XXI ENTAC – Encontro Nacional de Tecnologia do Ambiente Construído
14 a 16 de outubro de 2026 | Goiânia-Brasil
DOI: https://doi.org/10.46421/entac.v21i1.8318

Daylight metrics and user perception in classrooms

Métricas de iluminação natural e percepção do usuário em salas de aula

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Abstract
Classrooms play a fundamental role in students' learning process, influencing their well-being, health, and academic performance; in this context, daylighting emerges as a crucial element, contributing to visual comfort and to the regulation of circadian rhythms and the prevention of health issues. This study investigates daylight performance in classrooms based on the international standard EN 17037:2018 and the Brazilian standard NBR 15215-3:2024. The objective is to compare dynamic daylight metrics through computer simulations with user perceptions obtained through a survey targeting classroom users. Results reveal that in poorly lit classrooms, users demonstrate greater tolerance to daylight conditions, while in well-lit spaces, they tend to be more exigent with respect to daylight quality. Also, users accept lower illuminance levels and higher DGP than those prescribed by standards. This research concludes that user perception should be used to calibrate daylight metrics threshold values.

Keywords: Daylighting. Spatial Daylight Autonomy. Computational simulation. Classrooms. Visual perception.

Resumo
As salas de aula desempenham um papel fundamental no processo de aprendizagem dos alunos, influenciando seu bem-estar, saúde e desempenho acadêmico; nesse contexto, a iluminação natural surge como um elemento crucial, contribuindo para o conforto visual e para a regulação dos ritmos circadianos e a prevenção de problemas de saúde. Este estudo investiga o desempenho da luz natural em salas de aula com base na norma internacional EN 17037:2018 e na norma brasileira NBR 15215-3:2024. O objetivo é comparar as métricas dinâmicas de luz natural através de simulações computacionais com as percepções dos usuários por meio de pesquisa direcionada aos usuários das salas de aula. Os resultados revelam que, em com pouca iluminação, os usuários demonstram maior tolerância às condições de luz natural, enquanto em espaços bem iluminados, tendem a ser mais exigentes em relação à qualidade da luz natural. Além disso, os usuários aceitam níveis de iluminância mais baixos e DGP mais alto do que os prescritos pelas normas. Esta pesquisa conclui a percepção do usuário deve ser usada para calibrar valores normativos dispostos em regulamentos relativos à normalização em iluminação natural.

Palavras-chave: Iluminação natural. Autonomia de luz natural. Simulação computacional. Salas de aula. Percepção visual.

Como citar:
VECCHINI, L. M., SOUZA, R. V. G. Daylight metrics and user perception in classrooms. In: ENCONTRO NACIONAL DE TECNOLOGIA DO AMBIENTE CONSTRUÍDO, 21, 2026, Goiânia. Anais... Goiânia: ANTAC, 2026.

INTRODUCTION

Ongoing studies exam the relationship between human health and well-being [1] and the ability to adapt to prevailing spaces conditions, which encompass the physical aspects of Internal Environmental Quality (IEQ) [2, 3], such as thermal, visual, acoustic and air quality conditions.

As for the visual conditions, the benefits of daylight exposure on cognitive function, psychological state and behavior are significant [4]. Because daylight levels are dynamic, the daylight performance needs to be considered over time. One has also to consider that side lit spaces such as classrooms inherently have non-uniform illuminance distributions presenting higher illuminances near the windows [5]. This means that although good daylighting should cover a significant part of the space, it is not always possible to attain.

Daylight plays a crucial role in human comfort and in regulating the circadian cycle, as described in CIE S 026/E:2018 [6]. Daylight influences the release of sleep hormones, controls heart rate and potentially alleviates seasonal depression [7]. In a post-pandemic scenario, the importance of daylight has become even more pronounced, as prolonged periods of indoor confinement have heightened awareness of the role daylight plays in supporting mental health, regulating circadian rhythms and enhancing overall well-being [8, 9].

Actually, the most widely used analysis method to evaluate daylighting performance is Climate-Based Daylight Modeling (CBDM). This analysis evaluates the distribution of internal illuminance due to daylight, either under specific conditions or throughout the entire year [10]. Several software programs are available for conducting computational simulations and Radiance is identified as the primary algorithm [11].

Standards have been established to define the required amount of daylight in indoor spaces. One key metric is the Spatial Daylight Autonomy, sDA, which measures the sufficiency of illuminance for a given area [12]. It provides a percentage of floor area that exceeds a specified illuminance level for a given percentage of a building occupation hours [13]. The European standard EN 17.037:2018 - *Daylight in Buildings* [5] has incorporated sDA and stablishes two daylight illuminance threshold values: a minimum illuminance of 100 lux and a target illuminance of 300 lux. The Brazilian standard ABNT NBR 15215:2024-3 [14] followed EN 17037 directives, but established a new target illuminance criteria (Table 1), where the sDA threshold was reduced from 300 lux to 250 lux, based on studies conducted by Heschong (2012) [15]. To meet the minimum requirement for both standards, a 50% time threshold has been defined.

Table 1: ABNT 15.215-3:2024 Recommendation for daylight provision through openings – non-residential buildings

Recommendation Level	Target Illuminance	Fraction of space for target level	Minimum Target Illuminance	Fraction of space for minimum target level	Fraction of daylight hours
Level I		40%		60%	
Level II	250 lx	55%	100 lx	75%	50%
Level III		70%		90%	

Source: ABNT 15.215-3:2024.

Daylight Glare Probability, DGP, quantifies the likelihood of glare caused by daylight. Glare is known to be a negative visual sensation, resulting from areas with luminance levels higher than those to which the eyes are adapted, leading to discomfort [16]. Furthermore, glare is influenced by factors such as vertical luminance, the viewing angle of the light source and contrast [17]. The evaluation considers that glare protection to ensure visual comfort is needed if there's a view direction that exceeds a certain DGP in 5% of annual exposure time.

Additionally, Annual Sunlight Exposure metric, ASE, which provides a second dimension of daylight analysis, looking at one potential source of visual discomfort, measures the percentage of occupied floor area that receives more than 1000 lux of direct sunlight for over 250 hours annually, complementing the analysis of daylight availability [13].

In this context, the objective of this study is to evaluate the dynamic metrics proposed by both EN 17037:2018 [5] and ABNT NBR 15.215-3:2024 [14] through computational simulation, comparing simulation results with users' perceptions.

METHODOLOGY

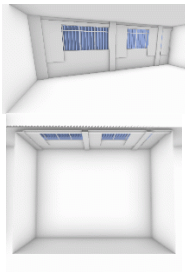
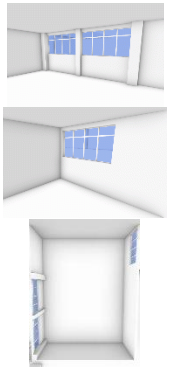
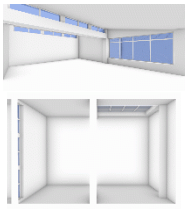
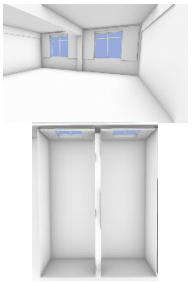
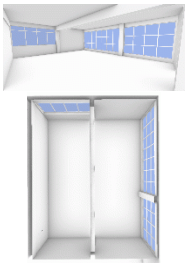
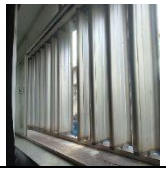
For this analysis, classrooms at the School of Architecture of the Federal University of Minas Gerais (S 19°55' and W 43°55') were selected as a case study. This research does not aim to evaluate the overall architectural design performance regarding daylighting but rather to investigate whether users' perception of well-lit areas is more consistent with sDA calculated using 250 lux or 300 lux thresholds. And if glare perception matches the indication of glare discomfort given by DGP simulations.

The interior furniture was not considered. Despite the flexibility in classroom layouts, only elements that could affect the results, such as blackout curtains, were included in this study. The openings and other relevant aspects of each evaluated classroom are detailed in Table 2. Work planes were considered at 0.75 m above the floor.

Rhinoceros 7 was used with ClimateStudio plugin, developed by Solemma [18]. The building environment data was sourced from BH Map [19] and the climatic file used was BRA_MG_Belo.Horizonte-Prates.AP.836724_TMYx.2009-2023, available at Climate One Building [20].

DOI: https://doi.org/10.46421/entac.v21i1.8318

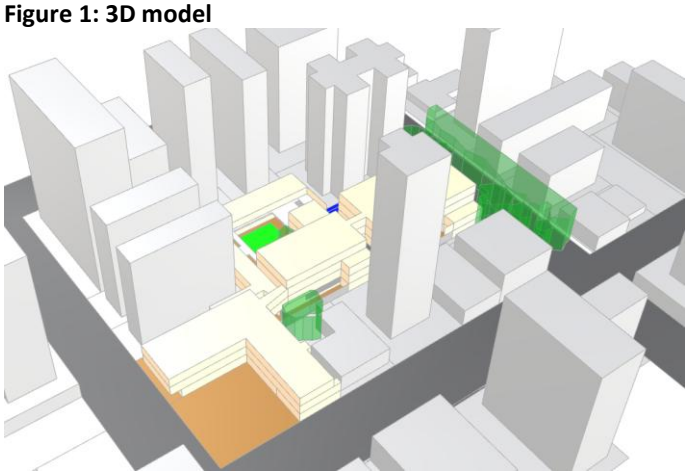
Table 2: Description of the rooms evaluated

-	Room 116	Room 118	Room 134A	Room 412	Room 413A
Floor	1st Floor 	1st Floor 	2st Floor 	4st Floor 	4st Floor 
Openings	NW 	SE and NE 	NW and SW 	SE 	SE and SW 
3D Model					
Others	Solar protection devices and blackout curtains 	-	Solar protection devices and sheds 	Blackout curtains	-

Source: the authors.

The 3D model considering the surrounding buildings and trees can be seen in Figure 1.

Figure 1: 3D model



Source: the authors.

Table 3 presents surface reflectance and visible light transmission used in the model. A translucent material was assigned to the trees [21] and the tree canopies were modeled without upper surfaces to prevent light from passing through the material twice [22].

Table 3: Surfaces optical characteristics

Surface	**ClimateStudio material**	**Reflectance**
Wall: white mortar	Dupont Dirty White 118	47.5%
Partition wall: yellowed PVC	Yellow Plaster Wall	71.2%
Floor: gray porcelain tile	Grey floor Tile	26.2%
Floor: yellowish	Beige Floor	49.4%
Floor: wood parquet	Wood Floor2	35.1%
Ceiling: white mortar	Ceiling LM83	70.0%
Window frame	Grey Aluminum Window Frame	43.3%
Brise-soleil and metal louvers	Grey Window Frame	18.1%
Curtains	Cubicle Partition Fabric	42.8%
Exterior Wall	Dirty Exterior Concrete	28.1%
Exterior Floor	Exterior Concrete floor 2	25.5%
Grass	Greenish Grass	10.4%
Perimeter wall	Concrete Block Barrier	23.7%
Surrounding	Concrete Exterior Wall 3	38.0%
White surrounding	Light Grey Plaster Facade	54.9%
Metal roofing	Metal Reflector On Ceiling	57.2%
Streets	Asphalt	8.2%
Surface	**Translucent material**	**VLT**
Single glazing	Clear	87.7%
Dirty glazing	Solar bronze	53.0%
Film-coated glazing	Vistacool on Pacifica	31.8%
Vegetation	Pacifica	41.2%

Source: the authors.

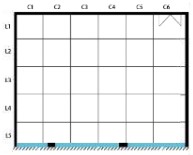
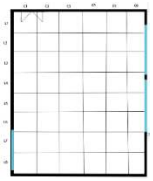
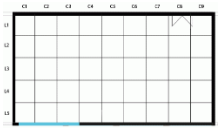
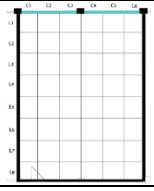
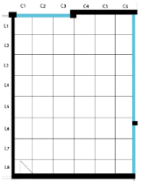
To calibrate the model, *isolux* curves were generated following ABNT NBR 15215-4:2024 [23], based on *in situ* illuminance measurements taken at three different times of the day (morning, noon and afternoon) on May 25 and November 9, 2024. The simulated model was then adjusted to match the exact day, time and sky condition present during the measurements.

Simulations were performed for $sDA_{300,50\%}$ and $sDA_{250,50\%}$, ASE and DGP.

The questionnaire aimed to gather user perceptions regarding the availability of daylight and glare perception. To enhance the evaluation, responses were treated using a Likert scale, which measures the level of agreement or disagreement with the proposed statements. Additionally, the mean deviation of each response was calculated to assess variability or consistency among participants [24].

The most critical question in the study was: "To what extent do you consider the classroom to be well-lit at this moment?". Participants were asked to select which grid quadrants in a map of numbered rows and columns (Table 4) they perceived as well-lit. This data was used to generate a heatmap, which was then compared with CBDM simulation results.

Table 4: Grid of each room

Room 116	Room 118	Room 134A	Room 412	Room 413A
				

Source: the authors.

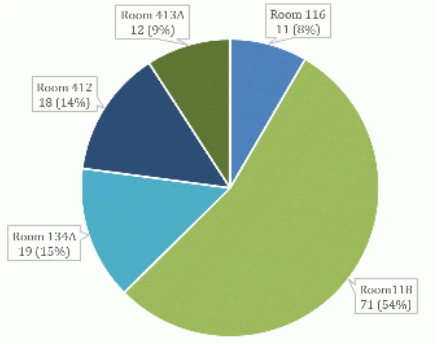
This grid-based approach was proposed based on the Daylit Area method [25], which provides a simplified approach for defining and evaluating naturally lit areas.

User perception data was collected through a questionnaire conducted from September 21 to November 15, 2024, and the questionary ethics was approved in Plataforma Brazil.

RESULTS

The questionnaire received 131 responses (Figure 2). The typical participant was a student (98%), considered to be seated at a classroom desk. A large portion of participants were under 24 years of age (85%) and wore glasses or corrective lenses (67%). Regarding their sensitivity to excessive light, in general, participants defined it as "acceptable" (52%).

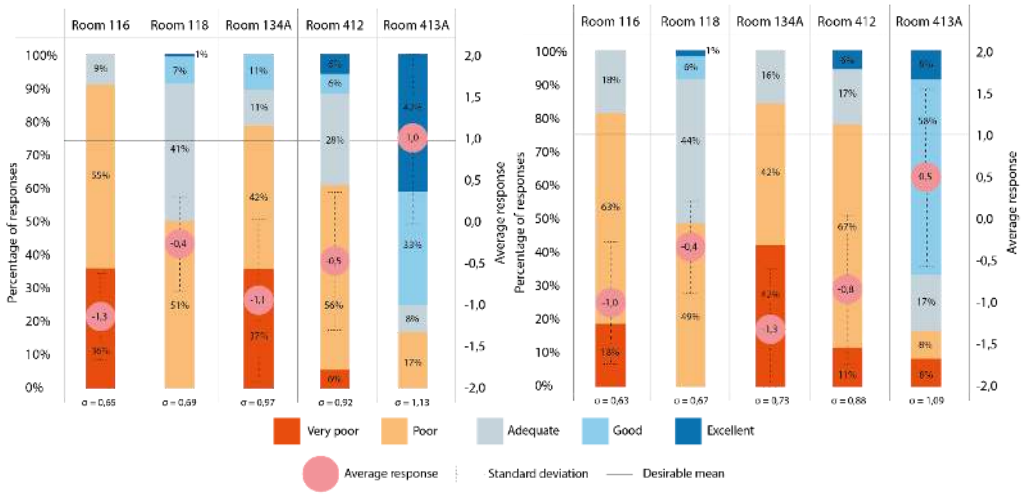
Figure 2: Distribution of responses in evaluated classrooms



Source: the authors.

Figure 3 presents the responses regarding the perception of daylighting in the evaluated classrooms in Likert scale. It is considered that the lighting will be deemed good if the average responses is ≥1.

Figure 3: "*For you, the quantity of daylighting that enters through the openings in the classroom is:*" (left) and "*Without turning on the lights/lamps, how do you consider the daylighting in the classroom*?" (right)

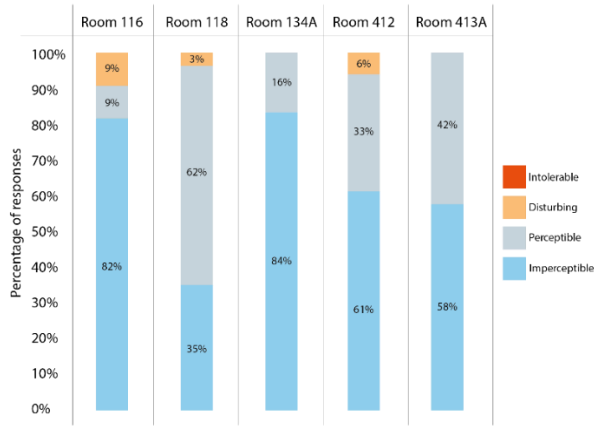


Source: the authors.

In Figure 3, most of the classrooms evaluated received similar ratings across both aspects. This suggests that, for most users, the perception of daylight quantity is closely associated with its perceived adequacy for performing classroom activities. Only classroom 413A is perceived as presenting good daylighting. Classrooms 118 and 412 are perceived as neutral and in Classroom 134A daylighting is perceived as poor.

Figure 4 presents users' perception of glare. Glare was predominantly perceived as *imperceptible* or *just perceptible* and never perceived as *intolerable*. The divergence between simulated results and user feedback suggests that the perceived severity of glare is relatively lower then showed by simulations, potentially influenced by the users' position and view direction within the space.

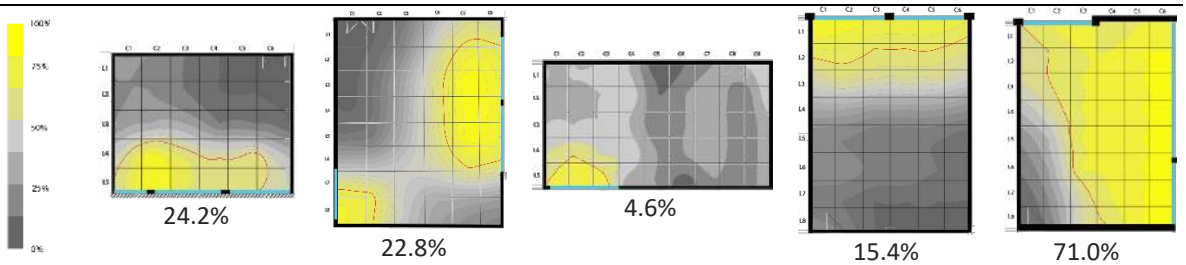
Figure 4: "*How do you consider glare in this classroom*?"



Source: the authors.

Table 4 presents the heatmap derived from the questionnaire responses to the question "To what extent do you consider the room well-lit at the moment?". The area in which 80% of participants agreed that the space was well lit, based on responses to the questionnaire, is indicated.

Table 4: Results of "To what extent do you consider the room well-lit at the moment?"

Room	116	118	134A	412	413A
	Area of agreement among more than 80% of the participants				
					
	24.2%	22.8%	4.6%	15.4%	71.0%

Source: the authors.

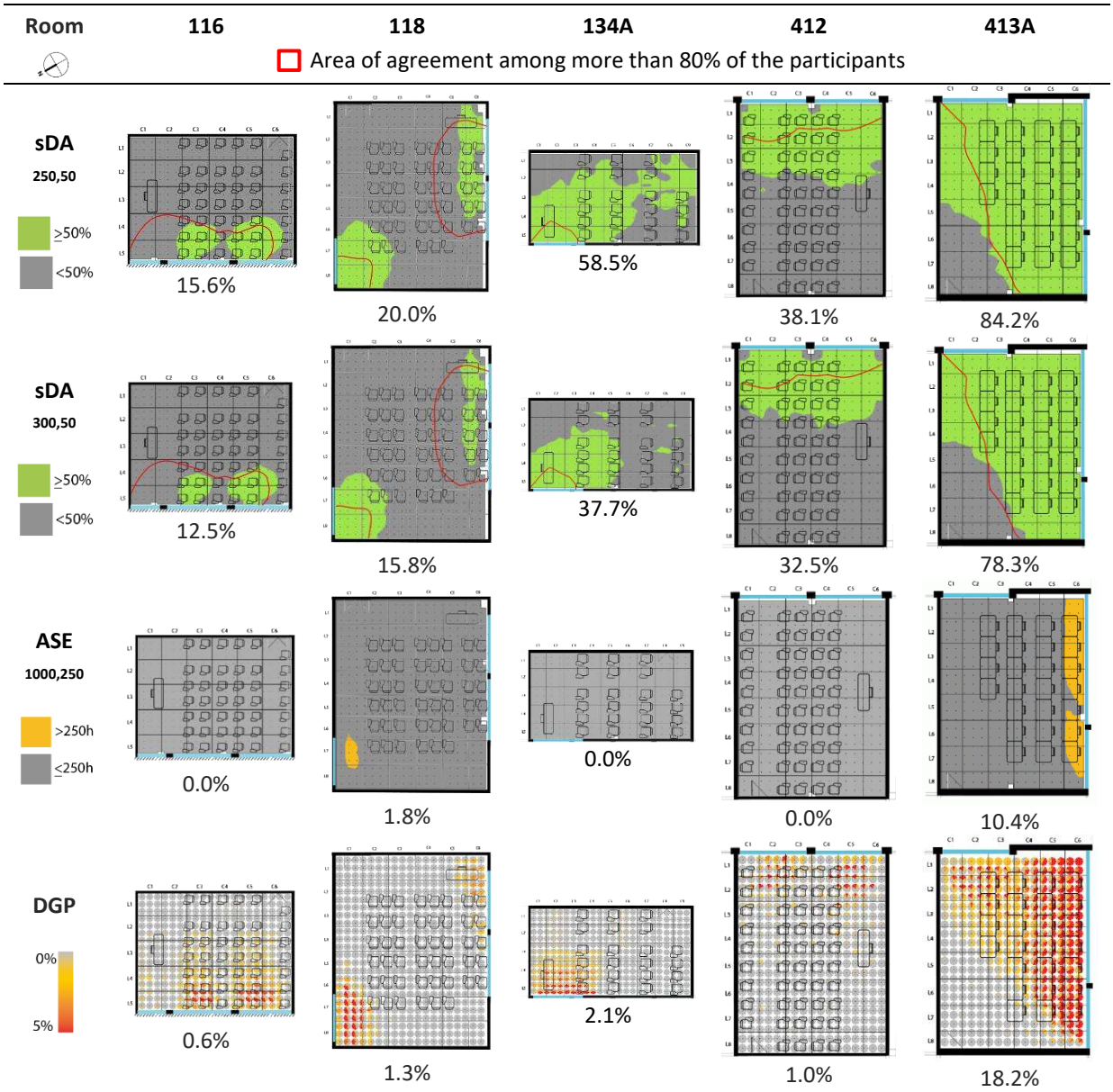
In Table 5 presents the simulation results for each classroom along with the corresponding heatmap. It was observed that in spaces under generally lower daylight levels conditions, participants were more inclined to consider a given quadrant adequately illuminated, potentially due to reduced expectations or adaptation to lower daylighting levels. In contrast, in spaces where simulations predicted high levels of daylight availability, users appeared to apply stricter criteria in their assessments. This suggests that when daylight is abundant, the perception of what constitutes a "well-lit" area becomes more discerning, likely influenced by greater contrast within the space and elevated visual expectations.

ASE values were generally low across most classrooms, with only a few localized hotspots. These zones were typically adjacent to window openings or occurred in spaces without effective solar control strategies. Despite the presence of high-illuminance areas in the simulation results, users' feedback did not consistently indicate discomfort or dissatisfaction. This suggests that occupants may tolerate moderate variations in daylight levels, depending on the specific task being performed or the time of day.

Furthermore, the DGP results did not correspond to the glare-related discomfort reported by users. A likely explanation for this discrepancy is the viewing direction of the occupants. As most participants were presumably seated at desks, their gaze would have been oriented either perpendicular or opposite to the windows, thereby minimizing direct exposure to glare sources.

DOI: https://doi.org/10.46421/entac.v21i1.8318

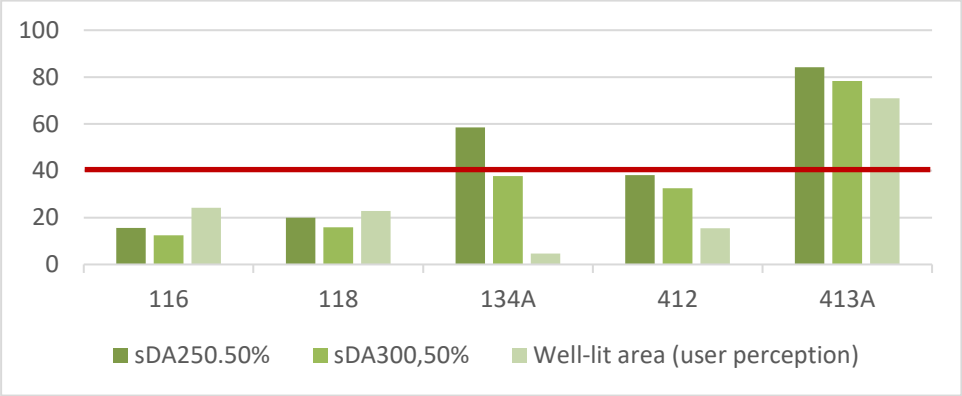
Table 5: Results of $sDA_{250,50}$, $sDA_{300,50}$, $ASE_{1000,250}$ and DGP



Source: the authors.

Figure 5 shows a comparison of the percentage areas considered as presenting $sDA_{250,50\%}$, $sDA_{300,50\%}$ and perceived as well-lit areas by users for each classroom. It can be seen that in classrooms with lower sDA, user perception seems to align with $sDA_{250,50\%}$ while in classrooms with higher sDA, user perception seems to align with $sDA_{300,50\%}$. An exception in the comparison between user perception and daylight availability simulation results occurs in Classroom 134A. This classroom presents sheds oriented to Southwest and windows oriented to Northwest. Both the sheds and the solar protection devices located in the window need maintenance as surfaces are degraded and very dirty. In this sense simulations seem to have overestimated the daylighting potential in this classroom. $sDA_{250,50\%}$ and $sDA_{300,50\%}$ are quite different in this classroom also indicating a more deemed space.

Figure 5: $sDA_{250,50\%}$, $sDA_{300,50\%}$ and well-lit percentage areas according to users



Source: the authors.

Figure 5 shows that the 40% minimum threshold for $sDA_{250,50\%}$ is not met by most rooms. This underperformance may be related with the presence of blackout curtains, solar protection devices and orientation, which likely reduce daylight availability and impact the results.

The evaluation of daylighting by users is directly influenced by the interaction between quantity, quality and glare. The analysis of these three dimensions reveals that user satisfaction with daylighting is not only determined by illuminance levels but also by how light is distributed throughout the space and its impact on visual comfort.

CONCLUSION

Exposure to daylight above 250 lux seems to ensure adequate daylighting conditions in internal spaces when compared to the responses obtained through the questionnaire. Users adjust their perception to the available conditions and often develop a certain tolerance to daylighting limitations. In these cases, any increase in lighting compared to the surrounding spaces may be considered enough to perform the intended task. The opposite occurs in already well-lit spaces. Users become accustomed to higher levels of illuminance levels and present a higher request to consider areas in the space as well-lit. It is believed that this happens because the brighter the spaces, the more likely is that discrepancies or insufficiencies in areas that might seem dim or poorly lit in comparison to the rest of the space are noticed. Finally, glare appears to have little influence on the visual perception of illuminance levels the occupants. Attention should be paid to the orientation of the students view directions relative to the openings.

Due to software restrictions, daylight simulations could only be performed on an annual basis, preventing the analysis of specific periods that matched the questionnaire dates potentially influencing the comparison between simulated and perceived conditions. The temporal mismatch between simulation and survey data is acknowledged as a limitation that may affect the precision of comparisons. Furthermore, the sample classrooms may also limit the generalizability of the findings to other building types or configurations.

ACKNOWLEDGMENTS

Authors would like to thank the National Council for Scientific and Technological Development (CNPq) for providing financial support for this research.

DECLARATION

The authors declare that they did not use generative AI or AI-assisted technologies in the preparation of this manuscript.

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