Design Strategies Applied to Classroom's Daylight Design

Optimization of classrooms design

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ABSTRACT: This paper explains how the optimized classrooms were selected and the results that were achieved by the optimizations carried out and finalized. The context of the research is the city of Concepción, in Chile. Virtual models of classrooms were evaluated using the Radiance software. We used a methodology that allowed us to determine the luminous conditions under different types of skies, seasons of the year and times of the day. The evaluation of the typologies was performed based on three defined criteria, in order to achieve the stated design objectives. We defined the optimal solutions for each orientation and, finally, we stated design recommendations for daylit classrooms to ensure the visual comfort of the students. These recommendations link all that found in the initial analysis with that found in the optimization stage.

Keywords: daylighting, classrooms design, glare, visual comfort.

INTRODUCTION

With the purpose of improving the lighting conditions of public school's classrooms in Chile, an exploratory study of their lighting strategies was carried out in order to improve the visual comfort conditions of the students.

In Chile, the relationship between daylighting and wellbeing, and between visual comfort and performance, has not yet been explored.

In order to create a guideline that aids the design of lighting strategies, five classroom typologies were simulated, which were evaluated using the analysis criteria based on a better visual comfort, [1] i.e.:

- *Criterion 1. Providing an adequate amount of daylight in the classroom:* evaluated using a dynamic metric based on the Lightsolve illuminance metric [2], which presents the evolution of illuminance performance over the year in temporal maps [3]. The range varied according to the task performed in the classroom: 'in range' illuminances are those between 500-1500 lux; 'too low', < 300 lux; or 'too high', > 2000 lux. The students' work plane and the blackboard surface were studied. The target illuminance is reached for adequate at least 50% of the time of the year the illuminance "in range" and optimal when the illuminance "in range" is reached for at least 55% of the time of the year. It is also important to analyze the spatial distribution in the classroom to complement the analysis of horizontal illuminance; we considered the percentage of space whose values are in range throughout the year.
- *Criterion 2. Achieving the adequate daylight uniformity in the workplane*: The goal is to achieve a properly balanced daylighting illumination, both in the area of the workplane and in the area of the whiteboard. For this criterion was defined aim that *adequate level of uniformity* is reached when higher than 0.6 and optimal when the *uniformity is higher than 0.7.*
- *Criterion 3. Ensuring visual comfort in the field of view of the students:* The risk of glare was evaluated through the calculation of the Daylight Glare Probability (DGP), which was calculated for one direction: the horizontal view in the direction of the whiteboard [4]. The information of DGP is displayed in temporal maps. According to what the human subjects rated, as proposed by Wienold, we suggest as an "appropriate" visual comfort in the classroom, the DGP values of less than 35 %, these values having been rated as "imperceptible".

The objective of this paper is to detail those typologies that obtained optimal results for each one of the criteria and show the design recommendations that derived from them, following that found after carrying out the analysis of the aforementioned criteria.

CASES FOR DAYLIGHT OPTIMIZATION

Continuity was sought for the study carried out using these new criteria, and this was provided through the redesigning and revaluating of the typologies that had already been studied. Typologies with four orientations were studied, and their modelling was conducted for classrooms located in Concepción in the south of Chile at 36°46'S, 73°3' W. [5].

For the selection of the typologies to be optimized, the results of the temporal illuminance maps and of the

spatial maps were observed. The differences produced between them, in some cases, were not evident. Once we defined the existence of these differences, a multiple comparison procedure was carried out. This consisted of a measurement comparison test developed by Tukey, the mathematician, called the *"Honestly Significant Difference"* (HSD) [6].
From the fifteen sensors measured inside the classroom, three were selected that were located transversal to the façade, in the middle of the horizontal grid. The three sensors had the following order: in Zone 1, next to the window; in Zone 2, which corresponds to the central part of the classroom; in Zone 3, area far from the façade.

From the conclusions derived from the differences found, we decided to optimize the North, East and West-facing classroom typologies g1, g2 and g3. In the case of the Southern orientation, the selection of the classroom was not based on this differentiation method. We proved in a previous evaluation that this orientation was favourable to obtain a positive result, deciding to optimize those typologies that did not provide an optimal solution for the stated criteria as a result. We considered the optimization of typologies g2, g4 and g5 (see Figure 1).

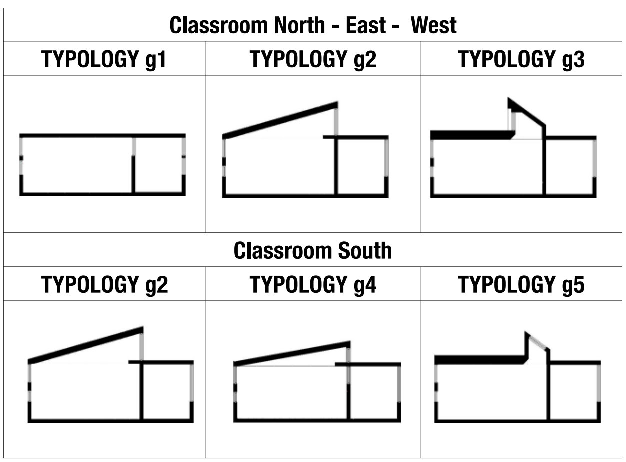


Figure 1: Typologies to be optimized.

DESIGN STRATEGIES

These are architectural solutions that are feasible in every project that was considered for the optimization proposals. In the selected typologies, the redesign of their daylighting strategy was carried out so that it does not block the view to the outside through the viewing window and the sunlight protection elements were considered as fixed. For this study, the use of mobile sunlight protections was not considered.

Optimization for North-facing Classrooms: Three typologies were intervened in order to control and protect it from direct sunlight penetration, with the purpose of reducing the high illuminances produced in the critical areas. The typologies are intervened as follows:

- The high window is protected in a bid to reduce the illuminances and luminances coming through it from the sky, placing an external element on its top, i.e. an external overhang. The proposed dimension of it is 0.5m wide, placed along the length of the high window;
- The viewing window is protected during the critical periods, by placing an external overhang over it. This is 0.8m wide similar to the height of the window;
- We aimed at blocking the direct sunlight penetration coming from the high window, protecting the students seated right under it, by placing a 0.5m wide internal lightshelf.

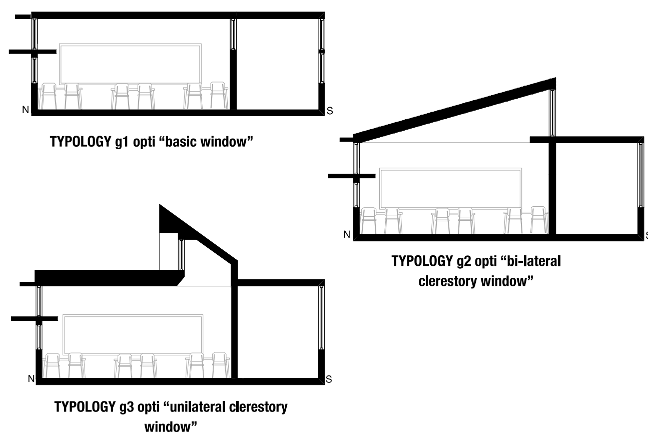


Figure 2: Sectional cut of North-facing typologies

Optimization of South-facing Classrooms: The proposed typologies were adjusted in order to achieve an optimal solution. These typologies were intervened as follows:

- In typologies g2 and g4, we propose to protect the Northern window to reduce the high illuminance in the critical area and in the central area of the classroom. The elements that make up the clerestory window were protected with a 0.6m external projection.
- In typology g2, the type of glass of the Northern clerestory window was modified, proposing a diffuse glass with a visible light transmittance (VT) equal to 50%.
- In typology g5, we increased the skylight area by 50%, meaning it went from $1m^2$ to $1.5m^2$. We considered the use of a diffuse glass with VT=50% to protect the area under the skylight.

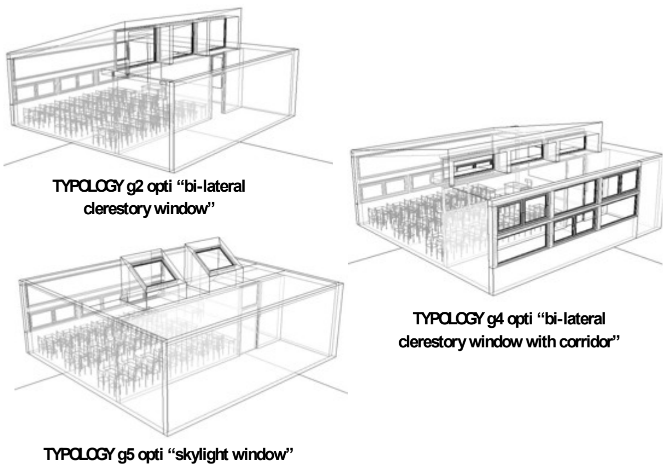


Figure 3: 3D models of South-facing typologies.

Optimization for East and West-facing classrooms: For the optimization of these typologies, the architectural interventions proposed are the same for both of them. We searched for the *adequate daylighting levels* because none of the verified typologies achieved them. In the East-facing typologies, we aimed to reduce the high illuminance, which occurred during the mornings of the critical periods. In the West-facing typologies, we aimed to reduce these high illuminances obtained during the afternoons of the same periods. Typologies g1, g2 and g3 were intervened as follows:

- In typology g1, the high window was protected with a 0.8m overhang. The view window was protected with a 0.8m external overhang and with vertical elements of the same dimensions.

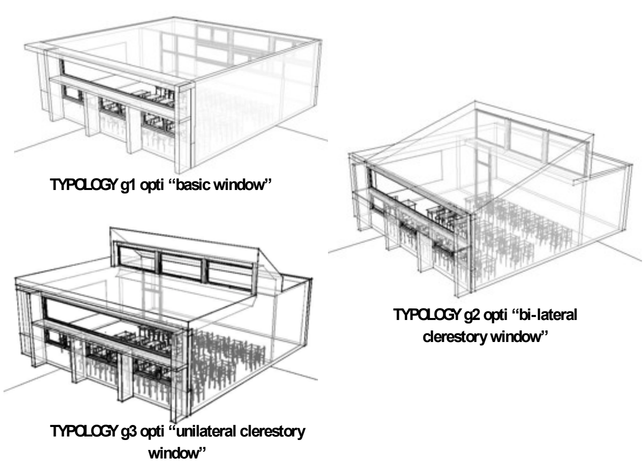


Figure 4: 3D models of East and West-facing typologies.

- In typologies g2 and g3, we used an external overhang and vertical elements to protect the low window. For the high facade window and the clerestory window, we used a diffuse glass, with visible light transmitted (VT) equal to 50%.

RESULTS FROM THE ANALYSIS

As explained above, the analysis is based on the fulfilment of the aforementioned visual comfort criteria, which allows for the qualitative comparison of the lighting conditions of the classrooms. These criteria and their objectives are explained in the introduction of this document.

After the simulations were carried out, with the design optimization proposals, we could see that, for the East and West-facing classrooms the optimal targets of the criteria were not achieved.

On the other hand, the optimal fulfilment of the proposed criteria was achieved for the North and south-facing classrooms, whose results are detailed below.

Results for North-facing classrooms: For typologies g1, g2 and g3 it was possible to demonstrate that, by placing horizontal elements to protect the high and view windows, we significantly improved the daylight in the classroom throughout the year while providing, in addition, the necessary protection for the critical periods, more specifically, in the winter period.

More specifically, we were able to achieve between 500 and 1500 lux, considered as adequate for the performance of visual tasks, for over half the year, covering over 60% and 75% of the whiteboard and classroom areas, respectively (see Table 1). In this way, what is considered as optimal for the first criterion was achieved.

As for the uniformity obtained, both in the whiteboard and work surface areas, we could see that the optimal ranges for the evaluation of uniformity were not achieved, obtaining results of between 0.5 -0.7, considered as adequate; therefore, the second criterion is not fulfilled.

Table 1: Comparison of percentages, summarizing the Horizontal Temporal Illuminance maps of the original and optimized North-facing Typologies.

Horizontal Illuminace temporal maps-North Optimized

TYPOLOGY g1		OPTI	TYPOLOGY g2		OPTI	TYPOLOGY g3		OPTI
Too Low	34%	36%	Too Low	32%	35%	Too Low	32%	35%
In range	42%	55%	In range	32%	59%	In range	25%	55%
Too high	24%	9%	Too high	37%	6%	Too high	44%	8%

In terms of visual comfort, evaluated considering the glare in the visual field, for typologies g1 and g2 it was possible to verify that the proposed architectural solutions were able to reduce the glare probabilities in the studied position in both cases. However, a glare risk can be identified in the winter period, between 8am and 2pm, which varied from 40% to 50%, with values under 30% for the rest of the year, which qualifies as imperceptible according to the rating scale proposed by Wienold [7].

Results for South-facing classrooms: It is worth mentioning that during the first evaluation, two typologies obtained the optimal targets for each criterion (typology g1 and typology g3).

After the optimization, the solution proposed for typology g2 was not completely efficient, achieving only a 22% reduction of high illuminances during the year. For typologies g4 and g5, on the contrary, optimal daylighting levels were achieved during the same period on the student's workplane (see Table 2). On the whiteboard, we could verify that all typologies obtained optimal daylight levels.

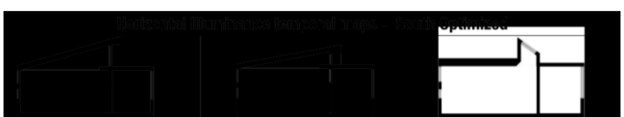
Upon examining the illuminance distribution in the classroom area, we could confirm that typologies g4 and g5 obtained an optimal spatial distribution of the light.

For typology g2, the area of the classroom with an adequate lighting was increased by 24%, though keeping high illuminances in the area near the windows.

In terms of the daylighting uniformity obtained, we could observe that they all maintain uniformity within the 0.5 – 0.7 range. In particular, in typology using diffuse glass, which helps preventing the contrast problems found, optimized g5 the uniformity.

Table 2: Comparison of percentages summarizing the Horizontal Temporal Illuminance maps of the original and optimized South-facing classroom Typologies

Horizontal Illuminance temporal maps - South Optimized



TYPOLOGY g2 Original		OPTI	TYPOLOGY g4 Original		OPTI	TYPOLOGY g5 Original		OPTI
Too Low	31%	34%	Too Low	32%	34%	Too Low	38%	36%
In range	33%	52%	In range	50%	55%	In range	54%	55%
Too high	36%	14%	Too high	18%	11%	Too high	8%	9%

For the glare issue, and since optimal solutions were present before this stage for typologies g2, g4 and g5, this criterion was not evaluated for said cases. For typologies g1 and g3, the student's visual comfort is achieved since there are no glare sources present in the studied visual field.

DESIGN RECOMMENDATIONS

The design recommendations are the synthesis of all the simulations carried out, whose objective is to provide recommendations that serve as a guideline for the architectural design that will make up the directives for classroom's daylight design.

In the design of the classroom's organization, three main daylit areas are considered: the critical area, the protected area and the workplane area. These areas present different daylight requirements, which are explained below:

a) Critical area: it is a stripe next to the perimeter protection facade of the workplane area. The classroom exposed to the incidence of direct sunlight, without lightshelves, must keep this protective stripe through a separation, with a proposed minimum of 1m. The objective is to prevent exposing the students to high illuminances and to sunlight penetration, which have an incidence on the visual comfort, provoking glare.

b) Protected area: its design must be focused on avoiding the penetration of direct sunlight and on controlling the variations on luminous intensity. The lighting strategies for this area must be differentiated of separate from the daylight strategy of the classroom.

c) Workplane area: this area must be protected from direct sunlight penetration through sunlight control elements. In the classrooms with sunlight incidence, the effectiveness of protection for the critical periods must be tested.

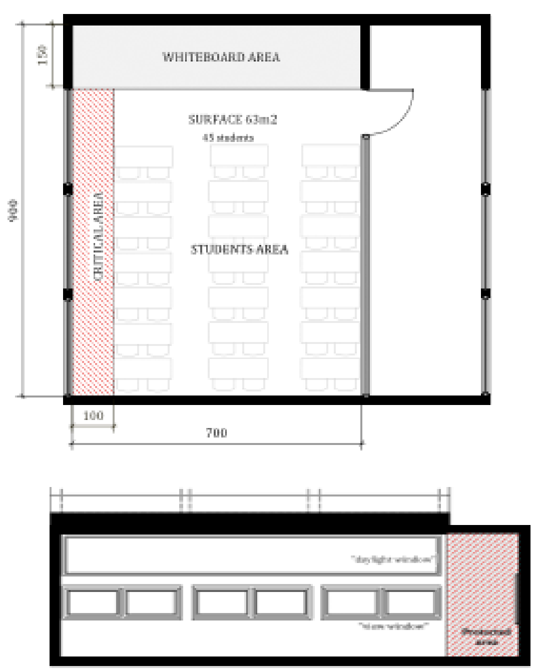


Figure 5: Classroom plans that portray the increase on the classroom surface, with and without critical area.

Starting from that applied in the typologies, we recommend conceiving, for these areas, a main window with two stripes of windows. The first one located at eye level, to generate a view towards the outside, becoming the “view window”; and the second one at a higher level to maximize the daylight penetration in the classroom, becoming the “daylight window”.

Once this general organization is stated, we explain the design considerations to protect the facade window or the light collecting elements. They are based on those evaluated in this study. We have to remember that the view window’s protection was always thought as one that did not block the passage of light and the view to the outside; and that the high window was protected in order to control and reduce the high illuminances in the critical area. The recommendations are stated from the problematic to be solved and, then, the recommended elements. These problems are described below:

a) *Reducing the high illuminances in the perimeter of the critical area*: we could verify and prove the effectiveness of three architectonic elements applied to the Northern facade. They turned out to be effective, because the sunlight penetration is blocked in three of the four evaluated periods. Only in winter do we have direct sunlight penetration, period for which we must consider some sort of mobile protection, such as curtains, only for the view window. These elements are overhang daylight window, located on the top part as protection against direct sunlight radiation, reducing the sunlight contribution in the critical area; Interior lightshelf, that serves as protection from the incidence or direct sunlight coming from the high window and acts as a light diffuser, combined with the “overhang daylight window”, protecting the students located right under it; and overhang view window located on the view window, its dimension must be equivalent to the height of the view window. It is an efficient protection to achieve the visual comfort of the students located in this perimeter.

b) *Reducing the high illuminances in the central area:* when using the lighting strategies such as the “clerestory window”, we could prove the effectiveness of applying an exterior overhang (of 0.6m), in the North-facing classrooms with unilateral strategies and in the South-facing classrooms with bilateral strategies.

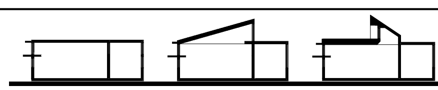
c) Stopping the direct radiation through the glass: it includes the reduction of the luminous transmission coefficient of the glass. We recommend not using simple glass since they have a direct incidence on the obtained lighting levels. In any unprotected window, a low luminous transmission coefficient glass must be used. We recommend a Double or low E glass (VT=70%). This was applied and tested in the Northern facade of the optimized classrooms.

When selecting a daylight strategy, we must prioritize those that allow accessing as deep as possible with the light, and that allow for the reduction of the glare probabilities. With respect to the daylight strategies, we recommend the following:

a) For the North-facing classrooms, we recommend those strategies with bilateral orientation similar to the “bilateral clerestory window” of typology g2 (see Figure 6). We proved that the aforementioned, together with the due protection of the Northern window, provides excellent results.

b) For the South-facing classrooms, we recommend the use of unilateral orientation strategies, similar to the “unilateral clerestory window” of typology g3 (see Figure 7). These strategies ensure the visual comfort of the students.

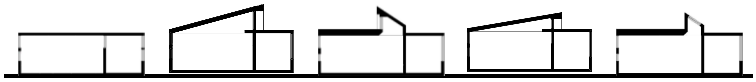
Is we decide to use a bilateral orientation strategy (South–North), we must consider the indicated sunlight protections.



	Design criteria	Typology g1 Opti Basic and corridor	Typology g2 Opti Clerestory bi-lat window	Typology g3 Opti Clerestory uni-lat window
1	Daylight Levels workplane	○○	○○	○
	Daylight distribution	○○	○○	○○
	Daylight Levels whiteboard	○○	○○	○○
2	Daylight uniformity workplane	○	○	○
	Daylight uniformity whiteboard	○	○	○
3	Low glare	○	○	N.E

Extremely good application	○○
Good application	○
Poor application	⊙
Extremely poor application	⊙⊙
Mixed benefits	○/⊙
Not evaluated	N.E

Figure 6: Criteria for daylighting strategies in North-facing classroom



	Design criteria	Typology g1 Basic and corridor	Typology g2 Opti Clerestory bi-lat window	Typology g3 Clerestory uni-lat window	Typology g4 Opti Clerestory bi-lat and corridor	Typology g5 Opti Skylight
1	Daylight levels workplane	○○	○	○○	○○	○○
	Daylight distribution	○○	○	○○	○○	○○
	Daylight levels whiteboard	○○	○○	○○	○○	○○
2	Daylight uniformity workplane	○	○	○○	○○	○
	Daylight uniformity whiteboard	○○	N.E	○○	○	N.E
3	Low glare	○○	N.E	○○	N.E	N.E

Figure 7: Criteria for daylighting strategies in South-facing classroom

CONCLUSION

In relation to the design of daylighting strategies and their integration, we conclude that:

The visual comfort of the students will be reached if we achieve a solution, with the daylight strategies, that prevents direct sunlight penetration. Therefore, the design will be a consequence of the application of strategies that achieve a diffuse light inside the classroom without harming the levels and distribution of the light, which must be kept in time and through the different seasons of the year.

The daylight strategies should consider, in their design, a critical area in relation to that defined for each orientation and consider, for all the cases, a protected area (whiteboard area).

- In relation to lighting distribution and uniformity, those with a double contribution of daylight have been found more efficient. Typology g2 (bi-lateral clerestory window) and typology g3 (uni-lateral clerestory window), which were the least favorable ones at the beginning, provided good results after the sunlight penetration was controlled and regulated, for North and South-facing classrooms.

In relation to indirect light contribution, the classrooms following typology g1 (basic window) were the most favorable ones for all orientations. This allows us to conclude that the light contribution from the corridor is favorable to achieve an adequate lighting for the students working in the area farthest from the window.

In relation to the least advisable recommendation, we found the East and West-facing classrooms to be the most unfavorable ones due to the limited sunlight control they provide. The intervention of these classrooms with the incorporation of fix sunlight protections may lead to a reduction of the light levels necessary for the critical periods. It is more advisable to consider the use of mobile sunlight protections that allow for a regulation of the light necessary, which can become a new matter of study.

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