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Acoustic and Luminous Performance Evaluations in Classrooms in Curitiba, Brazil

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Key Words
School buildings · Luminous comfort · Acoustic comfort · Daylighting · Acoustic treatment · Computer simulation

Abstract
This study is part of a standardized project in public schools in the Brazilian State of Paraná and analyzes acoustic and luminous qualities in classrooms. The acoustic analysis, conducted by measurements of background noise, reverberation time, and sound insulation, reveals the poor acoustic quality of the classrooms. Acoustic simulation results suggest the need for perforated plywood underneath the ceiling to reduce reverberation time and increase the overall acoustic comfort of the classrooms. The luminous performance analysis is based on computational simulations with daylighting programs for different combinations of days, schedules, and solar orientation of the buildings. Results show daylighting levels for various positions of the building. This allows the designer to choose the best way of siting the building with respect to aspects of the locality and the resulting quality of the indoor space. Finally, shading elements are designed for each orientation in order to improve daylighting levels and the building's overall thermal performance.

Introduction

The relationship between education, technology, and employment has intensified to the extent that the educational level of a person determines one's entry point and ultimate position in society. In Brazil, finding a place in a public school is generally limited to the available school quotas, without taking into account the quality of the educational conditions offered in all their aspects. However, one of the most important issues of education is related to the environmental comfort of the classrooms, since the physical characteristics of the room itself have

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direct implications on the quality of the relations established in school buildings; problems that may compromise the interaction needed between students and teachers and that, in turn, affect the social and professional development of the students. In recent years, Brazil has been constructing public schools through the means of a standardized project, repeated irrespective of local climatic conditions. The main purpose of this study was to evaluate both the acoustical and the visual qualities of classrooms in a standard project of the Brazilian public school system to see if they met basic comfort requirements.

In order to evaluate the acoustic quality of classrooms, three acoustical parameters were investigated: background noise level, reverberation time, and sound insulation. As the classrooms studied were built lacking any absorbent materials in their interior, simulations were performed in order to evaluate the correct placement of absorbent materials on room surfaces. The simulated materials, gypsum board, plywood, and perforated plywood, were tested to calculate their influence on reverberation time.

The luminous performance analysis was based on computer simulations of different lighting situations. In the first stage, the impact of different siting possibilities was tested. Siting is one of the most important issues for planning a new school building that may later allow an appropriate use of daylight, to improve or diminish solar exposure (thermal effect), and also permits the treatment of possible noise and pollutant sources. This stage took into consideration different orientations of the building for the optimal use of daylighting. Daylighting levels were analyzed and, in a second step, appropriate shading devices were designed in order to minimize the possibility of classroom overheating.

Description of School Building Type – Standard 023

The school building type evaluated – named Standard 023 – is widely used in the Public School Network in the Brazilian State of Paraná, located in southern Brazil. Designed for use in public schools, it consists of classrooms oriented to both sides of a central corridor. Classrooms are ≈7 m long (façade) and 7 m wide with a ceiling height of 3.1 m (Figure 1). Walls separating the corridor and the classroom have a ventilation opening and permanent lighting through transparent bricks. The maximum capacity of each classroom is around 40 students.

Each classroom has two windows (3.40 × 1.50 m) and its walls are made of conventional brick masonry, painted in light colors. The reinforced concrete ceiling is painted white and the floor is covered with ceramic veneer in light colors. The classrooms analyzed had an internal area of ≈50 m and the window-to-wall ratio (WWR: net glazing area to gross exterior wall area) was equivalent to 0.40 (Figures 2 and 3).

Fig. 1. Example of a classroom – Standard 023.

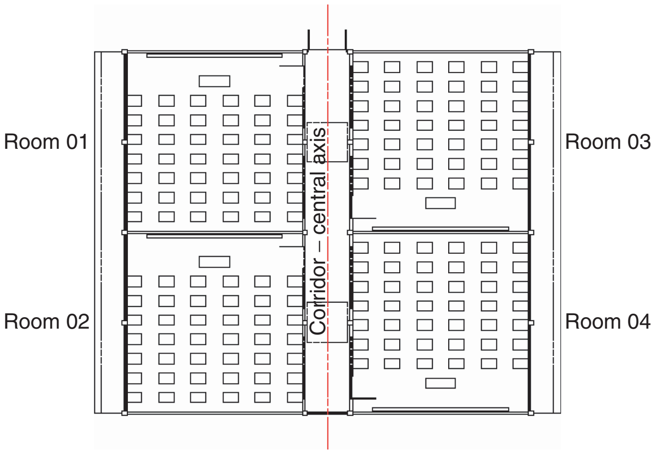

Fig. 2. Floor plan – Standard 023.

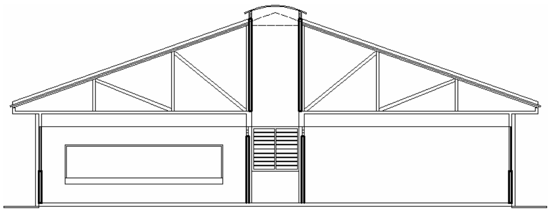

Fig. 3. Cross section – Standard 023.

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Climatic Region

The Brazilian State of Paraná has a population of 10,387,378 inhabitants distributed over an area of 199,800 km^2. Two climate types can be identified in this region, according to Köppen's system: (a) subtropical climate type (Cfa), characterized by a monthly temperature average below 18°C in winter and above 22°C in summer, with a concentration of rain storms in summer but without any definite dry season; and (b) temperate climate type (Cfb), characterized by a monthly temperature average below 18°C in winter and below 22°C in summer, with mild summer periods and no defined dry season.

The latitude range of the State lies between 23° S and 26° S, which is relatively small, so that conclusions regarding daylighting potentials can be extended for the entire region.

It was verified that although Standard-023 was adopted in many cities in the State of Paraná, it is in Curitiba and in its Metropolitan Area that this school type is most concentrated, thus helping to determine the choice of Curitiba (25° 31′ S, 917 m elevation) as a reference for daylighting analyses (for the acoustic evaluations, the school monitored was also located in this city). For the calculation of appropriate shading elements regarding the aspect of thermal comfort, monthly temperature averages were used in order to assess comfort conditions. In this study, the adaptive approach originally proposed by Nicol and Humphreys [1] was used for establishing ideal operating temperatures. The adaptive approach goes under the assumption that "if a change occurs such as produces discomfort, people reach for ways which tend to restore their comfort". For naturally ventilated buildings, ASHRAE Standard 55 suggests an alternative for the PMV-based method for establishing a comfort zone. Optimum comfort temperature T_{comf} is therefore calculated based on the monthly mean ambient temperature $T_{\mathrm{a,out}}$ [2]:

$$T_{\mathrm{comf}} = 0.31 \times T_{\mathrm{a,out}} + 17.8. \quad (1)$$

The comfort range for 90% acceptability is 5°C and for 80% acceptability is 7°C. For the test reference year (TRY) of Curitiba, optimal operative temperatures are as presented in Table 1.

Recommended Limits for Background Noise and Reverberation Time

Background noise is one of the components that affect the acoustic comfort of classrooms. There are established recommendations limiting background noise in several countries, such as Brazil, France, Germany, United Kingdom, and the USA. Limiting levels for the indoor background noise are shown in Table 2 [3–5].

Reverberation time is an important parameter that interferes with the acoustic quality of a classroom. It is strongly dependent on: (1) room volume, (2) the sound frequency in the room, and (3) the total sound absorption in the room [6]. Many national and international recommendations include reverberation time limits, as shown in Table 3 [3–5].

Table 1. Optimal operating temperatures for Curitiba's TRY

Month	Comfort Operating Temperatures (°C)
Jan	24.2
Feb	24.2
Mar	23.9
Apr	22.9
May	22.3
Jun	21.9
Jul	21.7
Aug	22.0
Sep	22.6
Oct	22.2
Nov	23.4
Dec	23.3

Table 2. Background noise limits – equivalent continuous sound level LAeq (dB)

Country	Noise descriptor	Year of the definition	Classroom	Library
Brazil	L_{Aeq}	1987	40–50	35–45
France	L_{Aeq}	2002	38	33
Germany	L_{Aeq}	1987	30–40	30–40
USA	L_{Aeq}	2002	35–40	35–40

Table 3. Recommendations for reverberation time (RT) (furnished, unoccupied rooms)

Country	Reverberation time (s)
Brazil	$150 \leq V < 300\,m^3$, $0.5 \leq RT \leq 0.7$ (for 500–1000–2000 Hz)
France	$V \leq 250\,m^3$, $0.4 < RT < 0.8$ (for 500–1000–2000 Hz) $V > 250\,m^3$, $0.6 < RT < 1.2$ (for 500–1000–2000 Hz)
Germany	$0.8 < RT < 1.0$ (for 500–1000–2000 Hz)
USA	$V < 283\,m^3$, $RT = 0.6$; $283\,m^3 < V \leq 566\,m^3$, $RT = 0.7$ (for 500–1000–2000 Hz)

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Recommended Lighting Levels for School Buildings

In Brazil, lighting levels for an assortment of activities are recommended by the Brazilian Standard NBR 5413 [7], which establishes average illuminance for the purpose of designing indoor artificial lighting systems. In school buildings, recommended average levels for classrooms range between 200 and 500 lux. The planner should therefore specify the proper lighting level according to the average age of the users, overall room reflectance, and the velocity and precision required for the task involved. Generally, it is suggested that an average illuminance is adopted. In the present case, as the classrooms were used not only by children but also by adults, the highest illuminance was used as a reference. For the purpose of analysis, a variation around the adopted reference of 500 lux was applied. In the first stage, 30% above and below the adopted reference value were used in order to define the optimal range, as suggested by NBR 5413. However, due to the readings in the result charts generated by RADIANCE (minimal gradation of 200 lux in order to have a significant range in lighting levels for the evaluated classroom), the optimal range considered for the analysis was as follows:

$$\text{insufficient} < 300\,\text{lux} < \text{adequate} < 700\,\text{lux} < \text{excessive}$$

Acoustic Analysis – Measurements of Background Noise, Reverberation Time, and Sound Insulation

Four classrooms built according to the Standard-023 were evaluated. Reverberation time was measured for the following situations: (1) empty classroom, (2) classroom with 20 students, (3) classroom filled to the maximum capacity, i.e., 40 students.

Background noise in the classrooms (closed doors and open windows) was measured for the following situations: (1) measurement in room 03, while room 01 has normal ongoing class, and rooms 02 and 04 have children in silence, (2) measurement in room 03, while rooms 01, 02, and 04 conduct normal classes. Reverberation time was measured following ISO 3382 [8]. In all situations, room 03 remained empty and the other three rooms were filled to the maximum capacity of 40 students.

Background noise was measured in 10 positions around the school during a 5-min span for each position. The equivalent sound level L_{eq}, expressed in dB(A), was measured in five positions inside each classroom. Background noise was also measured in three positions inside the classrooms during a 5-min measurement period.

The weighted apparent sound reduction index [9] was measured for the wall separating the classroom from the corridor, which includes a door and transparent bricks.

The equipment used were from Brüel and Kjaer [10]: (1) sound analyzer BK 2260, (2) sound amplifier 2271, (3) sound source,(4) building acoustic software BZ 7204, (5) building acoustic software Qualifier 7830, and (6) sound level meter Mediator BK 2238. All measurements were carried out under ideal meteorological conditions (i.e., no wind or rain).

The classrooms studied here were built without any acoustical treatment. Simulations of the reverberation time were performed with BK ODEON Version 8.5, using different types of materials to investigate their effects on the reverberation time. The materials tested for the simulations were: (1) gypsum board, (2) plywood, and (3) perforated plywood.

Daylighting Analysis

As already mentioned, this study consisted of an analysis of daylighting potentials for different orientations of the school building according to Standard-023, with the aim of facilitating positioning of the school building. Evaluations were carried out by means of computer simulations. The building axis, defined by the central corridor, was rotated (N-S, E-W, NW-SE, NE-SW), and simulations for classrooms on both sides of the building were performed for summer and winter conditions, for three different hours of the day. Owing to the mirrored configuration of the school building, in many cases an unbalanced situation was observed in both classrooms with regard to daylight levels. Thus, for the purpose of analysis, next to the verification of prescribed lighting requirements, a second criterion was adopted: to avoid an uneven distribution of daylighting in the school building as a whole. The uneven pattern of daylight distribution resulted in the design of different shading devices on both sides of the building. Such shading devices were designed according to a procedure proposed by Olgyay and Olgyay [11], which takes into account the dates and hours when outdoor air temperature exceeds a reference comfort temperature. The reference comfort temperature suggested by these authors which when surpassed required that shading elements should be used on the façade analyzed (70°F (21.1°C) increased by 2.25°F (1.26°C) to account for a variation of the 40° N reference latitude), was substituted

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by the varying optimal operating temperatures of Table 1. Assuming that when overheating is present shading strategies may help alleviate discomfort, solar charts can be used for the periods of the year when overheating is liable to occur, in order to identify the shading angles (α, β, and γ) adopted in the shading devices (Figure 4).

Simulations were carried out using two programs: ECOTECT and RADIANCE. ECOTECT (version 5.20, Square One) was used in order to input the 3-D geometry of the school building and its orientation, define camera views of the classrooms, and perform simulations with overcast skies. In addition to this, geometric definitions, orientations, and camera views were exported to the RADIANCE Synthetic Imaging System (available free from Lawrence Berkeley Laboratories), which allowed the rendering of indoor lighting levels under overcast and clear sky conditions. In the present case, the Desktop RADIANCE 1.02 was used.

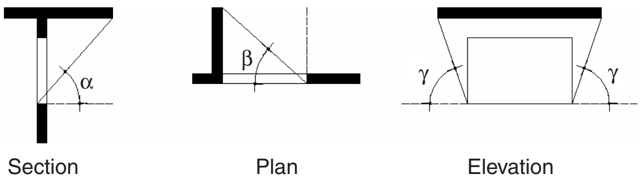

Fig. 4. Shading angles α, β, and γ.

For the daylighting simulations, various spots within the classroom at a height of 0.75 m (workplace), corresponding to positions of school tables, were tested for the dates of June 21st and December 21st (winter and summer solstices), for 3 h of the day: 9 am, 12 pm, and 3 pm. Individual illuminance ratings were identified in Isolux curves generated by RADIANCE, and were subsequently compared to recommended lighting levels (Figure 5). Computations considered five internal reflections of the incoming sun rays.

Daylighting evaluations were made for each classroom, within each axis orientation of the building (N-S, E-W, NW-SE, NE-SW), before and after shading devices were integrated onto the façades. The percentage of adequate school tables for each condition was used as an indicator of the overall luminous performance of the classroom.

Acoustic Analysis

The school, located on the outskirts of Curitiba, is in an area classified as residential, according to the government.

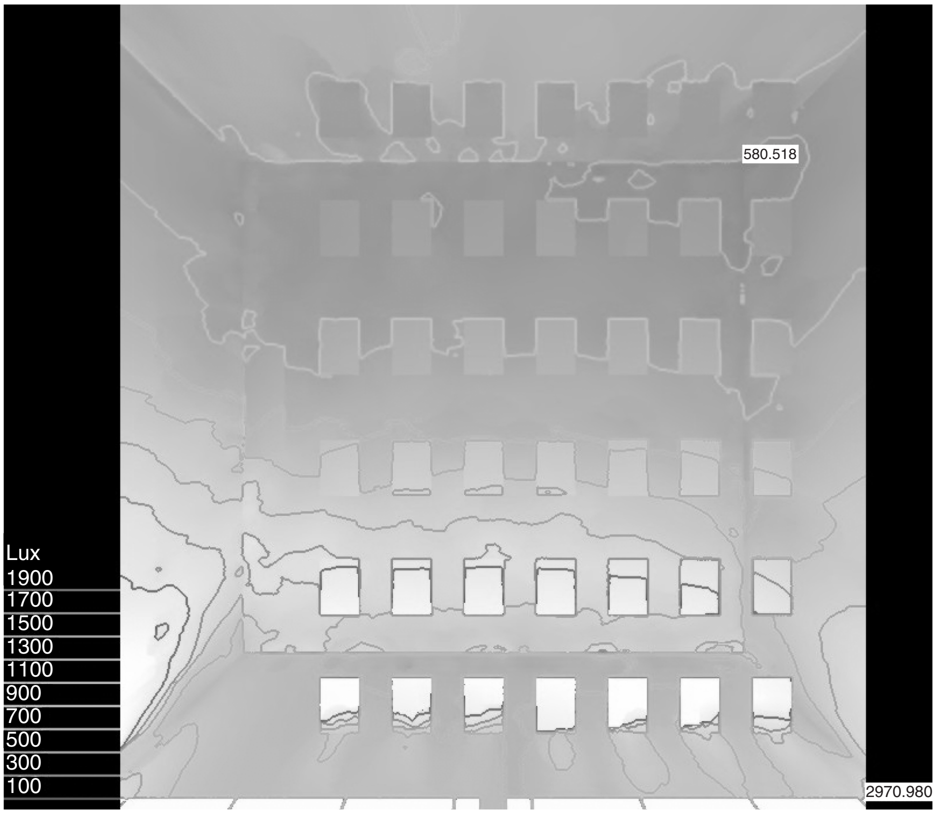

Fig. 5. RADIANCE image with Isolux curves.

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Local legislation establishes that the external background noise for daytime (7 am–7 pm) should not exceed 55 dB(A) [12]. The mean equivalent sound level for background noise was 53.5 dB(A), which means that the school is located in a quiet urban zone where the limit of sound emission is respected.

Background noise was measured in classroom 03, while room 01 had a normal class taking place, and rooms 02 and 04 were occupied, but with students and teacher in silence. The mean equivalent sound level measured at three positions in the room was $L_{eq} = 56.2$ dB(A). In another test, background noise was measured in room 03, while all other rooms had normal classes going on, which resulted in the measured L_{eq} 63.3 dB(A).

For both situations, background noise levels inside the rooms were above recommended limits, as shown in Table 1. Therefore, the classrooms evaluated could be considered uncomfortable based on this criterion. Another finding arising from the measurements was that the noise generated inside the other classrooms was responsible for the background noise inside the observation classroom number 03. It should be remembered that the school is located in a quiet zone. Therefore, background noise is not an environmental problem for this school; the school is a problem in itself.

The walls between the classrooms and the corridor have permanent ventilation openings through transparent bricks. The measured weighted apparent sound reduction index R'_W [9,13] for the wall, with a door and transparent bricks, was $R'_W = 17$ dB, which is considerably low.

The low value of the weighted apparent sound reduction index $R'_W = 17$ dB contributed significantly to the noise transmission from one room to the other, and in turn, contributed to the elevated levels of background noise inside the classrooms.

The required sound reduction index between a classroom and corridor in Germany is $R'_W = 52$ dB [14]. The recommendation of the Building Bulletin 93 – "Acoustic Design of Schools", from the United Kingdom [4], is a value of $R'_W = 55$ dB for the airborne sound insulation between corridor and primary/secondary classroom. However, in Brazil, there is no legislation for sound insulation with respect to exterior noise for classrooms and the internal sound insulation with regard to room function.

Table 4 shows the data on the measurements of reverberation times. As observed in Table 3, measured reverberation times were above the recommended limits.

The high reverberation times were an indication of the lack of absorbing materials inside the classrooms, resulting in poor acoustic quality. Reverberating environments affect the ability to concentrate and speech intelligibility, forcing teachers to speak louder. It also increases the background noise levels, which in turn hampers speech intelligibility even more. The Brazilian classroom evaluated only reached adequate reverberation times when the classroom was fully occupied, i.e., with 40 students.

Table 4. Reverberation times for classroom Standard 023 (furnished classroom)

Classroom 01	Reverberation time (s)		
	Octave band center frequency		
	500 Hz	1000 Hz	2000 Hz
Empty	1.7	1.7	1.4
20 students	1.2	0.9	0.9
40 students	0.8	0.7	0.6

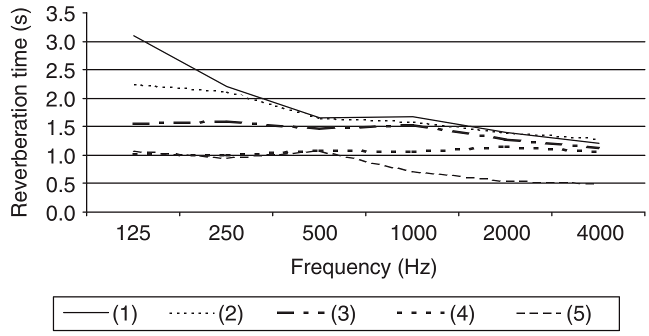

Fig. 6. Comparison between reverberation times: (1) ____ measured: ceiling without acoustic treatment, (2) ….. calculated: ceiling without acoustic treatment, (3) _._._ calculated with layer of gypsum 40 cm below ceiling, (4) - - - calculated with layer of plywood directly applied to ceiling, and (5) _ _ _ _ calculated with layer of perforated plywood directly applied to ceiling.

As demonstrated above, the classrooms evaluated were built lacking any acoustical treatment. In order to investigate the influence of a simple hypothetical acoustical treatment on the reverberation time inside these classrooms, placement of absorbing materials underneath the ceiling (gypsum board, plywood, and perforated plywood) was simulated, and the calculated reverberation times are shown in Figure 6.

It was clear that this procedure would have a significant positive influence on the reverberation times (Figure 6) and the best results were provided by plywood and perforated plywood. The use of perforated plywood would bring the reverberation times close to the values recommended by the Brazilian Standard for Acoustic Comfort in Closed Rooms, NBR 12179 [15] (Table 5). The acoustic treatment of the ceiling would render these classrooms considerably more acoustically comfortable.

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Table 5. Comparison between reverberation times (furnished and unoccupied classrooms)

Classroom 01	Reverberation time (s)		
	Octave band center frequency		
	500 Hz	1000 Hz	2000 Hz
Ceiling without acoustical treatment	1.7	1.7	1.4
Ceiling with perforated plywood	1.1	0.7	0.6

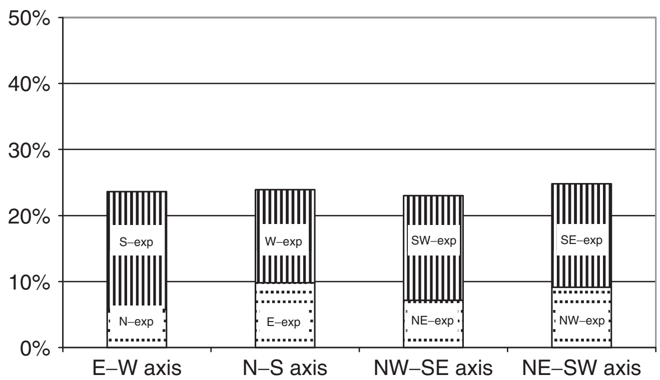

Fig. 7. Daily percentages of adequate workplaces and daylight distribution – clear sky conditions, without shading devices (columns show totals for both opposing exposures).

Results from the Daylighting Analysis

Consideration of both the above mentioned criteria for evaluating the overall luminous performance of the building (percentage of adequate workplaces and a balanced distribution of daylight in classrooms on opposing facades) can assist planners in choosing a more suitable orientation of the building, in order to avoid possible sources of noise or pollutants.

Graphically, it can be noticed that opposing façades do not allow the same daylight to be received. Figure 7 presents both the total of daily percentages of adequate workplaces during winter and summer, and the daylight distribution in both classrooms (in opposing orientations according to the diverse axes N-S, E-W, NW-SE, and NE-SW). For such conditions (without shading devices), orienting the school building according to a N-S axis allows a more even daylight distribution in classrooms with an east or west exposure.

The analysis showed that a disproportionate percentage of school tables, due to the high WWR of 0.40, was having excessive daylight (above 700 lux). Under such conditions, not only does glare become a problem, but also a significant thermal effect can be produced. According to the procedure suggested by Olgyay and Olgyay [11], average temperatures were calculated for every 2 h, based on Curitiba's TRY and compared to comfort temperatures, obtained by means of the adaptive comfort approach (Table 1).

In Table 6, periods of possible overheating can be identified: in January, from 12 to 6 pm; in February, also from 12 to 6 pm; and in March, from 2 to 6 pm. However, as differences in relation to the reference temperature were not significant for some hours of the day for these three months, the period between 4 and 6 pm was considered irrelevant for the design of shading devices. Shading masks were traced on the sun path diagram to respond to the possible overheating periods for the different building axis orientations, exemplified here for a NW-SE building axis orientation (Figure 8).

The shading mask plotted on the solar chart yielded the angles $\alpha = 75^\circ$, $\beta = 15^\circ$, and $\gamma = 50^\circ$ (northeast façade) and $\alpha = 40^\circ$, $\beta = 30^\circ$ and $\gamma = 25^\circ$ (southwest façade). Accordingly, light gray shading devices of unfinished concrete were designed to account for the needed shading effect. After adding shading devices to individual façades, simulations were run for the same configurations considered before. Figure 9 presents the results of both the totals of daily percentages of adequate workplaces in winter and summer, and the daylight distribution in both classrooms (in opposing orientations according to the diverse axes N-S, E-W, NW-SE, and NE-SW).

For such conditions (with shading devices), orienting the school building according to an intermediate situation (NE-SW axis with façade orientations to NW and SE) allows a more even exposure to daylight. In addition, a general increase in the percentage of adequate workplaces was verified, especially for the NW-SE axis, as excessive daylight was controlled to a certain extent.

It is also useful to know how the use of shading devices would affect the luminous performance of such classrooms under overcast conditions. Such conditions were considered for daylighting simulations of classrooms with shading devices, as this configuration would mean less available daylight. It should be stressed that for this second configuration not all classrooms were necessarily provided with shading elements. For overcast conditions, as expected, lighting levels are greatly reduced, particularly in winter. Luminous performance in classrooms without shading devices (those oriented to S, E, NE, SE) were generally higher than that in classrooms with shading elements (façades oriented to N, W, SW, and NW), which had overall lighting levels lower than recommended (Figure 10).

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Table 6. Identification of periods of possible overheating

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0–2 am	18.1	18.4	17.2	14.5	12.4	11.3	10.1	11.3	12.8	12.1	15.8	15.3
2–4 am	17.6	18.0	16.8	14.3	11.9	10.8	9.6	10.8	12.3	11.8	15.5	14.9
4–6 am	16.9	17.7	16.4	14.0	11.3	10.3	9.0	10.1	11.9	11.5	15.1	14.4
6–8 am	17.0	17.8	16.3	13.8	10.6	9.7	8.3	9.7	11.5	11.7	15.5	14.9
8–10 am	19.7	19.9	18.3	15.2	12.1	11.0	9.4	11.0	13.5	13.5	17.7	17.6
10–12 pm	23.0	22.7	21.2	17.6	15.9	14.5	13.4	14.8	17.2	15.8	19.9	20.3
12–2 pm	**25.3**	**24.6**	23.3	19.5	18.8	16.8	16.8	17.9	19.5	17.5	21.2	21.7
2–4 pm	**26.1**	**25.0**	**24.6**	20.5	19.9	17.6	18.1	19.1	20.7	18.0	21.8	22.3
4–6 pm	**24.3***	**24.2***	**23.9***	19.5	19.2	16.8	17.5	18.4	19.8	17.2	21.2	21.1
6–8 pm	21.7	21.8	20.7	17.0	16.1	14.2	14.6	15.5	16.9	15.0	18.8	18.6
8–10 pm	19.4	19.7	18.4	15.4	13.8	12.6	12.2	13.1	14.6	13.4	16.9	16.5
10–12 am	18.6	19.0	17.7	14.7	13.0	11.6	11.0	11.9	13.6	12.6	16.3	15.8
Comfort operating temperature (°C)	**24.2**	**24.2**	**23.9**	**22.9**	**22.3**	**21.9**	**21.7**	**22.0**	**22.6**	**22.2**	**23.4**	**23.3**

*Considered irrelevant.

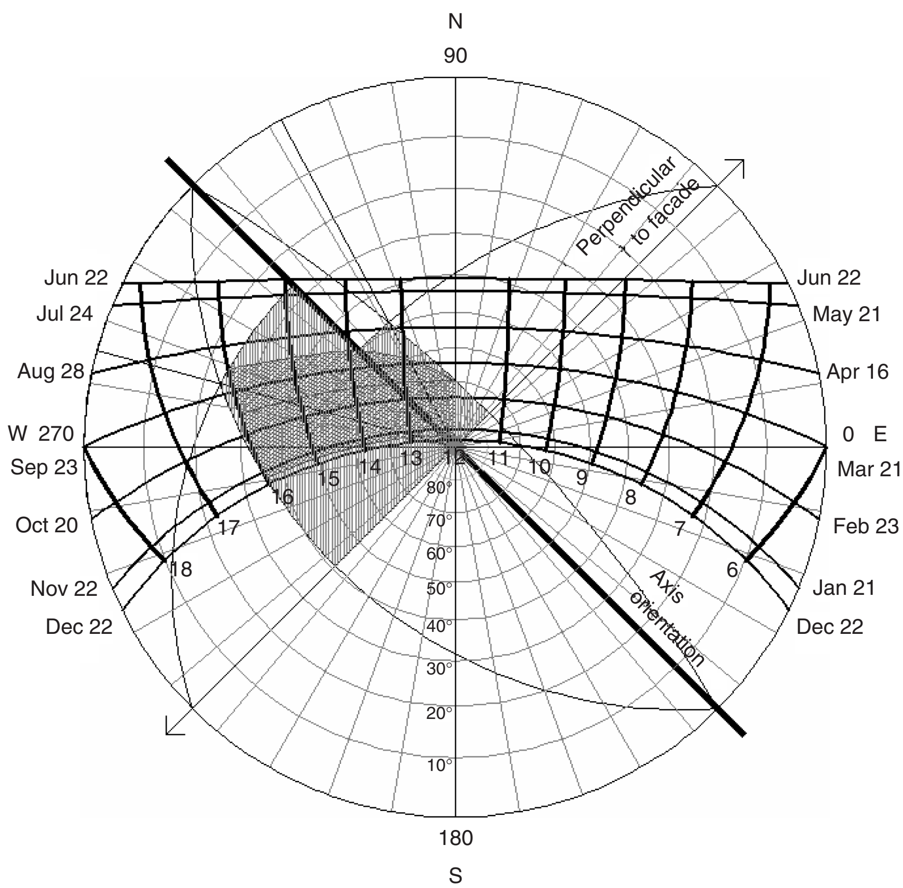

Fig. 8. Periods of possible overheating and resulting shading mask for a NW-SE axis.

As a measure to check and compare daylight distribution between both classrooms in opposing façades, an index (termed 'daylight distribution index') was developed, which took into account the highest percentage of adequate workplaces between both rooms, divided by the smallest percentage of adequate workplaces. The closer the index approached to "1", the more daylight was distributed in both spaces.

Results from the use of the daylight distribution index showed that although providing only one classroom on

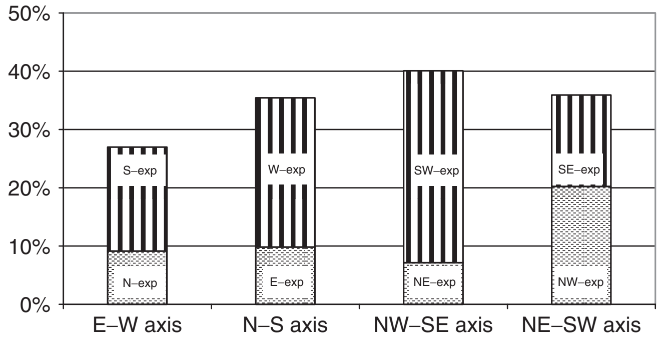

Fig. 9. Daily percentages of adequate workplaces and daylight distribution – clear sky conditions, with shading devices (columns show totals for both opposing exposures).

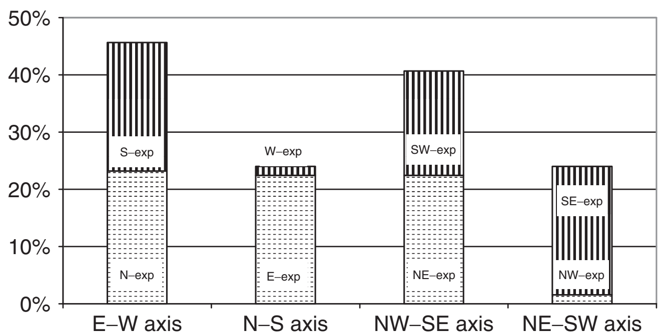

Fig. 10. Daily percentage of adequate workplaces and daylight distribution – overcast sky conditions, with shading devices (columns show totals for both opposing exposures).

Table 7. Daylight distribution index

AXIS	CONDITION		
	Without shading elements	With shading elements	With shading elements (overcast sky)
E-W	0.32	0.51	0.97
N-S	0.70	0.39	0.07
NW-SE	0.45	0.22	0.81
NE-SW	0.58	0.77	0.07

one side of the building with shading devices may increase daylighting efficiency (in this case, reducing glare) and has a positive effect on the thermal quality of the space, daylight distribution as a whole might diminish. As a consequence, the unshaded classroom will maintain a similar performance, whereas the shaded one will show improvement (see Table 7).

The reduction in daylighting levels due to the factor of shading devices can be observed more strikingly in the

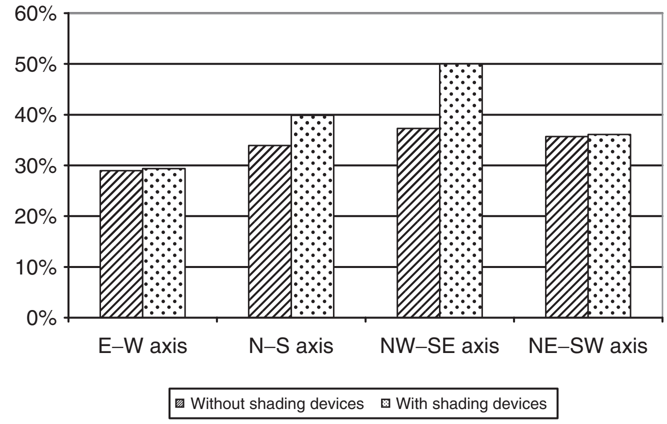

Fig. 11. Total daily percentages of adequate workplaces in both classrooms – clear sky conditions, with and without shading devices (winter).

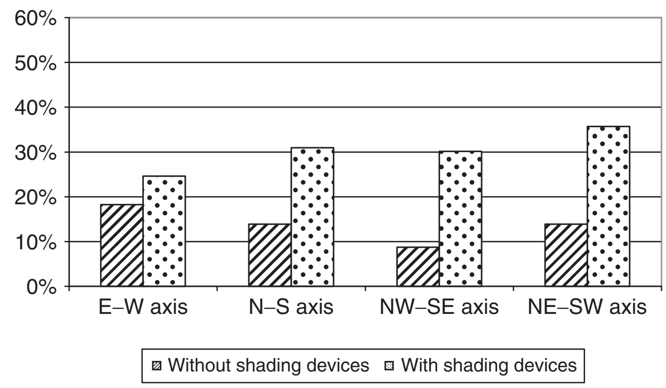

Fig. 12. Total daily percentages of adequate workplaces in both classrooms – clear sky conditions, with and without shading devices (summer).

graphs for each separate season (winter and summer) (Figures 11 and 12).

In winter, two of the tested orientations (N-S and NW-SE axes) presented significant increases in the percentage of adequate workplaces, as glare problems were minimized. In summer, an increase in luminous performance was noticed for all axis orientations.

Conclusions

The present survey has evaluated acoustic and luminous characteristics of rooms built as modular classrooms to find out if they met basic requirements for these specific areas. The acoustic study focused on the background noise, reverberation time, and noise insulation simulations. Values of background noise and reverberation time were compared with prescribed values according to the Brazilian and international standards.

Background noise levels measured in the classrooms were much higher than the values recommended by both national and international standards. The probable explanation for the high levels of background noise inside the classrooms is a lack of acoustic insulation between the classrooms and the corridor. Regarding the reverberation time, it could be shown that Brazilian classrooms do not satisfy any of the technical standard recommendations cited in this study, except when the classrooms are fully occupied, with 40 students. It was also verified that the classrooms were characterized by a lack of absorbent materials, confirmed by the high reverberation times. Simulations of reverberation time demonstrated that a simple acoustical enhancement of the ceiling would significantly improve reverberation time inside the classroom, thus rendering them acoustically acceptable according to the values of reverberation time established, not only by the Brazilian Standard NBR 12179, but also by the international standards.

The evaluation of daylighting levels indicated that all orientations of the central building axis, defined by the central corridor, were substantially high. This occurred as a direct consequence of the high WWR of 0.40. As excessive daylight may be associated with an increase in thermal conditions within the building due to direct solar contact, shading devices were designed for each individual façade according to a procedure suggested by Olgyay and Olgyay [11]. For Curitiba, that meant providing some of the school building façades with shading elements.

As a consequence of using such elements, the luminous performance of the building as a whole increased for all axis orientations, for both summer and winter. As a second criterion of analysis, an index was developed to account for the daylight distribution among classrooms with opposing façades. Results show the pros and cons of each situation. Although the project analyzed (school building type Standard-023) was favored because of its large window areas, the method presented in this study can support the choice of siting and the design of shading strategies in buildings with definite constraints, such as existent noise sources and obstacles to direct solar exposure.

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