Daylighting Design Strategies for Office Spaces in Different Chilean Climates

Cecilia Palarino-Vico and María Beatriz Piderit-Moreno

Abstract The chapter discusses the optimization of daylighting strategies to achieve visual comfort in side-lit office spaces. Glazed facades are commonly used in the design of office buildings, where direct sunlight causes visual glare, and the prolonged use of dynamic user-operated shading devices reduces daylighting and blocks the view outside. Visual comfort at the use stage depends on early design decisions appropriate to each context to maximize uniform daylight indoors and control glare risk. This may be a challenge in extensive territories with great variability of prevalent skies and daylight availability. The research was carried out in an experimental office space prototype, analyzing daylight strategies in three Chilean cities with different climate conditions. They were evaluated using the climate-based daylight modeling method and validated with the dynamic daylighting metrics in sustainable codes. The chapter provides a selection of daylighting strategies suitable for different climates. It illustrates the daylight performance regarding illumination level and the potential glare control to achieve visual comfort for the occupants.

Keywords Daylighting · Side-lit office · Daylight strategies · Design optimization · Daylight performance

1 Introduction

Office buildings often have glazed facades to capture the maximum daylight in side-lit office spaces with limited daylight potential. For instance, research in Santiago

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Table 1 Summary of daylight parameters and target values [7]

Daylight metrics	Acceptance	Preference	Source
sDA 300 lx, 50%	55% of the area	75% of the area	[5]
ASE 1000 lx, 250 h	20% of the area	10% of the area	[5]
UDI-c 100 lx to 3000 lx	80% occurrence	Non-specified	[6]
UDI-e > 3000 lx	Non-specified	Non-specified	[6]

de Chile showed that the fully glazed façade is the city's predominant type of office building [1]. Its use has become widespread in all locations and climates. However, in some contexts, overexposure produces high ranges of illuminance, glare, and contrasts, affecting the occupants' visual comfort. Continued and unplanned use of user-operated dynamic sun shading devices affects daylight illumination levels and the view out. These two parameters help create healthy environments and benefit the productivity of the occupants [2, 3].

Daylighting design strategies optimized for the building context are a valuable opportunity to use available resources effectively. The approach should be balanced to achieve adequate daylighting, around 500 lx for workstations with computer screens [4] while controlling potential visual discomfort and taking advantage of views outside. The objective here is to answer the question, what are the most effective strategies to meet daylighting expectations in side-lit office spaces in different climatic contexts regarding prevailing sky and daylight availability?

The chapter proposes daylighting strategies in three climatic contexts in Chile, representative of conditions with different requirements. The lighting performance of the strategies is analyzed through dynamic daylighting metrics in the sustainable codes, which integrate the evaluation of daylight provision and potential glare prediction into a combined approach, shown in Table 1. Spatial Daylight Autonomy (sDA) measures the minimum requirement of 300 lx, at least 50% of the operating hours, analyzed with Annual Sunlight Exposure (ASE), which measures the maximum requirement of 1000 lx for 250 h over the course of a year to control high illuminances [5]. Furthermore, the Useful Daylight Illuminance (UDI) measures illuminance in a range between 100 lx and 3000 lx, considering autonomous between 300 lx and 3000 lx, and over-lit when it exceeds 3000 lx [6].

The evaluation is made using climate-based daylight simulation (CBDM), with the DIVA plugin for the Rhinoceros 3D NURBS modeler, which uses a Radiance ray tracer to simulate illuminance distributions [8]. The light scene is built with an architectural 3D model and a climate file (energy plus weather) for each location to conclude the effectiveness of the design criteria applied.

2 Daylighting Design Strategies

The research focuses on strategies for catching, transmitting, distributing, and controlling daylight. Table 2 summarizes design recommendations developed by leading entities in advanced daylighting and energy design. The recommendations guide decisions on building shape, openings, and interiors to define the experimental prototype (See Fig. 1) and solar devices for optimizing each climate.

The experimental model is an office prototype of 84 m^2. It is characterized by a square floor plan with 9.15 m sides (maximum distance from the occupant to the façade to provide daylight and views of the exterior). The ceiling has a height of 3.0 m which increases to 3.35 m near the façade to enhance daylight capture and reflections. The opening is north-oriented, with an area of 12 m^2, in the central position of a wall area of 30.6 m^2. It determines a window-to-wall ratio (WWR) of 40%, according to the energy criteria guided by ASHRAE. The opening is 5.0 m wide and divided into two sections: an upper opening for daylighting (Daylight Window) and a lower opening for exterior views (View Window). The opening starts at 0.8 m to provide views outside from the seated position of the occupant.

3 Optimization of Daylighting Strategies in Three Climatic Contexts

Given the wide spectrum of daylight and sky variations, a detailed site analysis of the Chilean climatic context is carried out by looking at the Köppen–Geiger climate classification, average temperatures (T° Avg.), and frequency of skies: overcast, intermediate, and clear using the ASRC-CIE model [12, 13]. The cities of Calama (22°28′0″S, 68°55′60″W), Santiago (33°27′0″S, 70°40′25″W), and Puerto Montt (41°28′18″S, 72°56′23″W) show three different conditions described in Table 3.

3.1 Strategies for CIE Predominant Clear Sky (Calama)

The city of Calama requires solar shading strategies throughout the year. The proposal applies a fixed external shading device of horizontal louvers 10 cm apart, which effectively obstructs solar angles (89° sum., 44° wint.) and provides views of the exterior. The material of the louvers is permeable to daylight transmission, with a 50% perforated surface, distant from the opening to create a ventilated gap to reduce the radiant temperature. Simulation results show a uniform daylight pattern with acceptable visual comfort thresholds in Fig. 2.

Table 2 Design criteria for side-lit office spaces [7]

Building components	Source
Building form	
Geometry/Floor Plan	[1, 3]
- Distance of occupants from façade 9.15 m (max.)	
- Regular occupied areas distance from façade 4.55 m > 40%	
- Occupied areas distance from façade 6.0 m > 75%	
- Maximum floorplan depth without the use of skylight 18.2 m	
Geometry/Height	[1]
- Ceiling height (min.) > 2.75 m and in public spaces >3.10–3.65 m	
Orientation	[1, 3]
- Dominant orientation north–south facades within 15°	
- Prioritize floorplans extension towards the east–west	
Fenestration	
Wall–window ratio	[1, 3]
- WWR (20%–1%)—Preferred north/south	
Window distribution	[9–11]
- View Window (VW) + Daylight Window (DW)	
- VW height: from 0.75 m up to 1.80–2.20 m; from floor overcast sky	
- DW height: up to the ceiling (2.20–3.35 m)	
Glazing (Visible light transmission—VT)	[9–11]
- Windows in general VT −0.6/0.7	
- Daylight Window VT > 0.6/0.7	
- View Window VT < 0.6/0.7 (also east/west façade)	
- Avoid reflective or tinted glass	
Devices	
Daylight	[9–11]
- Light shelves/Reflector devices/Diffuser screens/Light guiding shade	
Fixed shading	[9–11]
- Horizontal: Overhang/Louvers/Multiple blades/Vertical panel	
- Vertical: Façade screens/Brise-soleil/Vertical fins/Slanted vertical fins/in colder climates or overcast sky perforated materials	
Dynamic shading Internal	[9–11]
- Roller blinds/Venetian blinds/Curtains/Vertical louver blinds	
Interiors	
Program zoning	[9–11]
- Open-plan office: north/south prior orientation, primary daylighting area	
- Circulation: Between workstations at the end of daylighting area	
- Private office: east/west prior orientation, glazed walls parallel to the façade	

(continued)

Table 2 (continued)

Building components	Source
Partitions - Workstation partitions $h < 1.2$ m and parallel to the window - Panels perpendicular to window ($h > 1.2$ m), translucent panels ($h > 1.65$ m) - Prior perpendicular orientation of user to window	[10]
Reflectance (LVR) - Light reflectance values (LRV) 80% ceiling—50% walls—20% floors - Avoid the "cave effect" with high LVR in the perimeter zone - Increase LVR of daylight surface devices	[10]

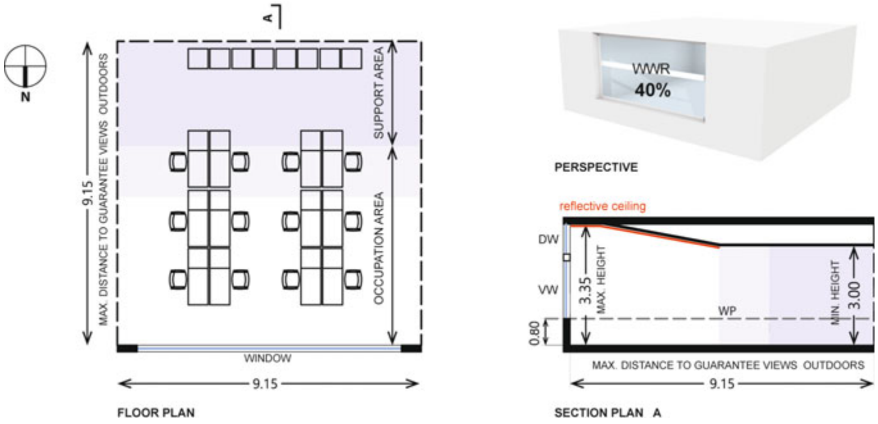
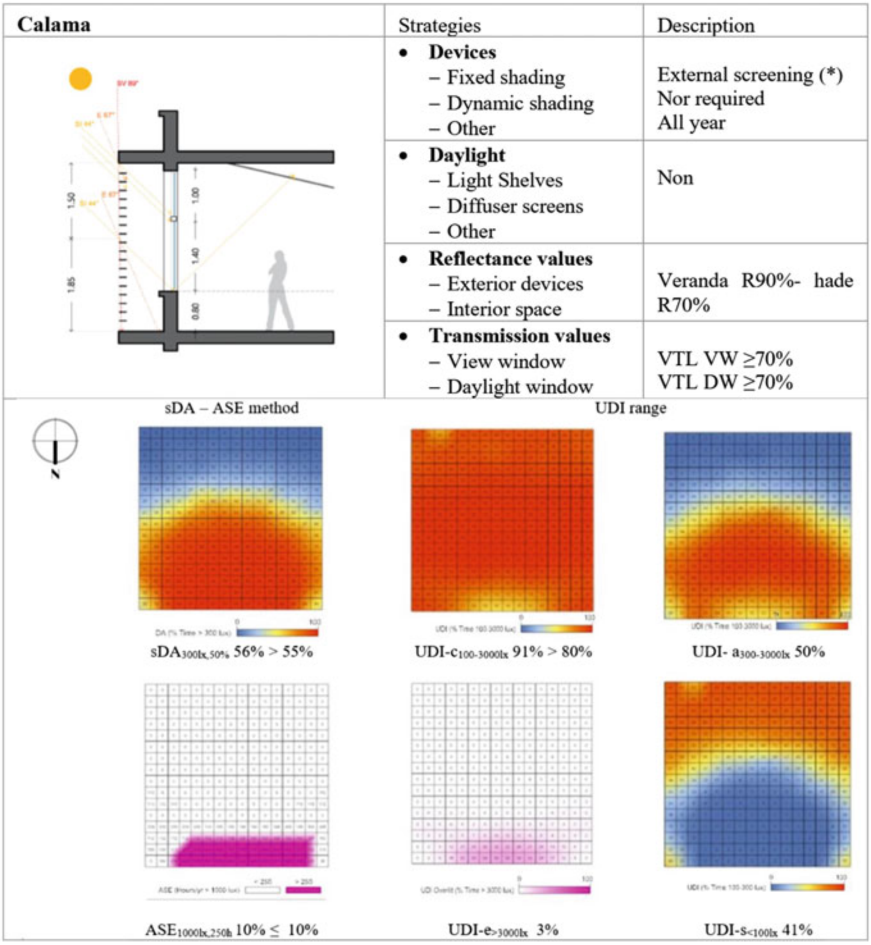


Fig. 1 Prototype office model [7]

Table 3 Characteristics of the case studies

Cities	Köppen Geiger	T°max Avg. (°C)	T°min Avg. (°C)	Frequency (%) of CIE sky			
				Clear (%)	Cl. Turb. (%)	Interm. (%)	Overcast (%)
Calama	BWk	24.1	5.1	50	23	16	11
Santiago	Csb	29.8	11.4	19	22	30	29
Puerto Montt	Cfb	19.6	9.4	10	12	32	46



Calama	Strategies	Description
	• **Devices** – Fixed shading – Dynamic shading – Other	External screening (*) Nor required All year
	• **Daylight** – Light Shelves – Diffuser screens – Other	Non
	• **Reflectance values** – Exterior devices – Interior space	Veranda R90%- hade R70%
	• **Transmission values** – View window – Daylight window	VTL VW ≥70% VTL DW ≥70%

sDA – ASE method

UDI range

sDA$_{300lx,50\%}$ 56% > 55%

UDI-c$_{100\text{-}3000lx}$ 91% > 80%

UDI- a$_{300\text{-}3000lx}$ 50%

ASE$_{1000lx,250h}$ 10% ≤ 10%

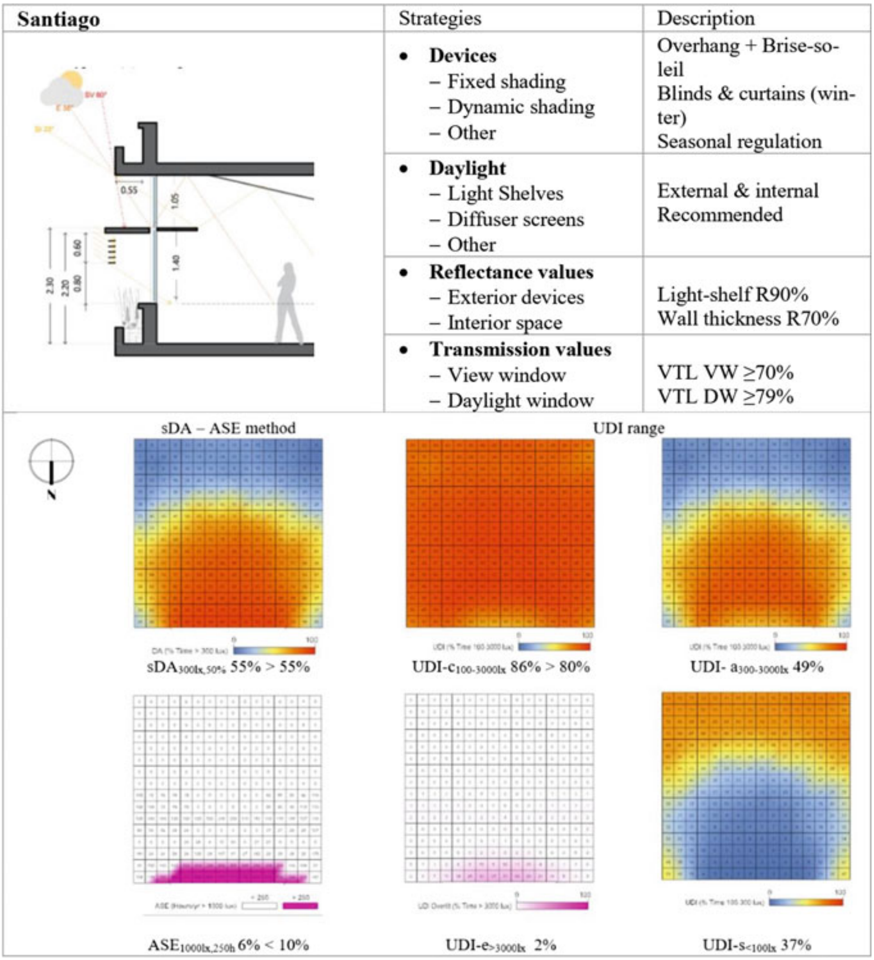
UDI-e$_{>3000lx}$ 3%

UDI-s$_{<100lx}$ 41%

Fig. 2 Optimized façade strategies and illuminance distribution in Calama

3.2 *Strategies for CIE Predominant Intermediate Sky (Santiago)*

The city of Santiago requires mixed winter–summer strategies. The aim is to capture passive solar gain in winter when overcast skies predominate and low overheating. Overhangs are applied to the outside of openings to effectively control the sun in summer and at the equinoxes. In addition, the visual window has fixed exterior horizontal slats spaced at 10 cm to protect the desk from direct sunlight in winter. An interior lighting shelf increases and redirects the light to improve reflections and prevents glare at desks. Simulation results show a uniform daylight pattern with acceptable visual comfort thresholds Fig. 3.

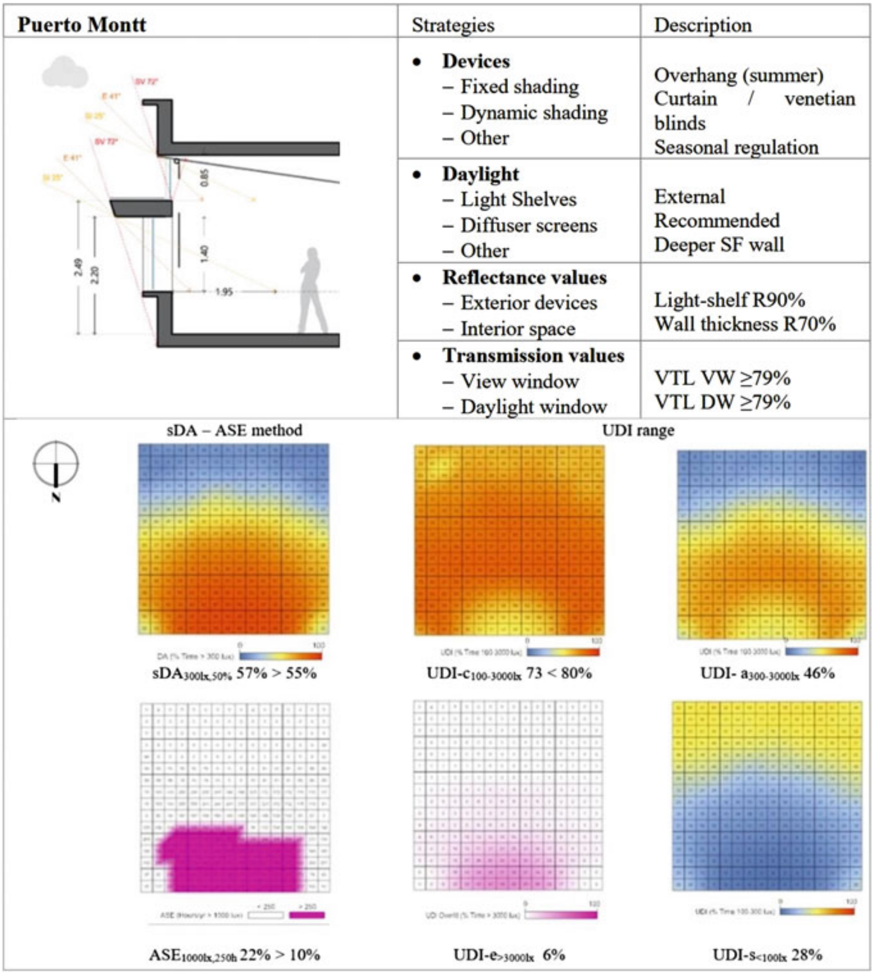


Santiago	Strategies	Description
	Devices – Fixed shading – Dynamic shading – Other	Overhang + Brise-soleil Blinds & curtains (winter) Seasonal regulation
	Daylight – Light Shelves – Diffuser screens – Other	External & internal Recommended
	Reflectance values – Exterior devices – Interior space	Light-shelf R90% Wall thickness R70%
	Transmission values – View window – Daylight window	VTL VW ≥70% VTL DW ≥79%

Fig. 3 Optimized façade strategies and illuminance distribution in Santiago

3.3 *Strategies for CIE Predominant Overcast Sky (Puerto Montt)*

The city of Puerto Montt requires passive solar gain strategies during most of the year due to low temperatures and the frequency of overcast skies in winter and at equinoxes. A horizontal overhang is planned to control solar radiation in summer. However, dynamic devices (translucent curtain type) are also necessary to regulate sunlight on the work plane during short periods of the year. Due to the limited availability of daylight, internal reflections are enhanced by increasing the reflectance



Puerto Montt	Strategies	Description
	• **Devices** – Fixed shading – Dynamic shading – Other	Overhang (summer) Curtain / venetian blinds Seasonal regulation
	• **Daylight** – Light Shelves – Diffuser screens – Other	External Recommended Deeper SF wall
	• **Reflectance values** – Exterior devices – Interior space	Light-shelf R90% Wall thickness R70%
	• **Transmission values** – View window – Daylight window	VTL VW ≥79% VTL DW ≥79%

Fig. 4 Optimized façade strategies and illuminance distribution in Puerto Montt

of materials. Simulation results show a uniform daylight pattern with acceptable visual comfort thresholds in Fig. 4.

4 Results

The dynamic simulation analyzes the experimental model to establish the base lighting performance in the three locations, shown in Fig. 5. Daylight availability metrics achieve satisfactory illuminance levels, meeting the thresholds of sustainable codes.

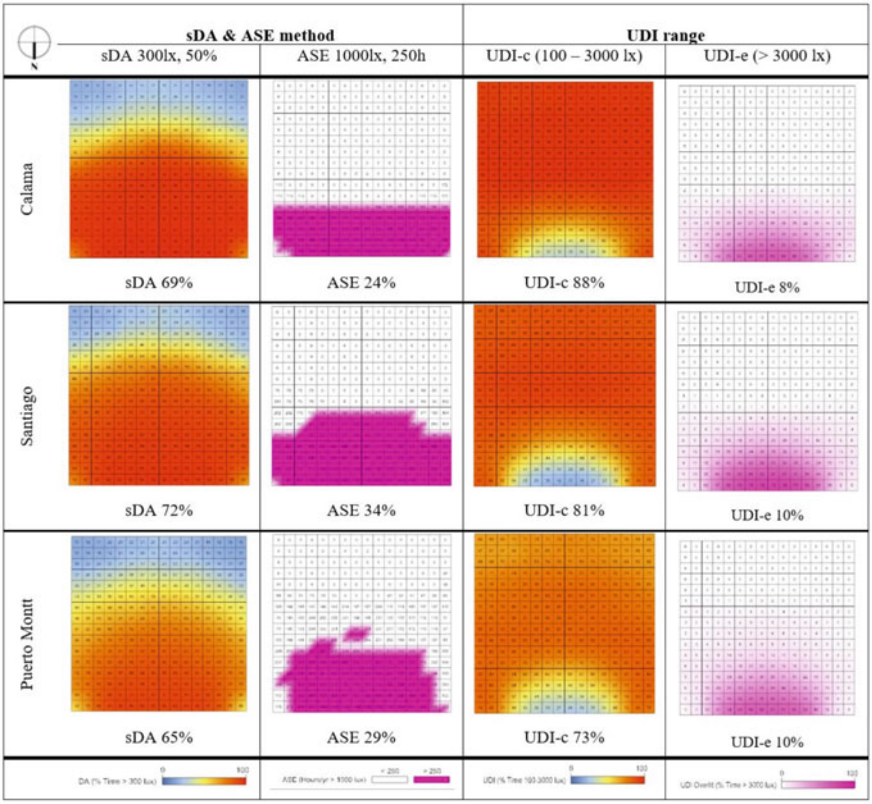


Fig. 5 luminance distribution maps sDA & ASE and UDI range, three climates

However, high illuminance (>1000 lx) for prolonged periods (>250 h) is a constant because the models do not have devices that are appropriate for the climatic contexts. Solar control designs are important to reduce high illuminances, and the results show that the strategies proposed in Section 3 satisfactorily achieve the objectives defined according to the needs of the different contexts.

In Calama, with clear skies and hot temperatures, the daylight performance reaches sDA 69% and ASE 24%. The optimization achieves sDA 56% and ASE 10%, meeting the LM-83 code requirement. In addition, the optimization improves the UDI-c by 91% (base performance UDI-c 88%), meeting the PSBP requirement. Regarding the range segments, it achieves an autonomy UDI-a 50% and over-illumination in the area near the window at 3%. Sunscreens regulate high illuminances and play a fundamental role in climates with high solar presence.

In Santiago, with intermediate sky and temperatures, daylight performance achieved sDA 72% and ASE 34%, and then with the optimization, achieves sDA 55% and ASE 6%, complying with the LM-83 code requirement. The case presented the most accentuated sun exposure. However, sunscreens show effective sunlight regulation. In addition, it increased the UDI-c value to 86% (the base performance was UDI-c 81%), meeting the PSBP requirement. Regarding the range segments, it achieves a UDI-a of 49% and over-lighting in the nearby window area of 2%.

In Puerto Montt, with an overcast sky and cold temperatures, the initial daylight performance was sDA 65% and ASE 29%, decreasing to sDA 57% and ASE 22%. Compliance with LM-83 is conditioned because ASE exceeds 20%. The high illuminances respond to the projected passive gain strategy, designed for a predominantly overcast sky. The values indicate the need for user-operated dynamic shades. On the other hand, UDI-c 73% is below the 80% required by PSBP, which is explained by the low daylight availability from the overcast sky. Regarding the UDI range, it achieves a UDI-a of 46% and over-lighting in the nearby window area of 6%.

5 Discussion

The results demonstrate that integrating passive strategies can balance illuminance levels and high illuminance control. The dynamic metrics used to evaluate daylighting performance show that the results are close to the required thresholds defined by the codes for occupant visual comfort. The evaluation method and daylight metrics applied are widely used. They were developed in the Northern Hemisphere, established in sustainable standards, and are the reference for developing standards applied in the Southern Hemisphere. The results show that compliance with the lighting performance of the optimized designs is achieved in two of the three climates. In latitudes and overcast climates such as Puerto Montt, the illuminance values do not meet the illuminance range or threshold requirements.

Studies have concluded that the lighting environment of a location influences people's tolerance to illuminance levels [14]. This suggests that matching thresholds to sky conditions would be more useful for users than the standard. And there is research such as that of Marins et al. [15] that shows that light levels traditionally considered low are perceived as sufficient by people between 150 and 300 lx [16, 17] and that there is no consensus among researchers about which metric and which illuminance and time ranges, limits, or thresholds, best describes people's perception of light sufficiency [18]. Therefore, the authors assume that the strategies applied in this climate are valid and effectively optimize the model.

6 Conclusions

The review of three cities in Chile with different sky conditions shows that the requirements vary in each location depending on the availability of daylight and the incidence of sunlight. Regarding design criteria for climate optimization, there are enough works focused on passive strategies. This work allowed testing their application in different sky conditions in Chile, selecting the most important strategies, classifying them, and organizing them in a checklist for easy application by designers. The key aspect to optimize the criteria was observing how the strategies impact the amount and distribution of daylight in the space through the CBDM methods, and the UDI, SDA, and ASE metrics. It puts into perspective the need to reflect on the most appropriate thresholds to evaluate such large and variable territories concerning daylight availability for validating the designs.

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