Analysis of the Rochavera Building Envelopment for enhanced daylight distribution

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Abstract

The size of a light opening in a building, as well as the choice of glass and design of the façade, directly affects thermal performance and luminous comfort. Although Sao Paulo has a humid subtropical climate, with summer temperatures reaching up to 35ºC and winter temperatures averaging 15ºC, it is common to see office buildings with glass-skin façades and no sunshades.

The Rochavera Building was completed in 2010 and was Sao Paulo's first office building to obtain LEED Gold Certification. According to Aflalo and Gasperini, the architecture firm behind the building, and CEBRACE, the glass supplier, sustainability and energy efficiency were a concern since the first sketches were made. As a result, the building envelopment is made up of a glass and granite façade, which led to an 80% heat reduction. However due to glass' solar heat gain coefficient, visible light transmission is only 21%.

The goal of this work is to calculate internal daylight availability via computer simulations, and to propose an alternative envelopment, which reduces glare and enhances diffuse daylight distribution while maintaining the efiiciency that guided the original design. The comparison of the original and proposed designs is made through computer simulations. Thermal Loads are evaluated in order to assess the impacts of the proposed envelopment on the existing building's energy efficiency. The results of this research are meant to guide new office building projects in Sao Paulo.

Keywords: Solar control glass, Energy efficiency, Daylight, Envelopment, Parametric design, Simulation, Thermal performance.

1. Parametric Design

The demand for high-performance design has become a goal in architectural projects since the world energy crisis in the 1970's. Research of form and function has benefited greatly since then, as buildings' environmental performance could be assessed and modified during the design process.

Although Sao Paulo has a humid subtropical climate, with summer temperatures reaching 35°C and winter temperatures dropping to an average of 15°C, it is common to see office buildings with glass-skin façades, and no sunshades. Despite the use of solar control glass in almost every building project from the last two decades, it is not enough to avoid the penetration of direct sunlight and glare near the openings.

Based on these observations, this paper—which is part of broader doctoral research—studied the building skin of one of the Rochavera towers, with the goal of achieving better daylight distribution. Following computer-simulated comparisons, the building envelopment proposed herein emerged as one of the best applications for increasing daylight penetration and reducing glare efficiently.

This paper discusses the building's existing energy efficiency, not its environmental quality, which has diverse indicators. The concept of environmental quality is systemic and involves several aspects [1]. Nevertheless, for the purposes of this research it is possible to leave aside the environmental quality until later studies about dynamic interrelations.

Parametric design through computer simulation indicates that the results can positively influence decision-making regarding the design of the buildings' shape and performance. Software developments have made these simulations easier to conduct and the results more accurate and more comprehensive, providing specific design solutions justified by performance results.

2. Rochavera Corporate Towers

The group of four office towers, known as the Rochavera Corporate Towers, were designed by Aflalo e Gasperini Arquitetos, a renowned architecture firm in Brazil. The Rochavera Corporate Towers are located on a 33,000 square-meter plot in the southern region of the city of Sao Paulo. Figure 1 shows the four towers, situated next to the Pinheiros River; figure 2 shows Towers A and B.

Figure 1. The four towers, next to the Pinheiros River. [2]

Figure 2. Towers A and B. [3]

The Rochavera Corporate Towers achieved gold certification in Leadership in Energy & Environmental Design – LEED. The project has several features that guarantee its environmental and social sustainability. Regarding energy management, various techniques were employed, such as automated and high-efficiency artificial lighting throughout the complex; an air conditioning system with central gas-fired power generators; the installation of a high-performance elevator system, automated through the use of electronic identification badges, and the use of natural light. High-performance glass covers 41% of its façade, providing a heat barrier that demands less energy consumption. All these features resulted in a higher construction cost, roughly 2-3% higher than for regular buildings. However, Rochavera saves between 20 and 30% more energy compared to Sao Paulo's regular office buildings. Thus, the increased cost of construction is paid for in the energy savings made within the first decade of the towers' lifecycle. [4]

The four towers are asymmetric and the three highest towers have a nine-degree inclination, providing more floor space on upper floors, which can be seen in figures 1, 2, and 3. Towers A and B have 18 office levels and a double-height ceiling on the ground floor. Due to the inclined façade, the distance between the core of the structures and the façades varies from 11.40m to 21.30m on the highest floor [3].

The three highest towers are quite similar. Their exteriors are made up of a glass-skin façade and prefabricated concrete sills coated with granite. The glass-skin façade is made of high-efficiency glass with fine soundproofing. [3]

Figure 3 indicates the section of Towers A and C; figure 4 shows the floor plan of the 18th floor of Towers A and B.

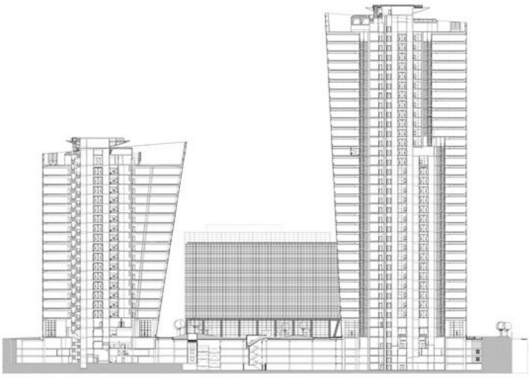

Figure 3. Section of Towers A and C. [3]

Figure 4. Floor plan of the 18th floor in Towers A and B. [3]

2.1 Computer Simulation: Daysim and Relux

2.1.1 Defining the parameters

Although energy efficiency software has made many advances and use of such tools has increased significantly, the results still stir debate. As stated by Hensen and Lamberts [5], it is still uncommon to report confidence levels based on simulation results due to the uncertainties of occupant behavior and its effects on real efficiency. Nevertheless, it is not rare to observe the constant use of blinds and artificial lighting even in clear sky days, without glare, according to Mardaljevic, Heschong and Lee. [6]

The sky model adopted in daylight simulations for the city of Sao Paulo has caused debate among local researchers. Static simulations of natural daylight can be done for an overcast sky, following the model from the Commission Internationale de l'Eclairage (CIE), using the Daylight Factor, as in this way the analysis of the building's behavior is conducted under the condition of extreme natural lighting. However, the use of parameters closer to real sky conditions affords results that are also closer to real conditions, which in turn suggests solutions that utilize systems specific to each situation, such as artificial lighting, air conditioning or building materials.

Dynamic daylight simulation software, such as *Daysim*, uses weather files to calculate annual indoor illuminance and illuminance profiles under more than one sky model [7]. Due to the climate file itself, however, the results can still generate uncertainties. According to Reinhart [7], Daysim extracts hourly direct and diffuse irradiances from the weather file, which are not measured frequently in most meteorological stations in Brazil, as reported by Teramoto and Escobedo [8]. Roriz [9], the company responsible for the collection of climate data used in the development of the Energyplus Weather Data file (EPW), stated that it had detected some inconsistent solar irradiances in the Instituto Nacional de Meteorologia (INMET) database. As such, this observation required a data correction, made by comparing with other climate data references. Roriz asserts that this method does not therefore produce a conclusive result, as the adopted references present monthly averages and they do not meet the minimum requirements demanded by main thermal-efficiency simulation software.

Another aspect to be considered is how Daysim provides the results. The software provides results in two main ways: Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA). The available illuminance ranges indicated by the UDI are limited because they present the illuminance as follows: less than 100 lux; from 100 lux to 2,000 lux; over 2,000 lux. The second range is wide and does not indicate the limit of 500 lux, the average illuminance level for office buildings, according to national and international standards. The third range suggests that illuminances over 2,000 lux may cause glare, which might not occur in spaces with diffuse daylight.

Daylight Autonomy is defined as the percentage of occupied hours per year in which the minimum illuminance level (500 lux) can be maintained by daylight alone, considering all sky conditions throughout the year. [7]

Relux software develops static analysis using some CIE sky models: clear sky, clear sky with sun, intermediate sky, intermediate sky with sun, and overcast sky. This type of simulation provides hourly analysis of internal illuminance, according to the latitude and longitude of project location. The results are also measured in lux, allowing one to infer which regions will suffer from glare.

Given the possibilities of analysis provided by Daysim and Relux, this research evaluated the 11th floor of Tower A of the Rochavera Corporate Towers by combining the results produced by both software programs, in order to obtain a more precise analysis of the building's behavior.

The Sao Paulo city sky was analyzed for broader doctoral research, and it was determined that the intermediate sky occurs more frequently than other weather patterns; thus this sky model was used in the static simulation.

3. Daylight evaluation of the Rochavera Building

Dynamic computer simulations were generated using Daysim, according to the climate file for the city of Sao Paulo. The models were made in SketchUp and exported to Daysim. The parameters considered were static shading design with active default behavior—in other words, a user operates the electric lighting in relation to ambient daylight conditions by opening the blinds in the morning, and partly closing them during the day to avoid direct sunlight [7]. The grid of sensors registered data every $0.50m^2$.

Relux static simulations were generated on the autumn equinox, March 21st, at 9am, noon, and 4pm, without considering daylight savings time. Although simulations for the summer and winter solstices were also generated, this paper presents only the simulations for the autumn equinox on March 21st, under an intermediate sky with sun. Ceiling, wall and floor reflectance were taken into account at 70%, 50% and 20% levels respectively. The Relux pseudo-color results are displayed in a grid of squares representing every $5m^2$ of the tested area.

The illuminance scale for the static simulation is as follows from left to right: 100 lux; 200 lux; 300 lux; 500 lux; 750 lux; 1,000 lux.

3.1. Results with building's original glass-skin façade

The following analysis indicates the performance of Rochavera's original glass-skin façade. Visible light transmittance (Tvis) is 21%, without sunshades. The façade was simulated in both Daysim and Relux. The ceiling height is 2.80m, the sill height is 0.80m and the window height is 2.00m.

Figures 5 and 6 indicate the building's annual performance for the minimum illuminance level established (500 lux). It is verified that the established illuminance is achieved up to 2.50m from the openings, with exception of the inclined façade. According to Daysim, daylight autonomy (as defined above in section 2.1.1) reaches 58%, in the areas close to the floor's vertices.

Figures 7, 8, and 9 show the Relux simulations. Figure 7 indicates that the maximum illuminance obtained at 9am is 1,980 lux and the average illuminance is 192 lux. It was noticed that the range of 500 lux is achieved only at approximately 4m from the northeastern and southeastern façade. The 100-200 lux range is achieved 6.00m from the same façades. Both southwestern and northwestern façades obtained few areas with 500 lux and up to 4.00m for the 100-200 lux range. From these results, it can be inferred that workstations near the northeastern and southeastern openings may suffer from glare due to the angle of the sun and the lack of sunshades.

Figure 8 demonstrates an equilibrium between all the façades at noon, with 500 lux up to approximately 1.00m from the northeastern façade. The reduction of glare area can be seen from the northeastern façade, regardless of a small area over 1,000 lux. Figure 9 shows an area over 1,000 lux up to approximately 3.00m from the northwestern façade and 2.00m from the southwestern façade, suggesting a probable glare due to direct sunlight and the lack of sunshades.

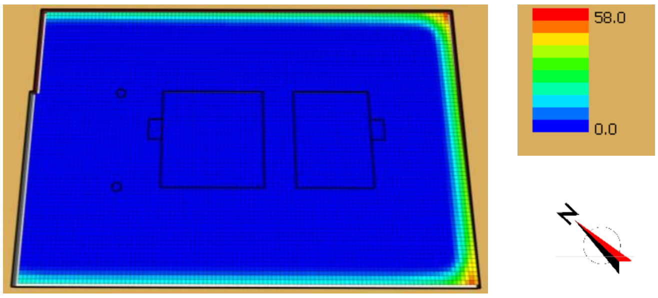

Figure 5. Daylight Autonomy, Daysim.

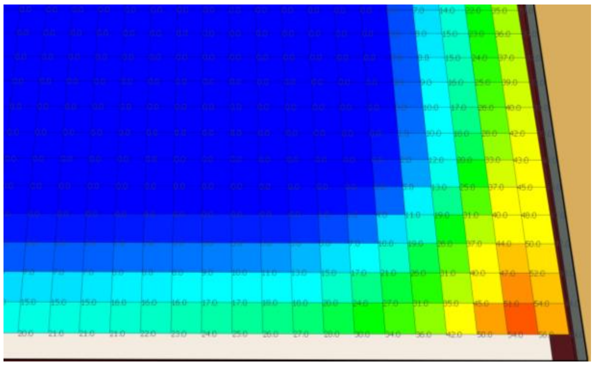

Figure 6. Node Values.

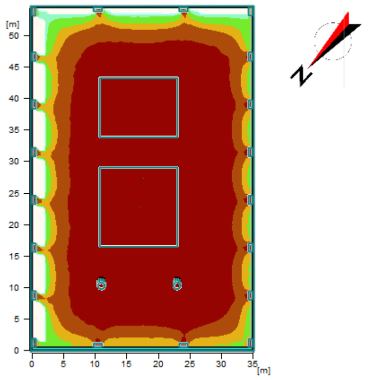

Figure 7. Relux simulation at 9am Emax[1]: 1,980 lux. Ē[2]: 192 lux.

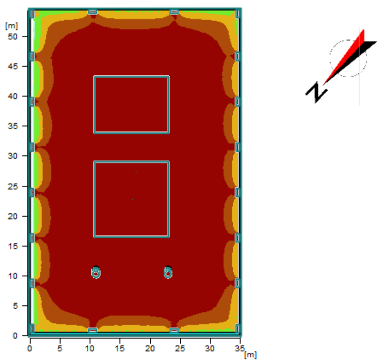

Figure 8. Relux simulation at noon Emax: 1,550 lux. Ē: 92 lux.

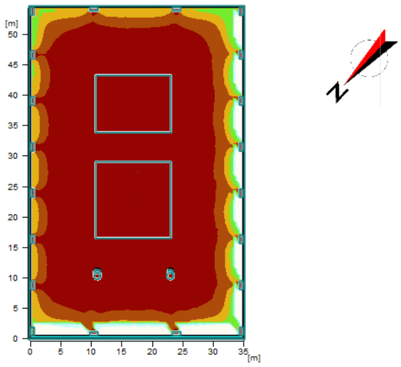

Figure 9. Relux simulation at 4pm - Emax: 1,330 lux. Ē: 145 lux.

3.2. Results of glass-skin façade with light shelf and Tvis change

In this simulation, a light shelf with 1.00m width was inserted on all façades. The light shelf was placed 2.10m from the floor, which results in two small areas of glass of 1.35m (below the shelf) and 0.65m (above the shelf). The glass' visible light transmittance (Tvis) above the light shelf is 70% and below it, the same as with the original façade (21%). The finish of the light shelf was considered white, with a reflectance factor of 50%, just like the walls. It is noteworthy that an increase in reflectance can generate improvement in the distribution of daylight.

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[1] Maximum illuminance.

[2] Average illuminance.

The decision to maintain the same light visible transmission for the glass below the shelf was because of the proximity of the glass to the workstations, and the solar heat gain due to the size of the opening. As the original glass is a solar control glass, it allows the reduction of thermal gains, resulting in a more comfortable solution regarding convection and radiation heat exchanges.

Figures 10 and 11 point out the increased reach of illuminance in the 500 lux range from 2.50m (in the former simulation) to approximately 6.50m (in this simulation) from the opening, with the exception of the inclined façade where the 500 lux range is achieved close to the floor's vertices. According to Daysim, daylight autonomy reached 77%, an increase of 19% compared to Rochavera's original solution.

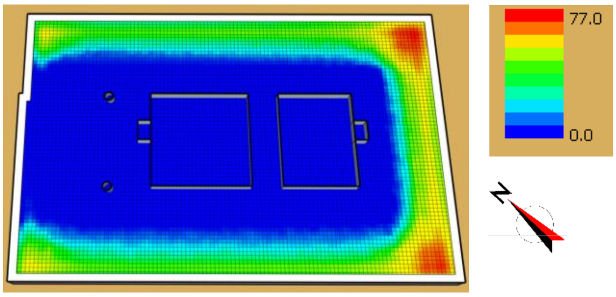

Figure 10. Daylight Autonomy, Daysim.

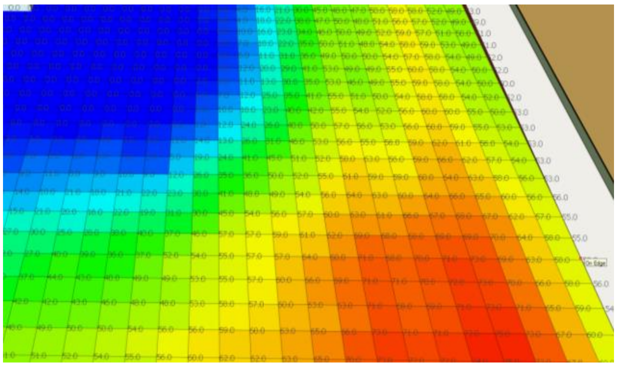

Figure 11. Node Values.

Figures 12, 13 and 14 indicate the building's performance in the static simulation.

Figure 12 reveals the decrease of areas where illuminance is over 1,000 lux, although maximum illuminance in some areas is 3,540 lux. It shows the possibility of glare from the northeastern and southeastern façades. The 100-200 lux range reaches the core from both the northeastern and southeastern façades. There was a small increase in the area of the 200-300 lux range, due to light shelf inter-reflections and the Tvis change. Areas with illuminance of up to 500 lux remained nearly the same compared to the original glass-skin simulation.

At noon however, depicted in figure 13, there was a reduction in the 300-500 lux range area. The range can be seen until about 2.00m from the openings of the northwestern façade. The overview of the 4pm simulation is quite similar to the 9am simulation. There was not a significant reduction in the area of the 1,000 lux range in the northwestern façade.

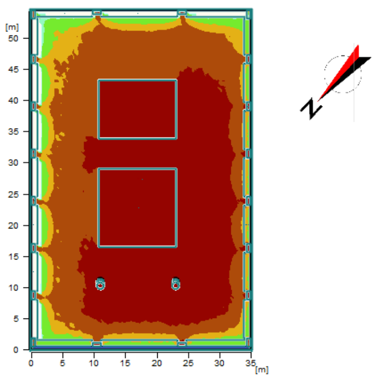

Figure 12. Relux simulation for 9am – Emax: 3,540 lux. Ē: 210 lux.

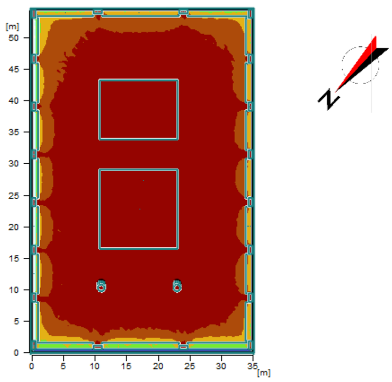

Figure 13. Relux simulation for noon – Emax: 1,610 lux. Ē: 101 lux.

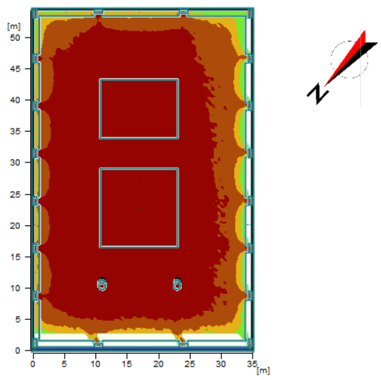

Figure 14. Relux simulation for 4pm – Emax: 3,420 lux. Ē: 170 lux.

The use of the light shelf produced a significant increase in daylight autonomy. The adoption of this device, in addition to the 70% Tvis glass above the light shelf, may cause glare during some periods of the day, which makes blinds a necessary feature. However, this scenario allows for the use of blinds only below the light shelf, which enables some daylight use. More simulations and studies are required to verify the performance of daylight with closed blinds.

Figure 15 shows a generic section of an office building, indicating the possible use of blinds below a light shelf. A solar screen could also be used, in the place of blinds. The material's specific light and heat transmission could also potentially improve thermal comfort. It is noteworthy that other façade solutions could be applied if solar screens were used.

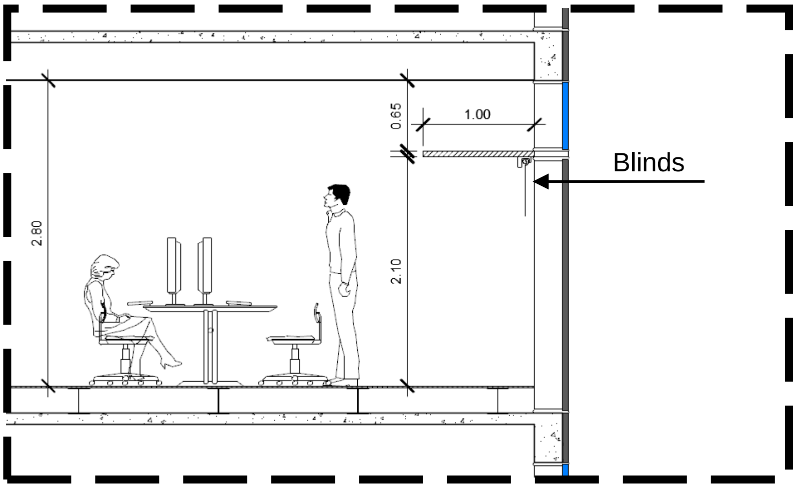

Figure 15. Generic section of an office Building with light shelf and blinds.

3.3. Glass-skin façade with extended light shelf and Tvis change

Based on the previous simulations, an extended light shelf of 0.50m width was proposed for installation outside the building. The glass areas remained unchanged, as well as their visible light transmittance: Tvis is 70% above the lightshelf and 21% below it.

Figure 16 shows this proposed façade, as modeled in SketchUp and uploaded to Daysim for simulation.

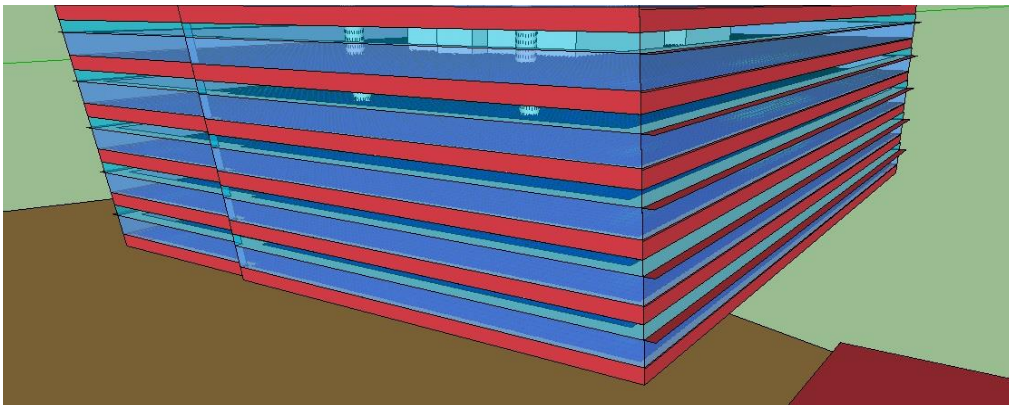

Figure 16. Perspective of part of the building with the addition of the extended light shelf to the exterior. This model was created in SketchUp.

Figures 17 and 18 show the simulation results from this model. It is important to note that the inclined façade remained unchanged, without the addition of the extended light shelf to the exterior, as the original design.

This is because of the low recurrence of the 500 lux range, as shown in figures 5, 10 and 17, in the daylight autonomy simulation.

An increase of the area in the 500 lux range can be measured to approximately 7.00m from the openings, with exception of the inclined façade, where the 500 lux range is achieved close to the floor's vertices. According to Daysim, daylight autonomy reaches 92%, which is an increase of 15% from the previous alternative, and a total increase of 34% from the original.

Figures 19 to 21 show the performance of the building in the static simulation.

Figure 19 points out that the area of illuminance in the 300-500 lux range reaches up to 2.50m from the northeastern façade. Close to the building's core, the 100-200 lux range is apparent from the abovementioned façade. The decrease of the maximum illuminance, and consequently the reduction of glare can also be noted, which indicates an increase of diffuse daylight in the building's interior.

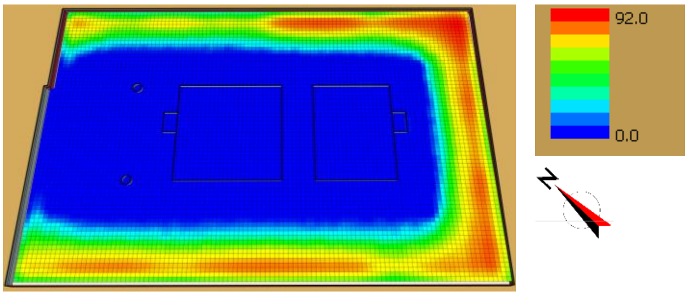

Figure 17. Daylight Autonomy, Daysim.

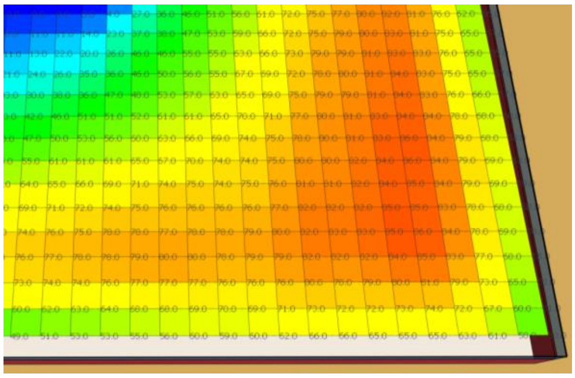

Figure 18. Node Values.

Although figure 20 shows a small area with illuminance over 1,000 lux, it evidences that daylight reaches the 500 lux range only from the northeastern and northwestern façades. Figure 21 indicates a probable glare from the northwestern façade, where illuminances of over 3,000 lux were measured. The southwestern façade has an area measuring in the 300-500 lux range up to approximately 2.00m from the openings.

The increased efficiency of the extended light shelf can be seen mainly in the noontime simulation, where the sunshade achieves its total efficiency. During other periods it achieves only partial efficiency.

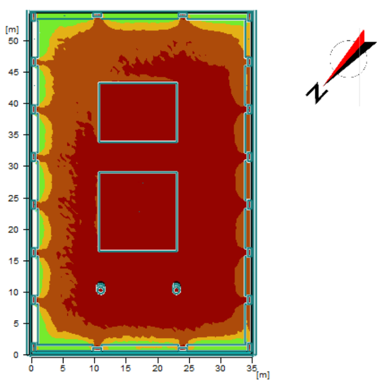

Figure 19. Relux simulation for 9am Emax: 1,620 lux. Ē: 138 lux.

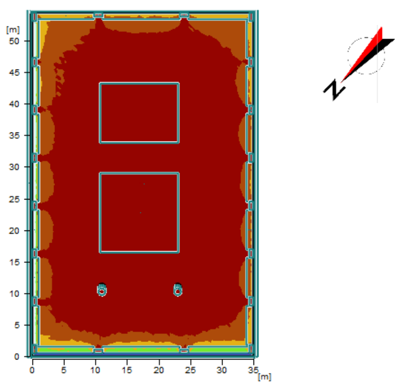

Figure 20. Relux simulation for noon – Emax: 1,430lux. Ē: 91 lux.

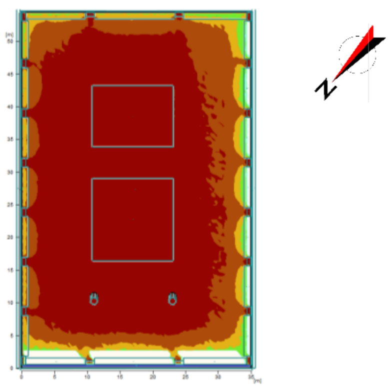

Figure 21. Relux simulation for 4pm Emax: 3,410lux. Ē: 152 lux.

The use of this solution in the simulation revealed an increase of diffuse daylight and overall daylight autonomy in the established 500 lux range, with a low probability of glare. As the northwestern façade presented low daylight autonomy in the Daysim simulation, an extended light shelf is not recommended for this facade. However blinds or solar screens may be used on this façade to reduce discomfort caused by excessive luminosity during the afternoon. As the blinds would be installed at the level below the light shelf, some daylight could still be used.

Figure 22 depicts a generic section of an office building, suggesting the abovementioned system, including the blinds.

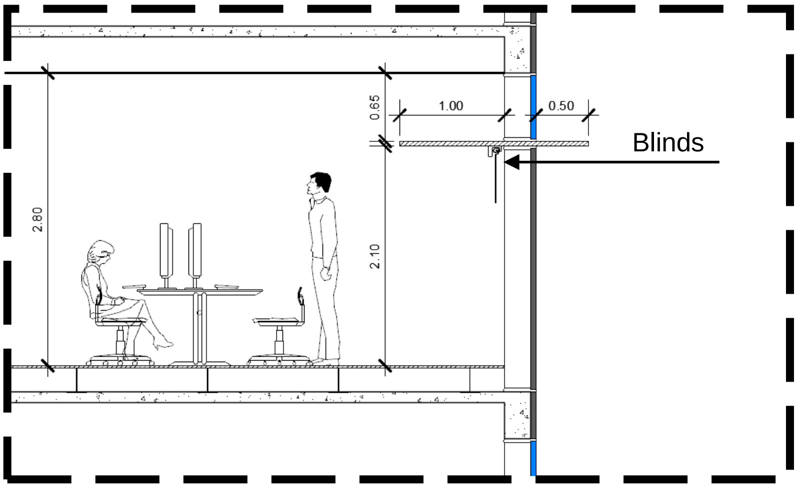

Figure 22. Generic section of an office building with extended light shelf and blinds.

4. Relationship between natural daylight and thermal performance of the alternative (proposed) building envelopment

Adjusting the building envelopment from a 2m-high glass-skin, with a consistent Tvis of 21%, to an envelopment that includes a light shelf with glass above it with a Tvis of 70%, and glass below it with a Tvis of 21%, produced a 34% increase in the building's daylight autonomy, with low glare probability, as compared to the original design.

The glass used in the Rochavera complex has a solar heat gain coefficient of 0.30, while the glass above the light shelf in the proposed model has a heat gain coefficient of 0.40. The proposed model therefore results in a 10% increase in solar heat gain, according to the thermal calculation made at 9am from part of the southeastern façade. As a consequence, the proposed model will increase the internal temperature of the structure.

As the existing air conditioning system insufflates air through the ceiling, the change in the building's glass-skin would increase energy consumption. However, Leite [10] compared and analyzed two air-conditioning systems: air cooled through the ceiling versus through the floor. According to the author of the study, the insufflation of air through the ceiling demands only the cooling of the first 2m of height, which may allow for energy savings in the air conditioning system. The author has done real scale experiments to verify the benefits of cooling air in the floor and insufflating through the ceiling:

> The "Floor Air Distribution System, with Displacement Flow" is installed in one of the ambients. The air is cooled in a machine on the upper floor and conveyed by a pipe down to the void of the high flooring (plenum), which turns into a cooled and pressurized air chamber. The cool air undergoes a difference in pressure, through diffusers, into the ambient. When contacting the heat sources (people and equipment), the air is warmed, which allows it to go up to the ceiling by natural convection, wherefrom it leaves through grids. "The comfort is due to the low-speed air insufflation..." [11]

The use of this air cooling system, added to the glass-skin system proposed by this work, would result in a concentration of warm air near the ceiling, which is the air conditioning return zone. Studies would be necessary to verify whether heat exchange by radiation would affect occupants’ thermal comfort.

5. Conclusions

The research indicates that the proposed modifications to the façades could result in an increase in diffuse daylight distribution and a reduction in glare. The performance of the light shelf was amplified due to the application of a glass area of 0.65m with higher visible light transmittance. The light transmission below the light shelf was maintained as in the original specification because of its proximity to work areas and the size of the glass area.

The glass-skin proposal resulted in a 10% increase in solar gains, which would result in higher air conditioning consumption. However, moving the insufflation area from the ceiling to the floor would neutralize this difference.

It should be stressed that the suggested modifications stand alone, amongst very few other proposed alternatives. Further studies of the glass-skin façade system, as well as of the air conditioning system proposed by Leite, are needed to understand the building’s behavior and the thermal comfort of occupants throughout the year.

This research indicates tools that can be used to improve the design process for office buildings in the city of Sao Paulo.

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