded to the transparent common glass, followed by the absorbent glass, since these types of glass allow the penetration of a greater amount of daylight to the interior environment, compared to the low-e glass. For thermo-energetic performance, the best results were for transparent common glass (in the north, east and northeast orientations) and for absorbent glass (in the west and northwest orientations), as the models presented higher need for heating than cooling, resulting in a decrease in heating consumption. The use of light colors (80% reflection) on all internal walls for the lighting performance of all models in all solar orientations increased by 1% in DA and for thermo-energetic performance decreased consumption in all orientations, up to 0.9% (in the east orientation). That is, the light colors have minimally improved both the lighting performance and the thermo-energetic performance of the models. From these analyses, it was observed that the models that presented better lighting and thermo-energetic performance under the dimerized artificial lighting condition were the same ones that had already obtained this evaluation in the previous condition (without artificial lighting): NW_XX_1_B (northwest solar orientation, without light shelves, with absorbent glass and all interior walls with light colors); and NW_XX_1_D (northwest solar orientation, no light shelves, absorbent glass and some dark colored inner walls). These two models presented a balance between DA and energy consumption values. About lighting performance, a dynamic analysis that evaluates the DA does not necessarily provide information about the quality of daylighting. Then, a qualitative evaluation of lighting performance was included, through the parameters of illuminance uniformity and the possibility of glare due to excess brightness or luminosity.

4.7 Daylighting Qualitative Assessment

It is showing the results of the qualitative evaluation of the illuminance uniformity and saturation dimness parameters of the model that presented the best daylighting and thermo-energetic performance, the NW_XX_1_B (northwest orientation, without light shelf, absorbent glass and light colors) as well as the one with the highest DA, NE-NW_XX_2_B (northeast or northwest, no light shelf, clear glass and light colors). The proposed model that presented the best performance of the lighting and thermo-energetic aspects was the one that presented the lowest consumption. However, it was not the same one that presented the best daylighting performance. Therefore, we evaluated these two proposed models. The results also include data on the evaluation of the model that
presented greater illuminance uniformity and lower possibility of glare, using light shelves, since several authors [1, 13, 18-20], previously mentioned, argue in favor of its benefit in the quality of illumination.

4.8 Illuminance Uniformity and Glare Assessment

The model with best daylighting and thermo-energetic performance, the NW_XX_1_B, presented lower possibility of glare and a minimal superiority regarding the illuminance uniformity, when compared to the higher DA model, the NE-NW_XX_2_B model. The difference between the two models was the type of glass used in the openings. It seems logical that the model containing absorbent glass reduced the possibility of glare when compared to the model with common glass, since the second one has higher light transmissivity. Based on these results, the NW_XX_1_B model was evaluated with the use of light shelves (NW_LS_1_B) and it was observed that in winter and summer solstices, under the condition of partially cloudy sky, there was less possibility of glare in the environments, when the results were compared to the NW_XX_1_B model. The illuminance uniformity of the proposed NW_LS_1_B model, with light shelves, remained the same as the model without light shelf, in winter and summer solstices, under clear sky condition. Now under a partially cloudy sky, the Chefia environment, which in the model without light shelves presented illuminance uniformity all times, no longer presented it in the model with light shelves. These results, regarding the boundary conditions of this research work, did not meet the literature claims that indicate a higher quality in the spatial distribution of light with the use of light shelves [1, 13, 18-20]. On the other hand, they are meeting about the reduction of the risk of glare, as there was a small reduction in the possibility of excessive contrasts in the model with light shelves. All environments that achieved good illuminance uniformity were noted to be small, rectangular in size, with larger openings in the wider wall of the room and most with two opposite windows. It was also noted that the Halls and the Secretariat, which are very deep environments, failed to achieve illuminance uniformity. The Secretariat environment does not receive direct solar radiation and the Meeting Room receives sun only in the morning, thus reducing the possibility of glare when observing data from a daytime period.

4.9 Financial Viability Verification

In the financial evaluation it was verified the energy saving (kWh/year) obtained in the proposed models that presented: (i) the best daylighting and thermo-energetic performance (NW_XX_1_B) and; (ii) the best DA (NE-NW_XX_2_B), and the proposed interventions (building characteristics and implementation of the dimerization system) were compared against the standard model, through the cost of kWh to monetarily measure the savings obtained. The building characteristics evaluated have no costs to be implemented. Therefore, only the amounts that should be invested for the implementation of the dimerization system were verified, and since it is a public work, the costs presented here were defined through the SINAPI basis and market quotations. After defining the investment cost, knowing the savings generated by the dimerized artificial lighting system, the simple payback was defined (Table 4). The most relevant intervention in the financial evaluation was the artificial lighting system with dimming, as a strategy to improve the building consumption. Dimerization showed a remarkable reduction of approximately 5,500 kWh/year.

| Models          | Proposed Interventions | Investment (R$) | Generated Savings (R$) | Lifespan (years) | Simple Payback (years) |
|-----------------|------------------------|-----------------|------------------------|------------------|------------------------|
| NW_XX_1_B       | Dimming lighting system | 2204.28         | 2015.94                | 20               | 1.09                   |
| NE-NW_XX_2_B    |                        | 2204.28         | 2046.34                | 20               | 1.08                   |

Table 4 Simple payback calculation (Authors, 2017).
kWh/year in both models, so this result reinforced the viability of dimerization, demonstrating the immediate payback time of one year.

5. Conclusion

It was concluded in this paper that solar orientation has the main impact on the daylighting and thermo-energetic performance of buildings. For the models and boundary conditions of this work, promote differences of up to 8.37% of DA, period of more than one month in the building opening hours, among the best (NE-NO) and the worst performance (SE-SO). This best lighting performance was at NE and NO, with a WWR of 37%. Proper solar orientation, with the highest WWR for NO, even saved 2% in the total consumption of the administrative building model, which is not a significant value, reinforcing that, for the thermo-energetic performance, models were simulated with the orientations of better lighting performances. Thus, regarding consumption, if they had been considered models oriented to the south, southeast and southwest, it would probably result in a higher percentage of economy. Another alternative evaluated, seeking to supply the need for a greater penetration of daylight in the back part of some environments and, similarly, to improve the thermo-energetic performance of the building was the use of light shelves, a strategy that did not significantly change the daylight autonomy of the building that had no impact on the consumption of the models. The use of light shelves decreased illuminance uniformity and minimally reduced the possibility of saturation glare. In a joint analysis of these effects, in the total hours evaluated, the light shelves caused worse light distribution than better reduction of the possibility of glare. This conclusion is contrary to the statements of several authors [1, 13, 18-20], who advise the use of light shelves, for providing benefits in the quality of daylighting, as well as reducing the consumption of the building, in certain orientations. Glass was one of the proposed characteristics that impacted the balance between the daylighting and thermo-energetic performance of the models. Among the three types of glasses evaluated the absorbent glass promoted, for the lighting performance, the lowest risk to the glare and the greater illuminance uniformity. For thermo-energetic performance, the absorbent glass was also responsible for the lower consumption, both in the evaluation condition without artificial lighting, that is, considering only the daylighting, as well as in the system complementation condition with dimmable controllers. As for colors, it was concluded that, in fact, light colors (80% reflection) slightly improved the daylighting and thermo-energetic performance of the models. However, the best strategy for this case study would be to replace the dark colors found in deeper walls of the environment, where light no longer penetrates so much, by light colors. For the administrative building model studied, it was concluded that the daylighting performance was more relevant than the thermo-energetic performance, because it allowed, through the adoption of some strategies, differences of up to two months of daylight autonomy, while about thermo-energetic performance, it achieved a maximum saving of 368.50 kWh/year, among models with the highest and lowest consumption. The highest consumption of models was related to equipment (51 to 81%), followed by artificial lighting (18 to 37%), and lastly by consumption with air conditioning, with percentages ranging from 7 to 19% for heating and 2 to 5% for cooling. Attention is drawn to the importance of the use of daylighting in the thermo-energetic performance of buildings, which in this case study reduced by up to 36% the total consumption of the building model studied, under the condition of daylight autonomy during working hours. However, the reduction in consumption was 23% with the dimmable lighting system, i.e. reduction of 5,500 kWh/year. It was concluded that it is necessary for both daylighting and thermo-energetic performance of the buildings to adopt an integrated lighting design combining daylighting and artificial lighting system
with dimerization, which in this case study presented economic viability, since it allows the immediate return on investment time in one year.

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