Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 74 -89
https://doi.org/10.22320/07190700.2022.12.01.05

Recibido 28/02/2022
Aceptado 25/05/2022

OPTIMIZATION OF CLASSROOM DESIGN: USE OF NATURAL LIGHT FOR VISUAL COMFORT IN VILLA MARÍA, ARGENTINA[1]

OPTIMIZACIÓN DEL DISEÑO DE AULAS: APROVECHAMIENTO DE LA LUZ NATURAL PARA CONFORT VISUAL EN VILLA MARÍA, ARGENTINA

David Salomón
Arquitecto, Proyectista, Secretaría de Planificación Técnica, Servicios y Mantenimiento, Universidad de Villa María (UNVM), Córdoba, Argentina
https://orcid.org/0000-0003-4029-7737
arqdavidsalomon@gmail.com

Sofia Avalos Ambroggio
Arquitecta, Docente de Cátedra, Facultad de Arquitectura Urbanismo y Diseño (FAUD-UNC), Universidad Nacional de Córdoba, Córdoba, Argentina
https://orcid.org/0000-0002-1520-5389
sofia.avalos@unc.edu.ar

1 This work was carried out in the framework of the Integrating Final Project of the Architectural Technology Specialty (ETArq) of the Faculty of Architecture, Urbanism and Design, National University of Córdoba, Argentina (FAUD-UNC).

RESUMEN

El presente trabajo aborda la problemática de la iluminación natural en edificios educativos, enfocándose en el estudio de estrategias de iluminación natural que contribuyan a alcanzar niveles recomendados de confort lumínico dentro de las aulas, correcta distribución de luz y reducción de deslumbramiento. Se analizó, en ese marco, un edificio del campus de la Universidad Nacional de Villa María, Córdoba, Argentina, en el que se evaluó el comportamiento de iluminación natural usando modelos de simulación y mediciones *in situ*. La labor se complementó evaluando el índice Daylight Glare Probability (DGP): verificando ocurrencia de deslumbramiento. El diagnóstico mostró exceso de iluminación en puntos cercanos a aberturas, iluminación insuficiente en puntos lejanos a las mismas, niveles bajos de uniformidad en la distribución de iluminación natural y umbrales intolerables de deslumbramiento. Consiguientemente, se propuso un nuevo ordenamiento del aula, incorporando elementos para la redirección de la luz solar y se verificó su desempeño. Los resultados de la propuesta evidenciaron importantes diferencias. Se consiguió una importante reducción de niveles de iluminación, alcanzando niveles de confort visual para aulas (300-500 lux promedio), mejoras en la uniformidad de luz natural, con su consecuente verificación según los estándares y una reducción significativa de niveles de deslumbramiento por penetración solar directa.

Palabras clave
iluminación natural, confort visual, deslumbramiento, edificios educativos.

ABSTRACT

The present work addresses the problem of natural lighting in educational buildings, focusing on the study of natural lighting strategies that contribute to reaching recommended levels of lighting comfort in classrooms, correct light distribution and glare reduction. In this framework, a building on the campus of the National University of Villa María, Córdoba, Argentina, was analyzed in which the behavior of natural lighting was evaluated using simulation models and in situ measurements. The work was complemented by evaluating the Daylight Glare Probability (DGP) index: verifying the occurrence of glare. The diagnosis showed excess lighting at points close to openings, insufficient lighting at points far from them, low levels of uniformity in the distribution of natural lighting and intolerable glare thresholds. Consequently, a new arrangement of the classroom was proposed, incorporating elements for the redirection of sunlight and its performance was verified. The results of the proposal showed important differences. A significant reduction in lighting levels was achieved, reaching levels of visual comfort for classrooms (300-500 average lux), improvements in the uniformity of natural light, with its consequent verification according to standards, and a significant reduction in glare levels due to penetration direct sun.

Keywords
use and management, occupancy, occupant behavior, thermal comfort, bioclimatic strategies

INTRODUCTION

The possibility of accessing daylight inside educational buildings is considered one of the most determining physical characteristics of a classroom (Phillips, 1997). Numerous authors agree that quality daylighting inside educational spaces not only favors the comfort of its occupants but also has a direct impact on teaching and learning activities, as well as on the academic performance of students (Gonzalo, Ledesma, Nota & Márquez, 2001; Heschong, Wright & Okura, 2013; Robles Machuca, 2014, among others). Meanwhile, the absence of quality daylighting can cause fatigue and psychophysical stress, affecting people's moods (Muñoz Núñez, 2010). It follows, then, that light conditioning, which includes quality daylighting in spaces intended for education, is a fundamentally important requirement.

In Argentina, the IRAM-AADL Standards constitute the regulatory framework of recommendations for energy efficiency and light comfort in institutional buildings. Law N°19587 on Health and Safety in the Workplace, regulated by Decree N° 351/79 (Chapter 12 "Lighting and Color", Articles 71 to 84, and Addendum IV), includes requirements for minimum lighting values tabulated in the IRAM AADL J20-06 (2017) Standard and establishes calculation procedures for average illuminance and lighting uniformity, together with admissible values. Likewise, the Superintendency of Occupational Hazards (SRT, in Spanish), of the Ministry of Labor, Employment, and Social Security, outlines procedures for measuring lighting in built spaces (SRT Resolution 84/2012).

However, the regulations and protocols on this issue are limited. The IRAM-AADL Standards are for guidance only and their application is voluntary, and there is no official body that checks the compliance with the requirements of Law 19.587. In this way, the objective of including design premises and strategies for lighting comfort falls on the will of professional design teams. The literature on the subject points out that, during the development stage of a project, designers must determine availability parameters and the selection of appropriate daylight data that will be used as a basis in the design proposal (Gonzalo *et al.*, 2001; Pattini, 2000). Nevertheless, there are few planning teams in charge of developing educational building projects that have suitable tools, with an established procedure to simulate the behavior of daylighting-associated indicators or specialized consultancies on the subject, so it is very difficult to foresee the future performance of the projected building.

As a result, many buildings have problems of little or no daylight penetration during working hours or even have excessive penetration of sunlight and glare issues. This leads to seeking ways to counteract the negative effects, often by using interior curtains that block the entry of daylight, or by complementing the lack of light with artificial lighting during daytime hours, which throws away the benefits of daylighting and increases the energy consumption of the building.

This study was carried out jointly with the Secretariat of Technical Planning, Services, and Maintenance of the University of Villa María, Córdoba, Argentina. The objective is to analyze the performance of an educational building and propose improvement alternatives to achieve the recommended levels of light comfort inside classrooms, incorporating passive solar energy strategies.

DAYLIGHTING IN EDUCATIONAL BUILDINGS

Both light comfort standards and the proposal of design recommendations to incorporate daylight in educational buildings have been the subject of study by different institutes and research organizations. In Chile, the Chilean Energy Efficiency Agency (AChEE, in Spanish) developed the Energy Efficiency Guide for Educational Establishments, *GEEEduc* (CITEC-UBB, 2012), which includes design strategies for the incorporation of daylight in educational spaces and recommendations to achieve visual comfort inside classrooms. Likewise, Piderit & Bodart (2012) propose design criteria for classroom organization, establishing areas with different lighting requirements. In the same vein, other studies present design strategies to optimize daylight in offices (Piderit & Bodart, 2012; Palarino & Piderit, 2020) and classrooms (Callejas, Pereira, Torres &Piderit, 2020).

In Argentina, the Infrastructure Directorate of the National Ministry of Education (DIMEN, in Spanish) establishes conditions and requirements for habitability in school buildings in the document "Basic Criteria and Regulations of School Architecture" (DIMEN, 1998). One of the basic objectives of building design focuses on "ensuring daylight and ventilation conditions as the main solution" (DIMEN, 1998, p. 57). This document proposes design strategies in terms of recommended orientations and dimensioning of openings. There are also several studies on the use of daylighting in buildings, some focused on the re-functionalization of built workspaces, whether classrooms or offices, using daylight (Ferrón, Pattini & Lara, 2010); classroom design strategies (Pattini,

Indicator	Ranges					
Mean illuminance (lux)	Insufficient	Deficient	Recommended	Excess light	Discomfort	[1]
	< 200	200 - 300	500 - 750	2000 - 5000	> 5000	
Uniformity of illuminance	Insufficient	Deficient	Acceptable	Good	Required	[2]
	< 0.2	0.2 - 0.3	0.3 - 0.4	0.04 - 0.05	> 0.5	
Glare (DGP) (%)	Imperceptible	Perceptible	Bothersome	Intolerable		[3]
	DGP < 34%	34% <DGP< 38%	38%<DGP<45%	45% < DGP		

Table 1. Daylighting indicators considered in this work. Source: Preparation by the authors based on [1] Callejas et al., (2020); Decree No. 351/79, DIMEN (1998); [2] Callejas et al. (2020); Decree No. 351/79; [3] Wienold and Christofferen (2006).

2009; Cisterna *et al*, 2015), controlling lighting levels and daylight distribution in classrooms (Hoses, San Juan, Melchiori & Viegas, 2001; Pattini & Kirschbaum, 2006); opening protection devices to avoid direct solar radiation (Ledesma *et al.*, 2004; 2005, Monteoliva, Villalba & Pattini, 2014); the use of light trays (Gonzalo *et al.*, 2001; Casabianca & Evans, 2003), and glare control (Pattini *et al.*, 2009).

DAYLIGHTING INDICATORS

Daylighting of indoor work or reading spaces should be diffuse, uniform, and have low contrast indices (Pattini *et al.*, 2009). The illuminance level (E) refers to the amount of luminous flow emitted by light sources, and that vertically or horizontally reach the surfaces (Robles Machuca, 2014). The indicator proposed by the Protocol of SRT Resolution 84/2012 to measure Illuminance is Mean Illuminance (Em). This protocol also proposes calculating the Uniformity of illuminance (U). This indicator complements illuminance analysis since it makes it possible to detect situations where the average for the mean Illuminance value masks horizontal illuminances below the acceptable value (Pattini *et al.*, 2009). Educational spaces require a suitable level of illuminance to ensure a relatively high uniformity of illumination (U) in the work area.

Glare is one of the most influential indicators of visual comfort (Monteoliva, Garretón, & Pattini, 2021). The Daylight Glare Probability (DGP) prediction model, developed by Wienold and Christofferen (2006), is considered one of the most accurate models for studying glare inside built spaces. It is defined as the probability of visual discomfort perceived by an occupant, due to differences between very dark and very bright areas, caused by direct solar penetration of a light source or excess lighting levels in an indoor environment (Palarino & Piderit, 2020). The permissible ranges of mean illuminance, daylight uniformity, and DPG are summarized in Table 1.

METHODOLOGY

Currently, the National University of Villa María (UNVM) is immersed in the transformation process of its campus, following the guidelines of the "Towards a Sustainable University City" Program (UNVM, 2019), which includes a strategic development master plan, the "UNVM Infrastructure Master Plan 2020-2021", led by the Secretariat of Planning, Technical, Services, and Maintenance (SPTSyM, in Spanish). One of the Program's goals is "to get to know and analyze the physical conditions and comfort levels presented by the buildings built on campus, to propose interventions that help improve working conditions in classrooms." (SPTSyM, 2020, p. 17). In this context, this work proposes evaluating the classrooms of one of the buildings to verify the daylighting indicators and propose improvement alternatives. The methodology used in this study (Figure 1) is presented below.

1. SELECTION OF THE CASE STUDY

A classroom was chosen that met the following criteria: 1. A classroom whose assessment was required within the SPTSyM Infrastructure Master Plan; and 2. A classroom that was considered as "standard", in the sense that the results of the evaluation could be extrapolated to other classrooms.

Following this, a building was chosen, "Institutos II- Rector Carlos Domínguez", which was originally

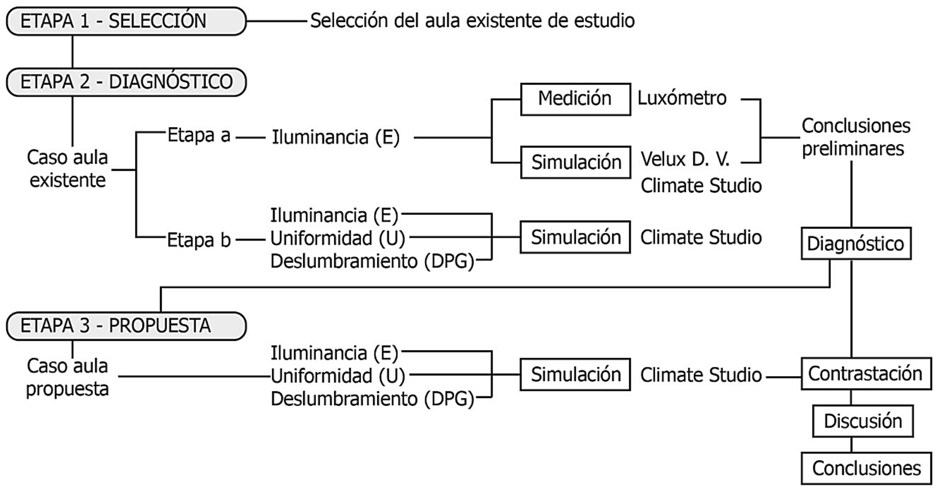

Figure. 1: Proposed methodology. Source: Preparation by the authors.

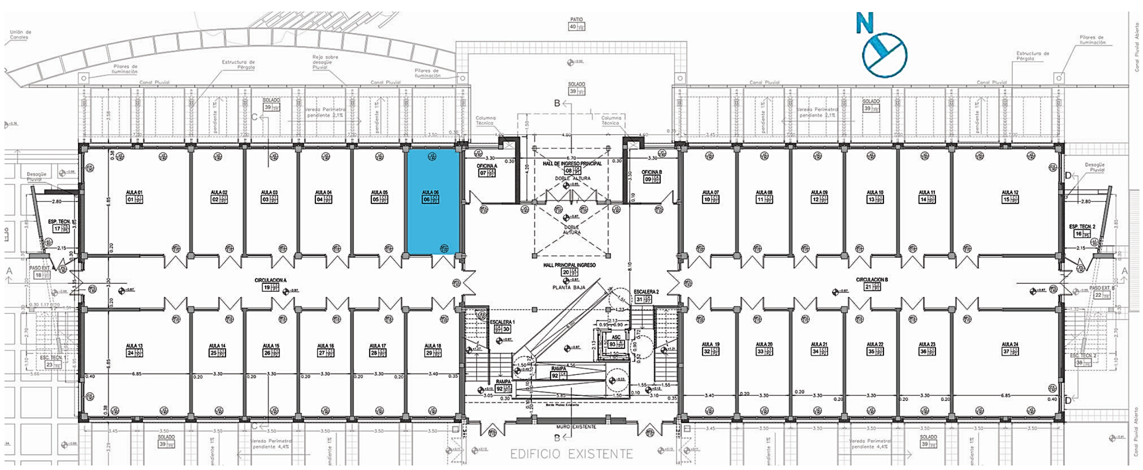

Figure 2: Selected classroom. Ground floor of the building “Institutos II”, UNVM. Source: Technical file of the building “Institutes II”, SPTSyM, UNVM.

Figure 3. Selected classroom. a) Interior view at the back of the classroom. b) Interior view to the front of the classroom. c) Interior view with closed curtains. d) Exterior view of the classroom - north facade. Source: Preparation by the authors.

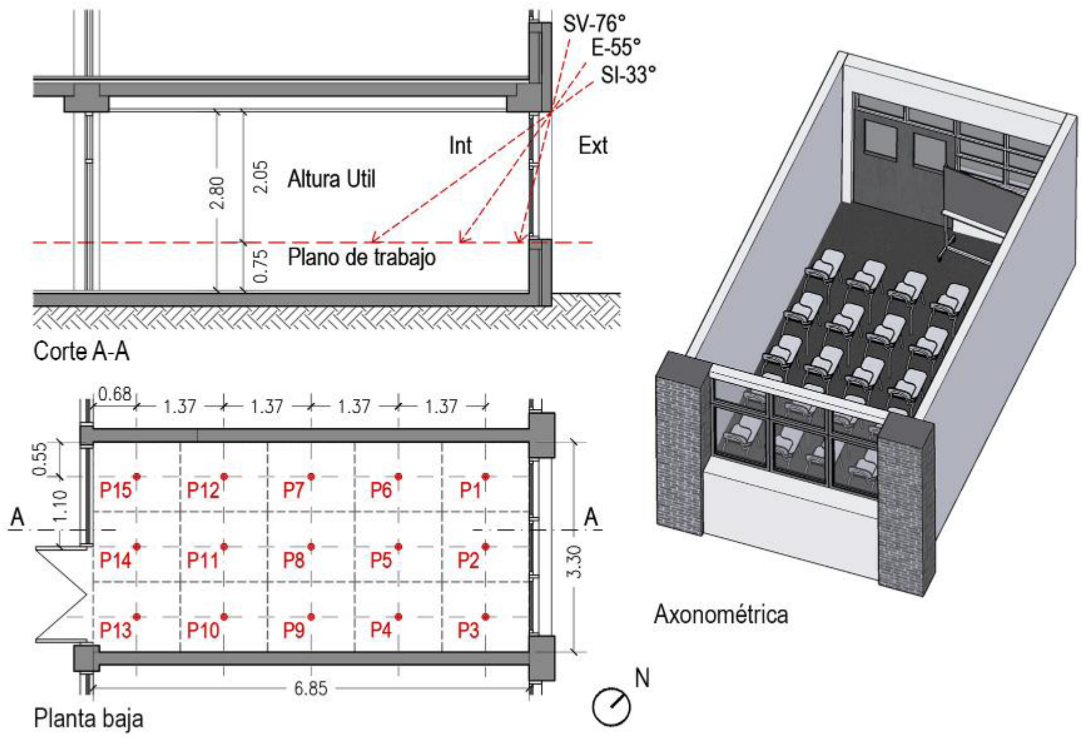

Figure. 4. Plan, cross-cut, and axonometric of the existing classroom with measurement and simulation points. Source: Own preparation.

designed as an administrative office building. The lack of physical space for teaching meant that the ground floor box offices were used as classrooms. The analyzed space is shown in Figures 2 and 3.

The chosen classroom is rectangular, measuring 6.85m x 3.30m. One of the short sides is an outside wall, which has an opening divided into 3 sections, facing north and without exterior protections. The whiteboard area is located next to the door; therefore, the opening is set at the back of the classroom, with its back to the desks. The opening has blackout curtains, which are closed when the classroom is in use (Figure 3).

2- DIAGNOSTIC STAGE.

Stage a

In the first stage, a preliminary exploratory study was made, which pursued two objectives. The first consisted in determining lighting levels of the existing classroom, comparing data obtained through two methods, onsite measurements and simulations, and using two pieces of lighting simulation software: Velux Daylighting Visualizer, developed by the Velux windows company, and Climate Studio, developed by Solemma as a plugin for Rhinoceros 3D, which uses the Radiance calculation engine.

Then, the data obtained were compared to appreciate if they yielded consistent results. It was decided to carry out this study on August 28th, 2019, between 9 am and 1 pm. Both the onsite measurements and the use of simulation software were carried out by architects working in UNVM's Planning area, that is to say, the process involved a previous training stage. Once the consistency of the data obtained was determined, the second objective was to evaluate which strategy (measurement or simulation) and which software (Velux or Climate Studio) best fit the daily work process followed by the Planning architects, to suggest a method to be used in future project processes.

The measurements were made following the procedure described in the "Lighting Measurement in the Work Environment Protocol" (SRT resolution 84/2012). The analyzed classroom was divided into a grid of 5 x 3 areas, resulting in 15 measurement points, one point for each desk, located at a height of 0.75m from the finished floor level (Figure 4). The measurements were made using a previously calibrated luxmeter. Data were collected once per hour, at 10 am (with cloudy sky), at 11 am (with intermediate sky), and at 12 pm and 1 pm (with clear sky). The simulations were configured using the same grid and height of points, to contrast the results with the measured data.

Stage b

Once both pieces of software were tested, it was determined that Climate Studio had a closer fit to the measurements, and its use was user-friendly for Planning architects. Stage 2 then focused on assessing

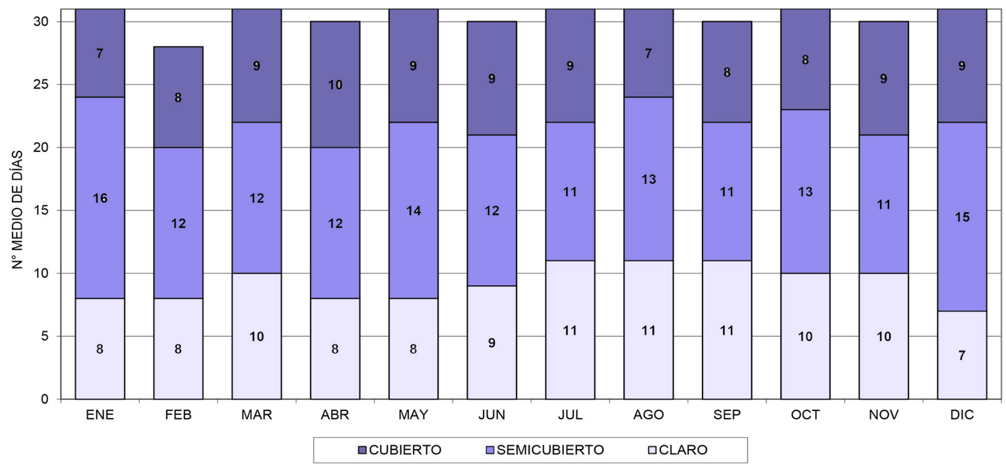

Figure. 5. Percentage of types of sky (overcast, partly cloudy, and clear) throughout the year. Source: Airport Weather Station data included in Gonzalo (2015).

Type of Surface	% Reflex.	Color			Spec.	Roughness
	R	R	G	B		
Walls (White Painted Room)	81.19%	0.830	0.808	0.719	0.36	0.200
Floor (Blue Carpet)	6.44%	0.037	0.07	0.300	0.01	0.300
Ceiling (White Painted Room)	82.20%	0.844	0.817	0.722	0.44	0.200
Equipment (Wood Laminate Table)	50.92%	0.603	0.471	0.304	1.41	0.100
Equipment Structure	47.21%	0.456	0.452	0.428	2.07	0.100
Whiteboard (Green Door Panel)	24.10%	0.211	0.254	0.202	0.17	0.200
Carpentry (White Aluminum)	78.24%	0.745	0.773	0.767	1.72	0.200
Light tray (Whiteboard Paint)	94.42%	0.895	0.897	0.867	4.99	0.010

Table 2. Levels and uniformity of illuminance in the existing classroom. Intermediate sky. Source: Preparation by the authors.

the lighting conditions of the chosen classroom based on the variables and indicators presented in Table 1: illuminance, uniformity of illuminance, and glare (DGP), using just the Climate Studio simulation software.

The simulated values correspond to an intermediate type of sky, predominant in Villa María. Figure 5 shows the monthly percentages of each type of sky during the months of the year (overcast, partly cloudy, and clear). The predominant skies are the partly-cloudy or intermediate ones.

Table 2 illustrates the types of surfaces used in the simulations, with their respective coefficients (Reflection [R], RGB Color Indices, Specularity, and Roughness). The materials presented were used both in the existing and the proposed classroom.

The points grid prepared previously was maintained and it was chosen to assemble a grid that contained simulated data for 3 months of the year and 3 times of the day. The months of March, July, and November were chosen, as these mark the start and end of the class periods. Data were simulated at 9 am, 1 pm, and 5 pm, following the teaching schedule. The results were compared with permissible ranges of mean illumination and uniformity of daylight, found in Addendum VI Decree 351/79 (Law No. 19,587).

The method selected to simulate glare was the Daylight Glare Probability (DGP). To define the evaluation point, the most unfavorable location that an observer could have inside the classroom was considered. In the case of the existing classroom, it was the position of the teacher sitting in front of the whiteboard (1.15 cm from the floor level), since to address the students they must look towards the window.

The range of light comfort parameters considered to analyze the results was: Illuminance between 500 and

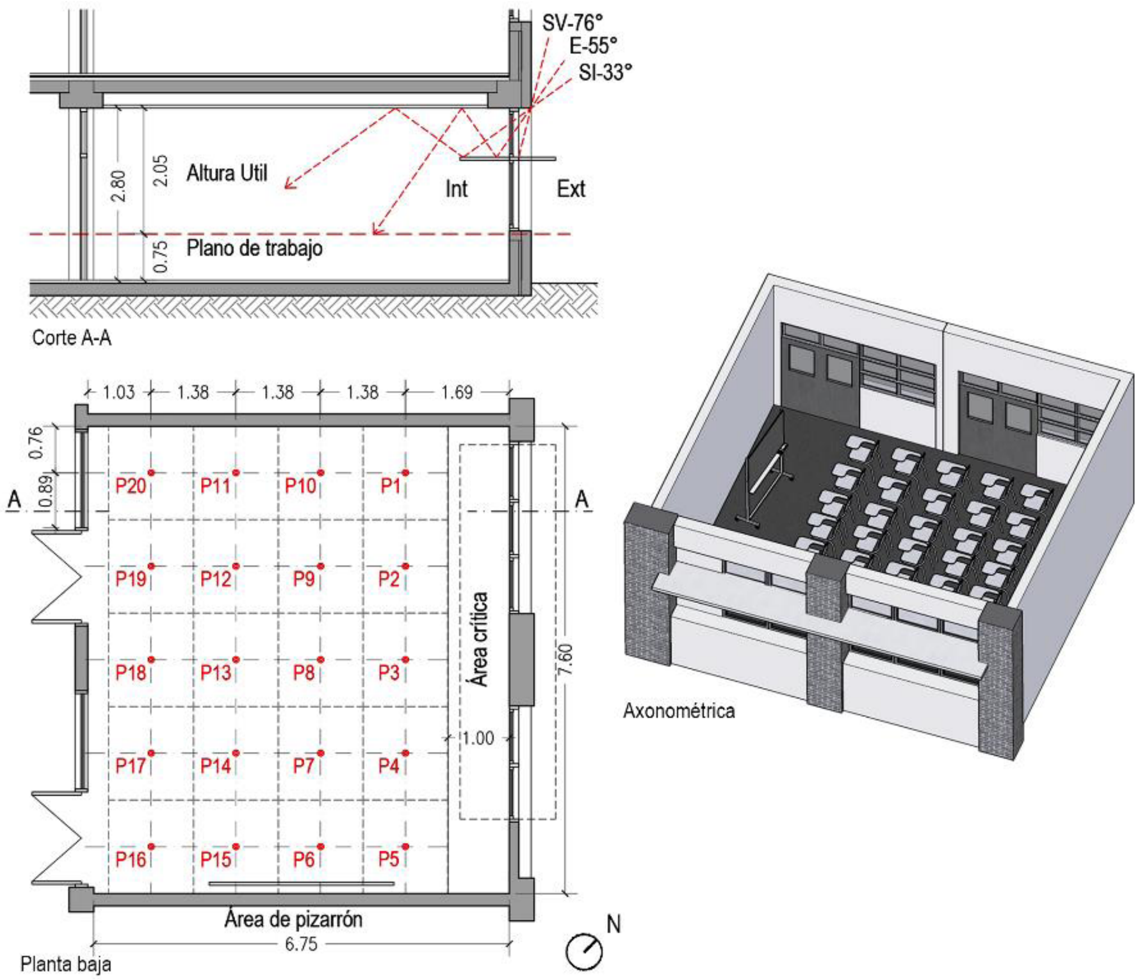

Figure 6. Plan, cross-section, and axonometric of the proposed classroom with measurement and simulation points. Source: Preparation by the authors.

750 lux levels (minimum and recommended levels for classrooms according to DIMEN, 1998, respectively); Uniformity of illuminance > 0.5 (according to the requirement of Decree No. 351/79); and a margin of glare perceptible up to 38% (levels established by Wienold & Christofferen, 2006).

3. PROPOSAL STAGE

This stage involved the elaboration and evaluation of an optimization proposal based on the diagnosis made, using the same indicators as those in the diagnostic stage, to assess the improvements.

It was considered that the building is already built, therefore, the proposed alternative had to feasibly be executed and easy to implement. The proposal is described below and detailed in Figure 6.

1. It was proposed to dismantle the partition wall between classrooms, combining two spaces to form a larger square classroom, with a greater opening to the outside.
2. The whiteboard location was moved to one of the side partitions of the classroom. In addition, it was proposed to protect the whiteboard area from direct solar penetration by replacing one of the glazed panels of the existing opening with a blind panel.
3. Changes were made in the desk layout, leaving a strip of 1.00 m from the outer wall (critical area) to avoid excess light values and visual discomfort on the work planes. With the new arrangement of the whiteboard, the openings are arranged to the left of the desks.
4. A light shelf was placed, dividing the existing opening into two vertical panels, to reflect the incident light towards the surface of the ceiling, thus achieving a greater light penetration and a more uniform distribution.

As in the diagnostic stage, to define the glare assessment point, the most unfavorable location that an observer could have inside the classroom was considered. After changing the whiteboard's location, the most unfavorable position is no longer that of the teacher, but that of a student sitting on the left side of the classroom, facing the whiteboard.

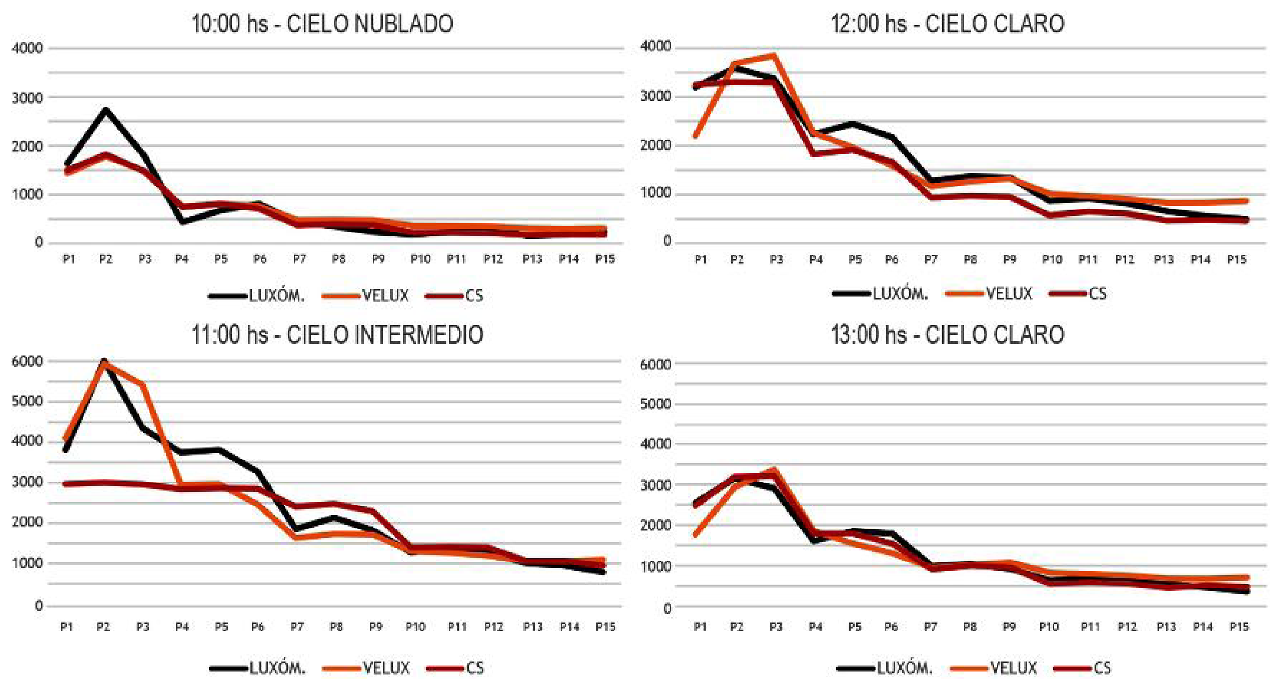

Figure 7 Comparative graphs between measured and simulated results. Source: Preparation by the authors.

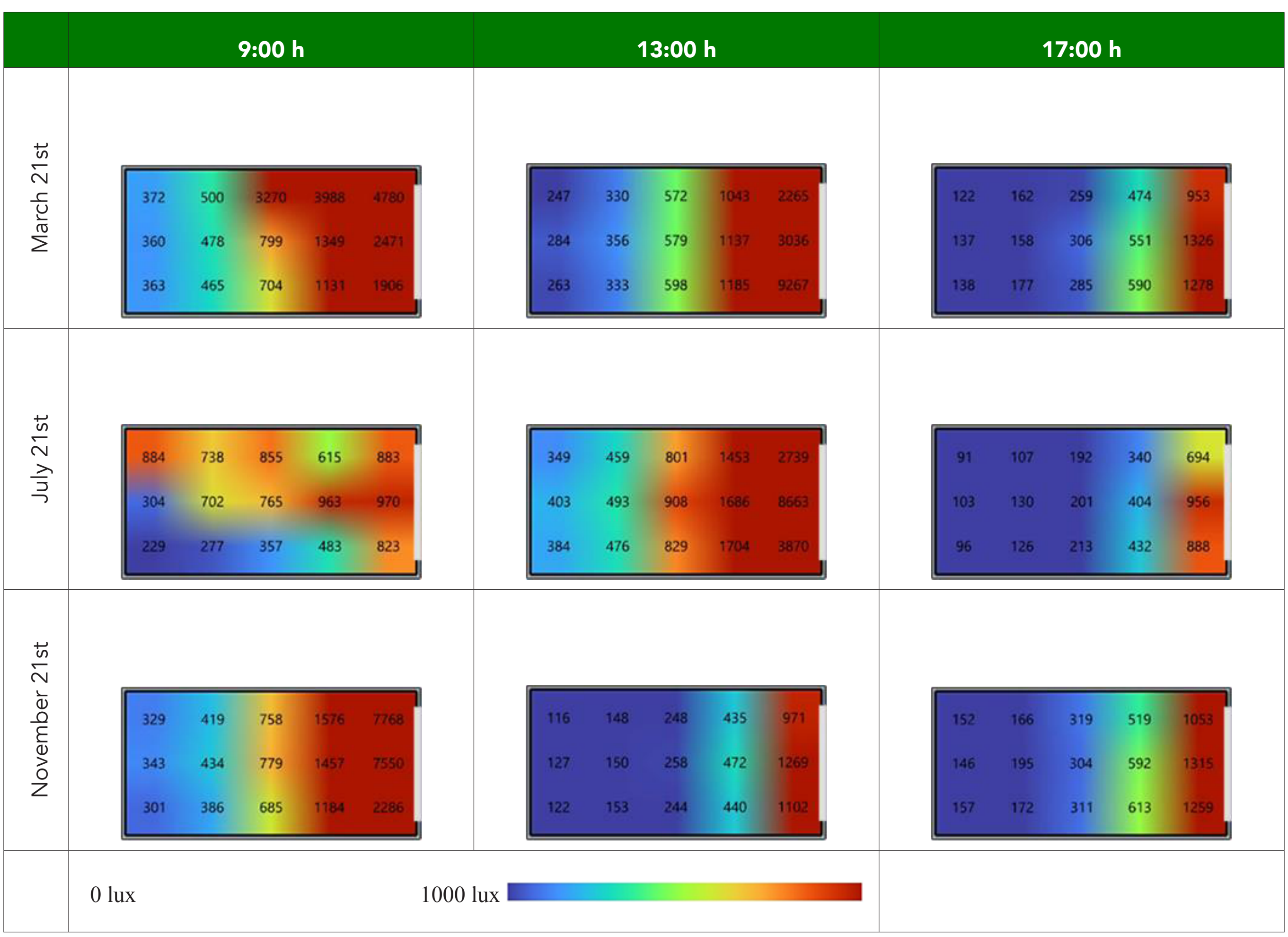

Figure 8. Lighting levels in the existing classroom. Intermediate sky. Source: Preparation by the authors

	March 21st			July 21st			November 21st		
	9:00	13:00	17:00	9:00	13:00	17:00	9:00	13:00	17:00
P-1	4780	2265	953	883	2739	694	7768	971	1053
P-2	2471	3036	1326	970	8663	956	7550	1269	1315
P-3	1906	9267	1278	823	3870	888	2286	1102	1259
P-4	1131	1185	590	483	1704	432	1184	440	613
P-5	1349	1137	551	963	1686	404	1457	472	592
P-6	3988	1043	474	615	1453	340	1576	435	519
P-7	3270	572	259	855	801	192	758	248	319
P-8	799	579	306	765	908	201	779	258	304
P-9	704	598	285	357	829	213	685	244	311
P-10	465	333	177	277	476	126	386	153	172
P-11	478	356	158	702	493	130	434	150	195
P-12	500	330	162	738	459	107	419	148	166
P-13	372	247	122	884	349	91	329	116	152
P-14	360	284	137	304	403	103	343	127	146
P-15	363	263	138	229	384	96	301	122	157
Emáx.	4780	9267	1326	970	8663	956	7768	1269	1315
Emin.	360	247	122	229	349	91	301	116	146
Emed.	1529.1	1433.0	461.1	656.5	1681.1	331.5	1750.3	417.0	484.9
Un	0.24	0.17	0.26	0.35	0.21	0.27	0.17	0.28	0.30

Table 3. Levels and uniformity of illuminance in the existing classroom. Intermediate sky. Source: Preparation by the authors.

RESULTS

DIAGNOSIS OF THE EXISTING CASE

Diagnosis: Stage a

Firstly, the results of lighting levels in the existing classroom, obtained by measurement and simulation, are presented comparatively (Figure 7). It can be seen that the simulated values are true to the values measured with a luxmeter. At 11 am, the intermediate sky condition shows a greater difference between the simulated and the measured results.

It is confirmed that the values obtained by Climate Studio are closer to the measurements than those obtained using Velux DV. This is because Climate Studio has a more accurate calculation engine.

The points closest to the window (P1 to P3) register values of more than 1000 lux in the four times analyzed, exceeding the recommended ranges and reaching, in some cases, points of visual discomfort (>5000 lux). All the points measured and simulated at 11 am have excess light values (> 1000 lux) for the considered range (between 500 and 750 lux). As the points move away from the window, the lighting level decreases. Points P4 to P7 show results close to the visual comfort range at 10 am (400 to 600 lux). However, from 11 am to 1 pm there is excess light (1000 to 2000 lux). The points that are in the middle of the classroom (P7 to P12) reach levels close to visual comfort at 12 pm and 1 pm. At the furthest points, P13 to P15, at 10 am, the illumination decreases to insufficient levels (<200 lux).

Diagnosis: Stage b

Next, the results of the evaluation of the indicators studied during 3 moments of the year are presented. Regarding lighting levels, the grid of Figure 8 and Table 3 shows lighting level results for the 3 months and simulated times.

A relationship with previous results is seen here: very high levels of Emax at points near openings, close to 9200 lux in the early hours of the morning (due to

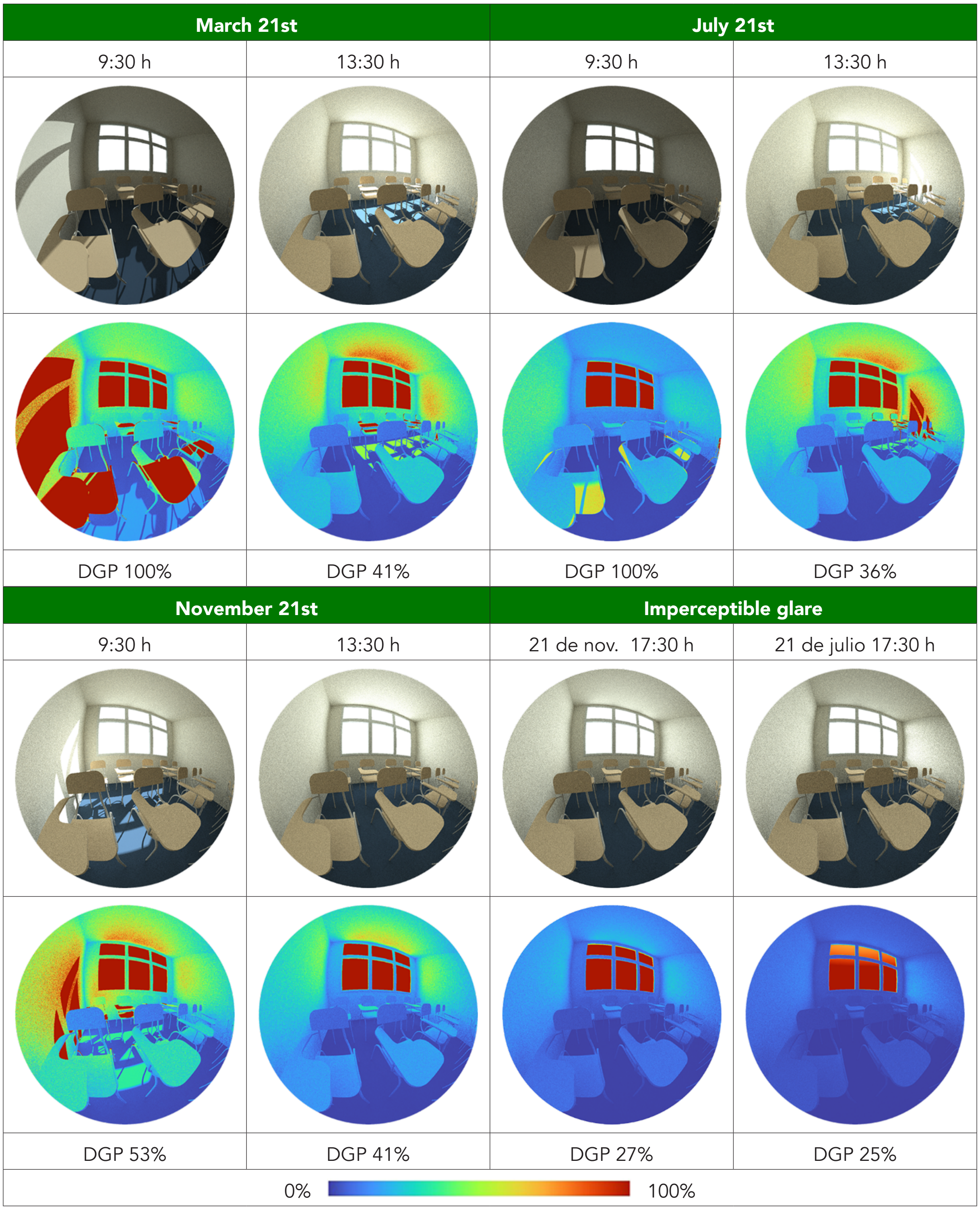

Figure 9. DPG glare values (%) of the existing classroom. Source: Preparation by the authors

direct solar penetration), which decrease during the day until reaching 1300 lux at 5 pm. The Emin values corresponding to the other end of the classroom show a significant reduction in illuminance, reaching levels of less than 300 lux at the same time.

As for uniformity in the daylight distribution, the values are, in all cases, below 0.5, i.e., none of them meet the established requirements. Only one of the cases (July at 9 am) has an acceptable uniformity. In general, the light uniformity is poor, as there are very bright spots and very poorly lit spots.

GLARE

Figure 9 expresses the results of the DGP index (%). It can be noted from this that the results are consistent with the previous illuminance values. The probability

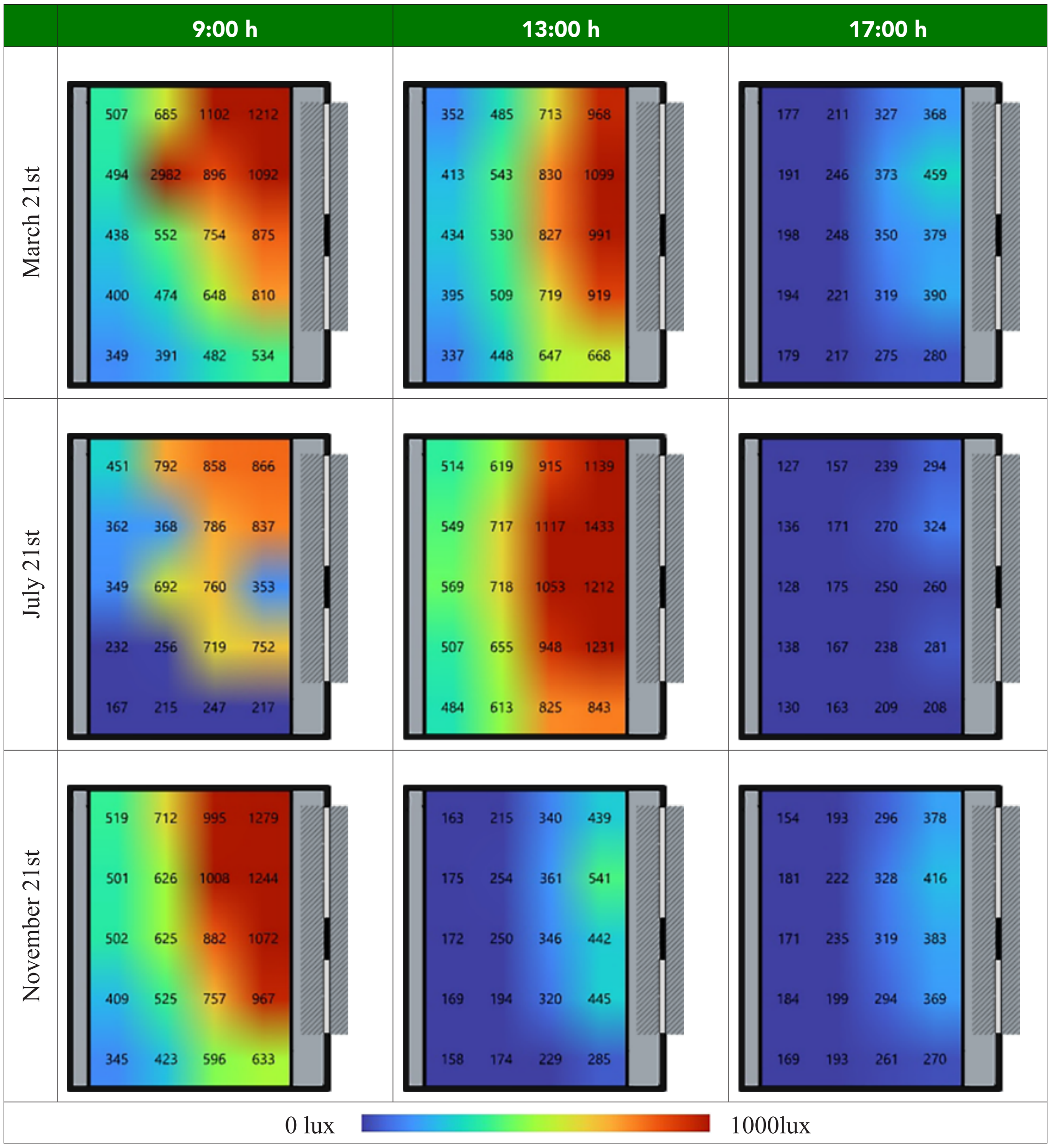

Figure 10. Lighting levels in the proposed classroom. Intermediate sky. Source: Preparation by the authors

of glare is highest during the morning in all cases, reaching peaks of 100% (intolerable) on March 21st and July 21st at 9:30 am, at times of direct solar penetration. This situation also coincides with the higher illuminance values and the low light distribution levels.

From 1:30 pm, the values begin to decrease. On July 21st, glare is noticeable according to the established ranges (36%). However, both March 21st and November 21st continue to present bothersome values (41%). At 5:30 pm, in all cases, the occurrence of glare is imperceptible, registering values of 29% (March 21st), 25% (July 21st), and 27% (November 21st).

PROPOSED CASE

LIGHTING LEVELS

The grids of Figure 10 and Table 4 show the lighting level results of the proposed classroom. On one hand, a considerable reduction in Emax can be observed, with values between 500 and 1000 lux, close to the openings, presenting a peak of 2962 lux on March 21st at 9 am. This happens because the light tray obstructs direct solar penetration.

The points in the sectors furthest from the openings have values between 350 and 510 lux during the morning in

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 74 -89
https://doi.org/10.22320/07190700.2022.12.01.05

	March 21st			July 21st			November 21st		
	9:00	13:00	17:00	9:00	13:00	17:00	9:00	13:00	17:00
P-1	1212	968	368	866	1139	294	1279	439	378
P-2	1092	1099	459	837	1433	324	1244	541	416
P-3	875	991	379	353	1212	260	1072	442	383
P-4	810	919	390	752	1231	281	967	445	369
P-5	534	668	280	217	843	208	633	285	270
P-6	482	647	275	247	825	209	596	229	261
P-7	648	719	319	719	948	238	757	320	294
P-8	754	827	350	760	1053	250	882	346	319
P-9	896	830	373	786	1117	270	1008	361	328
P-10	1102	713	327	858	915	239	995	340	296
P-11	685	485	211	792	619	157	712	215	193
P-12	2962	543	246	368	717	171	626	254	222
P-13	552	530	248	692	718	175	625	250	235
P-14	474	509	221	256	655	167	525	194	199
P-15	391	448	217	215	613	163	423	174	193
P-16	349	337	179	167	484	130	345	158	169
P-17	400	395	194	232	507	138	409	169	184
P-18	438	434	198	349	569	128	502	172	171
P-19	494	413	191	362	549	136	501	175	181
P-20	507	352	177	451	514	127	519	163	154
Emáx.	2962	1099	459	866	1433	324	1279	541	416
Emin.	349	337	177	167	484	127	345	158	154
Emed.	782.9	641.4	280.1	514.0	833.1	203.3	731.0	283.6	260.8
U	0.45	0.53	0.63	0.32	0.58	0.62	0.47	0.56	0.59

Table 4. Levels and uniformity of lighting in the proposed classroom. Intermediate sky. Source: Preparation by the authors.

March and July, reaching levels of visual comfort. It will be necessary to reinforce with artificial lighting in November at 1 pm and in the 3 months at 5 pm because the values are low (< 300 lux).

The uniformity in the daylight distribution registers an increase in all values, except in July (9 am), which shows a minimum decrease (from 0.35 to 0.32). The lowest uniformity values occur at 9 am (0.45 in March, 0.32 in July, and 0.47 in November), and are very close to the requirements established in Argentina (0.5). Even so, they are considered acceptable in the presented range. As of 1 pm, the uniformity registers results above 0.5 in all cases.

GLARE

The glare results of the proposed classroom are shown in Figure 11.

The results obtained are consistent with the reduction of illuminance values and the increase of uniformity in the daylight distribution. The glare probability also shows a significant reduction during the morning in all cases. Despite this, the values still correspond to the bothersome glare range with 44% (March 21st), 39% (July 21st), and 35% (November 21st). From 1:30 pm, the values are located in the range of perceptible (31% in March and July) and imperceptible (29% in November and all cases at 5:30 pm) glare.

Revista Hábitat Sustentable Vol. 12, N°. 1. ISSN 0719 - 0700 / Págs. 74 -89
https://doi.org/10.22320/07190700.2022.12.01.05

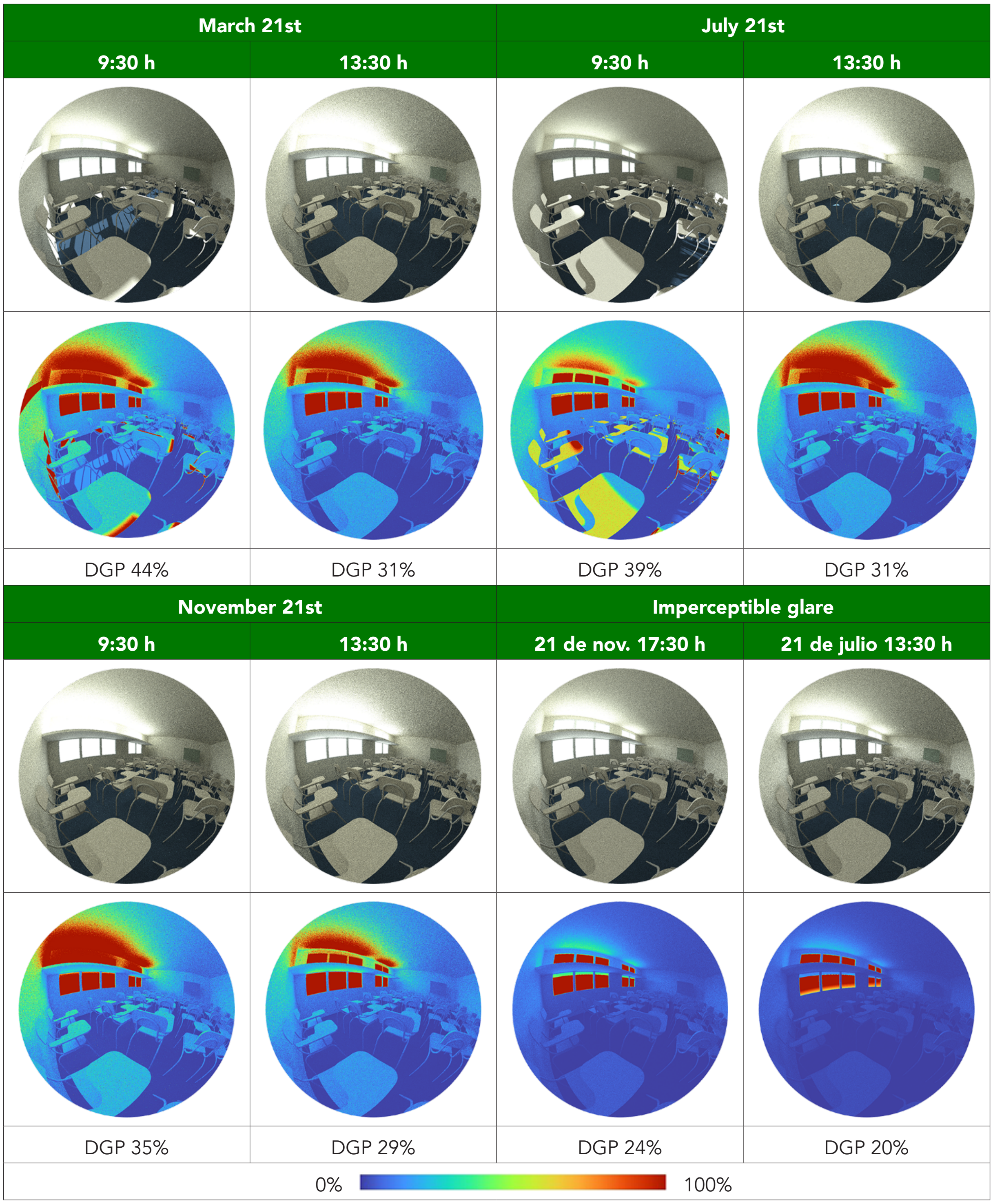

Figure 11. DPG glare values (%) of the proposed classroom. Source: Preparation by the authors.

DISCUSSION

The functional layout of the existing classroom is inefficient. The points with the highest level of illumination are found at the back of the classroom, next to the window, and not in the focal point of the students' attention (whiteboard area). Therefore, at times when artificial lights are not on, the students cast a shadow on the work plane of the desk. Likewise, the direct solar penetration there is during the morning causes the desks next to the window to have excess light on the work plane, reaching values of visual discomfort. The results also showed that there are serious problems of glare that a person looking at the window would have, namely, compromising the work performance of the teacher who looks at the desks from the whiteboard area.

The proposed alternative involved significant improvements in the classroom. The proposed desk layout prevents students from casting shade on the work plane, and the teacher from looking towards the windows when teaching. The incorporation of a light tray made it possible to block direct solar radiation, preventing its incidence on the work planes, which significantly improves illuminance values near the window. In addition, the reflective surface of the tray allowed reflecting incident light into the classroom, allowing a more uniform distribution of lighting inside the classroom. Although significant reductions were achieved, there is still room for improvement. The lighting uniformity values are still low (<0.50) and the glare values express the perception of some discomfort during the morning (44% and 39%). Table 5 summarizes the results obtained and comparatively presents them, to show the improvements achieved.

CONCLUSIONS

This work aimed at identifying passive design strategies to achieve recommended levels of indoor light comfort in educational buildings. The results obtained show the achievement of the goals set out. Added to this, the results have the benefit of potential electricity saving from using daylighting, which can be quantified in subsequent studies.

The discussion of the results indicates that they can continue to be optimized, especially during morning hours. In future studies, it may be proposed to incorporate interior roller-type curtains with sunscreen fabrics, which act as diffusing screens, to achieve a more uniform illuminance and avoid bothersome glare. In the same way, the results obtained can be considered in the design, to integrate daylighting with artificial lighting, in the choice of suitable types of lights.

Both the performance of the existing classroom, the design of alternatives, and the preview of results were possible thanks to the use of measurement and simulation tools and procedures, which allowed training professional architects from SPTSyM - UNVM in the management of daylighting-associated indicators and their inclusion within design practices. The Climate Studio software was chosen over the Velux Daylight Visualizer Software, given its easy operation, its better graphical interface, its extensive library of materials, and a better fit of its results to the measurement values. These tools and work procedures will be taken into account in the development of future projects.

ACKNOWLEDGMENTS

Their authorities, Mariana Gatani Ph.D., and Gabriela Sánchez M.A are also thanked. In addition, thanks are given to Carlos Azócar, Secretary of Technical Planning, Services, and Maintenance of the UNVM, Córdoba, Argentina, and his entire team, who with their skills and experience contributed to making this study.

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	Indic.	March 21st			July 21st			November 21st		
		09:00	13:00	17:00	09:00	13:00	17:00	09:00	13:00	17:00
AE	E max	4780	9267	1326	970	8663	956	7768	1296	1315
	E min	360	247	122	229	349	91	301	116	146
	E med	1529.1	1433.0	461.1	656.5	1681.1	331.5	1750.3	417.0	484.9
AP	E max	2962	1099	459	866	1433	324	1279	541	416
	E min	349	337	177	167	484	127	345	158	154
	E med	782.9	641.4	280.1	514.0	822.1	203.3	731.0	283.6	260.0
AE	U	0.24	0.17	0.26	0.35	0.21	0.27	0.17	0.28	0.30
AP	U	0.45	0.53	0.63	0.32	0.59	0.62	0.47	0.56	0.59
AE	DGP	100%	41%	29%	100%	36%	25%	53%	41%	27%
AP	DGP	44%	31%	23%	39%	31%	20%	35%	29%	24%

Table 5. Comparative analysis between the existing and proposed classroom. Source: Preparation by the authors.

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