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GLAZING FOR DOUBLE SKIN FACADE: *DAYLIGHTING UNDER DIFFERENT TRANSMITTANCE COMPOSITION*

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ABSTRACT: Over the years, the interest in double skin facades (DSF) has increased since it is a design solution offering buildings a modern and transparent appearance. They are well known for improving comfortable conditions for hot and cold climates. However, studies focusing on the incidence of daylighting in such systems, especially regarding the impacts of the materials applied to the DSF layers on the lighting penetration and distribution into the rooms are still few. Thus, this study aims to analyse the daylighting performance of different glazing transmittances applied to the inner and outer skins of an educational DSF building in southern Brazil (lat. 30º S). Analyses were performed considering two metrics: Spatial Daylight Autonomy ($sDA_{300/50\%}$) and Annual Sunlight Exposure ($ASE_{1000,250h}$). Using Grasshopper and ClimateStudio Plugins for Rhinoceros 3D, simulations were carried out considering seven different types of glazing. The results demonstrated that the use of glazing with high transmittance promotes an increase in daylighting accompanied by an increase in the risk of visual discomfort. Furthermore, none of the simulated cases presented acceptable results for the sDA_{300} and ASE_{1000} variables, but the most adequate results were found in the cases that used glazing transmittances of 16% and 53% on the outer and inner DSF layers, respectively. In conclusion, for middle latitudes, the use of high transmittance glazing should be avoided in the DSF. It can be useful if it is associated with a medium transmittance glazing applied to the inner layer.

KEYWORDS: Daylighting; Double Skin Façade; Glass transmittance; Parametric Simulation; Dynamic Daylight Performance Metrics.

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RESUMO: Ao longo dos anos, o interesse por fachadas duplas (DSF) aumentou, pois é uma solução de design que oferece uma aparência moderna e transparente aos edifícios. Elas são bem conhecidas por melhorar as condições de conforto em climas quentes e frios. No entanto, ainda são poucos os estudos que se concentram na incidência da iluminação natural em tais sistemas, especialmente no que diz respeito aos impactos dos materiais aplicados nas camadas da DSF sobre a penetração e distribuição da luz nos ambientes. Assim, este estudo tem como objetivo analisar o desempenho da iluminação natural de diferentes transmitâncias de vidros aplicados nas camadas interna e externa de um edifício educacional com DSF no sul do Brasil (lat. 30º Sul). Foram realizadas análises considerando duas métricas: Spatial Daylight Autonomy ($sDA_{300/50\%}$) e Annual Sunlight Exposure ($ASE_{1000,250h}$). Utilizando os plugins Grasshopper e ClimateStudio para Rhinoceros 3D, foram realizadas simulações considerando sete tipos diferentes de vidros. Os resultados demonstraram que o uso de vidros com alta transmitância promovem um aumento na iluminação natural acompanhado de um aumento no risco de desconforto visual. Além disso, nenhum dos casos simulados apresentou resultados aceitáveis para as variáveis sDA_{300} e ASE_{1000}, mas os resultados mais adequados foram encontrados nos casos que utilizaram transmitâncias de vidros de 16% e 53% nas camadas externa e interna da DSF, respectivamente. Em conclusão, para latitudes médias, deve-se evitar o uso de vidros de alta transmitância na DSF. Pode ser útil se for associado a um vidro de transmitância média aplicado à camada interna.

PALAVRAS-CHAVE: Iluminação natural; Fachada Dupla; Transmitância do vidro; Simulação Paramétrica; Métricas dinâmicas de desempenho da iluminação natural.

Introduction

One of the challenges for the future of sustainable development is the design of buildings that use fewer resources and provide comfortable and healthy conditions to their users. In this sense, an important factor that must be considered in the conception of buildings is the appropriate daylighting, along with the control of glare and solar energy gains, which offers not only benefits for health and well-being, but also has a significant potential for energy savings (CHESHIRE and GODEFROY, 2020).

Therefore, the interest in double skin facades (DSF) has increased since it is a design solution that offers a modern and transparent appearance to buildings, capable of providing comfortable conditions for warm climates (BARBOSA and IP, 2016) and reducing heating loads in temperate areas (POMPONI et al., 2016). It consists of adding an external skin (usually made of glass) over the conventional facade of a building, creating an intermediate space between the layers (ZHOU and CHEN, 2010). In buildings with DSF, the solar radiation goes through the façade layers and the daylighting will depend on the reflectivity, transmittance, and absorption ratios of direct and diffuse radiations of each layer (LUO et al., 2018); thus, the phenomenon will involve more reflections than in a conventional façade. Although there are several relevant studies on the thermal performance of the system (BARBOSA and IP, 2014; POMPONI et al., 2015), there are still a few studies that have tested different glazing types and their relationship with the incidence of daylighting in such buildings.

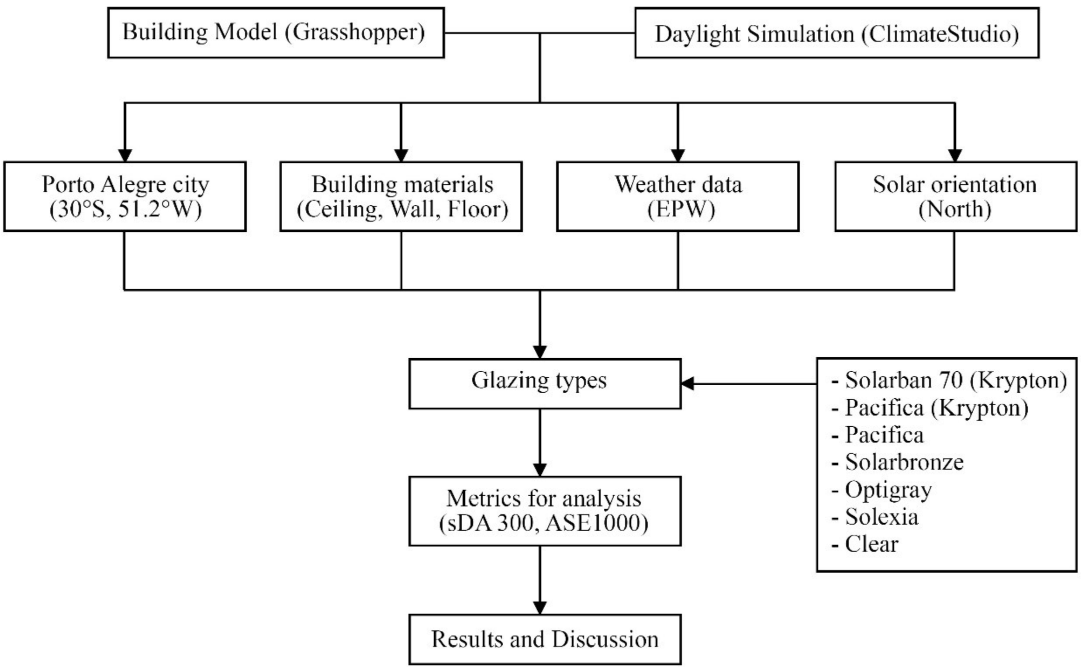
The study by Elayeb et al. (2017), for instance, tested different glazing types applied to the DSF inner skin (clear reflective, high absorptive, and blue tinted), while maintaining a highly absorptive glazing on the outer layer. They used a south-DSF box-window model (which has the cavity divided horizontally and vertically along the construction axes, on a room-by-room or on an individual window element basis) and simulations were carried out in a low latitude city (Selangor, Malaysia, lat. 2.9° N). They observed that for the 1m-cavity case, when using high absorptive, clear, or reflective glazing may result in inadequate daylighting levels. Therefore, glazing with middle transmittances (between 32 and 58%) provide useful daylighting levels for the office. Hamza and Dudek (2005), on the other hand, simulated the DSF applied to the east and west facings of a model in Cairo, Egypt (lat. 30°N) and tested four glazing types (16, 38 and 49% transmittance and spectrally selective). They found that during the summer months, on both the east and west orientations, the use of reflective glazing will result in glare and high intensities of light near the window area and the use of a spectrally selective glazing is predicted to create a more uniform daylit in the interior. EL AHMAR and FIORAVANTI (2015) explained that in the case of the DSF system, the inner façade layer is already shaded by the added layer, which reduces the amount of light entering the building.

Thus, although previous studies provide some insightful contributions regarding this parameter’s impact on natural lighting, a comparative evaluation of different glazing transmittance applied on both inner and outer layers on a north-facing façade is still necessary. Moreover, many of the studies on daylighting in DSF were conducted in Asia (ZHANG et al., 2022; SRISAMRANRUNGRUANG and HIYAMA, 2021) and Europe (BUENO et al., 2017), highlighting the need for more studies in the southern hemisphere since the climatic characteristics, solar cycles, construction techniques, and design trends are different from the northern hemisphere. Moreover, many of the studies on the system were carried out on the office typology (ELBATRAN et al., 2021), and the applicability of the DSF in other typologies such as educational buildings was little explored. Due to the negative influence that unsatisfactory lighting can have on students' learning and performance, providing comfortable conditions is essential. Thus, this study aims to analyse the daylighting performance of different glazing transmittances on the inner and outer skins of an educational DSF building in southern Brazil. The study tested alternative scenarios, giving a broader understanding of the impacts of the DSF on the internal daylighting of institutional facilities under middle latitudes.

Methodology

For this study, an educational building, based on the building by the Porto Alegre Federal University of Health Sciences (UFCSPA), was modelled using the parametric design software Grasshopper and ClimateStudio Plugins for Rhinoceros 3D. The simulations considered the climatic conditions of Porto Alegre (lat. 30°S) city in Brazil. Characteristics of the surrounding environment, such as vegetation and nearby buildings were not considered. Figure 1 shows the methodology scheme used for the study.

Figure 1: Method overview



Source: The authors

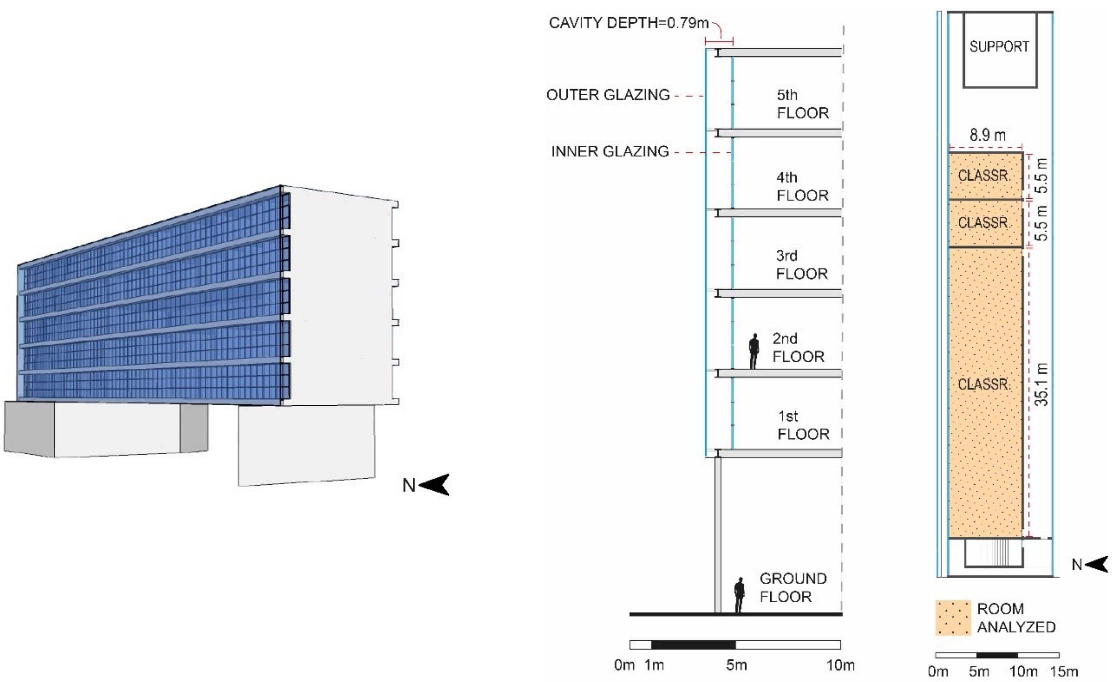
2.1 Porto Alegre Climate Characterization

The city of Porto Alegre is classified as a humid subtropical climate, according to the Köppen and Geiger categorization, with average annual temperature, relative humidity, and horizontal global radiation of 19.3°C, 82%, and 197.9Wh/m², respectively. The average monthly wind speed is 2m/s. In general, during the cold seasons (from June to September), the air temperature levels are at the lowest, reaching an average of 15°C, while during the summer, the average air temperature reaches 24°C. Precipitation levels are the lowest in April (24mm), whereas humidity levels are the lowest in December (71%). On the other hand, during the hot seasons, humidity reaches a peak of 81%, and accumulated precipitation 521mm.

2.2 Model Description

The building model used in this study has five floors with a floor height of 3.4m and a ground floor. The DSF multi-storey type (which has the cavity adjoined vertically and horizontally by a number of rooms, covering the entire façade of the building) was applied to the north facing (Figure 2). The results present a detailed analysis of the 3rd floor, which is in the middle of the building height above ground.

Figure 2: Building model, section and third-floor floorplan



Source: The authors

2.3 Modelling process and simulation analysis

For this study, seven different glazing types (from low to high transmittances) were applied alternately on the internal and external surfaces of the DSF, resulting in 49 combinations. In order to avoid the influence of other visual properties, glazing with similar and low reflectance was chosen. The properties of the materials used are shown in Table 1. The configuration of the building envelope was based on the normative LM 83-12 (2019).

Table 1: Characterization of the materials used.

Building envelope	**Reflectance (%)**	**Equivalent colour (CASTRO et al.; 2020)**	
Ceiling	70	Ice	
Wall	50	Honey	
Floor	20	Dark blue	
Glazing types	**Layers**	**Light transmittance (%)**	**Light reflectance (%)**
Solarban 70 (Krypton)	Double	16.8	5.9
Pacifica (Krypton)	Double	29.6	5.3
Pacifica	Single	44.4	5.6
Solarbronze	Single	53.4	6.0
Optigray	Single	62.8	6.2
Solexia	Single	76.8	7.5
Clear	Single	87.7	8.4

2.4 Metrics used for the analysis

The parameters used for the analysis on the daylighting were based on the LM 83-12 (2019) normative, which has been used in recent studies (ELBATRAN and ISMAEEL, 2021). Analyses were performed considering two metrics: spatial Daylight autonomy ($sDA_{300/50\%}$) and Annual Sunlight Exposure (ASE_{1000}) (Table 2). The first corresponds to the percentage of a space that receives a minimum target illuminance of 300 lux for at least 50% of the annual occupied hours. The second refers to the percentage of space that receives too much direct sunlight (1000 lux or more for at least 250 occupied hours per year) at the working plane height, which can cause visual discomfort. The analysis, based on the sDA_{300} metric in conjunction with the ASE_{1000} metric, allows a better observation of the quality of the daylighting, as the ASE_{1000} allows the measurement of the unwanted lighting that may be accompanied by ideal sDA_{300} values. In addition, direct sunlight should be avoided inside the building, especially in warmer climates or periods, as it enhances the risk of discomfort (BUGEAT et al., 2020).

Table 2: Parameters of analysis for sDA_{300} and ASE_{1000}.

sDA_{300}	ASE_{1000}
>55% acceptance	<10% acceptance
>75% preference	

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A grid with virtual sensors was set in the room on a virtual surface at 0.75m height with 30cm of distance between each of them. For the analysis, the occupancy hours were considered between 8 a.m. and 6 p.m.

3 RESULTS AND DISCUSSION

Table 3 shows the sDA_{300} and ASE_{1000} results for all the cases simulated. In the table, values highlighted in green, grey, and red are those preferred, accepted, and unacceptable, respectively. There is a steady increase in the percentage of the room that receives a minimum illuminance of 300 lux with the increase of glazing transmittance both for the inner and the outer layers. It was interesting to notice that similar sDA_{300} values were found for the cases with the same glazing transmittances regardless of their position on the façade. This gives autonomy to the designer when conceiving the building design as they can decide the position for the higher and lower transmittance glazing. It's worth remembering, however, that the glazing used have similar reflectance levels.

It was also observed that when using a very low transmittance glazing (16%), i.e. with high absorptive coating, either on the inner or the outer layer, acceptable sDA_{300} values are never met. This means that even for middle latitudes, where the sun is lower than in the cities close to the equator, the use of glazing with very low transmittance on both inner and outer layers of the DSF may result in poor daylight inside the room. This was also observed by Elayeb et al. (2017), although their study was conducted in a low latitude, where the is sun positioned higher in the sky.

Concerning the excessive direct sunlight reaching the interior environment, the results demonstrate a direct relationship between the increase in the autonomy of daylighting and the increase in the risk of visual discomfort in the building. In the model analysed, none of the cases tested presented acceptable results for both sDA_{300} and ASE_{1000}, showing that the scenarios that receive the minimum target illuminance of 300 lux for at least 50% of the annual occupied hours also presented too much direct sunlight (1000 lux or more for at least 250 occupied hours per year) at the working plane height.

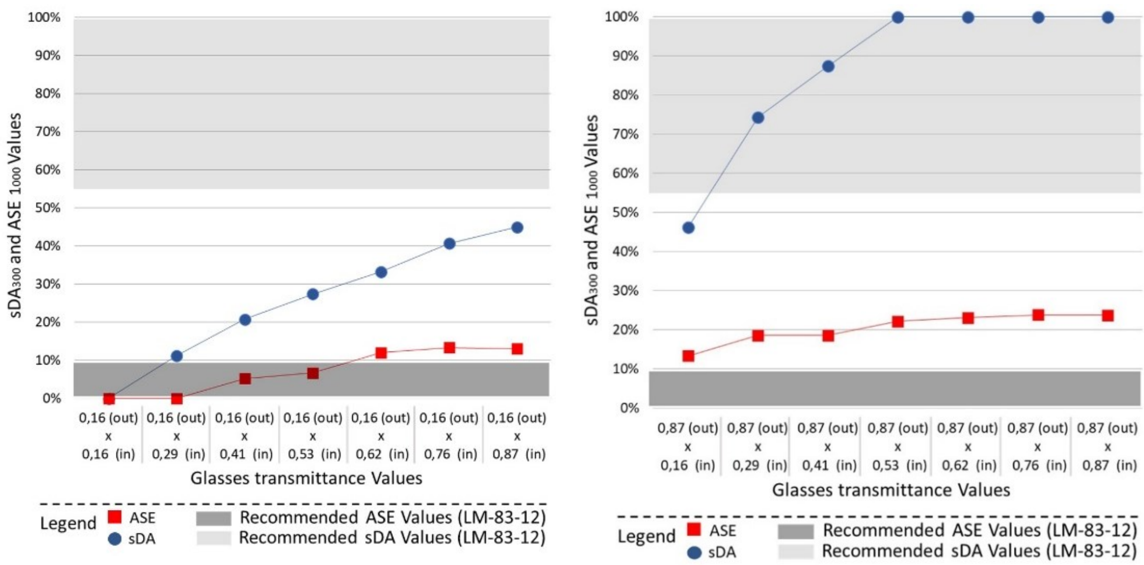
Table 3: Results of sDA_{300} and ASE_{1000} for glazing transmittances combinations

		sDA	ASE	sDA	ASE	sDA	ASE	sDA	ASE	sDA	ASE	sDA	ASE	sDA	ASE
		Inner: 16%		Inner: 29%		Inner:4 1%		Inner: 53%		Inner: 62%		Inner: 76%		Inner: 87%	
Outer layer transmittance:	16%	0	0	11	0	20	5	27	7	34	12	41	13	46	13
	29%	11	0	29	7	41	13	48	13	59	17	69	19	74	19
	41%	21	5	41	13	56	17	67	19	74	19	82	19	87	19
	53%	27	7	48	13	67	19	77	19	83	19	97	20	100	22
	62%	33	12	59	17	74	19	83	19	92	19	100	22	100	23
	76%	41	13	69	19	81	19	96	20	100	22	100	24	100	24
	87%	45	13	74	19	88	19	100	22	100	23	100	24	100	24

Figure 3 presents the results of glazing combinations with low (16%) and high (87%) glazing transmittances applied to the outer skin. Figure 3a shows that the use of low-transmittance glazing applied to the DSF outer skin, even associated with medium or high-transmittance glazing placed on the inner skin, results in a very poorly light environment.

Figure 3b shows the resulting values for the cases with a high transmittance glazing (87%) applied to the outer facade. Although none of the simulated cases presented ASE_{1000} values within the range recommended by LM-83-12, some improvements are seen compared to the cases with low transmittance glazing placed on the outer skin. The use of a low transmittance glazing on the inner skin (87% outer and 16% inner) results in a reduction in the ASE_{1000} values compared to the combination that used high levels of transmittance (87% outer and 87% inner), which are 13% and 24%, respectively. This indicates that the association of glazing with high and low transmittances is not useful, as the sDA300 values can be as low as 45% while the ASE_{1000} remains above the maximum value, which affects the quality of daylighting in the internal environment.

Figure 3: Results of glazing combinations with (a) low (16%) and (b) high (87%) glazing transmittances applied to the DSF outer skin



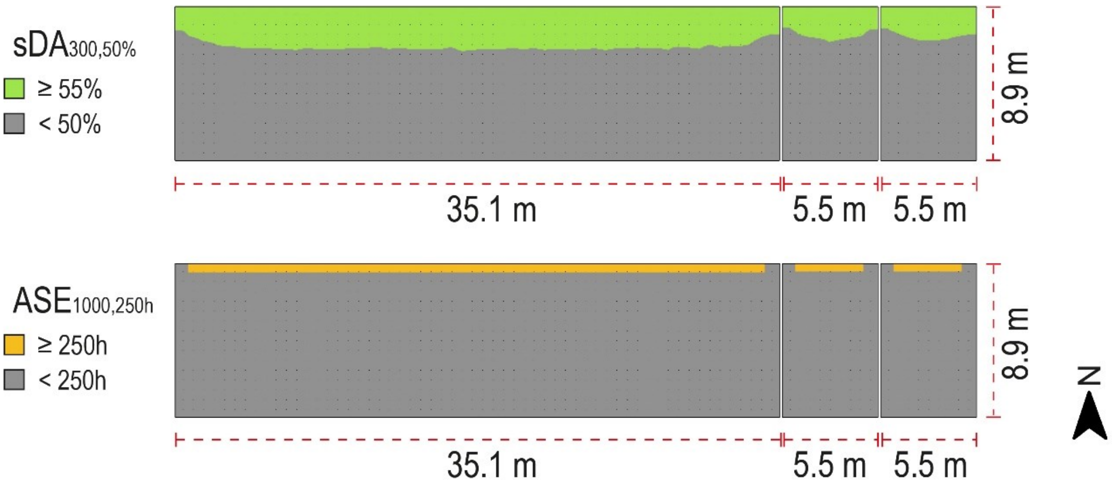
(a) (b)

Source: The authors

However, combining a high transmittance glazing (87%) on the outer skin with a low-medium transmittance on the inner skin (29%) meets the minimum lighting requirements, while the ASE_{1000} values remain below 20%. In this case, it will still be necessary to apply a strategy to avoid direct sunlight on the inner environment such as the application of shading devices within the cavity or by using a more reflective glazing on the outer skin. In this last case, part of the lighting rays will be reflected outside before entering the cavity. Another possible solution would be to reduce the window-to-wall ratio of the building, as in the cases tested both facades are fully glazed.

Figure 4 presents the acceptable sDA_{300} and ASE_{1000} areas for the case with glazing transmittances of 41% and 16% applied to the DSF outer and inner layers, respectively. It shows that acceptable daylighting levels are located close to the DSF on the north facade of the building, but it covers less than half of the room depth (around 1.2m from the facade). On the other hand, the case resulted in the lowest ASE_{1000} values found; being restricted to a small area of about 30cm from the north window.

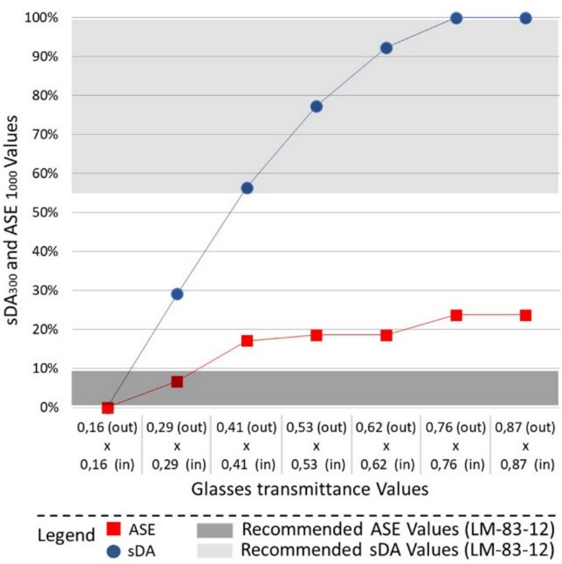
Figure 4: Results of useful and excessive daylighting of the case with glazing transmittances of 41% and 16% applied to the outer and inner layers, respectively.



Source: The authors

Figure 5 presents the values of the parameters using combinations of glazing with identical transmittances. As the glazing transmittance values increased, it was observed a gradual increase in the daylighting reaching the room. In addition, it was noted that the use of highly transmittance glazing, above 76%, the values of the parameters used were similar.

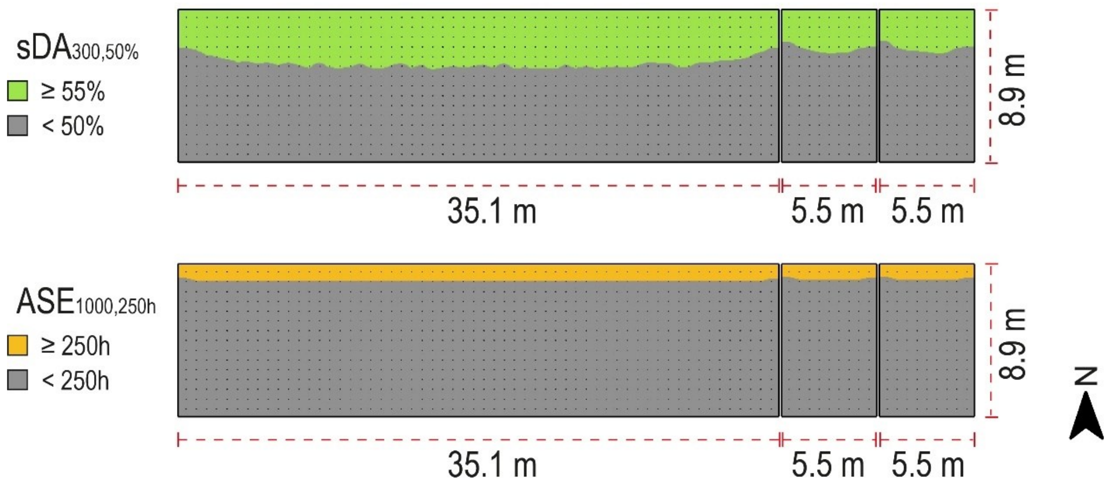
Figure 5: Results of glazing combinations with a similar glazing transmittance applied to the inner and outer skins.



Source: The authors

Figure 6 shows the sDA_{300} and ASE_{1000} values of the cases with low (29%) glazing transmittances applied to both skins. The ASE_{1000} value is within the acceptable, less 10% of the floor, and it is the lowest found among the cases considering those with acceptable range for sDA_{300}. It is interesting to notice that for the larger room, almost half of the floor plan presented daylight levels above 300lux. However, in the smaller rooms, those values slightly dropped to the area closer to the north facade. Despite that, the sDA_{300} does not reach the minimum considered adequate, reaching up to 0%. However, considering that this light is not prejudicial for human comfort, the glazing combination is suitable.

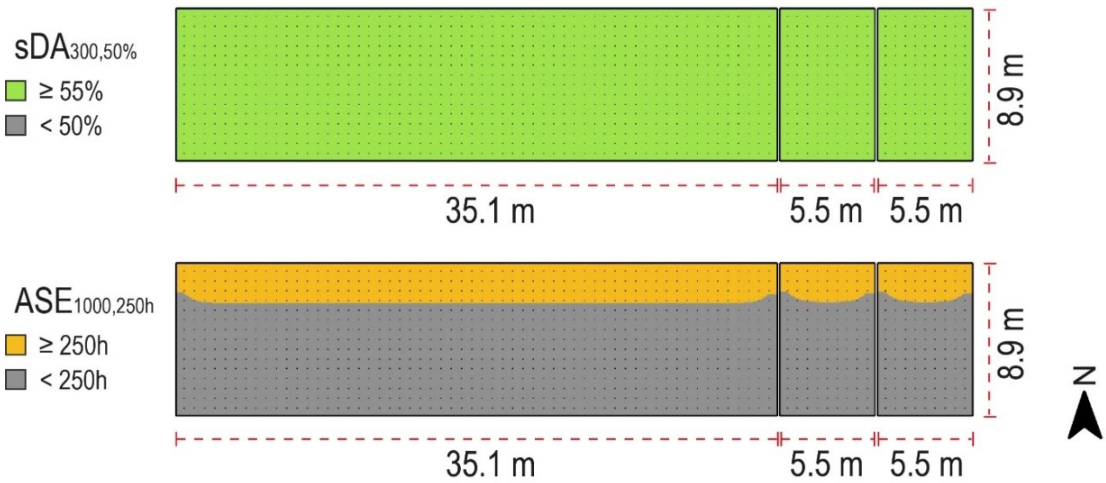
Figure 6: Results of glazing combinations with low (29%) glazing transmittances applied to the DSF inner and outer skin



Source: The authors

Figure 7 shows the sDA_{300} and ASE_{1000} values of the case with high glazing transmittances (87%) applied to both skins. In this scenario, all rooms were naturally illuminated with daylight levels exceeding 300 lux. This outcome is favourable as it ensures ample daylight autonomy, eliminating the need for artificial lighting during a significant portion of the day. However, the ASE_{1000} result is not acceptable as it reaches above 10% of the floor. This may result in visual discomfort and therefore, this case could be considered the worst case analysed.

Figure 7: Results of glazing combinations with high (87%) glazing transmittances applied to the DSF inner and outer skin



Source: The authors

Although none of the results were satisfactory according to the metrics and parameters determined, the best results were found with the combination of the cases with glazing transmittances of 16% (outer) and 53% (inner); and 29% (outer) / 29% (inner). They promote the maximum autonomy of daylighting and the lowest ASE_{1000} values. Thus, the data suggested that the use of high transmittance glazing in a DSF is not appropriate for middle latitudes if there is no association with medium transmittance glass. Differently from other similar research (EL AHMAR et al., 2015; ELAYEB et al., 2017), applying the DSF in middle latitudes may result in more concerns regarding the prevention of excessive lighting from entering the internal room than in reaching the minimal lighting requirements.

4 Concluding remarks

This study aimed to analyse the daylighting performance of different glazing transmittances applied to the inner and outer skins of an educational DSF building in southern Brazil. The analysis was carried out considering dynamic daylight performance metrics. The main findings include:

- Regardless of the position of the glazing transmittance on the façade, similar values of sDA300 were found, which gives autonomy to the designer when at the building conception phase;
- None of the simulated cases presented jointly acceptable results of the sDA_{300} and ASE_{1000};

- Best results were found with the combination of the cases with medium glazing transmittances - 16% (outer) and 53% (inner); and 29% (outer) / 29% (inner).
- For middle latitudes, the use of high-transmittance glazing in a DSF is not appropriate if there is no association with low-transmittance glazing.

The results demonstrate that, for middle latitudes, the application of DSF may result in excessive daylight, which can be an issue as the use of glazing with high levels of transmittance results in an increase in daylighting accompanied by an increase in the risk of visual discomfort. The most suitable combination of glazing for the inner and outer DSF layers should consider at least one of the skins with medium transmittance, for example, 53%. In any case, shading mechanisms – such as blinds and architectural design features – including walkway path and vegetation within the DSF cavity might be useful to limit direct sun rays and consequently excessive daylight from entering the internal room – may be useful.

An important limitation of this study relies on the absence of an immediate environment that would weaken the entrance of daylighting in the internal environment. The model simulated without an outdoor scenario hinders the entry of indirect lighting and enhances the entry of direct sunlight. Nearby surfaces function as a mechanism for conducting indirect lighting through the reflection of light rays through the physical properties of the walls, such as the reflectance index of the material covering the surface.

For future research, a full parametric study is still very much needed, considering the façade variables and materials and building features under different latitudes and climate conditions.

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