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Decision-making pathways to daylight efficiency for office buildings with balconies in the tropics

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The authors declare further bellow their individual contributions to the paper entitled "*Decision-making pathways to daylight efficiency for office buildings with balconies in the tropics*", according to the categories stated in Table 1.

Table 1: Categories provided by Elsevier to characterize authors' contribution.

Term	Definition
Conceptualization	Ideas; formulation or evolution of overarching research goals and aims
Methodology	Development or design of methodology; creation of models
Validation	Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs
Formal analysis	Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data
Investigation	Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection
Writing - Original Draft	Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation)
Writing - Review & Editing	Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or post-publication stages
Visualization	Preparation, creation and/or presentation of the published work, specifically visualization/ data presentation
Supervision	Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team
Project administration	Management and coordination responsibility for the research activity planning and execution
Funding acquisition	Acquisition of the financial support for the project leading to this publication

Íris Maria C. F. W. Loche: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization, Funding acquisition

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Decision-making pathways to daylight efficiency for office buildings with balconies in the tropics

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Abstract

Daylight in the indoor environment is directly influenced by the building surroundings, envelope and its shading devices, such as balconies. Despite their potential in contributing to increase shaded periods and, at the same time, act as a daylight distribution system, balconies are not designed to their full potential when used in office buildings and the literature lack studies that investigate the effect of balconies on their luminous performance. This study aims to explore this niche: the integration of balconies to the design of office buildings in the tropics, in order to improve their daylight performance. The research method was based on a parametric design approach in combination with daylight simulations, while combining a systematic analysis with a data mining algorithm. The study revealed successful combinations of building design parameters as well as important cut-off points for design decision-making to achieve daylight efficiency in typical mixed-mode office buildings in the city of São Paulo, Brazil. Results provided multiple design routes to achieve successful performance targets showing that, if properly dimensioned, balconies could be an efficient shading device and daylight diffuser. As a key contribution, successful combinations of design parameters that allow deeper balconies to yield better Useful Daylight Illuminance levels were identified. Further details about when balconies stop influencing daylight performance results as well as when an increase in balcony depth becomes beneficial to performance were reported in attempt to develop design guidelines for the early design stages for office buildings in São Paulo.

Keywords: office building; balcony; visual comfort; daylight performance; decision-making; data mining

1- Introduction

This study aimed to identify decision-making pathways to design efficient balconies for office buildings in the tropics, considering improving indoor daylight conditions in the climate of the city of São Paulo (Brazil). Balconies are common architectural features in residential and hospitality buildings used for several purposes which span from having a semi-private outdoor space, which can afford social activities, over urban greenery and farming in multi-storey buildings, up to providing 'immersive' experiences to unique outdoor sceneries. From a building physics perspective, balconies are powerful shading devices. With larger depths and widths, they demonstrate great potential in increasing diffuse daylight into office spaces while reducing undesirable direct solar radiation with the effect of diminishing cooling loads commonly present in the tropics.

However, despite their large potential in contributing to well-being, sustainability and comfort, balconies are not used to their potential in office spaces in the tropics. In São Paulo, for instance, they tend to be shallow (normally 0.5 m depth) and primarily used to accommodate air conditioning condensers from split unit systems, rather than thought as a multipurpose and multi-functional façade element. More than half (56%) of the office buildings in São Paulo are supplied with split air conditioning systems, locally controlled and metered (i.e. per room) with a mixed-mode regime [1]. They are office rooms rented by small companies, in a market scenario of medium-rise buildings with small office floor plans and mixed-mode operation systems, in opposition to wide open plan office buildings, which usually consists of non-operating curtain-wall façade systems.

This study aimed to explore the integration of balconies to the design of office buildings using a parametric design approach in combination with daylighting simulations. It did not see balconies in isolation but as an element of façade design. Therefore, it focuses on unfolding the most important combination of design parameters to be used in the early design stages for balconies to become efficient shading devices and daylight diffusers in a 'typical' mixed-mode office building in São Paulo. The richness of parametric design possibilities was explored via an extensive systematic analysis of simulation results in combination with the application of a datamining technique to show pathways of successful parametric combinations towards achieving different sets of daylight targets for comfort and well-being.

2- Background

Daylight has a positive impact on human well-being, particularly in workplaces, leading to better productivity and higher employee satisfaction [2,3] . Besides its human health benefits, the daylight is monetarily valued, providing energy savings with electric lighting and impacting the real estate market, mainly in dense urban environments. According to Turan et al. [2] in Manhattan, NY, tenants are willing to pay up to 6% more for office rooms with high daylight access over those with low daylight access. Daylight is therefore a fundamental component to achieve indoor wellbeing, energy efficiency and sustainability, stated through building regulations, urban zoning policies and green building certifications, which determine targets for building daylight performance.

Daylight performance can be evaluated through different daylight metrics. Static daylight measures, widely criticised throughout the literature [4–6], are still being adopted as a performance measure for daylighting in building regulations such as the Brazilian Standards (NBR ISO 8995-1 and NBR 15575-1), to provide guidelines for lighting in residential buildings and workplaces [7,8]. Despite the fact that there is still no consensus on a metric that should replace the daylight factor, it is commonly agreed in the literature that Climate-Based Daylight Modelling (CBDM) [4,9], which uses real sun and sky conditions from standard weather files to quantify daylight and visual performance, could be the most suitable approach to assess daylight availability and distribution.

Daylight in an indoor environment is directly influenced by the building envelope and its shading devices, which are used to avoid glare and improve visual comfort, but also decrease the incidence of direct daylight in interior spaces [10,11]. Balconies are horizontal overhanging structures enclosed by walls or parapets that behave as an eave to the lower floor, reducing the incidence of direct solar radiation, while allowing the penetration of reflected and diffuse light [12]. Investigations about the effects of balconies on the luminous performance of office buildings have not been sufficiently explored yet. A systematic literature review identified that 62% of the papers on the subject investigated residential and hotel buildings. Moreover, also 62% used computer simulation tools as part of their methods, but only 12% used CBDM daylight metrics. The parameters analysed include the façade's Window-to-Wall Ratio (WWR), the glazing's visible transmittance, the balcony's configuration (width, depth, parapet material and solar orientation), the room's depth and the floor height.

Results presented by Al-Sallal et al. [13], Kim and Kim [11] and Gábrova [14] through daylight simulations showed that the presence of balconies increased daylight uniformity and decreased glare and illuminance levels in the indoor environment. Gábrova [14] stated that the use of balconies increased daylight uniformity up to 55% inside the room. Al-Sallal et al. [13] showed that a 3-meters wide balcony was able to eliminate glare inside the room. Kim and Kim [11] stated that balconies 3 and 6-meters deep decreased illuminance levels by 18% and 46%, respectively. Gábrova [14] showed that balconies 0.75, 1.0, 1.25 and 1.5-meters deep decreased illuminance levels by 20%, 25%, 30% and 35%, respectively.

Xue et al. [12] and Dahlan et al. [15,16] investigated the impact of balconies on the luminous performance of residential buildings through field measurements and questionnaires applied to the occupants. Their results complied with daylight simulation results found in the literature, confirming that balconies reduce direct daylight incidence and increase visual comfort in indoor spaces. Regarding the balcony's parapet material, Dahlan et al. [16] showed that balconies with an opaque parapet provided higher levels of visual comfort than balconies with glazing parapet. Liu and Chen [17] pointed out the WWR as an outstanding parameter in daylight performance for buildings with balconies, indicating that the smaller the WWR the shallower the balcony should be in order to avoid a negative impact on the indoor daylight availability. As to the window glazing properties, Kim and Kim [18] stated that, in order to provide the same visual comfort as a balcony does, the glazing visible transmittance should be lower than 0.54. Liu and Chen [17] pointed out the floor level as the parameter with lower impact on the luminous performance of indoor environments, when considering an isolated building with balconies.

To the best of authors' knowledge, there are no studies that investigate the effect of balconies on the luminous performance of office buildings, perhaps because balconies are seen as a space of no use in commercial environments. Yet, the use of balconies in office buildings has been growing in recent years. In the city of São Paulo, Brazil, 23% of the mixed-mode office buildings are provided with exterior shading devices, of which 92% are balconies [19]. Between 1995 and 2015 alone, the use of balconies has increased by 85%, potentially related to the increasing use of split air-conditioning units, which demand an outdoor area to allocate the condenser [20]. This can be seen as an opportunity to promote the use of balconies in office buildings as they could be justified as a space to accommodate building services as well as act as a daylight and shading control system.

Already overheated by internal gains, office buildings need to minimise incident solar radiation and annual solar exposure to reduce cooling energy consumption, particularly in the tropics [21]. Balconies can offer possibilities to increase shaded periods and, at the same time, act as a daylight distribution system due to their special configuration, which can block direct sunlight but potentially contribute to increase reflected daylight. Seeing balconies as an architectural element to reduce overheating and at the same time act as a potential daylight system distributor, this study focused on exploring what balcony configuration together with window design parameters could improve daylight performance and contribute to reduce overheating in office buildings in São Paulo. The study was undertaken in a 'typical' mixed mode office building in São Paulo and simulation results were classified using systematic analysis in combination with a decision tree algorithm.

3- Methodology

The research design used in this study was threefold: It started by defining and parameterizing a ‘typical’ mixed-mode office building for the city of São Paulo based on a dataset of surveyed buildings developed by Neves et al. [20] and Pereira and Neves [22]. Daylight simulations were then undertaken for a dataset of 6,360 combinations of parameters using specific weather data for São Paulo (latitude: 23°32'56" South, longitude: 46°38'20" West, altitude 800 m). CBDM metrics and relevant performance thresholds were specified to enable comparability and classification of daylight results. In the second stage, results were systematically analysed to identify effective combinations of parameters, with specific attention to the role of balconies, to reach the prescribed thresholds for daylight performance. In the third stage, results were mined and grouped using a decision tree algorithm to increase the number of successful combinations of design parameters to achieve daylight performance thresholds. Combining stages two and three would provide enough breath for designers to reach daylight performance targets in the early design stages, when simulation is potentially expensive and unavailable. The proposed research design was depicted in Figure 1 and further detailed in the following subsections.

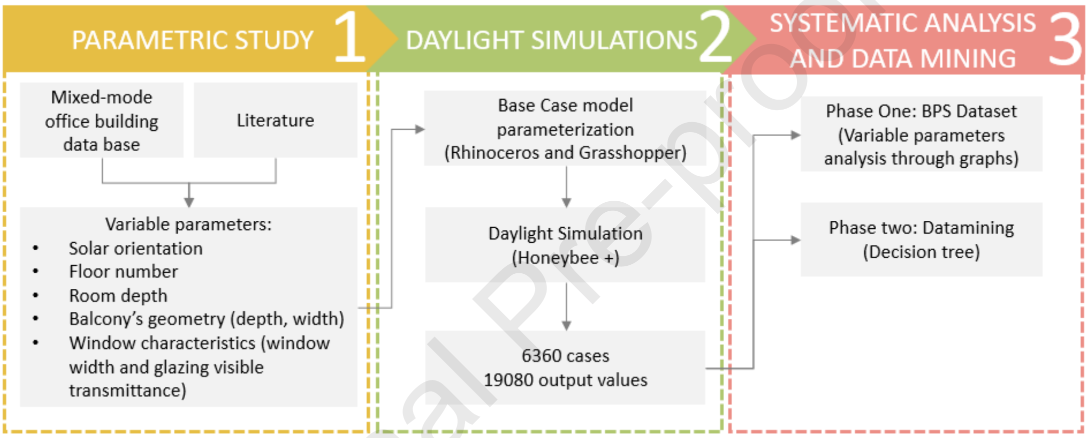


Figure 1: Research design workflow.

3.1- Parametric study

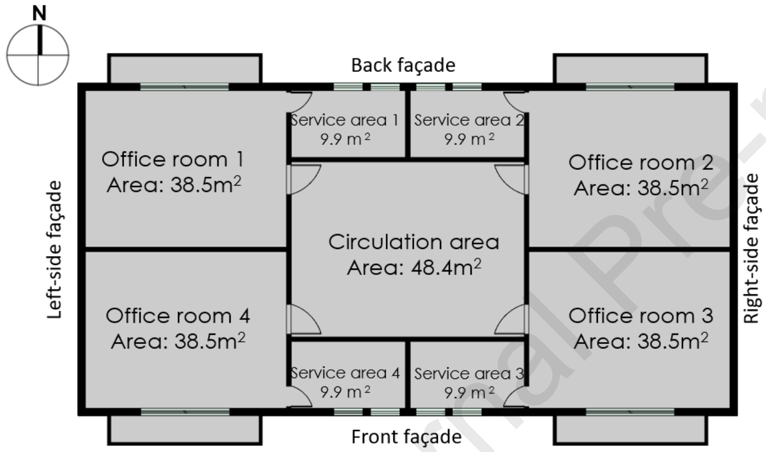
According to Neves et al. [20] and Pereira and Neves[22] , mixed-mode office buildings located in the city of São Paulo (Brazil) are mostly medium-rise buildings with multiple office units per floor (four to five units, in most cases), served by operable windows and individual air-conditioning systems, both manually operated in a concurrent mode. Each unit is normally a different tenancy and most office buildings have no building facilities manager.

A database with a sample of 153 surveyed case studies of mixed-mode office buildings in São Paulo [20,22] was used as a reference to create a representative of ‘typical’ mixed-mode office room model, which was used as a base case to develop the parametric study proposed in this research. This corresponds to 10% of offices of this type in São Paulo and was considered a representative sample to extract typical features. The selection of the sample took into consideration the following criteria: small office rooms, excluding wide open plan office buildings (which usually consists of non-operating curtain wall façade systems); individual air-conditioning systems, consisting of independent outdoor air units per office room (excluding central systems, which usually corresponds to fully air-conditioned buildings); office buildings built between 1995 and 2016.

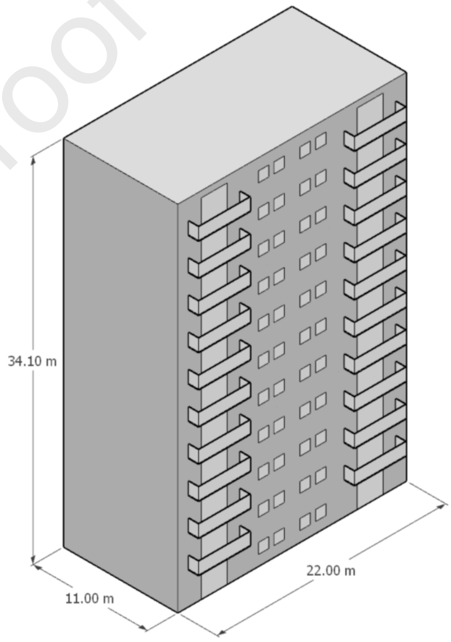
The geometry and envelope design parameters were chosen according to the highest frequency values, for categorical variables, and the mean values, for continuous variables, from the database. The indoor surfaces’ reflectance was defined according to the NBR ISO/CIE 8995-1 Brazilian standard [8] and the ground surface reflectance according to IES LM 83-12 approved method [9]. The base case characteristics are shown in Table 1 and illustrated in Figure 2.

Table 1: Base case model characteristics

Parameter	Value
Building orientation (longitudinal axis)	North - South
Number of floors	11
Office room shape	Normally rectangular
Office room area	38.5 m^2 (5.5 m x 7 m)
Office room height (floor-to-ceiling)	2.75 m
Wall thickness	0.25 m
External wall and balcony's external surface reflectance	0.30 - dark colour
Internal wall and balcony's internal surface reflectance	0.5
Room's and balcony's floor reflectance	0.2
Ceiling reflectance	0.7
Ground surface reflectance (albedo)	0.1



a) Floor plan



b) Building axonometric

Figure 2: Base case model (a) floor plan (b) building elevation
Source: the authors.

The literature suggests that balconies, window features and their configurations impact the luminous performance of indoor environments [13,17]. Specifically, balcony's geometry (depth, width and location), window characteristics (window width and glazing visible transmittance), building's solar orientation and floor height were also considered as important variables in daylight performance of buildings with balconies. The abovementioned parameters were therefore selected as the main parameters to be used in a sensitivity analysis in the base case building. Table 2 illustrates the range of variation used for these parameters based on the database from Pereira and Neves [22].

Table 2: Base case variable parameters

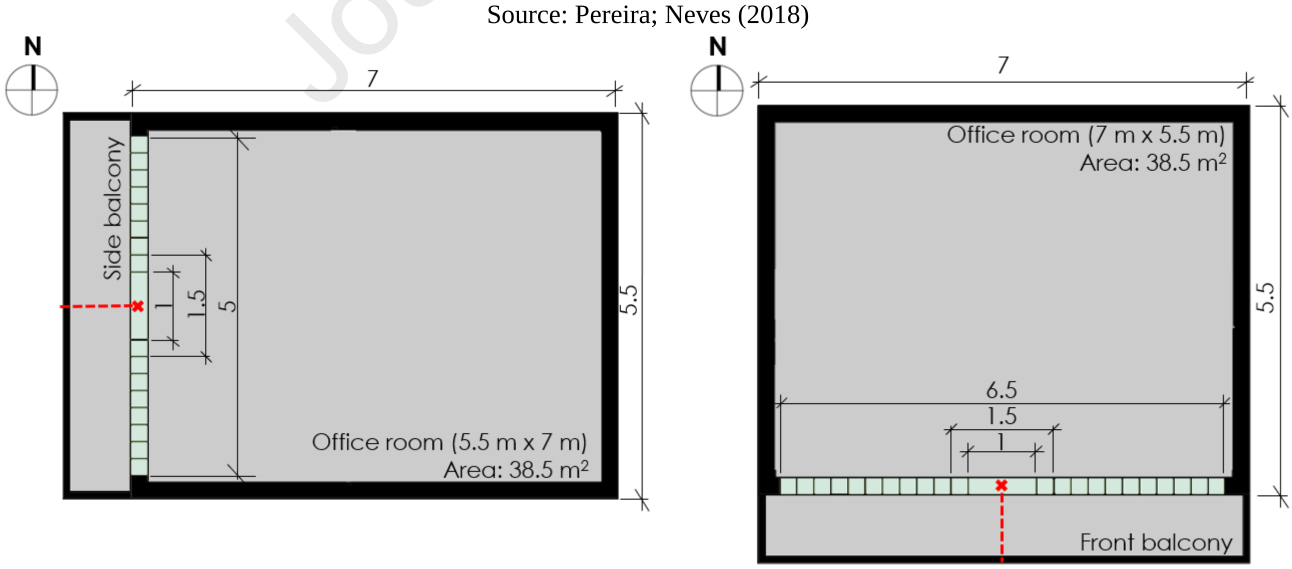
Parameter	Value
Balcony depth	0.0 m (no balcony) / 0.5 m / 1.0 m / 1.5 m / 2.0 m
Room's width and depth	Side façade (5.5 m width and 7 m depth) / front façade (7 m width and 5.5 m depth)
Balcony width	Ratio of balcony width to window width (0.5, 1.0, 2.0)

Glazing visible transmittance	0.88 (clear glass) / 0.48 (laminated glass)
Window width	1.0 m to 6.5 m (increments of 0.5 m) for the front façade 1.0 m to 5.0 m (increments of 0.5 m) for the side façade
Office room solar orientation	North / South / West / East
Floor number	Upper floor (10th floor – 30.1 m height) / middle floor (6th floor – 18.6 m height) / lower floor (1st floor – 3.1 m height)

Balcony and room's geometry were selected based on the most common dimensions found in the database of Pereira and Neves [22]. According to Pereira and Neves [22] , the 0.5 m depth balconies are designed to house the outdoor air conditioning units, while balconies used as a liveable area, connecting indoor and outdoor spaces, are usually 1 m to 2 m deep (Figure 3). The room configuration shows that the office spaces from the selected sample tend to be small and normally used by 2 to 3 people. Parametric variations were applied to the four basic orientations to illustrate their effect in daylight conditions for a lower, middle and top floor. The window width, one of the most impacting parameters on daylight performance, was varied from 1 m up to 5 m (representing a fully glazed façade). Thus, increments of 0.5 m were used to iterate between the minimum and maximum scenarios. Windows and balconies were always considered as central to the room, increasing its width symmetrically for both sides (Figure 4).

(a) Office building with balconies
(b) Office room with balcony
(c) Balcony used to house the condenser unit

Figure 3: Examples of office buildings with balconies
Source: Pereira; Neves (2018)



(a) Office room floor plan: side balcony
(b) Office room floor plan: front balcony

(c) Office room section
Figure 4: Office room dimensions
Source: the authors

The ratio of balcony width to window is proposed to evaluate the impact of the balcony's width and the corresponding window width, as illustrated in Table 3. This variable represents a façade compositional rule based on a central axis symmetry, enabling the investigation of apertures in connection with their corresponding daylight systems. This parameter allowed to simplify the number of cases when varying balcony's width and facilitated results comparison. Even though ratios 2 and 1 are considered to be more usual in the building façades, the 0.5 ratio was also selected to have its performance evaluated as a possible design scenario, despite not being commonly found in practice.

Table 3: Ratio of balcony width to window width *(colours should be used in print)*

Window width (m)	**Ratio of balcony width to window width**		
	2	1	0.5
1			
1.5			
2			
2.5			
3			
3.5			
4			
4.5			
5			
5.5			
6			
6.5			

3.2- Daylight simulations

The plug-in Grasshopper [23] was used to model the base case geometry, which consists of the entire building, as shown in Figure 2. Daylight simulations were run in Honeybee+ [24], a plug-in for Grasshopper that connects the Rhinoceros' shape parameterization with Radiance and Daysim for daylight simulation. To perform the simulations, the 2-phase Radiance-based method was used. The Radiance input parameters were chosen through Honeybee+ based on the simulation complexity, which was set as "medium complexity" due to the number of simulated cases (Table 4). The grid configuration and sky density were set according to the IES LM 83-12 approved method [9]. Simulations were run without any urban surrounding to assess daylight scenarios with the worst condition for direct incident solar radiation.

Table 4: Radiance input parameters

Parameter	**value**
Ambient bounces (ab)	5
Ambient divisions (ad)	15,000
Ambient resolution (ar)	64
Ambient super-samples (as)	2,048
Ambient accuracy	0.2
Work plane	Grid size: 0.5 m Height: 0.8 m Offset from the walls: 0.5 m
Sky density	Reinhart sky

Three climate-based metrics were used to assess the daylight performance of the office room and its design variants: Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (sDA) and Annual Solar Exposure (ASE). The UDI is defined as the annual occurrence of illuminances across the work plane that are within a range considered "useful" by occupants, when artificial lighting is not necessary. For office buildings, the UDI useful range was identified by Mardaljevic et al. [4] as being 300-3000 lux, with the upper value considered a good proxy for excessive illuminance. The sDA is a measure of daylight illuminance sufficiency for a given area, reporting a percentage of floor area that exceeds a 300-lux illuminance level for more than 50% of annual working hours (8 am to 6 pm). The sDA was ranked in the following daylight sufficiency levels, according to IES LM-83 [9] : preferred daylight sufficiency (must meet or exceed 75% of the analysis area), nominally accepted daylight sufficiency (must meet or exceed 55% of the analysis area), not accepted (sDA does not meet the minimum required value of 55% of the analysis area). The ASE describes the potential for visual discomfort and determines unsatisfactory visual comfort when its result is over 10% for daylit spaces [9]. This metric can also be used as a proxy for overheating, as it means the percentage of the year each point in space receives direct solar radiation.

The ASE and sDA metrics were reported together to provide a meaningful first-level understanding on how a space is expected to perform, since sDA sets a minimum value for daylight sufficiency but not any indication of an excess thereof whereas ASE sets a maximum value to prevent visual discomfort.

Daylight simulations were performed considering the occupancy period from 8 am to 6 pm, as suggested by IES LM 83[9], with no user interference, i.e. considering the worst-case scenario with no blinds. This setting is the same as the one from the Brazilian energy efficiency regulation [25] which also considers an occupancy period 10 h per day, without a lunchtime break. The weather file used to perform the simulations was a Typical Meteorological Year (TMY), based on weather data from the years 2000-2010, available in an EnergyPlus weather file (epw) format for the city of São Paulo, Brazil [26]. A cross combination of all the seven parametric variations described in Table 2 were combined into 6,360 simulations, meaning all design solutions were explored. Thus, simulation outputs for the three aforementioned daylight metrics comprised a total of 19,080 results.

3.3- Post-processing and data mining

Simulation post-processing was divided into two large steps (Figure 5). Initially a systematic analysis in the extensive dataset presented in the Appendix A was undertaken, starting with a sensitivity analysis of each parameter in the three CBDM (Section 4.1), followed by unfolding interesting pairwise combinations for design decision-making (Section 4.2). Further explorations specifically on identifying the role of balconies in daylight performance were undertaken via a combination of results from the sensitivity analysis, the pairwise comparisons and the information contained in the Appendix A, from which general rules were extracted and discussed (Section 4.3).

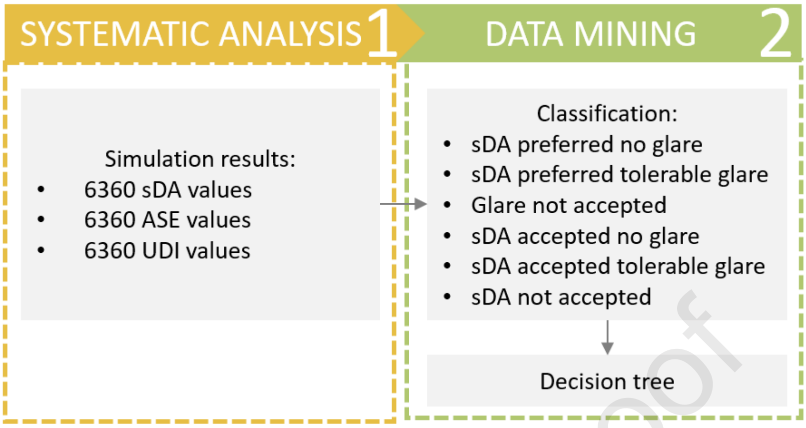


Figure 5: Results analysis diagram

Simulation results were grouped into six classes, for sDA and ASE only, using a data mining process so full patterns of successful combinations of design parameters could be quickly retrieved to aid design decision-making (section 4.4). Simulation results contained one nominal (solar orientation) and six numeric attributes (floor level, room depth, glazing visible transmittance, ratio of balcony width to window width, window width and balcony depth). Classes for nominal and numeric variables were described in Table 5, with a respective traffic light system indicating results practical suitability. The UDI metric was used specifically to further qualify cases in which the sDA was convergent above the threshold.

Table 5: Data classification

sDA		**ASE**		**Class**
numeric	nominal	numeric	nominal	
Higher or equal to 75%	Preferred	0%	No glare	sDA preferred no glare (green)
		Equal or lower than 10%	Tolerable glare	sDA preferred tolerable glare (yellow)
		Higher to 10%	Glare	Glare not accepted (red)
Lower than 75% and higher or equal to 55%	Accepted	0%	No glare	sDA accepted no glare (yellow)
		Equal or lower than 10%	Tolerable glare	sDA accepted tolerable glare (orange)
		Higher to 10%	Glare	Glare not accepted (red)
Lower than 55%	Not accepted	0%	No glare	sDA not accepted (red)
		Equal or lower than 10%	Tolerable glare	
		Higher to 10%	Glare	

Decision tree was considered the best data mining option to illustrate successful routes through combinations of parameters which would lead to sDA and ASE respectively above and below thresholds established in section 3.2 and further detailed in Table 5. Decision trees popularly known as 'recursive divide and conquer' data mining methods, select the best attribute among a set of alternatives to produce routes with maximum information gain. They start by statistically selecting the attribute for a root node, to then creating branches for each possible value and splitting instances into sub-sets, recursively repeating this process until each instance belongs to a class. The widely applied J48 algorithm [27] was used as a classifier for the decision tree and could hierarchically organise 6,360 instances creating clear paths to achieve the desirable classes. The algorithm is based on a top-down strategy and uses information gain to measure the amount of information provided by each attribute as a basis to determine which one best splits the dataset at each step [27] The data mining process was undertaken in WEKA [27], and the decision tree which provided simultaneously a satisfactory level of accuracy and complexity, achieving an 85% correctly classified instances was discussed in section 4.4, with its configuration synthesised in Figure 6. Successful end nodes of the decision tree are highlighted using the traffic light system proposed in Table 5, so designers can visualize the best routes to achieve performance.

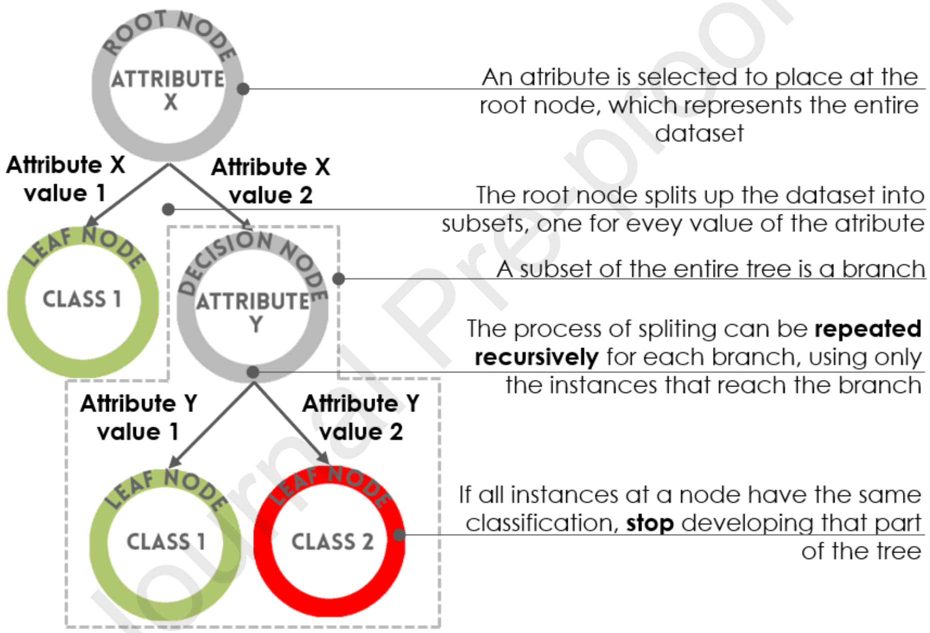


Figure 6: Decision tree configuration *(colours should be used in print)*

Source: the authors, based on information provided by Witten et al. [27]

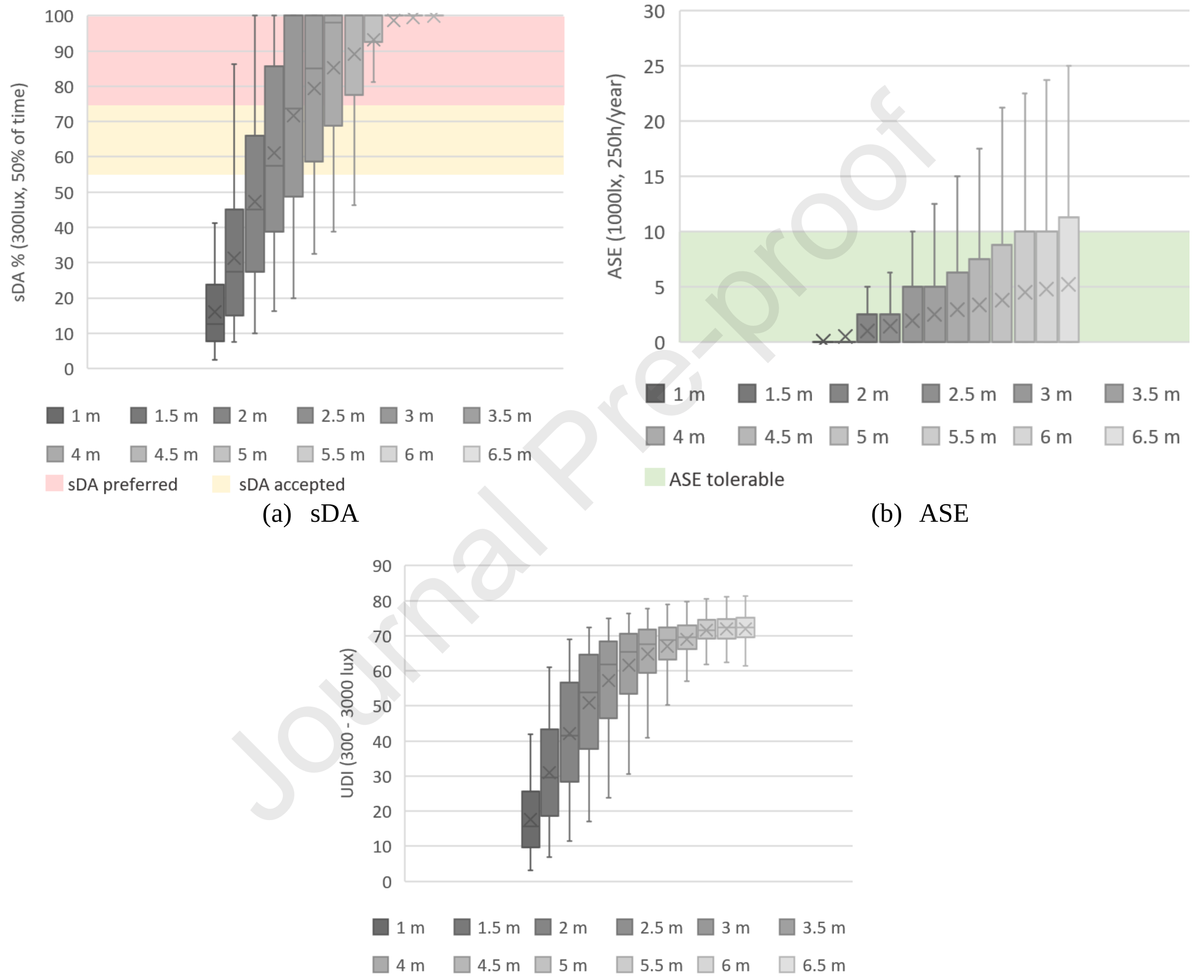
4- Results and discussion *(colours should be used in print for any figures in this section)*

4.1 Sensitivity analysis

Box plots were used to evaluate the sensitivity of each design parameter in sDA and ASE considering the thresholds illustrated in Table 5. UDI graphs were plotted when necessary to verify sDA results, especially when compressed around the upper threshold (sDA = 100%). Box plots for each parametric variation were presented with different shades of grey, with the cross illustrating the mean and the line within the box illustrating the median. The discussion attempted to extract relevant information for design decision-making, i.e. to gauge the impact of specific design parameters in daylight performance as well as to identify relevant dimensions to achieve specific performance thresholds.

4.1.1 - Window width

Window width seems to be the determinant parameter on office rooms' daylight performance. These findings echo the results shown by Al-Sallal et al.[13] and Liu and Chen [17]. All cases with windows width between 5 m and 6.5 m reached the sDA preferred class together with more than 50% of the cases with windows widths between 3.5 m and 4.5 m (Figure 7a). Cases with narrow windows (1 m and 1.5 m width) presented the best potential to prevent glare (Figure 7b) by keeping ASE results close to null but all windows up to 3 m width still complied with ASE below 10% as well as 75% of windows with up to 6 m width. UDI results confirmed that the room's daylight performance was directly proportional to the window width (Figure 7c) and indicated that windows with widths above 5.5 m provided nearly the same performance results (see three light grey box plots from Figure 7c). This was partially confirmed by the ASE figures which showed almost 3/4 of results falling within the 10% threshold, meaning windows above 6.5 m width would require more careful attention with regards to shading design.



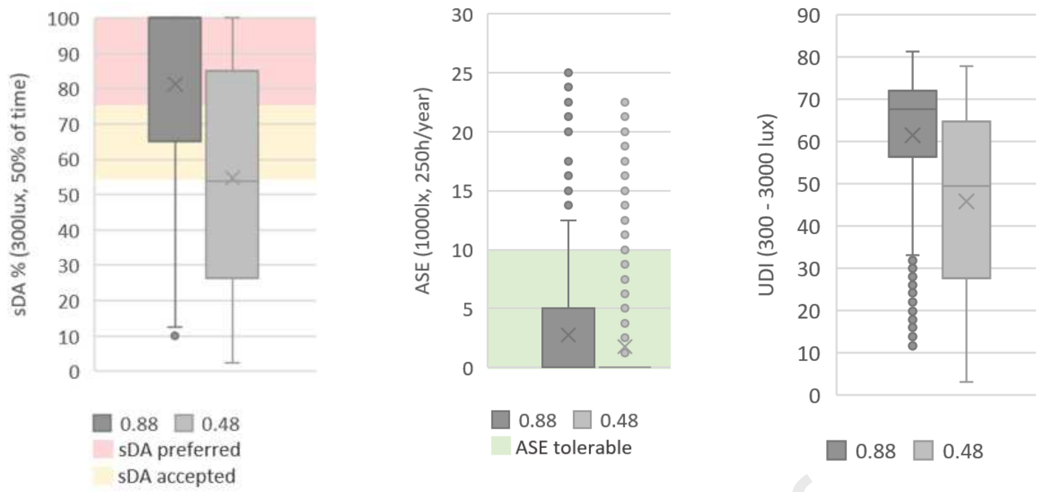
(a) sDA (b) ASE

(c) UDI

Figure 7: Dataset results for the window width

4.1.2 Glazing visible transmittance

While the majority of the cases (62%) with clear glass (Glazing visible transmittance =0.88) achieved the sDA preferred class, this class was reached by only 24% of the cases with laminated glass (glazing visible transmittance = 0.48) (Figure 8a). However, the glazing visible transmittance showed less impact on ASE than on sDA results. While 80% of the cases with laminated glass were classified as ASE=0%, 68% of the cases with clear glass achieved this threshold (Figure 8b), with more than 3/4 of cases with this type of glass falling within the ASE 10% threshold. UDI results confirmed sDA ones but showed that results for clear glass have an even higher impact on performance when compared to results for laminated glass (Figure 8c).

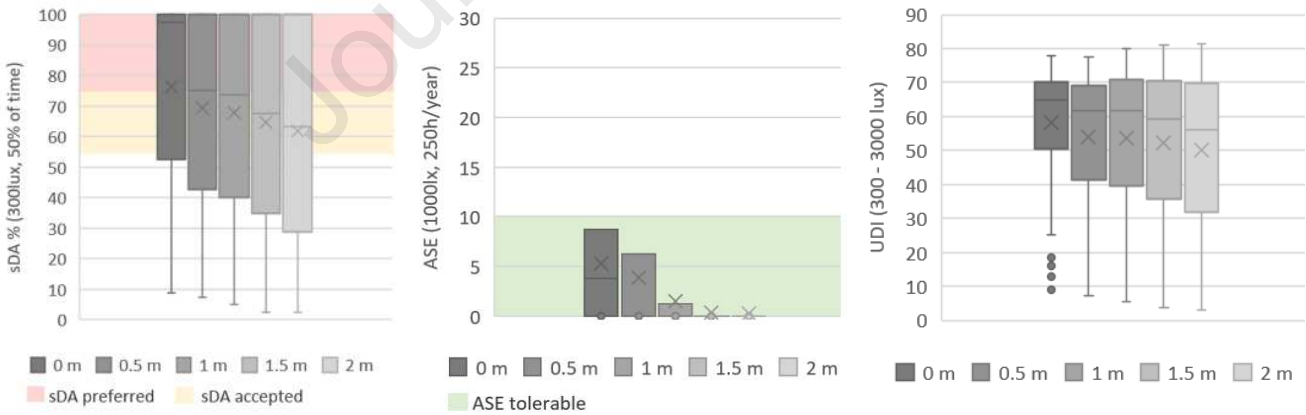


(a) sDA (b) ASE (c) UDI

Figure 8: Dataset results for the glazing visible transmittance

4.1.3 Balcony depth

Figure 9 illustrates the decrease in daylight illuminance levels resulting from the increase in balcony depth, as confirmed by Liu and Chen [17], Gábrova [14] and Kim and Kim [18]. Figure 9a, however, illustrated an interesting cut-off point for design decision-making as balcony depths below 1.0 m had, in the majority of cases, sDA values falling within the preferred threshold whereas balcony depths above 1.0 m would tend to have sDA values falling, on average, within the accepted threshold. As expected from Al-Sallal et al.[13], Kim and Kim[11], Gábrova[14], Xue et al. [12] and Dahlan et al.[15,16], the addition of balconies was determinant in reducing the ASE (Figure 9b). However, this study identified that balconies deeper than 1.5 m will achieve null ASE and therefore are optimum to avoid glare and overheating due to direct solar radiation. UDI results (Figure 9c) confirmed sDA ones, also showing that the upper UDI limit is not affected by the balcony depth, since the 3rd quartile is roughly the same for all cases.

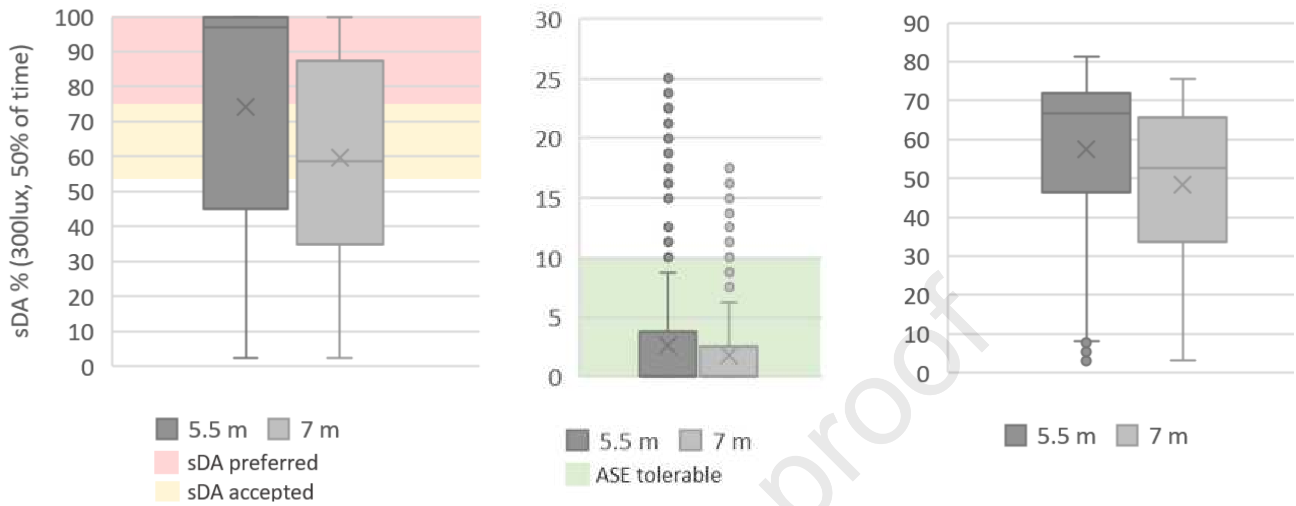


(a) sDA (b) ASE (c) UDI

Figure 9: Dataset results for the balcony depth

4.1.4 Room's width and depth

Room width and depth were investigated simultaneously by changing balcony and window positions from the front and back façades to side façades, as displayed in Figure 4, reflecting the most common floor plan proportions for mixed-mode office spaces in São Paulo [22]. As confirmed by Gábrova [14], results clearly showed that the shallower the room, the better the daylight performance. More than 50% of the front balcony cases (room depth 5.5 m) were classified as sDA preferred, while only 29% of the side balcony cases (room depth 7 m) achieved this threshold. UDI levels confirmed sDA values for shallower rooms showing however, that room depth does not really affect the shape of the distribution curve as average cases will have a UDI of 55% for shallower rooms and 45% for deeper rooms (Figure 10c). ASE results were however not significantly different as the vast majority of cases for both configurations fell within the 10% threshold (Figure 10b), none of them with means in the null category.

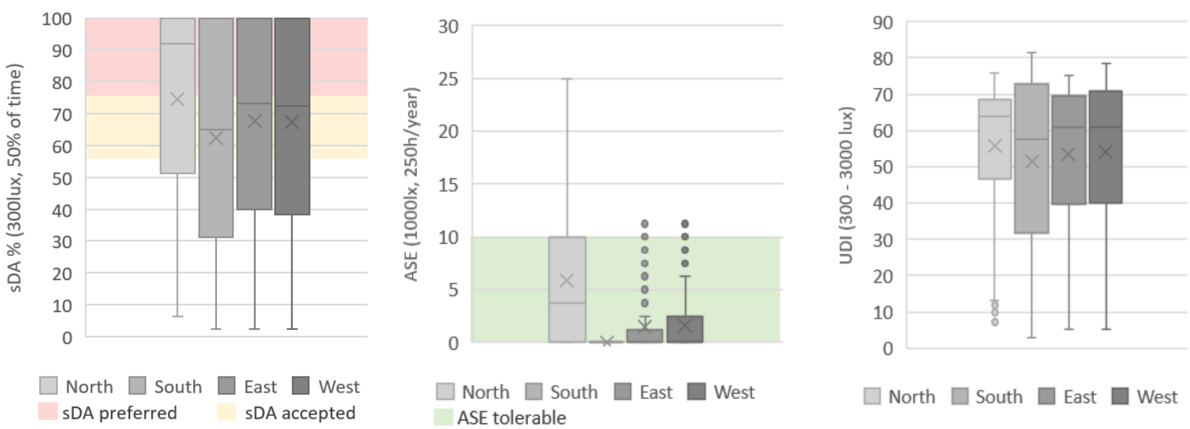


(a) sDA (b) ASE (c) UDI

Figure 10: Dataset results for the room depth

4.1.5 Solar orientation

In the Southern tropical climate, the North and the South façades receive, respectively, the highest and the lowest amount of direct and diffuse solar radiation during the year. Thus, the office room facing North showed the highest daylight levels (Figure 11a) but also the highest probability of glare (Figure 11b). More than 50% of the North-oriented rooms were classified as having preferred sDA level and tolerable glare from ASE. As to the UDI level, the North-oriented office rooms presented higher results for the 1st quartile, the median and the mean values, if compared to the other solar orientations, showing the potential for the North orientation to achieve the best daylight performance (Figure 11c). In opposition, the South-oriented rooms showed the best results for ASE and the lowest mean and median values for sDA and UDI, with mean and median values for the former barely achieving the acceptable threshold. The West and East façades exposed similar daylight performance to each other. The mean and median values for both solar orientations were classified as sDA acceptable and ASE tolerable, although the West façade resulted in higher levels of ASE, possibly due to the fact that the number of occupied hours in the afternoons is higher than in the mornings.

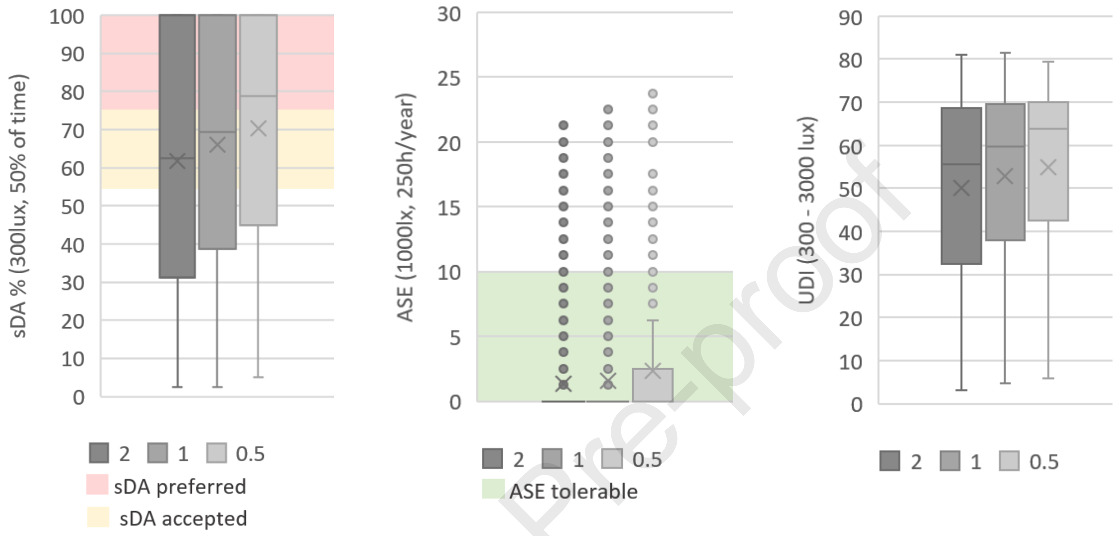


(a) sDA (b) ASE (c) UDI

Figure 11: Dataset results for the solar orientation

4.1.6 Ratio of balcony width to window width

The use of balconies wider than the windows (ratio of balcony width to window width = 2) decreased the daylight performance (Figure 12a) but also prevented glare (Figure 12b), echoing results found by [11,13,14]Al-Sallal et al. [13]. The ratio of balcony width to window width of 1 and 2 showed similar performance for ASE, with most part of the cases classified as null, reinforcing the importance of having balconies with full window width. UDI results again confirmed sDA ones in terms of how ratio of balcony width to window width affect not only the average figures but also their distribution (Figure 12c).



(a) sDA (b) ASE (c) UDI

Figure 12: Dataset results for the ratio of balcony width to window width

4.1.7 Floor level

Results from daylight simulations indicated that the floor level was the parameter with least impact on the room's daylight performance (Appendix A), findings echoed by Liu and Chen[17], likely to be related to the fact that the building was simulated without any urban surroundings. Higher floors indicated a small increase in sDA and UDI in relation to lower floors possibly due to the albedo setting. The presentation of box plots for this parameter was therefore deemed unnecessary.

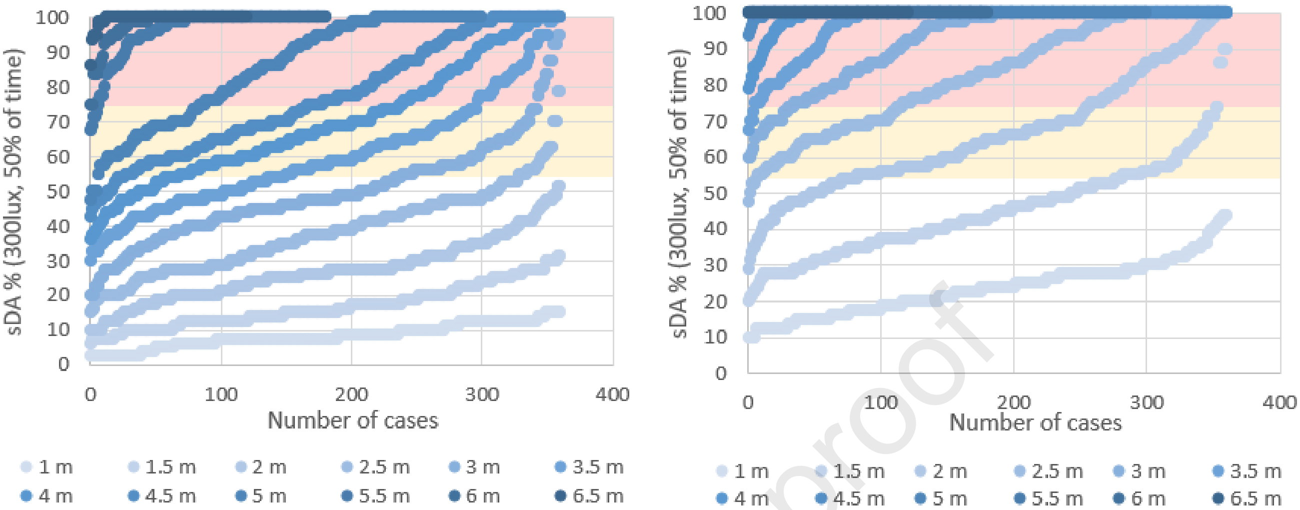
Nevertheless, in the case of densely built urban neighbourhoods, results would differ between higher, intermediary and lower floors. However, the development of suitable urban environments to undertake these experiments is still open to discussion as cities, especially in Brazil, have a very heterogeneous urban context meaning multiple types of geometric combinations for building height and lower floor configurations can be expected, making it difficult to extract typical cases to standardise the simulation of surrounding buildings.

4.2 Unfolding interesting pairwise combinations

To further extract relevant information for design decision-making, parameters were also analysed in pairs. Scatterplots were used to depict the most relevant pairwise comparisons, i.e. the ones from which it was possible to extract cut-off points for both parameters in relation to different performance thresholds. This section explored pairwise comparisons for the sDA metric only as ASE and UDI did not reveal any information different than the one received from the box plots. The analysis is focused on daylight illuminance sufficiency and does not include excessive illuminance (glare probability) or overheating probability issues.

4.2.1 Window width and glazing visible transmittance

When plotting window width against glazing visible transmittance it is possible to see that all windows wider than 4 m with clear glass achieved the sDA preferred threshold, whereas only windows wider than 6 m with laminated glass achieved this same threshold (Figure 13).

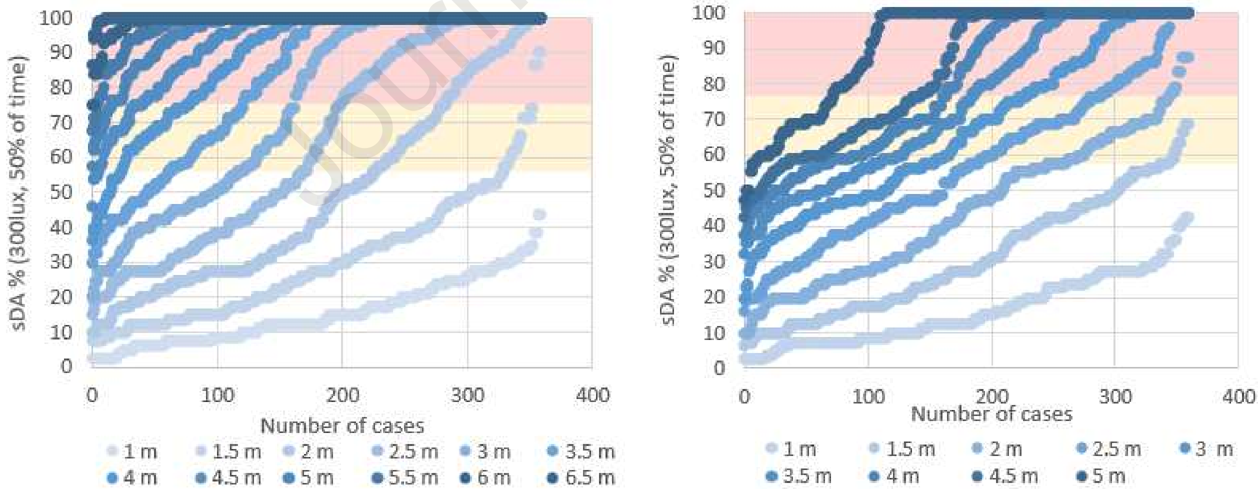


(a) Glazing Tvis 0.48 (b) Glazing Tvis 0.88

Figure 13: Scatter plots for sDA per window width

4.2.2 Window width and room depth

All the 5.5 m-deep rooms achieved preferred sDA thresholds when having windows wider than 5.5 m, whereas the 7 m-deep rooms did not achieve the preferred sDA threshold 100% of the time, even with a fully glazed facade (Figure 14).

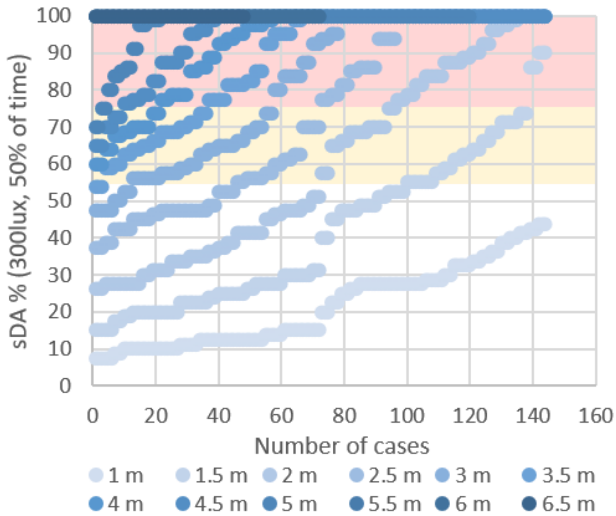


(a) Room depth = 5.5 m (b) Room depth= 7 m

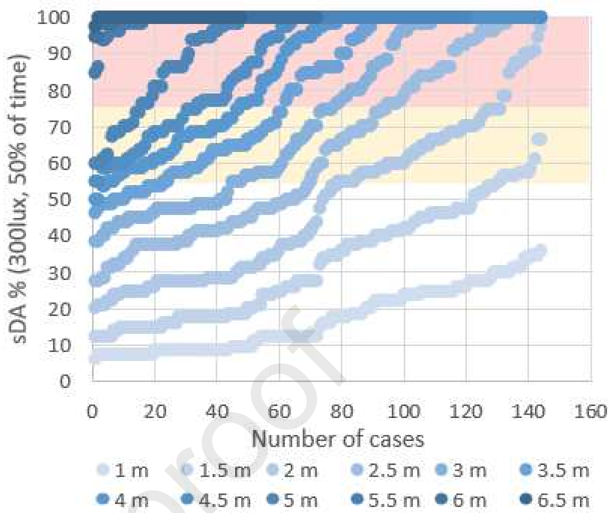
Figure 14: Scatter plots for sDA per window width

4.2.3 Window width and balcony depth

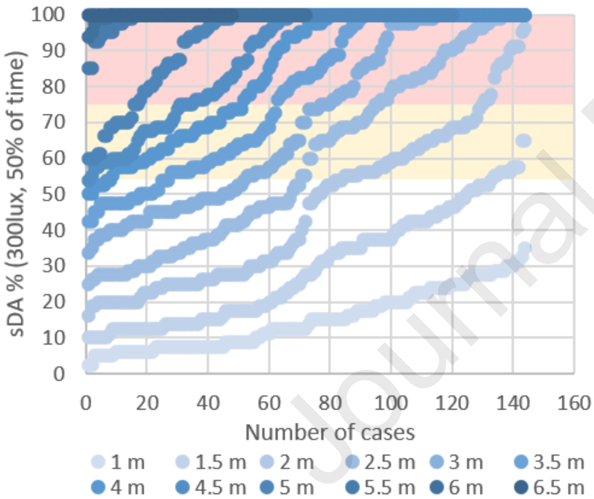
This pairwise combination showed that the deeper the balcony, the narrower the difference between sDA values falling within the preferred and acceptable thresholds. Figure 15 illustrated that when no balconies are present, the preferred threshold was achieved for all the scenarios with a 5 m width window whereas only a 3.5 m width window was necessary to achieve the acceptable one. Adding a balcony of 0.5 m and 1 m depth did not affect the window width needed to achieve the preferred threshold but did push the minimum width to achieve the accepted threshold to 4 m and 4.5 m, respectively. For balconies deeper than 1 m, for every increment of 0.5 m in depth, the distance between the preferred and acceptable thresholds seemed to remain constant.



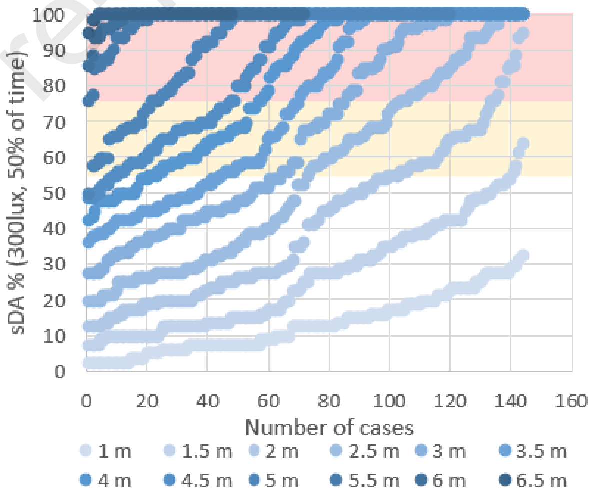
(a) Balcony depth = 0 m (without balconies)



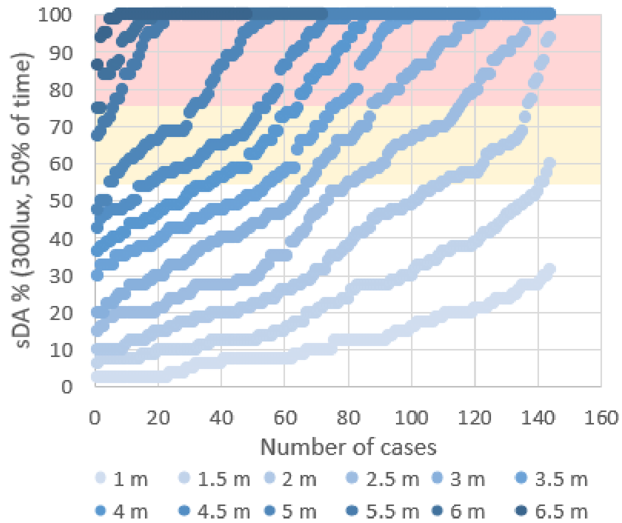
(a) Balcony depth = 0.5 m



(c) Balcony depth = 1 m



(d) Balcony depth = 1.5 m



(e) Balcony depth = 2 m

Figure 15: Scatter plots for sDA per window width

4.2.4 Window width and solar orientation

This pairwise combination, illustrated in Figure 16, showed that for the North orientation, the preferred sDA threshold was achieved for all scenarios with a 5 m window width whereas a 4 m window width was enough for all scenarios to achieve at least the acceptable sDA threshold. For the South façade, the preferred and acceptable thresholds were achieved with window widths of respectively 6 m and 5 m for all scenarios. The East and West orientations exhibited window width differences 0.5 m apart for all scenarios to achieve the preferred and acceptable thresholds.

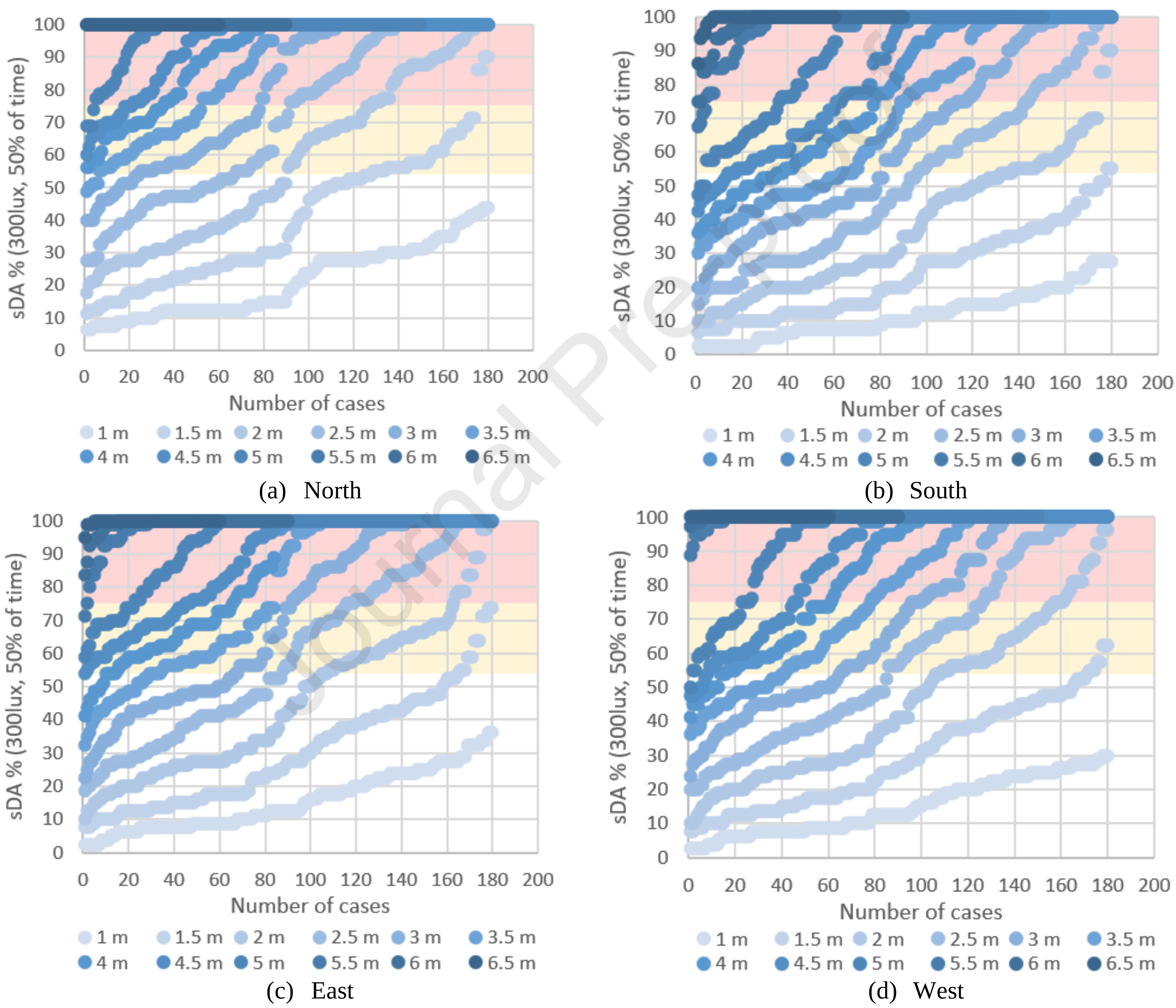


Figure 16: Scatter plots for sDA per window width

4.3 Extracting general rules

Results from section 4.1 showed the sensitivity of CBDM to each design parameter explored in this study when analysed in isolation, whereas results from section 4.2 attempted to unfold interesting pairwise combinations of parameters to examine how they, together, influenced sDA in particular. Whereas section 4.1 indicated that window width was potentially the most important parameter to achieve the targets, this was confirmed by the pairwise comparisons which showed that interesting thresholds could be identified when combining this parameter with the others. This section examined the summaries from section 4.1 and 4.2 in conjunction with Appendix A and attempted to provide general rules useful to designing medium rise mixed-mode office buildings in São Paulo, with or without balconies.

Table 6 shows general rules for window widths to achieve the sDA preferred threshold, for any balcony depth (from 0 m to 2 m) and ratio of balcony width to window width (0.5, 1 and 2) considered in this study. Window widths were established as a function of solar orientation, room depth and glass visible transmittance. The North façade contained the path to success with minimum dimensions, whereas the South orientation presented the worst-case scenario, needing the largest window widths for balconies to be used without affecting daylight performance. East and West orientations with shallow rooms and clear glass needed both 3 m window widths to achieve the preferred threshold but behaved differently when the room depth increased, and the glass visible transmittance decreased. No configuration achieved the preferred threshold when the room depth was 7 m and laminated glass was used.

Table 6: Rules to achieve preferred sDA for any balcony configuration

Solar orientation	Room depth (m)	Glass Tvis	Window width to achieve sDA preferred threshold (m)
North	5.5	0.88	>= 2.5
		0.48	>= 4.5
	7.0	0.88	>= 3.0
		0.48	-
South	5.5	0.88	>= 3.5
		0.48	>= 6.0
	7.0	0.88	>= 4.0
		0.48	-
East	5.5	0.88	>= 3.0
		0.48	>= 6.0
	7.0	0.88	>= 3.5
		0.48	-
West	5.5	0.88	>= 3.0
		0.48	>= 5.0
	7.0	0.88	>= 4.0
		0.48	-

Table 7 suggests the window width above which using deeper balconies improved UDI figures, i.e. when balconies were considered effective daylight diffusers. Deeper balconies could be particularly difficult to be used in the South façade and would improve performance only when used in shallow rooms with clear glass. It is important to notice that deeper balconies would never improve daylight performance of any configuration using laminated glass (Tvis = 0.48), therefore these values were not added to Table 7.

Table 7: Rules to achieve the same UDI for any balcony configuration and to improve UDI using deeper balconies.

Solar Orientation	Room depth (m)	Glass Tvis	Window width above which UDIs improve with deeper balconies (m)
North	5.5	0.88	>= 3.5
	7.0		>= 4.0
South	5.5		>= 5.0
	7.0		-
East	5.5		>= 4.5
	7.0		>= 4.5
West	5.5		>= 4.0

7.0	5.0

4.4 Data mining: Relevant combinations of design parameters to improve daylight performance.

Sections 4.1 to 4.3 showed limitations in further detailing causal relationships and extracting more specific rules when undertaking a systematic analysis. Therefore, this section focused on expanding this analysis to improve the search for successful routes towards sDA and ASE respectively above and below thresholds, through the use of data mining. As previously detailed in the methodology, Figure 17 depicted successful end nodes for a decision tree, produced by the J48 algorithm, using a traffic light system (discussed previously in Table 5), so designers could visualize the best routes to achieve any desired performance.

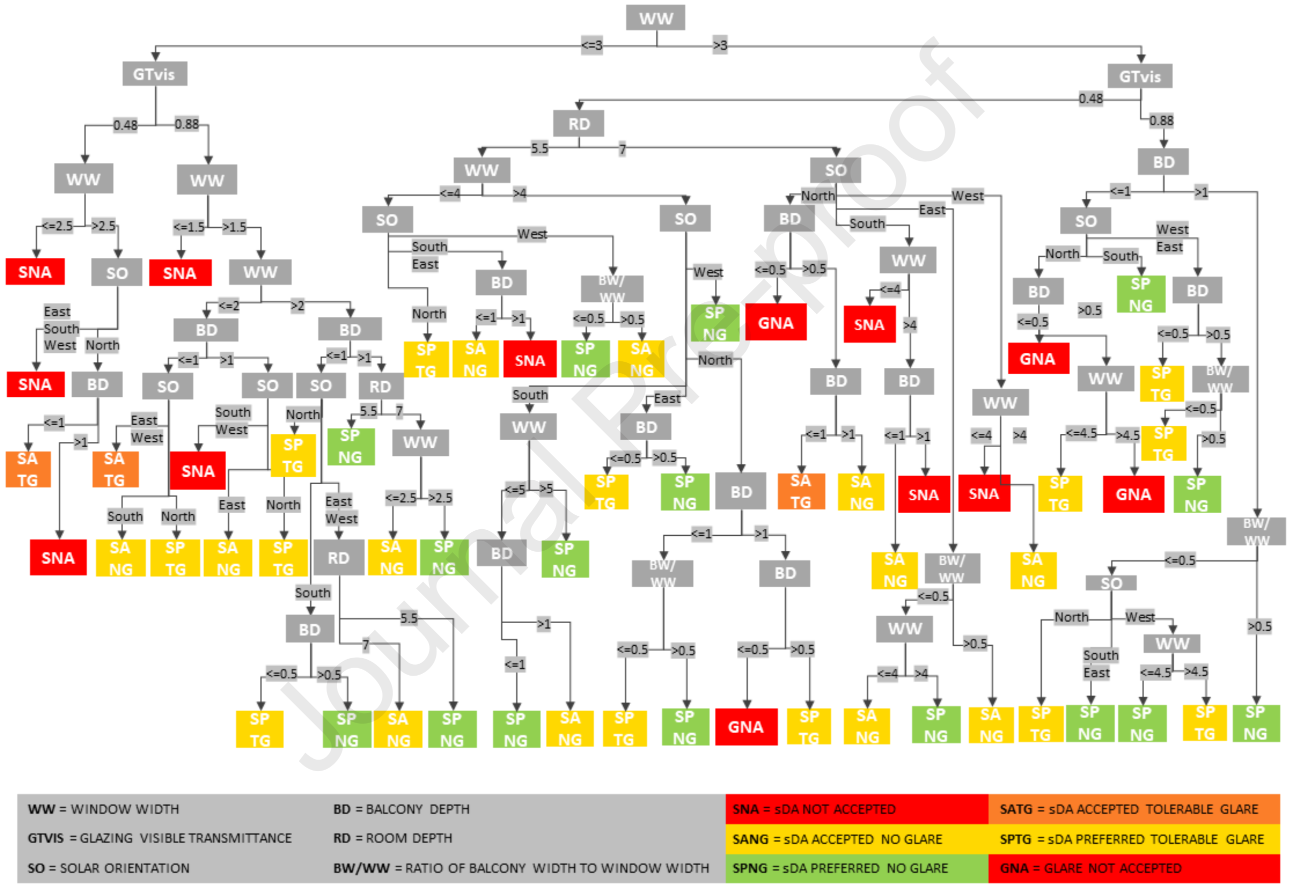


Figure 17: Decision tree

The decision tree from Figure 17 was achieved after multiple experiments in WEKA. Different decision tree settings were investigated altering the number of objects, to control complexity. A minimum number of objects of 3, yielded a confidence factor as high as 97%. However, these settings resulted in highly complex trees, with 298 end nodes, difficult to parse through and complex to be analysed. The tree displayed in Figure 17 provided simultaneously a satisfactory level of correctly classified instances (85%) and complexity and was achieved with the following settings: pruned, number of folds set to 3 and minimum number of objects set to 30. Decision tree paths led to 57 end nodes, from which 28% of them were highly successful (sDA preferred no glare), whereas 23% of them led to unacceptable results (both glare not accepted and sDA unacceptable) and should therefore be avoided. Thus, 77% of nodes were within the acceptable and/or tolerable thresholds and therefore yielded valid decision-making paths to be pursued.

Results depicted by the decision tree and summarised in Table 8, show general rules for which combination of parameters are likely to yield preferred sDA with no glare as well as which combinations of parameters should be avoided as they lead to either sDA or glare at not acceptable levels. Design parameters which do not belong to a specific rule marked as '-'. This table contains 29 rules from which 12 display combinations which should be avoided with the remaining ones listed deemed as highly successful. However, it is important to notice that window widths smaller than 3 m are not allowed by the São Paulo Building Regulation [28], despite showing acceptable results. This means, in principle, non-listed combinations should lead to the achievement of acceptable targets, bearing in mind the classification correctness of 85%.

Table 8: Rules extracted form the decision tree *(colours should be used in print for this table)*

Class	Window width (m)	Glazing Tvis	Solar orientation	Balcony Depth (m)	Room depth (m)	Ratio of balcony width to window width
sDa preferred no glare	> 2 to <= 3	0.88	East or West	<=1.0	5.5	-
	>2 to <= 3	0.88	South	=1.0	-	-
	>2 to <=3	0.88	-	>1.0	5.5	-
	= 3	0.88	-	>1.0	7.0	-
	> 3	0.88	South	<=1.0	-	-
	> 3	0.88	West and East	=1.0	-	>0.5
	> 3	0.88	-	>1.0	-	>0.5
	> 3	0.88	South or East	>1.0	-	-
	>3 to <= 4.5	0.88	West	>1.0	-	-
	> 4	0.48	East	-	7.0	<=0.5
	> 3 to <=4	0.48	West	-	5.5	<=0.5
	>4 to <=5	0.48	South	<=1.0	5.5	-
	>4	0.48	East	>0.5	5.5	-
	>4	0.48	West	-	5.5	-
	>4	0.48	North	<=1.0	5.5	>0.5
	>5	0.48	South	-	5.5	-
	>5	0.48	South	-	5.5	-
sDA not accepted	<=1.5	0.88	-	-	-	-
	<=2.5	0.48	-	-	-	-
	=3	0.48	South, East or West	-	-	-
	<=3	0.48	North	> 1.0	-	-
	<=2	0.88	South or West	>1.0	-	-
	>3 <=4	0.48	South or West	>1.0	7.0	-
	>4	0.48	South	> 1.0	7.0	-
	>3 <=4	0.48	South or East	>1.0	5.5	-
Glare not accepted	>3	0.88	North	<=0.5	-	-
	>4.5	0.88	North	<=1.0	-	-
	>3	0.48	North	<=0.5	7.0	-
	>4	0.48	North	<=0.5	5.5	-

Table 8 can be understood as a summary of more specific rules of thumbs for parametric combinations to be used when pursuing preferred sDA as well as those to be avoided as they yield not acceptable sDA and glare. In addition, it also enables one to derive the following general design recommendations for office buildings with balconies in Sao Paulo:

- Avoid windows in the North façade which contain balconies shallower or equal to 1 m and window widths higher or equal to 3.0 m as they tend to result in not acceptable glare.
- Avoid combinations with clear glass and windows narrower or equal to 1.5 m as they tend to cause not acceptable sDA.
- Avoid scenarios with laminated glass and windows narrower or equal to 2.5 m as they tend to result in not acceptable sDA.
- Pay special attention to window width when designing balconies with more than 1.0 m depth and using laminated glass so sDA values would not go below accepted level.

Interestingly, Table 8 showed how the ratio of balcony width to window width and the room depth can play a tricky role in pathways to success. This is because in 70% of the successful paths from Table 8 the ratio of balcony width to window width was not relevant in classifying the instances as sDA preferred. However, in 17% of the paths this variable needed to be higher than 1, whereas in the remaining 13% it needed to be lower or equal to 0.5. With regards to room depth, in 53% of the paths the 5.5 m depth was classified as highly successful, but it was possible to see this parameter did not play a role in 35% of the pathways to success and that 12% of the cases with room depths of 7 m still yielded highly successful results.

5 Conclusion

This paper discussed the use of balconies in medium-rise mixed-mode office buildings in the tropics by exploring decision-making pathways to achieve daylight efficiency and reduce incident solar radiation. Balconies, assumed to be an efficient shading device as well as a daylight diffuser, were assessed in combination with different window configurations via parametric studies coupled with daylight simulations for a 'typical' mixed-mode office building in São Paulo. Guidelines considering preferred and accepted sDA, as well as preferred and accepted ASE were extracted considering daylight sufficiency and probability of glare, in separation and simultaneously, in addition with the UDI metric to formulate rules and relevant combinations of design parameters useful to the early design stages.

The following main results and recommendations which come out of this study were:

- Window width and glazing visible transmittance were always essential parameters to achieve preferred and acceptable sDAs and ASE as well as UDIs, reinforcing what was already indicated in the literature. However, this study showed throughout the systematic analysis and confirmed through the decision tree – the window width as the root node and the glazing visible transmittance as the second node – that these two parameters are the most important ones in achieving daylight performance.
- Window width, when combined with any other parameter, produced relevant thresholds for design decision-making. This was particularly evident in the pairwise comparisons displayed in section 4.2, which all referred to window width, as well as conclusive Tables 6 and 7, in which window width was written as a function of solar orientation, glazing visible transmittance and room depth. It was also evident, from the decision tree, that the window width was constantly used as a design parameter to create new decision nodes, as well as from Table 8, in which this parameter was written as a function of all the others.
- The systematic analysis was very useful to identify relevant parameters and parametric combinations which would yield successful sDAs and UDIs but not very successful to detect combinations of design parameters to achieve preferred and acceptable ASEs.
- The systematic analysis produced cut-off points after which balcony configurations stopped influencing the achievement of preferred sDAs (Table 6). Although results in Table 6 did not consider glare, they were still a good indicator of which window widths to use with each

solar orientation, room depth and glazing visual transmittance to achieve preferred sDAs with any type of balcony configuration.

- The systematic analysis produced information about which combinations of design parameters for which deeper balconies would yield better UDIs (Table 7). Contrarily to Table 6, this table embedded information on the upper illuminance threshold (3000 lx) when recommending window widths as function of orientation, transmittance and room depth and therefore can be seen as complementary to information contained in Table 6.
- The datamining complemented the findings from the systematic analysis. In particular Table 8 provided more detailed information on how to achieve preferred performance with the inclusion of ASEs, also indicating parametric combination pathways to be completely avoided.

Future studies could address limitations of this study such as including different positioning of balconies in relation to windows, as this study only addressed balconies centred to window widths; addressing alternative material properties such as balconies with visible transmittance and different reflectance setting; increase the number of parameters related to glazing visible transmittance and room depths to include outliers from the database [20,22], to test a wider spectrum of possibilities and increase design variety. Future work could also assess how these parametric combinations are affected by a densely populated urban context which could possibly be favourable in achieving preferred ASEs but would likely jeopardize the achievements of preferred sDAs.

6- Acknowledgments

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Appendix A *(colours should be used in print for any figures in this appendix)*

In this dataset, the 6360 simulated cases, were derived from 7 variable parameters and three daylight metrics, leading to 19080 output values. To gather the large amount of data, a dataset with 32 graphs was created. Figure 18 provides a graphic structure to improve legibility of results.

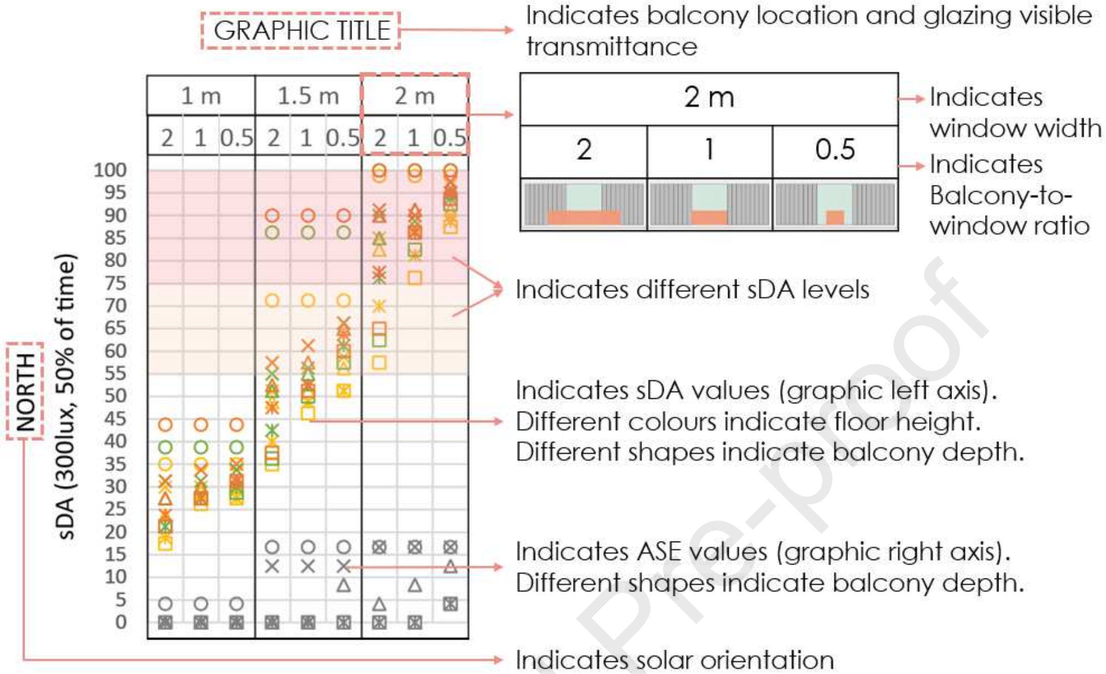
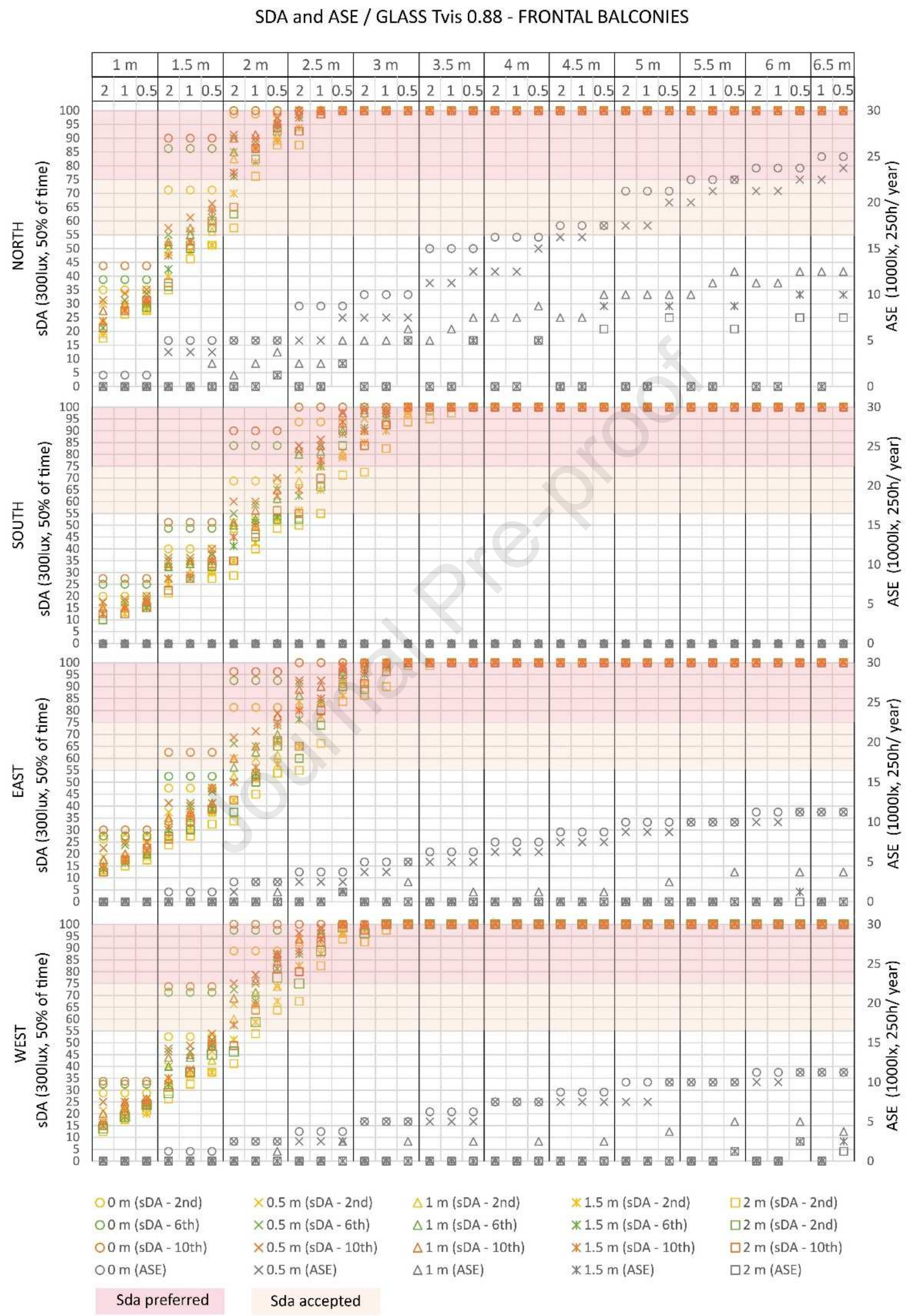
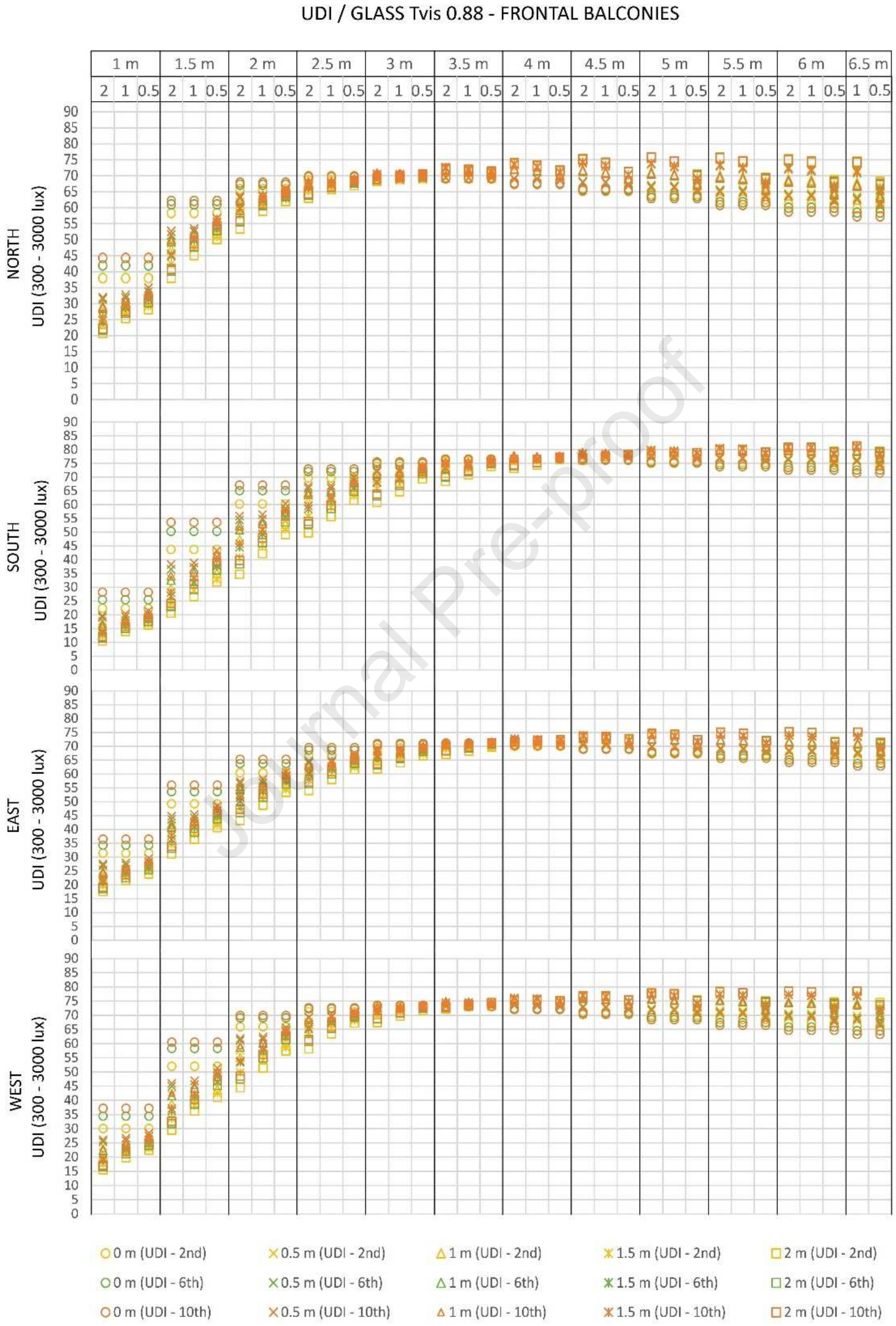
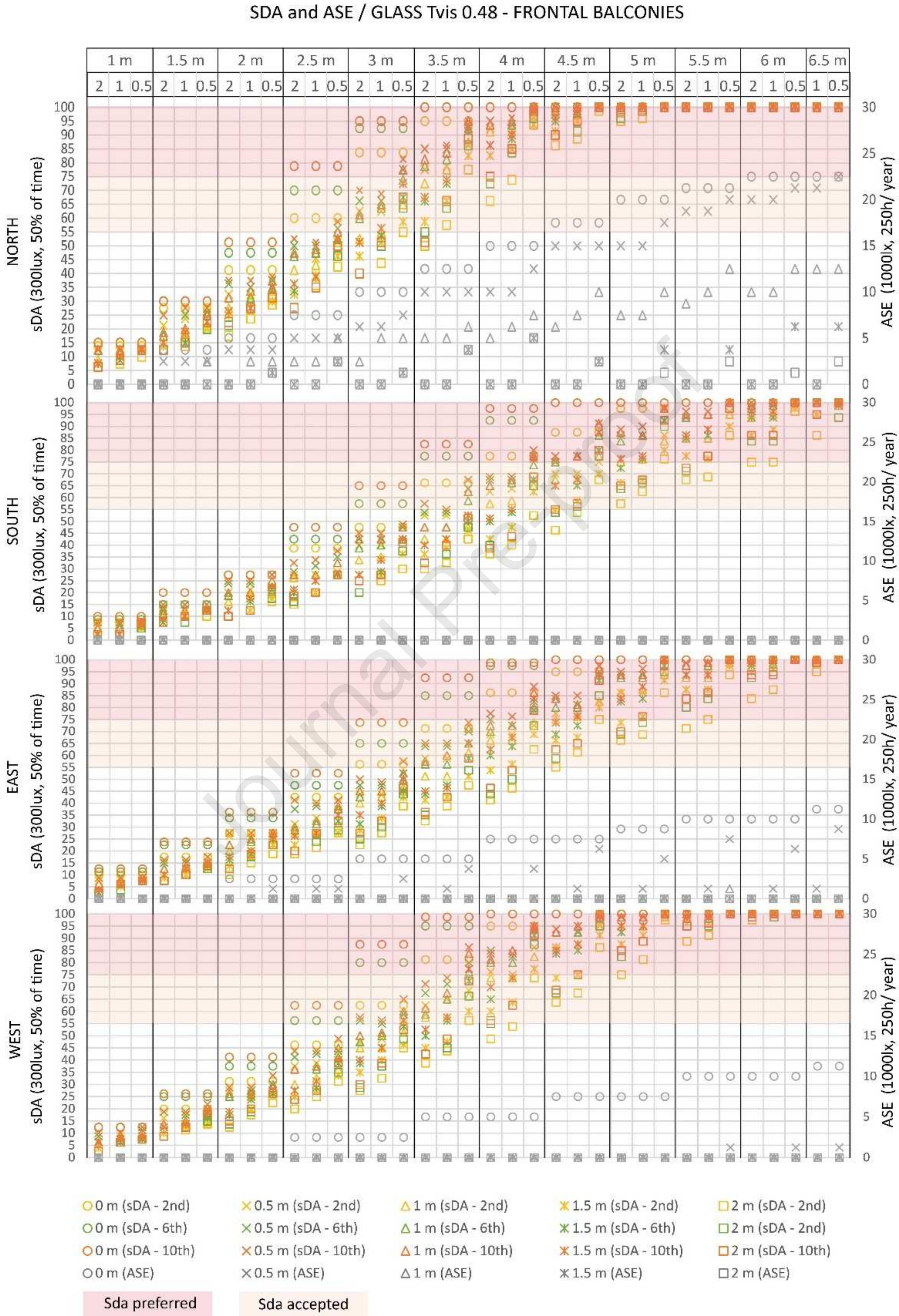
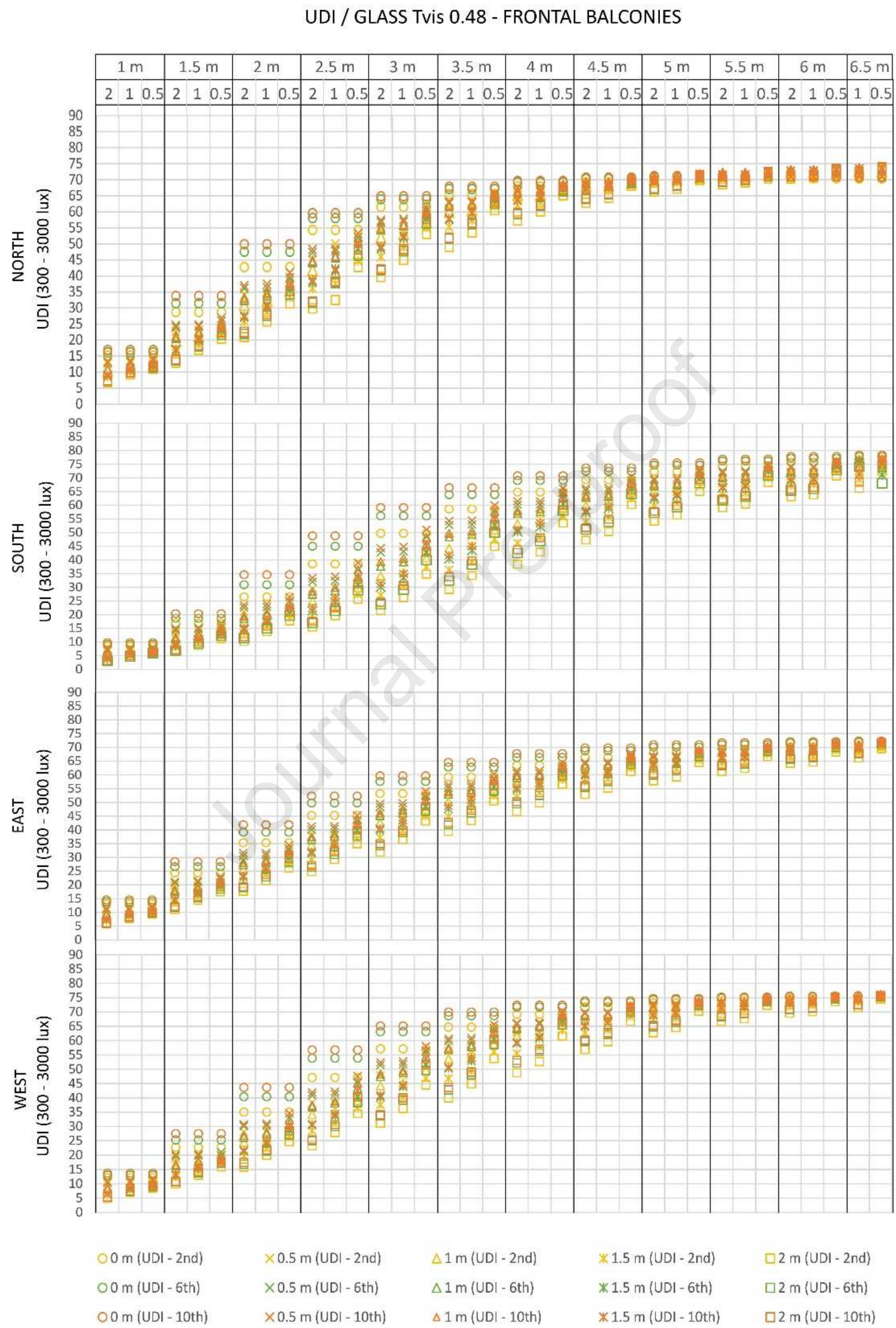


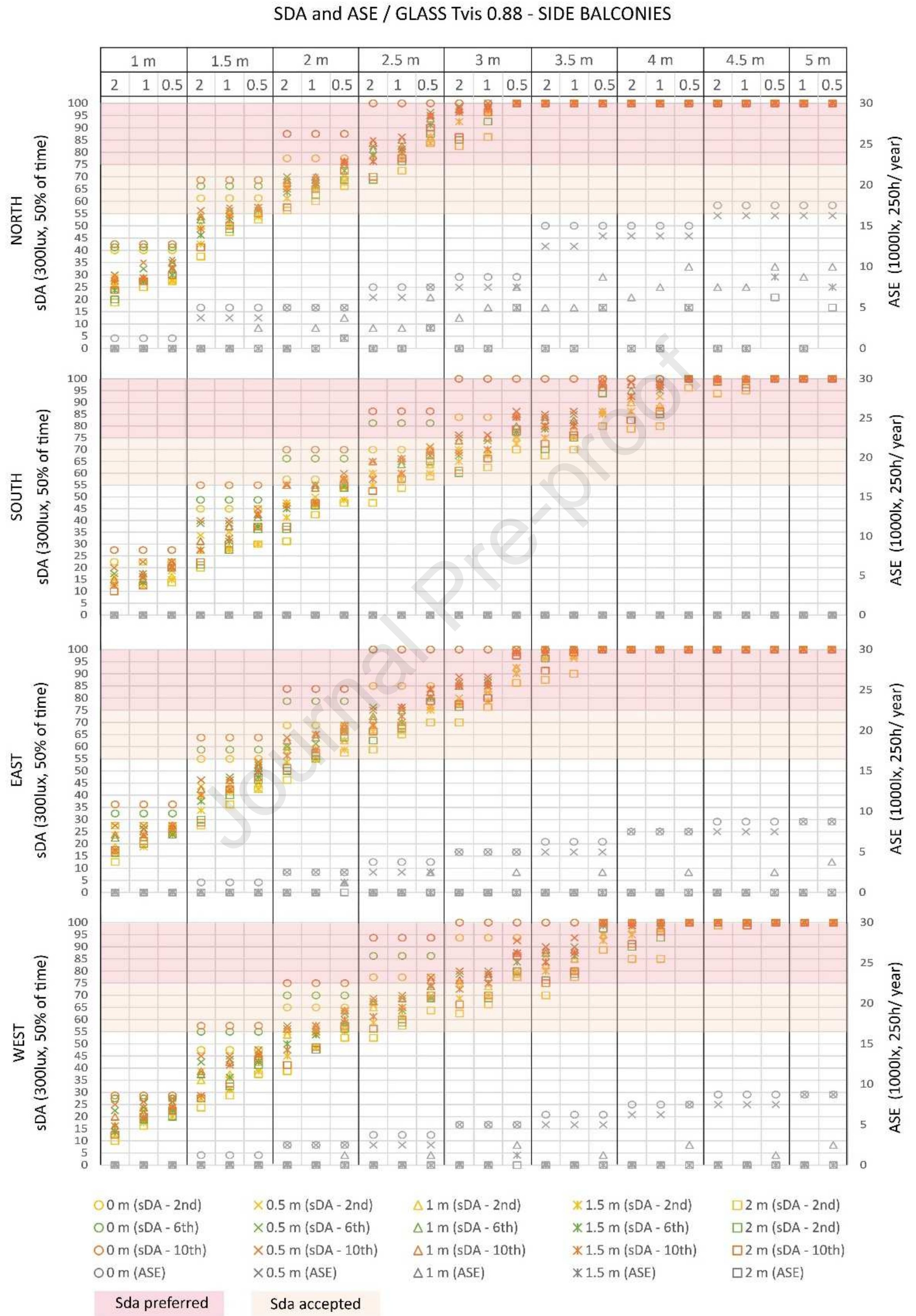
Figure 18: Graphic structure to improve legibility of results

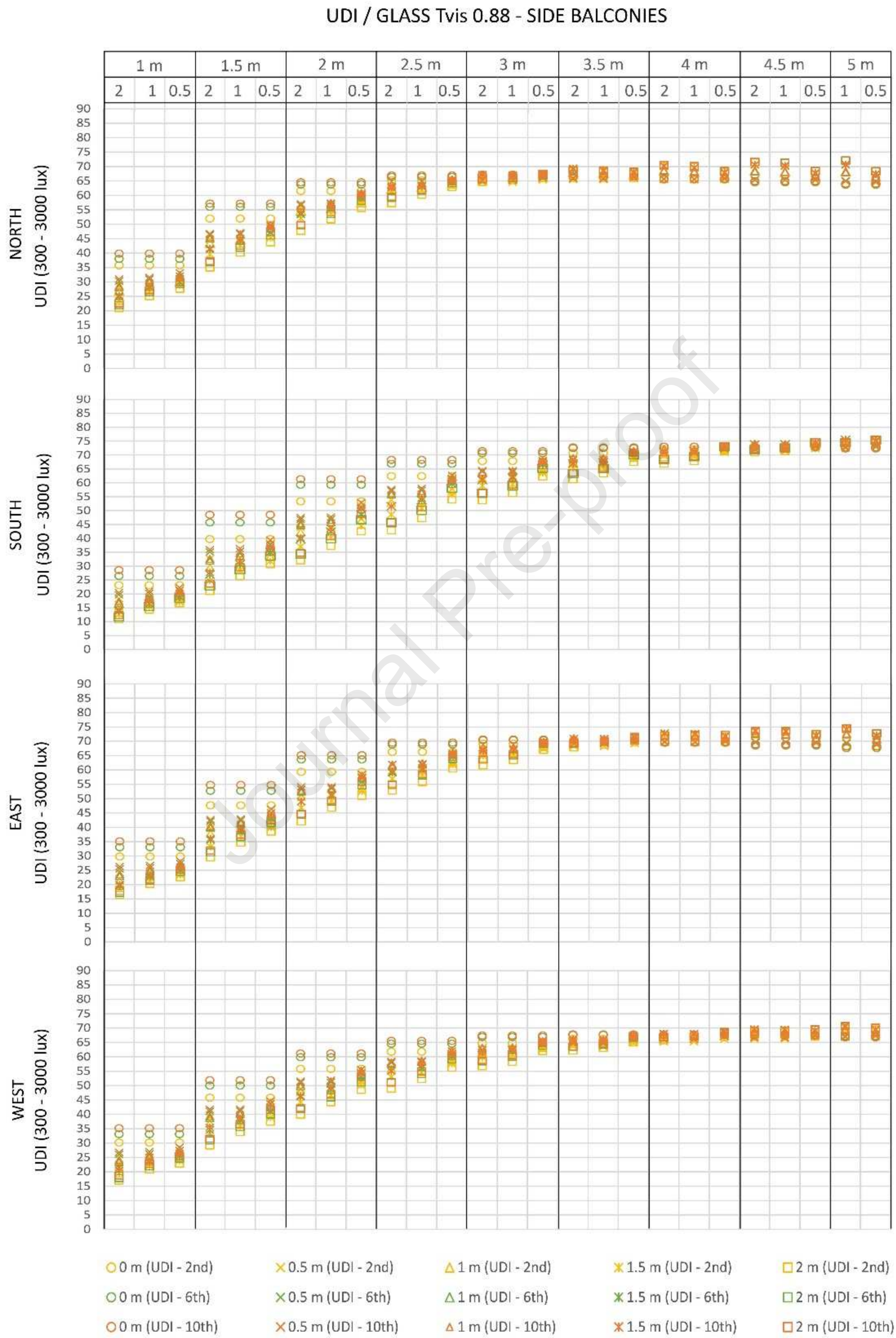

SDA and ASE / GLASS Tvis 0.88 - FRONTAL BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
5.5 m
6 m
6.5 m
2 1 0.5
NORTH
SOUTH
EAST
WEST
sDA (300lux, 50% of time)
ASE (1000lx, 250h/ year)
0 m (sDA - 2nd)
0.5 m (sDA - 2nd)
1 m (sDA - 2nd)
1.5 m (sDA - 2nd)
2 m (sDA - 2nd)
0 m (sDA - 6th)
0.5 m (sDA - 6th)
1 m (sDA - 6th)
1.5 m (sDA - 6th)
2 m (sDA - 2nd)
0 m (sDA - 10th)
0.5 m (sDA - 10th)
1 m (sDA - 10th)
1.5 m (sDA - 10th)
2 m (sDA - 10th)
0 m (ASE)
0.5 m (ASE)
1 m (ASE)
1.5 m (ASE)
2 m (ASE)
Sda preferred
Sda accepted

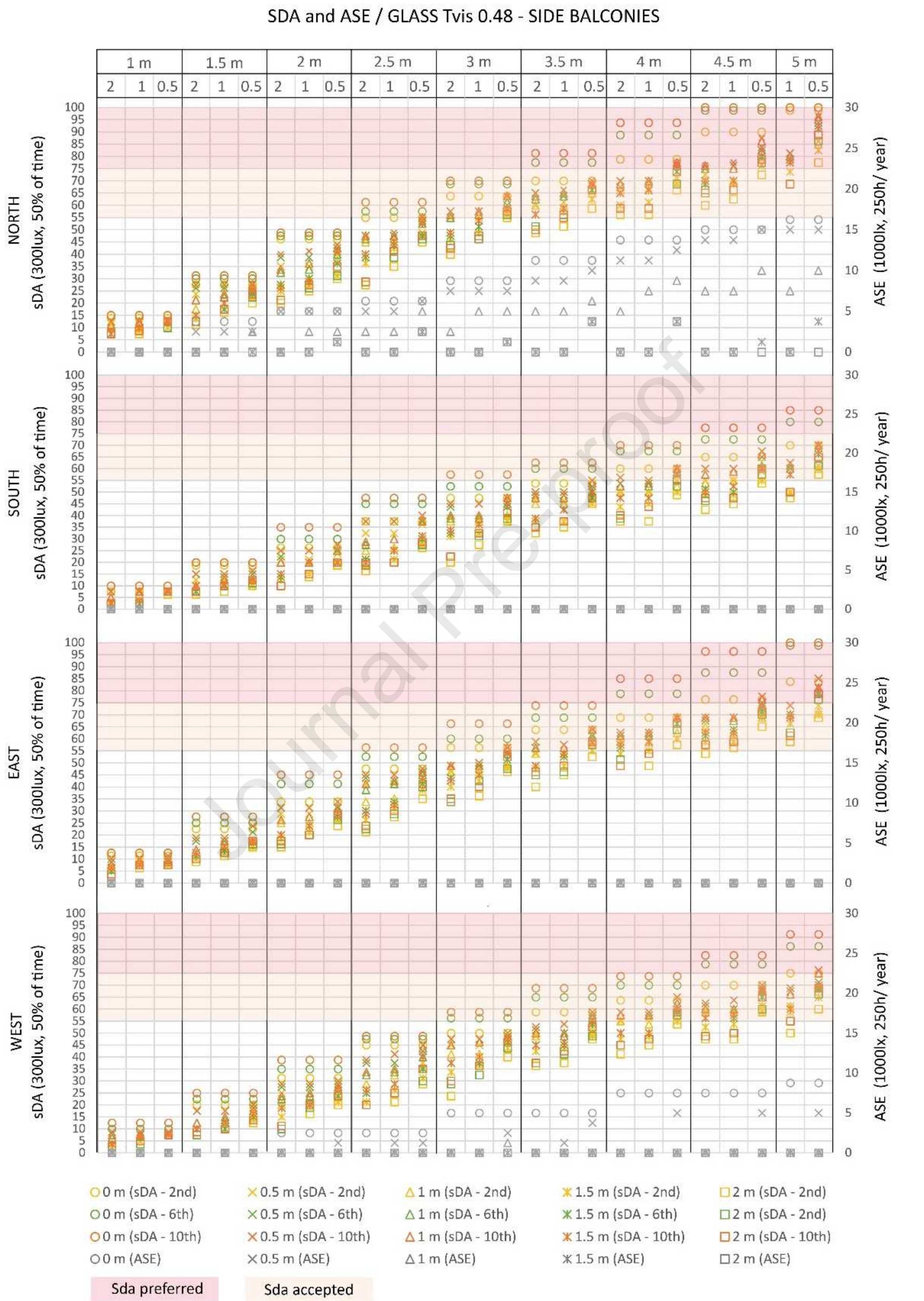

UDI / GLASS Tvis 0.88 - FRONTAL BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
5.5 m
6 m
6.5 m
NORTH UDI (300 - 3000 lux)
SOUTH UDI (300 - 3000 lux)
EAST UDI (300 - 3000 lux)
WEST UDI (300 - 3000 lux)
0 m (UDI - 2nd)
0.5 m (UDI - 2nd)
1 m (UDI - 2nd)
1.5 m (UDI - 2nd)
2 m (UDI - 2nd)
0 m (UDI - 6th)
0.5 m (UDI - 6th)
1 m (UDI - 6th)
1.5 m (UDI - 6th)
2 m (UDI - 6th)
0 m (UDI - 10th)
0.5 m (UDI - 10th)
1 m (UDI - 10th)
1.5 m (UDI - 10th)
2 m (UDI - 10th)

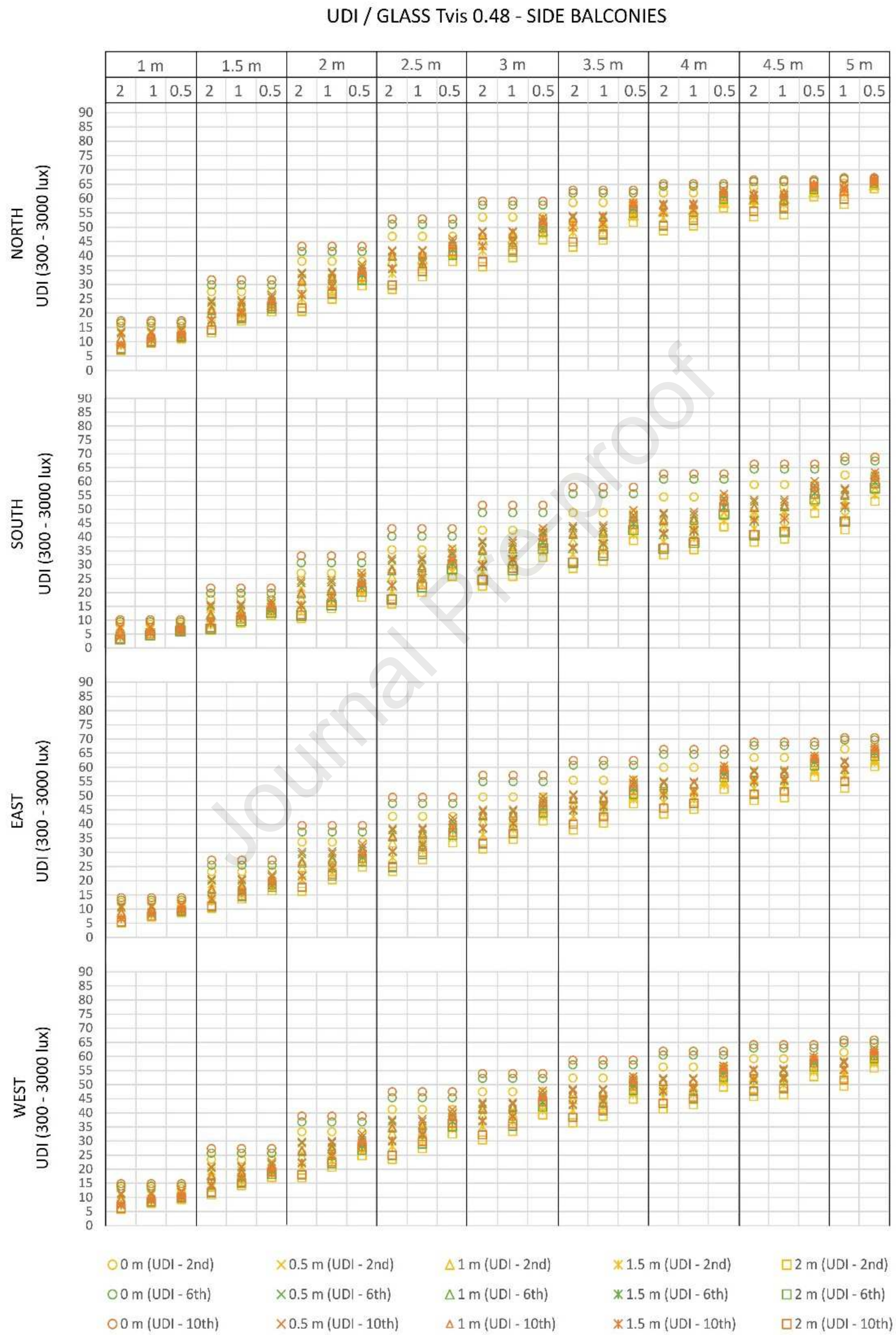

SDA and ASE / GLASS Tvis 0.48 - FRONTAL BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
5.5 m
6 m
6.5 m
NORTH sDA (300lux, 50% of time)
SOUTH sDA (300lux, 50% of time)
EAST sDA (300lux, 50% of time)
WEST sDA (300lux, 50% of time)
ASE (1000lx, 250h/ year)
0 m (sDA - 2nd)
0.5 m (sDA - 2nd)
1 m (sDA - 2nd)
1.5 m (sDA - 2nd)
2 m (sDA - 2nd)
0 m (sDA - 6th)
0.5 m (sDA - 6th)
1 m (sDA - 6th)
1.5 m (sDA - 6th)
2 m (sDA - 2nd)
0 m (sDA - 10th)
0.5 m (sDA - 10th)
1 m (sDA - 10th)
1.5 m (sDA - 10th)
2 m (sDA - 10th)
0 m (ASE)
0.5 m (ASE)
1 m (ASE)
1.5 m (ASE)
2 m (ASE)
Sda preferred
Sda accepted


UDI / GLASS Tvis 0.48 - FRONTAL BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
5.5 m
6 m
6.5 m
2 1 0.5
NORTH
SOUTH
EAST
WEST
UDI (300 - 3000 lux)
0 m (UDI - 2nd)
0.5 m (UDI - 2nd)
1 m (UDI - 2nd)
1.5 m (UDI - 2nd)
2 m (UDI - 2nd)
0 m (UDI - 6th)
0.5 m (UDI - 6th)
1 m (UDI - 6th)
1.5 m (UDI - 6th)
2 m (UDI - 6th)
0 m (UDI - 10th)
0.5 m (UDI - 10th)
1 m (UDI - 10th)
1.5 m (UDI - 10th)
2 m (UDI - 10th)


SDA and ASE / GLASS Tvis 0.88 - SIDE BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
NORTH
SOUTH
EAST
WEST
sDA (300lux, 50% of time)
ASE (1000lx, 250h/ year)
0 m (sDA - 2nd)
0 m (sDA - 6th)
0 m (sDA - 10th)
0 m (ASE)
0.5 m (sDA - 2nd)
0.5 m (sDA - 6th)
0.5 m (sDA - 10th)
0.5 m (ASE)
1 m (sDA - 2nd)
1 m (sDA - 6th)
1 m (sDA - 10th)
1 m (ASE)
1.5 m (sDA - 2nd)
1.5 m (sDA - 6th)
1.5 m (sDA - 10th)
1.5 m (ASE)
2 m (sDA - 2nd)
2 m (sDA - 2nd)
2 m (sDA - 10th)
2 m (ASE)
Sda preferred
Sda accepted


UDI / GLASS Tvis 0.88 - SIDE BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
2 1 0.5
NORTH
UDI (300 - 3000 lux)
SOUTH
UDI (300 - 3000 lux)
EAST
UDI (300 - 3000 lux)
WEST
UDI (300 - 3000 lux)
0 m (UDI - 2nd)
0.5 m (UDI - 2nd)
1 m (UDI - 2nd)
1.5 m (UDI - 2nd)
2 m (UDI - 2nd)
0 m (UDI - 6th)
0.5 m (UDI - 6th)
1 m (UDI - 6th)
1.5 m (UDI - 6th)
2 m (UDI - 6th)
0 m (UDI - 10th)
0.5 m (UDI - 10th)
1 m (UDI - 10th)
1.5 m (UDI - 10th)
2 m (UDI - 10th)


SDA and ASE / GLASS Tvis 0.48 - SIDE BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
2 1 0.5
NORTH
SOUTH
EAST
WEST
sDA (300lux, 50% of time)
ASE (1000lx, 250h/ year)
0 m (sDA - 2nd)
0 m (sDA - 6th)
0 m (sDA - 10th)
0 m (ASE)
0.5 m (sDA - 2nd)
0.5 m (sDA - 6th)
0.5 m (sDA - 10th)
0.5 m (ASE)
1 m (sDA - 2nd)
1 m (sDA - 6th)
1 m (sDA - 10th)
1 m (ASE)
1.5 m (sDA - 2nd)
1.5 m (sDA - 6th)
1.5 m (sDA - 10th)
1.5 m (ASE)
2 m (sDA - 2nd)
2 m (sDA - 2nd)
2 m (sDA - 10th)
2 m (ASE)
Sda preferred
Sda accepted


UDI / GLASS Tvis 0.48 - SIDE BALCONIES
1 m
1.5 m
2 m
2.5 m
3 m
3.5 m
4 m
4.5 m
5 m
2 1 0.5
NORTH UDI (300 - 3000 lux)
SOUTH UDI (300 - 3000 lux)
EAST UDI (300 - 3000 lux)
WEST UDI (300 - 3000 lux)
0 m (UDI - 2nd)
0.5 m (UDI - 2nd)
1 m (UDI - 2nd)
1.5 m (UDI - 2nd)
2 m (UDI - 2nd)
0 m (UDI - 6th)
0.5 m (UDI - 6th)
1 m (UDI - 6th)
1.5 m (UDI - 6th)
2 m (UDI - 6th)
0 m (UDI - 10th)
0.5 m (UDI - 10th)
1 m (UDI - 10th)
1.5 m (UDI - 10th)
2 m (UDI - 10th)

Manuscript: Decision-making pathways to daylight efficiency for office buildings with balconies in the tropics

Highlights

- Analysis of the role of balconies to improve daylight in office buildings
- Decision-making pathways to improve daylight whilst reducing cooling demand
- Cut-off points for design decision-making to achieve daylight efficiency

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: