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ANALYSIS OF GLARE IN CLASSROOMS UNDER ABNT NBR 15.215-3:2024 AND CONSIDERING USER'S PERSPECTIVE

ANÁLISE DE OFUSCAMENTO EM SALA DE AULA A PARTIR DA ABNT NBR 15.215-3:2024 CONSIDERANDO A PERSPECTIVA DO USUÁRIO

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ABSTRACT

The new version of the Brazilian standard for Daylighting - Part 3 - Procedures for the evaluation of daylighting in indoor spaces, ABNT NBR 15.215-3:2024 proposes assessing the quality of lighting in indoor spaces based on new parameters, including the phenomenon of glare. Glare caused by daylight can affect the performance of users in educational spaces. This study aimed to examine the occurrence of daylight glare in a classroom at the Federal University of Minas Gerais using computer simulation with the ClimateStudio plug-in for Rhinoceros software based on methodologies proposed in the Brazilian standard along with questionnaires. Users' perception indicated that the level of glare might be higher than predicted by the simulations. It was concluded that control devices are essential to mitigate discomfort caused by glare in daylit spaces.

Keywords: *Daylight Glare; NBR 15.215-3; Users.*

RESUMO

A nova versão da norma brasileira de Iluminação natural - Parte 3 - Procedimentos para avaliação da iluminação natural em espaços internos, ABNT NBR 15.215-3:2024 propõe a avaliação da qualidade da iluminação em ambientes internos com base em novos parâmetros, incluindo o fenômeno do ofuscamento. O ofuscamento gerado pela luz natural pode comprometer o desempenho de usuários em ambientes de ensino. Este estudo teve como objetivo examinar o ofuscamento em uma sala de aula da Universidade Federal de

Minas Gerais, utilizando simulação computacional com uso do plug-in ClimateStudio para o software Rhinoceros, e a aplicação de questionários, conforme metodologias propostas na norma brasileira. A percepção dos usuários indicou que o nível de ofuscamento pode ser superior ao previsto nas simulações. Concluiu-se que dispositivos de controle são fundamentais para reduzir o desconforto causado pelo ofuscamento em ambientes iluminados por luz natural.

Palavras-chave: *Ofuscamento pela luz natural; NBR 15.215-3; Usuário.*

1. INTRODUCTION

The Brazilian standard *NBR 15.215-3 Daylighting - Part 3: Procedures for evaluating daylighting indoors* was revised and published in June 2024. The new version of the standard recommends the evaluation of indoor daylighting based on the availability of daylight, quality of view out, protection against daylight glare, minimum and maximum annual exposure to direct sunlight, and introduced metrics to evaluate non-visual light stimulus (ABNT, 2024). Among these aspects, the present research addresses protection against daylight glare.

Glare is conceptualized by Boyce (2003) as a negative visual sensation experienced by the observer, caused by areas with luminance brightness higher than the luminance to which the eyes are adapted to. This condition produces discomfort or loss of visual performance and visibility. Glare can cause side effects or later effects such as headaches or fatigue (ABNT, 2024). The perception of glare is individual and depends on the distribution of luminance in the field of view and, consequently, on the spatial position and line of sight of the observer (Bommel, 2019).

The new version of NBR 15.215-3:2024 included the *Daylight Glare Probability* (DGP) metric to evaluate discomfort due to excessive glare. This metric calculates brightness based on contrast and saturation effects. To assess the daylight glare, it is essential to analyze the distribution of the different light intensities in the field of view, in addition to the size, intensity, and position of the glare source in relation to the line of sight (ABNT, 2024; Quek *et al*., 2021). Therefore, a DGP < 0.34 shows imperceptible glare; 0.34 ≤ DGP ≤ 0.38 shows noticeable glare; 0.38 < DGP ≤ 0.45 shows disturbing glare, and DGP > 0.45 is considered intolerable glare. The standard recommends analyzing protection against glare as a function of the space time of use. Thus, whenever DGP in space exceeds the threshold for disturbing glare (DGPe > 0.38) in more than 5% of the time of occupation of the environment some king of glare protection should be made available (ABNT, 2024).

The *Spatial Disturbing Glare (*sDG) index was developed to measure the excessive brightness of daylight throughout the year. Implemented in *ClimateStudio* plug-in for Rhinoceros software, this index points out the percentage of vision directions in which DGP glare exceeds 38% (disturbing or intolerable) in at least 5% of annual occupancy hours. The calculation is based on DGP values, considering eight directions of vision, from each point in a mesh adjusted to a specific vision height (Solemma, 2023). The spacing of the points should preferably be maintained between 0.5 m and 2.0 m (ABNT, 2024).

Although the Brazilian standard does not indicate the detection of glare through contrast ratios and vertical luminance values, Monteiro (2023) research explores such discomfort. When reviewing studies on the subject, the author pointed out that acceptable contrast ratios in the space overall luminance are from 1:10 to 1:11.7. Other studies cite that for luminance above 2,000 cd/m² there may be a perception of disturbing and intolerable glare.

The perception of users is recurrent in studies related to the daylighting of spaces. Examples are the research by Reinhart and Weissman (2012), with 60 occupants, and by Reinhart, Rahka and Weissman (2014) who applied questionnaires to define metrics such as sDA - Spatial Daylight Autonomy and UDI - Useful Daylight Illuminatince - in studies that had from 13 to 331 students.

The objective of this study was to analyze the glare in the Classroom 412 of the School of Architecture of the Federal University of Minas Gerais (UFMG), where a student with a disability (PwD), reported the existence of the problem. Based on the metrics of ABNT NBR 15.215-3:2024, the aim was to compare the results of computer simulations with the perception of users and, finally, to evaluate the efficacy of control devices to mitigate visual discomfort in space.

2. NATURAL LIGHTING IN CLASSROOMS

Current research on the space quality of classrooms argues that daylighting can influence not only comfort, but also student health, concentration, and learning (Chaidez *et al*., 2022; Korsavi, Zomorodian, Tahsildoost, 2016).

In this sense, Chaidez *et al*. (2022) used luxmeters to measure the illuminance of classrooms at a university in Tijuana, Mexico. The authors observed that, according to the orientation of the openings, some classrooms have insufficient daylight, while others present discomfort due to glare. A satisfaction survey was then carried out with the students. The survey showed that more than 60% of the students considered daylighting in the classrooms inadequate for carrying out the activities. Despite considering the lighting inadequate, about 70% of the students considered that the daylighting in the classrooms is tolerable. The authors associated this tolerance with the age of the students (between 19 and 22 years old), with mobility within the classroom, which makes it possible to choose where to sit, and with the possibility of turning on electric light in spaces that present insufficient daylight.

The study developed by Korsavi, Zomorodian and Tahsildoost (2016), in Iran, used a similar approach, exploring user satisfaction in university classrooms. The authors accessed the quality of daylighting through computer simulations and compared the results with the users' perception. The results indicated that the students' perception of daylighting was more optimistic than the results obtained by computer simulations. In contrast to the results of the simulations, most students do not perceive direct light and discomfort due to the occurrence of glare in areas with excessive daylighting. The authors interpreted that the quality of the natural views out that the windows provide may influence the degree of comfort experienced. In addition, the authors highlighted that regional and cultural factors can also influence perception surveys, given that the study was conducted in a city where sunlight is relatively intense. Thus, they concluded that, as students are used to high exposure to sunlight, culturally their expectations and feelings regarding the daylighting that enters the classroom are different from the expectations of people who live in less sunny regions.

In a previous study, conducted in the United States, Zomorodian and Tahsildoost (2019) evaluated the effectiveness of using dynamic metrics in predicting daylight quality and visual comfort in classrooms. This study also consisted of computer simulations and users survey. The authors concluded that each type of metric can provide a limited level of useful data for the different phases of architectural design. With this, they considered that, for the initial design phase, dynamic metrics are useful to obtain an overview of the performance of daylight. However, for the development of the project, temporal and spatial metrics, which have strict upper and lower limits, are more appropriate. The lack of information regarding the moderating effect of culture, age, or external vision on visual discomfort caused by glare was considered a gap that should be further investigated.

Within this context of user research, based on a systematic review of the literature, Bortolan, Ferreira, and Tezza (2019) investigated the state of the art of questionnaires derived from academic research, which had the evaluation of visual comfort as their theme. In total, 17 questionnaires were identified, with no restriction on dates, from national and international publications. The authors identified that the most recurrent questions address preferences, satisfaction, glare occurrence and light distribution. It was also recognized that most of the research that uses questionnaires to assess visual comfort explores office spaces. Of the 17 questionnaires analyzed, only one was aimed at classrooms.

Another field explored in the research on daylight glare addresses the influence of the materials of openings for daylighting. Thus, also within an educational building, Gonçalves *et al*. (2022) evaluated the effects of the renovation that took place in 2014 on the roof of the Vilanova Artigas building, headquarters of the Faculty of Architecture and Urbanism of the University of São Paulo (FAUUSP), in Brazil. The roof of this building has 40% of translucent area and in the hottest periods of the year users witnessed visual discomfort. During this renovation, the material of the roof domes, previously made of transparent colorless fiberglass, was replaced by milky acrylic. The evaluation, through computer simulations, confirmed that the chosen material ensured a homogeneous luminous space and that the glare inherent to the original design of the building was eliminated.

In addition to the influence of the materials of the openings, research on glare by sunlight explores the issue of the different layout configurations of the classrooms and the orientations of the windows. Garcia and Pereira (2020) analyzed daylight glare probability levels and sunlight incidence in a classroom using computer simulation. Using a representative module of a multi-story building located in Florianópolis, Brazil, the authors analyzed 60 different situations, considering different directions of vision, orientation and position of the user. The results confirmed that intolerable and uncomfortable levels decay as the user moves away from the window. Despite this confirmation, the results demonstrated that the use of spaces near the openings does not need to be unfeasible if due care is taken in the layout design, combining the position occupied, the direction of view and solar orientation.

Finally, research on glare also explores how to mitigate visual discomfort. The study by Carpanedo, Pagel and Maioli (2024) investigated the performance of daylight inside office spaces, considering different percentages of façade opening, types of windows, floor heights, in addition to variations in the light transmission of the windows and the presence, or not, of external solar protection. From computer simulations, the results proved the great influence of *the louvers* for visual comfort, either to increase the levels of uniformity of the admitted light, to reduce excessive illuminances, or to reduce the occurrence of intolerable glare. Even so, the authors emphasize the importance of adequate planning for the installation of *louvers*, depending on the characteristics and orientations of the windows.

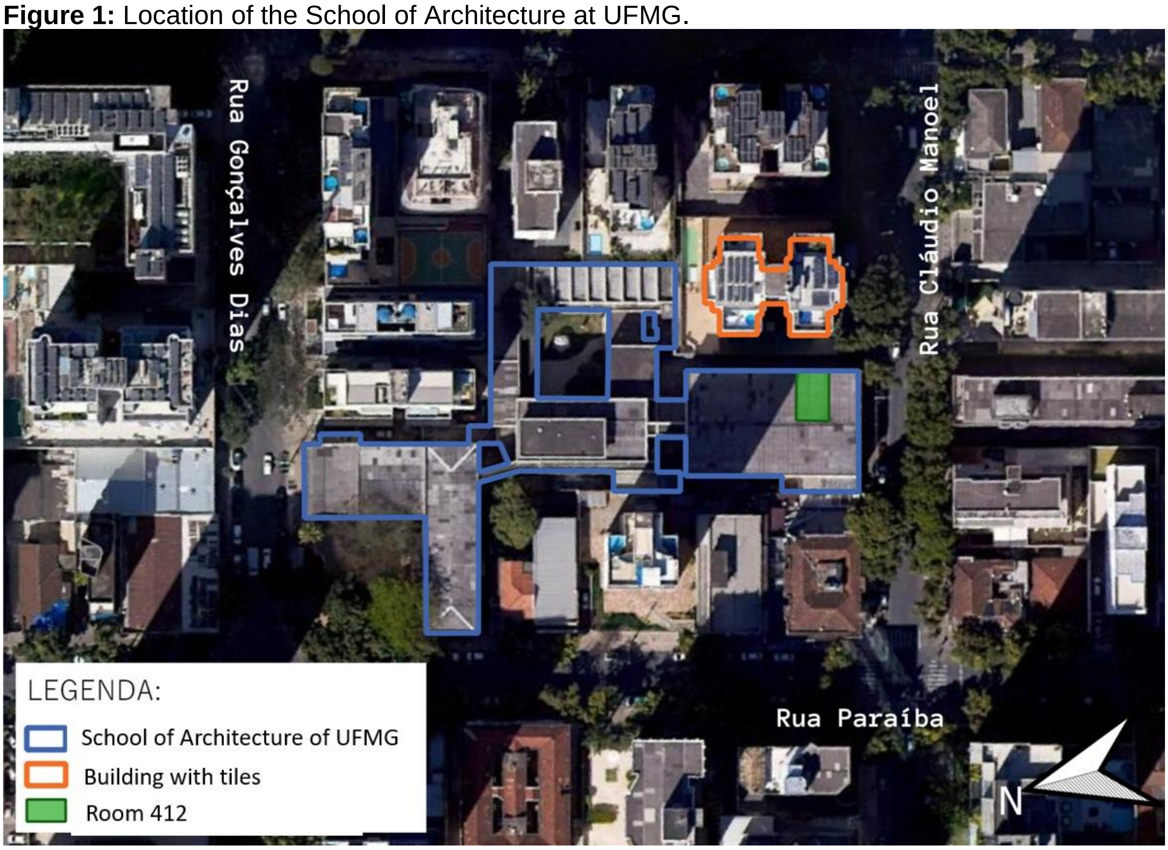
3. METHODOLOGICAL PROCEDURES

The present study was organized in five phases. The first phase involved the definition and description of the object of study. In the second phase, a computer simulation was performed to identify the presence of glare quantitatively, through the calculation of sDG (*Spatial Disturbing Glare*). The third phase consisted of the application of a questionnaire to assess the users' perception of glare in a qualitative analysis. The fourth phase involved the analysis of the results, crossing quantitative and qualitative data. Finally, the fifth phase was dedicated to the study of control devices to reduce visual discomfort caused by the daylight glare identified.

3.1. Study case

The object of study of the research was a classroom located at the School of Architecture of UFMG (Figure 1) in the city of Belo Horizonte.

Figure 1: Location of the School of Architecture at UFMG.



Source: Google Maps, adapted by the authors.

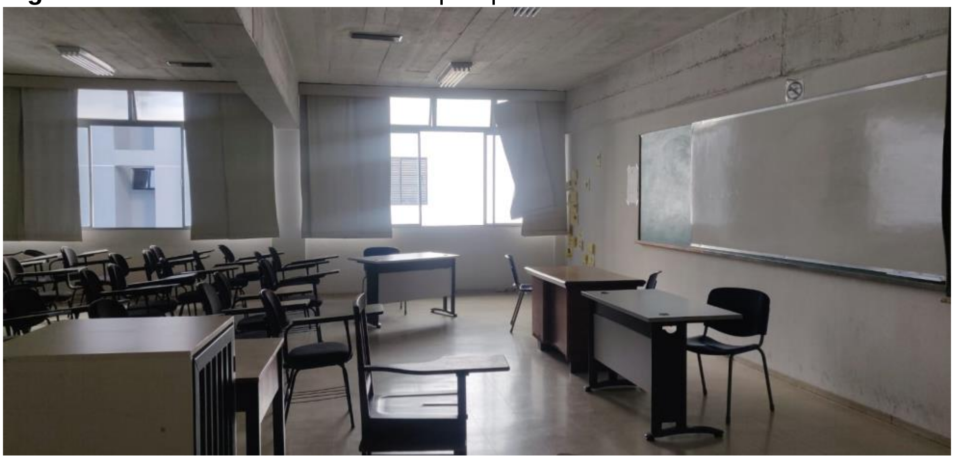
The region in which the building is located is characterized by an environment of great density and building verticalization. Thus, obstructions and external reflections alter the availability of daylight that enters the space (Figure 2).

Figure 2: Perspective of the surroundings of the School of Architecture of UFMG.

Source: Google Maps, Adapted by the authors.

Classroom 412 is located on the 4th floor of the building. The choice of this space occurred due to the discomfort perceived by one of the authors of the study. As a frequent visitor to the space, the student realized that the intense light coming from the side window, combined with the high reflectivity of the white tiles of the neighboring building, was causing excess glare. This brightness reflected on the board made it difficult to see both the whiteboard and the figure of the teacher. Figure 3 shows a photograph taken by the student with reduced mobility, from his habitual position in the classroom, before the beginning of the class. The photograph was taken on May 18, 2023, at 3 pm.

Figure 3: Classroom from the visual perspective of the student with reduced mobility.



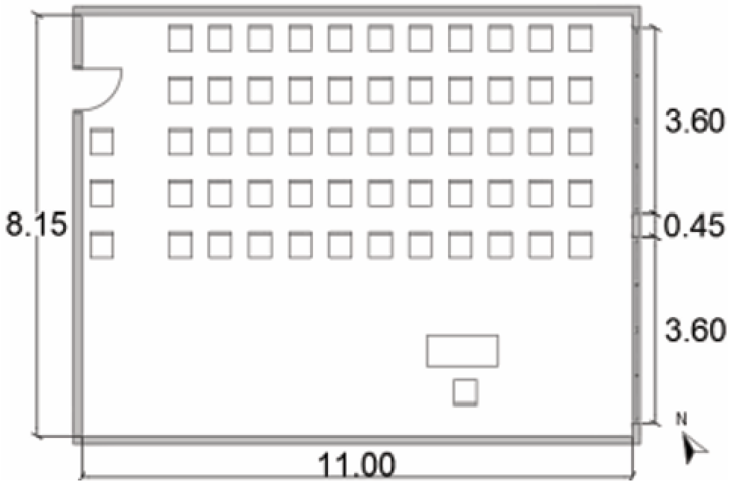
Source: Authors.

The student who has reduced mobility did not have the flexibility to change places. This is one of the scenarios in which the glare assessment is recommended: "in spaces where activities are similar to reading (...) and the user cannot freely choose his position and direction of viewing" (ABNT, 2024).

3.2. Characterization of the object of study

Classroom 412 is 11 meters long and 8.15 meters wide, with a ceiling height of 3 meters. The interior of this space has walls and ceiling finished in white paint, while the floor is covered by a light beige ceramic coating (Figure 3). In addition, it has large side openings facing east, closed with aluminum frames and 6mm thick colorless glass, with blackout *curtains*, and the *layout* is arranged so that the students' desks are parallel to tha opening, as shown in Figure 4.

Figure 4: Floor plan of the classroom.



Source: Authors.

3.3. Daylight glare computer simulation

In this study, computer simulation was employed to perform a quantitative assessment of daylight glare. For this, a three-dimensional modeling of the space was made in *SketchUp* and Rhinoceros software and, for the simulation, *ClimateStudio* plug-in for Rhinoceros was used. The plugin calculates the number of vision directions of users who face disturbing or intolerable glare, that is, DGP ≥ 0.38, in accordance with what is indicated by NBR 15.215-3 (ABNT, 2024). The result is a graphical map that shows the distribution of glare when the space is occupied above 0.38, using a color scale that goes from 0 to 5% of the hours. The plugin also provides the percentage of views with a glare probability over 0.38 in 5% of the time through the sDG index. The calculation is based on hourly DGP values for eight different viewing directions in each position (SOLEMMA, 2023). The viewing height considered was 1.2 meters from the ground, corresponding to the eye height of a seated observer (ABNT, 2024).

A three-dimensional model of space was developed in SketchUp software, due to its ease of modeling. Subsequently, the model was exported to Rhinoceros 7 software, which required adjustments to the three-dimensional model in which the necessary data for the simulation with *ClimateStudio* plug-in was configured. The input parameters used in the plug-in were: (1) the Belo Horizonte climate file, with climate data: BRA_MG_Belo.Horizonte-Prates.AP.836724_TMYx.2007-2021.epw (CLIMATE ONE BUILDING, 2023); (2) the analysis period: from 8 am to 6 pm, as (ABNT, 2024); (3) the grid of points: distance between points of 0.61 m and height of 1.2 m (ABNT, 2024); (4) the optical properties of the materials, obtained in the *ClimateStudio* plug-in, which includes a library of real materials, based on measurements with validated sources, using *DOE* (United States Department of Energy) benchmarks, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standards and IGDB (International Glazing Database) glazing products, as detailed in Table 1.

Table 1: Optical properties of the materials used in the simulation.

Surface	Material	Reflectivity/ Transmissivity
Walls	White wall	83,4%
Floor	Light Grey Ceramic Tile floor	60,4%
Ceiling	White ceiling	85,7%
Window	Clear - Clear	77,4%
Exterior tiled building	White Ceramic Tile wall	80,9%
Gray painting on tiled building	Grey Painted wall	45,8%
Curtain	Beige Curtain	57,3%
Whiteboard	Plastic Ceiling Vent E14 548	80,6%

Source: The authors.

For the opaque material values refer to reflectivity and in the case of the window, the value refers to the transmissivity of a clear glass. According to what is indicated by NBR 15.215-3:2024 (ABNT, 2024), a dirt factor of 5% was applied to the visible light transmission (Tvis) of the glass, and in the end, the glass with Tvis of 77.4% was considered in the simulation.

The settings of the simulation engine, Radiance, followed the default of the ClimateStudio plug-in, as indicated in Table 2.

Table 2: Simulation Engine Configuration Radiance.

Variable	Configuration	Equivalence
Samples per pass	64	Number of samples passed per sensor (BISSOLOTI, PEREIRA, 2019)
Max number of passes	100	Maximum number of passes of the simulation, before finishing (BISSOLOTI, PEREIRA, 2019)
Ambient Bounces	6	Number of internal diffuse reflections that are accounted for before a light ray is discarded (SOLEMMA, 2023)
Weight Limit	0,01	Limit in the variation of the optical path of light (SOLEMMA, 2023)

Source: Authors.

ClimateStudio allows the generation of fisheye images, made from the user's field of vision. These images include the demonstration of the vertical luminances present in the scene, with indication of the values in graphic scale, called false color images. In this study, these simulations were explored for May 9, at 2:30 pm. This day and time was chosen because it was the same day and time the questionnaire was applied to the users of Classroom 412.

3.4. Application of questionnaires

The experimental study based on the application of a questionnaire was used in this research to analyze the perception and satisfaction of users with the daylighting of the classroom, in addition to verifying possible visual discomforts. The questionnaire was applied to the users of classroom 412 on May 9, 2023, during an afternoon class, at 2:30 pm (Figures 5 and 6). The sample consisted of 62 students, of which 38 users answered all the questions, corresponding to 62% of the estimated public. The sky was clear with few clouds, as shown in the photograph taken from the classroom window, in Figure 7.

Figure 5: Classroom at the time of application of the questionnaire.

Source: Authors

Figure 6: Whiteboard in the classroom at the time of the questionnaire application.

Source: Authors.

Figure 7: Sky condition at the time of questionnaire application.

Source: Authors.

The questionnaire consisted of seven questions. Five of the questions offered answer options on a 5-point Likert scale, which ranged from negative to positive. The answers were evaluated with a scale ranging from -2 to 2, the negative values indicating a negative response and the positive values indicating positive assessment of the daylight quality of the space. In addition, the questionnaire included two questions with possible *yes* or *no* answers. At the end of the questionnaire, there was a space for respondents to add comments about the daylighting in the classroom in question.

3.5. Computer simulation for glare mitigation

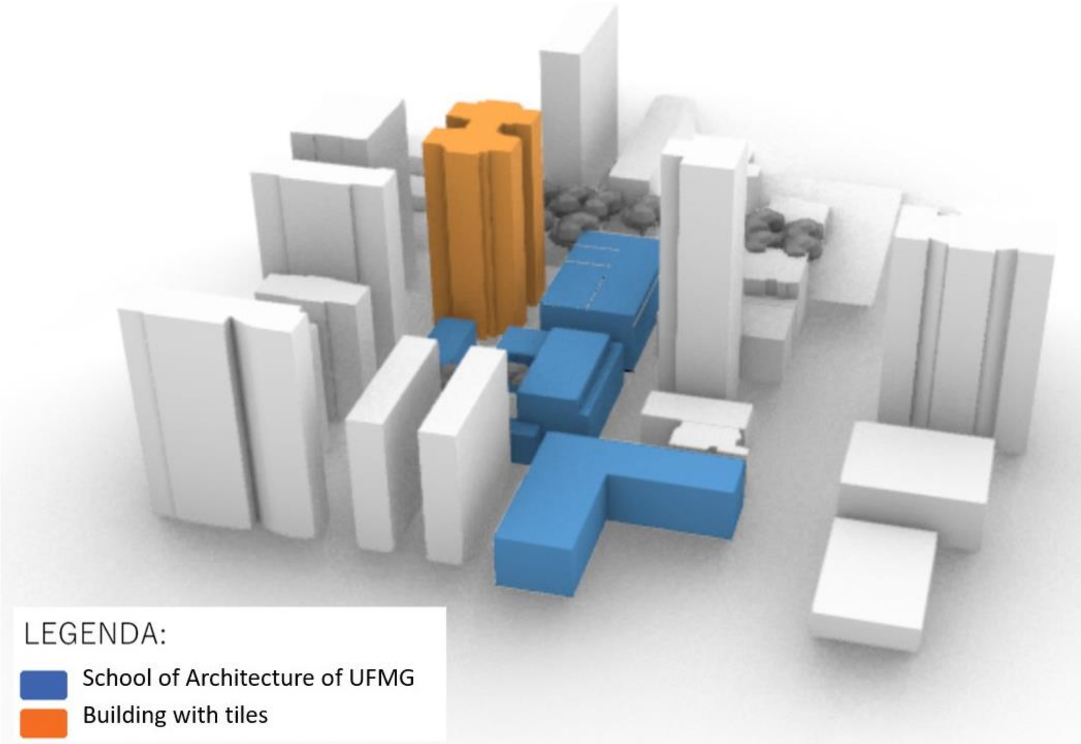
The verification of the occurrence of glare in Classroom 412, based on the results obtained in the computer simulation and in the questionnaire, showed the need to mitigate visual discomfort.

To control glare, a mobile sun protection device, which can be individually adjusted, is recommended by NBR 15.215-3:2024. Thus, a vertical mobile *metal brise soleil* was simulated, with fins the height of the classroom opening (200 cm), 15 cm long, 3 cm thick and 20 cm distance between plates. The solar protection device was simulated with a fin rotation angle of 0° and 45°, to test its behavior in the different configurations.

4. RESULTS

Figure 8 shows the three-dimensional model of the object of study, considering the surrounding buildings. The building marked in brown faces de window of the studied classroom and is finished in white reflective tiles.

Figure 8: 3D model of the surroundings of the object of study.

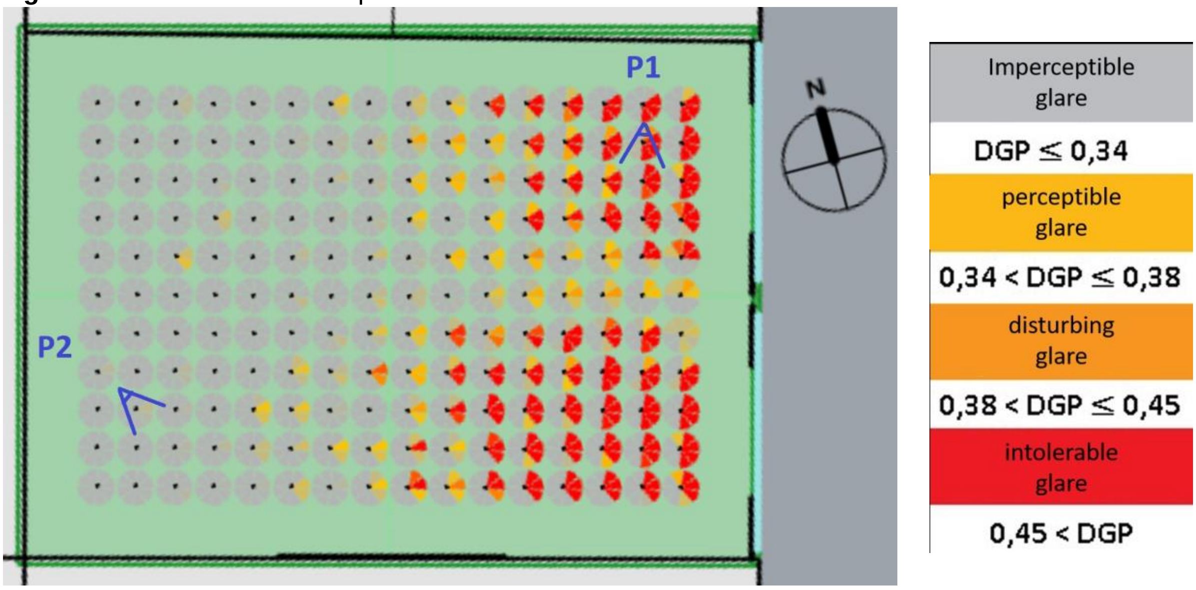


Source: Authors.

4.1. Daylight glare computer simulation

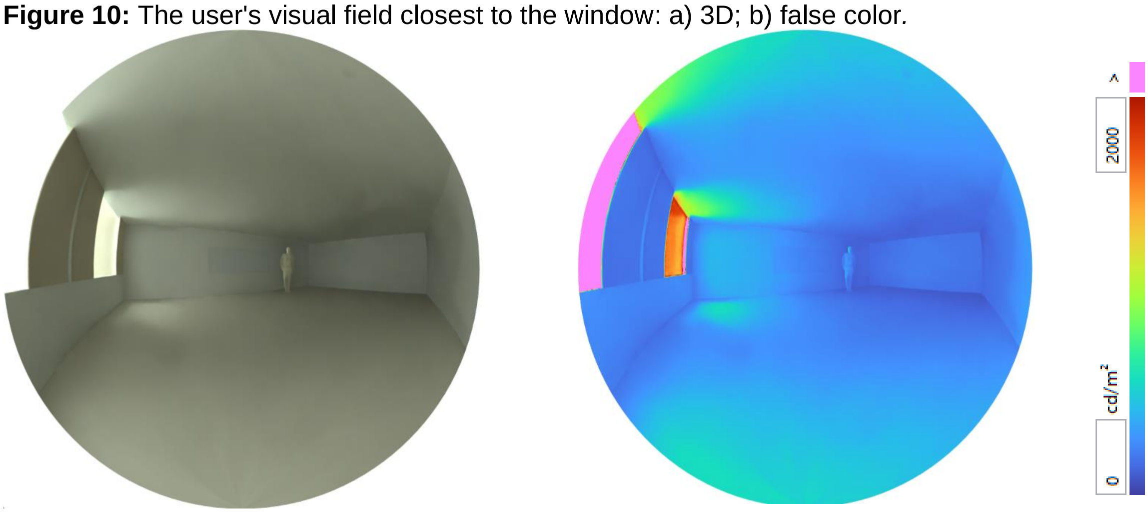
The computer simulation showed the occurrence of disturbing or intolerable glare in 9.4% of the vision directions in the analysis grid. Figure 9 shows the graphical results of sDG, obtained with the computer simulation. Figures 10 and 11 show the fisheye images in false color, according to the visual field of the seated user, with his gaze directed to the frame. These images were generated in the position of the observer sitting near the window (indicated as P1 in Figure 9), and in the position of the observer farthest from the windows (P2 in Figure 9). In Figure 9 it can be observed that the in the position in which the user that made de complaint seats, the plugin did not indicate the occurrence of daylight glare.

Figure 9: Classroom sDG Output.



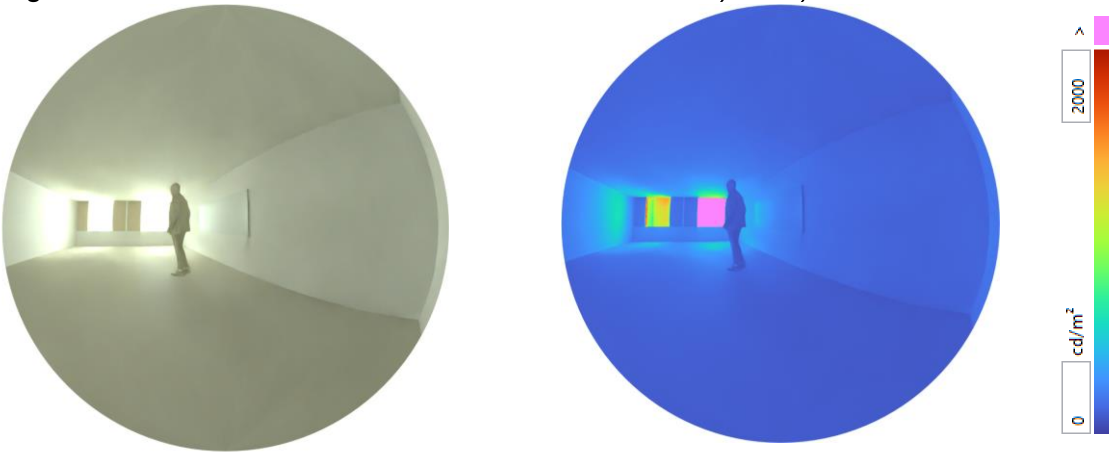
Source: Authors.

Figure 10: The user's visual field closest to the window: a) 3D; b) false color.



Source: Authors.

Figure 11: The user's visual field furthest from the window. a) 3D; b) false color.



Source: Authors.

Nevertheless, the fisheye visualization in figures 10 and 11 clearly indicate that users seated close to the window experience less daylight glare than the ones seated across the window. It is also noticeable that glare is experienced in the view of the whiteboard in this position and that the teacher is not clearly seen from this same position.

4.2. Application of questionnaires

The results of the questionnaire are presented in Table 3 which shows the answers to the objective questions with the Likert Scale.

Table 3: Results of the objective answers of the Likert Scale.

Question Topic	Likert scale responses					Weighted average
	-100% -80% -60% -40% -20% 0% 20% 40% 60% 80% 100%					
1.Presence of daylight in the classroom	8% 3% 24% 66% uncomfortable unimportant indifferent important very important					very important 1,4
2. Satisfaction regarding the amount of daylight	11% 39% 14% 26% 11% very satisfied dissatisfied indifferent satisfied very satisfied					indifferent -0,1
3.Difficulty seeing the painting due to the reflection of surroundings	29% 50% 14% 8% makes it very difficult makes it a little difficult indiferent doesn't make it difficult help					makes a little difficult -1,0
4.Discomfort caused by reflections from the neighboring building	13% -58% 24% 5% very uncomfortable uncomfortable indifferent comfortable very comfortable					uncomfortable -0,7
5. Discomfort due to the change of view from the window to the whiteboard	58% 37% 2% 3% bothers a lot bothers a little indifferent don't bother comfortable					It bothers me a lot -1,5
Values for the scale	(-2 a ≤ -1,2)	(>-1,2 a ≤ -0,4)	(>-0,4 a ≤ 0,4)	(>0,4 a ≤ 1,2)	(>1,2 a 2,0)	

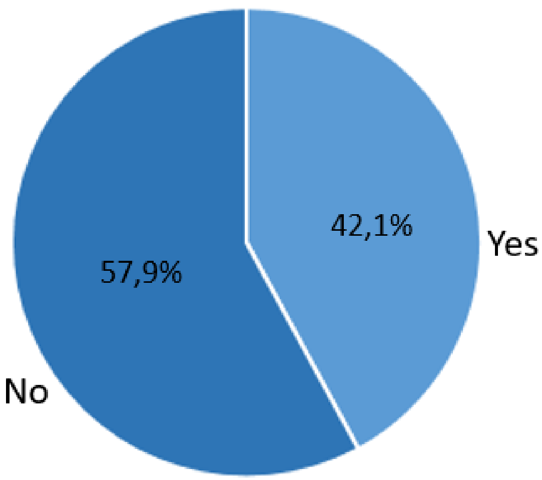
Source: Authors.

The results obtained by the questionary application show that daylighting is considered as highly important but at the same time most users feel great discomfort when changing the view direction from the window to the whiteboard indicating that the view out presents discomfort to users. This may explain why users feel indifferent to the daylighting in this classroom: while they declare to prefer daylight classrooms, this one presents discomfort coming from the external view out.

Graphs 1 and 2 show the results for the objective multiple-choice questions. When asked if they changed their position in the classroom due to perceived excess daylight and if they perceive shadows due to daylight in the task plane users tended to answer negatively. These answers are better explained by the open comments left by the users as shown in Table 4. The open comments indicate that although computer simulation show a high occurrence of daylight glare near the window, the view to the whiteboard if more comfortable from these positions that when across the room, facing the windows.

Graphs 1: Answers about changing the place or shadow on the desktop.

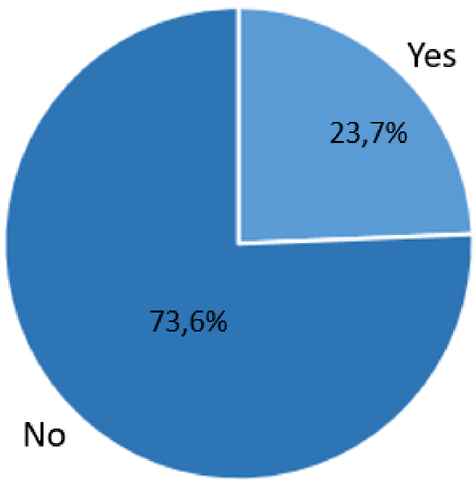
6. Have you ever switched places because of the excessive daylightt?



Source: Authors.

Graphs 2: Answers about changing the place or shadow on the desktop.

7. When you are writing, is there an uncomfortable shadow due to the presence of daylight?



Source: Authors.

Table 4: User reviews about the daylighting in the classroom.

	User commentaries
1	*Sitting near the window makes it easier to see the board, because sitting near the door, when looking towards the teacher, who is in the center of the classroom, the view ends up being dazzled by daylight*
2	*The building next door, covered with white tiles, reflects a lot of light into the interior of the classroom, which bothers the peripheral vision when looking at the painting, in addition to compromising the visualization of the slides*
3	*The classroom also gets extremely hot, I believe the problem involves both glare and lack of ventilation, due to the existence of the building in front of the window*

Source: Authors.

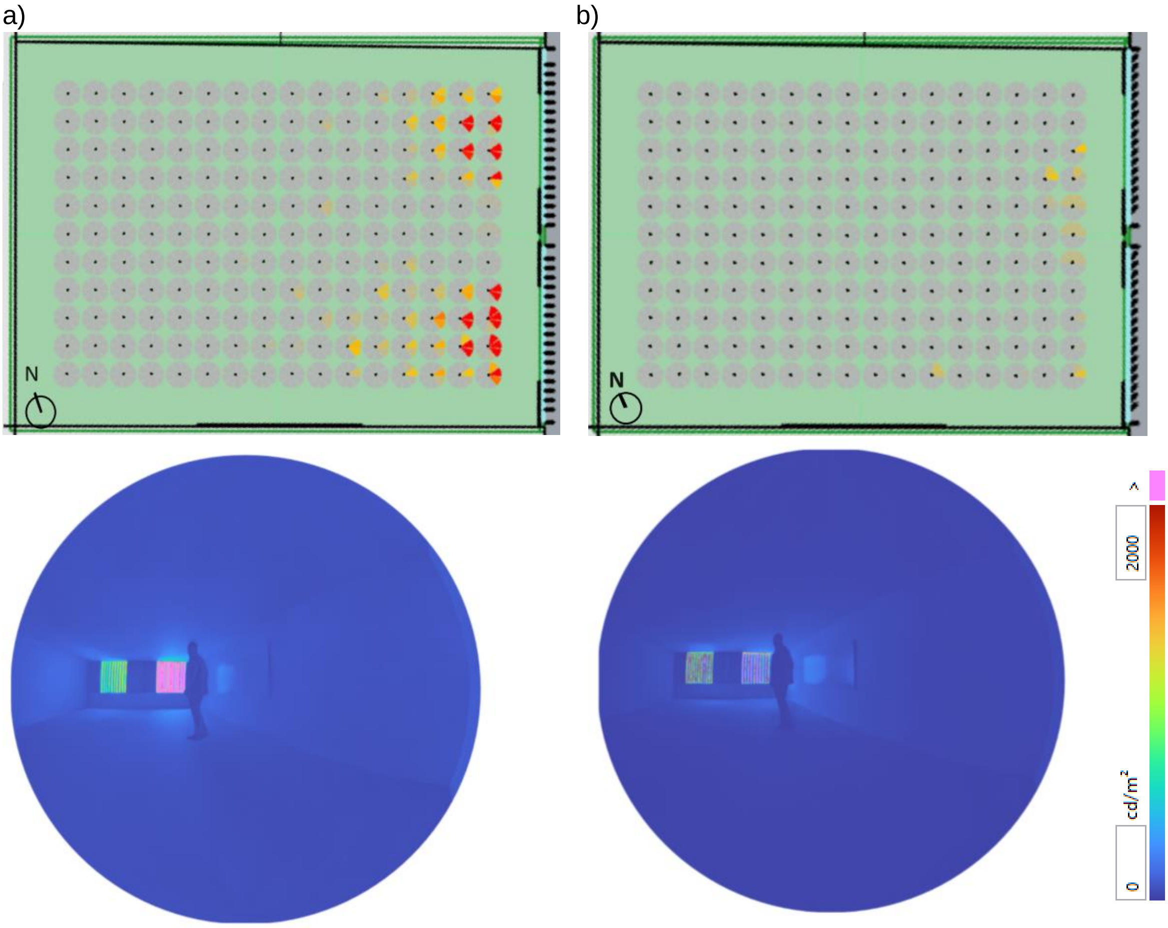
4.3. Computer simulation for daylight glare mitigation

As pointed out in the Brazilian Standard when high levels of daylight glare is perceived, protection devices should be implemented. As simulations and user responses both showed disturbance caused by de occurrence of daylight glare, a solar protection device as inserted in the windows with moveable vertical fins Although the classroom disposes of blackout curtains it was considered that those curtains would excessively darken the classroom and that external shading devices would be more adequate to control glare and maintain adequate daylight levels.

The results of the daylight glare simulation with the control external devices showed a sDG of 1.4% for the rotation angle of 0° and 0.0% for rotation angle of 45°. Figure 12 shows the graphical results of this simulation. This indicates that glare can be effectively controlled but users should be active in setting the better conditions for each situation.

Figure 12: Results of the brise soleil simulation: a) 0° rotation angle; b) 45° rotation angle.

a) b)



Source: Authors.

5. ANALYSIS OF THE RESULTS

5.1. Daylight glare computer simulation

The computer simulation showed that disturbing or intolerable glare occurs in 9.4% of the directions of vision analyzed in Classroom 412, in at least 5% of the occupation time. It was observed that the directions of vision that present the highest daylight glare probability are those facing the external opening or those in positions closer to the windows. In positions closer to the wall opposite the windows, the glare is considered imperceptible. Analyzing the positions of the users, it was observed that disturbing or intolerable glare occurs in 35% of the positions within the classroom. The graphic results generated by the plug-in also show that this discomfort occurs from 10 am to 5 pm, throughout the year.

According to the fisheye images (Figures 10 and 11) in false color, the vertical illuminance reaches 2,000 cd/m² for the observer positioned closest to the window (P1), intensifying the contrasts of the scene and indicating the presence of greater visual discomfort due to glare, according to the thresholds identified by Monteiro (2023). For the observer who is farther away from the window (P2), the contrasts are smaller, with vertical illuminances of up to 1,500 cd/m². However, very bright areas are still present in the field of view of the farthest observer, caused by the apertures, and glare is also noted in the reflection of light in the whiteboard (Figures 6 and 11.a). This situation can increase visual discomfort and result in a reduction in the performance of the space user.

5.2. Questionnaires application

Analyzing the answers of the Likert Scale, except for the results "very important" to the question about the importance of the presence of daylight in the classroom (question 1), and "indifferent" to the question satisfaction with daylight in the classroom (question 2), the other questions had mostly negative answers in relation to the perception of the presence of daylight in the classroom. This result is evidenced by the weighted average of -1.5, obtained in question 5.

The sixth question of the questionnaire evaluated the percentage of students who have already moved places due to excessive daylight. The answers showed that 42% of the students said they had made this change, which shows a high percentage, considering the limitations of classroom space in relation to the number of students, which reduces the flexibility of changing position. The seventh question addressed the students' perception of the discomfort caused by shadows during writing activities in the classroom. For this question, 29% of the students reported having noticed this discomfort. Given the same context of limited space in the classroom, it is reasonable to say that the discomfort with shadows affects a significant part of the students.

The users' comments covered questions related to their location in the classroom, the influence of the external building on the light incident inside the classroom, visual discomfort and even thermal discomfort provided by daylight.

5.3. Analysis of simulation and questionnaire results

By crossing the results obtained in the two methodologies applied, both the computer simulation and the users' perception identified daylight glare occurrence caused by the reflected brightness of the building in front of the window. The results indicate that, although students recognize the importance of daylighting for the study space, they consider daylight as uncomfortable in the given space, which leads them to change their position to avoid glare, when possible. In addition, veiling glare causes difficulties in viewing the content written on the board. The simulation suggests that the discomfort on the wall opposite the window is imperceptible, but students report that sitting in this position is not convenient due to the impairment of the visual field caused by daylight glare caused by the opening and by the reflections on the board. This suggests that users perceive glare in more directions and positions in the classroom than indicated by the computer simulation.

5.3. Computer simulation for glare mitigation

According to the simulation results, in both cases, the installation of the solar control device significantly reduced the most annoying glare (disturbing or intolerable), decreasing the discomfort by at least 85%. With the louvers positioned at 0°, disturbing or intolerable glare was still observed in 7% of the positions in the classroom, especially in the directions facing the windows. On the other hand, by rotating the louvers at 45°, glare control in the classroom was more effective, completely eliminating the occurrence of disturbing or intolerable glare. However, it should be noted that the use of control devices can reduce performance for other parameters of daylight quality, set by NBR 15.215-3:2024, such as the Availability of Daylight and the view out. Therefore, it is important that these devices have flexibility in their configuration and handling.

6. FINAL CONSIDERATIONS

The study showed the importance of cross-referencing the results of different methodologies in the analysis of glare caused by daylight. Computer simulation has advanced to calculate the discomfort caused by daylighting with the dynamics of daylight, showing, in addition to numerical results, different graphic shapes, which contributes to the understanding of the occurrence of the phenomenon in internal spaces and to the design process. However, it is important to consider the difference between the actual perception of users and the results obtained by computer simulation. While simulation helps identify and minimize discomfort during the design of a space, user experiences can vary and reveal additional nuisances. For a more detailed analysis, it is crucial to expand the study to include more spaces and a larger sample of participants in the subjective survey.

The built environment can contribute to the increase of daylight inside the spaces, as well as to the visual discomfort caused by it. As in the object of study, which shows that glare caused by daylight can occur both due to the direct vision of the sun's rays or to veiling reflections from other surfaces.

It is worth noting that the use of daylight control devices to control glare, such as louvers, can impact other aspects of lighting performance, such as the amount of daylight available in the indoor environment and the quality of outdoor vision, which should be explored in future studies. However, the use of mobile devices and the integration of daylighting into the artificial lighting system offers greater flexibility to users, who can modify the system according to the dynamics of daylight and their perception of uncomfortable glare in the classroom space.

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