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Renewable Energy 33 (2008) 1695–1702
RENEWABLE ENERGY
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Technical Note

Daylighting analysis in a public school in Curitiba, Brazil

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Received 23 May 2007; accepted 3 September 2007
Available online 22 October 2007

Abstract

This study analyzes classrooms, built according to a standard project of public schools in the Brazilian State of Paraná, concerning their luminic qualities. The daylighting analysis was based on computational simulations with daylighting programs, for different combinations of days, schedules and building solar orientations. Results show daylighting levels for diverse positions of the building, allowing the designer to choose the best form of building siting, considering local aspects and the quality of the resultant indoor space. Finally, shading elements were designed for each orientation in order to improve daylighting levels and the building's thermal performance.

Keywords: School buildings; Luminic comfort; Daylighting; Computer simulation; Building siting; Climate-responsive buildings

1. Introduction

The relationship between education, technology and employment has intensified to the extent that the educational level of a person determines one's insertion and position in the society. In Brazil, finding a place in a public school is generally limited to available school quota, not taking into account the quality of the offered educational conditions, in all its aspects. One of the most important issues is related to the environmental comfort of the classrooms, since the quality of the relations established in school buildings is a direct function of the physical characteristics of the built space, which may compromise the needed interaction between students and teachers and, by its turn, affect the social and professional development of the students. In recent years, Brazil has been implementing public schools by means of a multiple repetition of standardized projects, irrespective of local climatic conditions. The main purpose of this study is to evaluate the luminic quality of classrooms in a standard project of the Brazilian public school system.

At the present, even though latest surveys may offer a quite precise diagnosis on teaching and learning performances informing also about general running conditions of Brazilian school buildings and available equipment, there is a huge gap regarding comfort and performance evaluations of public school buildings under the aspects of building acoustics, daylighting potentials, thermal adequacy and climate-responsiveness. In the last decade, several studies have been carried out concerning such issues (Ornstein and Borelli Neto [1], Araújo [2], Bogo and Pereira [3], Cabús [4], Araújo [5], Xavier [6], Labaki and Bartholomei [7], Kowaltowski et al. [8], Loro [9], Pizarro [10]).

The analysis was based on computer simulations. At a first stage, the impact of different siting possibilities was tested. It is assumed that siting is one of the most important issues for planning a new school building, allowing an appropriate use of daylight, improving or diminishing solar gains (thermal effect) and permitting also the treatment of possible noise and pollutant sources. This stage involved the consideration of different orientations of the building for daylighting. Daylighting levels were

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doi:10.1016/j.renene.2007.09.002

analyzed and, in a second step, appropriate shading devices were designed in order to minimize possible overheating of the classrooms.

2. Description of school building type—Standard 023

The school building type evaluated—named Standard 023—is frequently used in the Public Schools Network in the Brazilian State of Paraná, located in southern Brazil. It is quite a common building type used in public schools, consisting of classrooms oriented to both sides of a central corridor. Classrooms are approximately 7 m long (façade) and 7 m wide with a ceiling height of 3.1 m. 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 pupils (Fig. 1).

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

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

3. Climatic region

The Brazilian State of Paraná has a population of 10,387,378 inhabitants distributed in 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 under 18 °C in winter and above 22 °C in summer, with a concentration of rain storms in summer but without a definition of a dry season and (b) temperate climate type (Cfb), characterized by a monthly temperature average under 18 °C in winter and under 22 °C in summer, mild summer periods and no defined dry season.

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

It was verified that although School 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 concentrated. This determined the choice of Curitiba

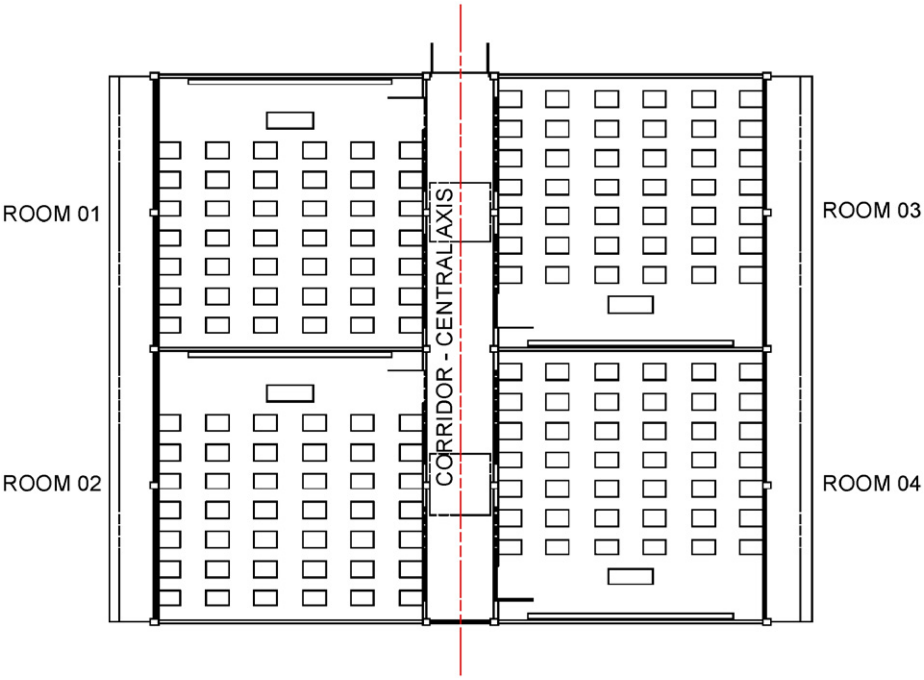

Fig. 2. Floor plan—Standard 023.

(25°31′S, 917 m elevation) as a reference for daylighting analyses. 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 [11] was used for establishing ideal operative temperatures. The adaptive approach goes under the assumption that "if a change occurs such as produce discomfort, people reach in 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 $T_{\mathrm{a,out}}$ [12]:

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

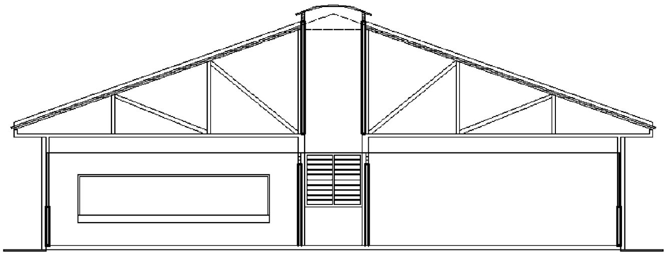

Fig. 3. Cross-section—Standard 023.

Table 1
Optimal operative temperatures for Curitiba's TRY

Month	Comfort operative temperatures (°C)
January	24.2
February	24.2
March	23.9
April	22.9
May	22.3
June	21.9
July	21.7
August	22.0
September	22.6
October	22.2
November	23.4
December	23.3

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

4. Recommended lighting levels for school buildings

In Brazil, lighting levels for diverse activities are recommended by the Brazilian Standard NBR 5413 (Interior Lighting—Specification: ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS [13]), which establishes average illuminances for the purpose of designing indoor artificial lighting systems. In school buildings, recommended average levels for classrooms range between 200 and 500 lx. The planner should then specify the proper lighting level according to the average age of the users, overall room reflectance, velocity and precision required for the task involved. Generally, it is suggested that an average illuminance is adopted. In our case, as the classrooms are used not only by children but also by adults, the highest illuminance was used as a reference. For the purpose of our analysis, a variation around the adopted reference of 500 lx was applied. At a 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 lx in order to have a significant range in lighting levels for the evaluated classroom), the optimal range considered for the analysis was as follows:

insufficient < 300 lx < adequate < 700 lx < excessive

5. Daylighting analysis

As already mentioned, the study comprised an analysis of daylighting potentials for different orientations of the school building Standard 023, with the aim of facilitating siting 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 and for three different hours of the day. Due to the mirrored configuration of the school building, in

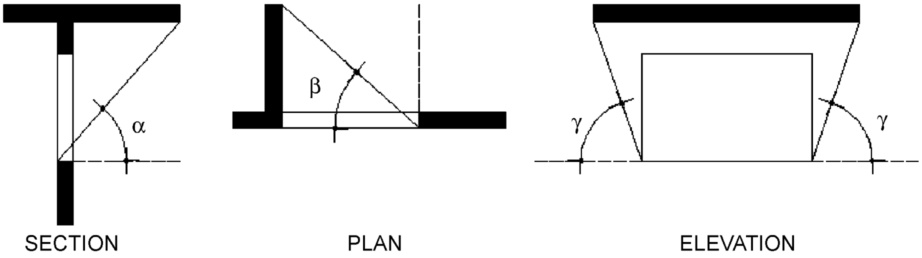

Fig. 4. Shading angles α, β and γ.

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 excessive uneven distribution of daylighting in the school building as a whole. The uneven pattern of daylight distribution was also responsible for 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 [14], 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, above which shading elements should be used in the analyzed façade (70 °F added by 2.25 °F to account for a variation of the 40°N reference latitude), was substituted by the varying optimal operative temperatures of Table 1. Assuming that when overheating is present shading strategies may help alleviate discomfort, solar charts can be used in such cases, for the periods of the year when overheating is liable to occur, in order to identify the shading angles α, β and γ to be adopted in the shading devices (Fig. 4).

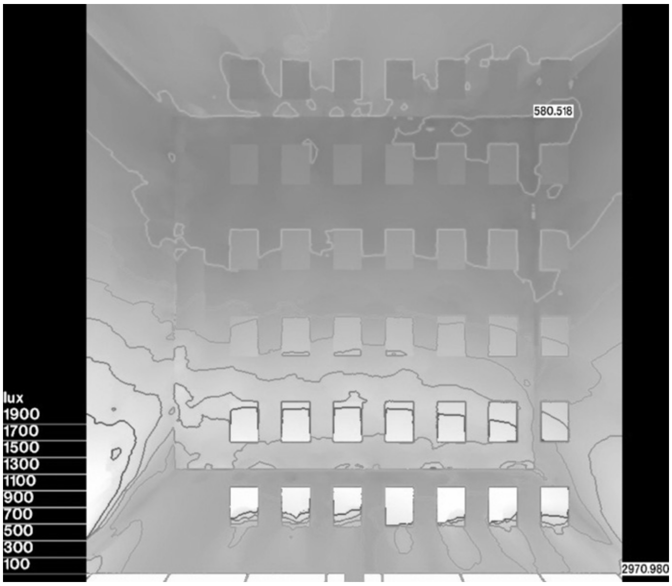

Fig. 5. RADIANCE image with Isolux curves.

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

For the daylighting simulations, various spots within the classroom at a height of 0.75 m (workplace), corresponding to positions of school tables, were considered for the dates of 21 June and 21 December (winter and summer solstices) and for 3 h of the day 9 a.m., 12 a.m. and 3 p.m. Individual illuminances were identified in Isolux curves, generated by RADIANCE and compared to recommended lighting levels (Fig. 5). Computations considered five internal reflections of the incoming sunray.

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

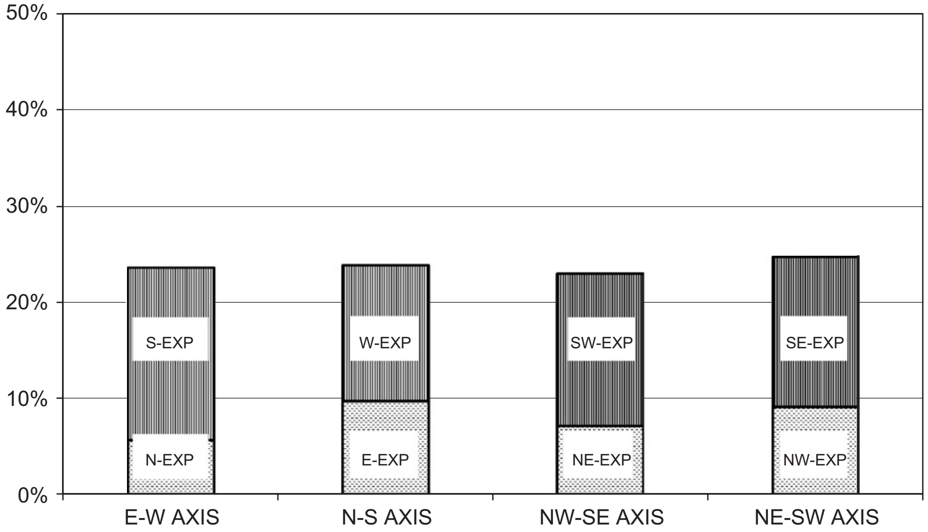

Fig. 6. Daily percentages of adequate workplaces and daylight distribution—clear sky conditions, without shading devices (columns show totals for both opposing exposures).

6. Discussion

The consideration of both above-mentioned criteria for evaluating the overall luminic performance of the building (percentage of adequate workplaces and a balanced distribution of daylight in classrooms on opposing façades) 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 opposite façades do not allow the same daylight to be received. Fig. 6 presents both the total of daily percentages of adequate workplaces in winter and in 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 an N–S axis allows a more even daylight distribution in classrooms with an east or west exposure.

The analysis showed that an expressive percentage of school tables, due to the high WWR of 0.40 were having excessive daylight (above 700 lx). Under such conditions, not only glare may occur, but also a significant thermal effect can be produced. According to the procedure suggested by Olgyay and Olgyay [14], 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 2, periods of possible overheating can be identified: in January, from 12 to 6 p.m.; in February, also from 12 to 6 p.m.; and in March, from 2 to 6 p.m. However, as differences in relation to the reference temperature were not significant in some hours of the day for these 3 months, the period between 4 and 6 p.m. was considered irrelevant for the design of shading devices. Shading masks were traced on the sunpath diagram to respond to the possible overheating periods, for the different building axis orientations, exemplified here for an NW–SE building axis orientation (Fig. 7).

The shading mask plotted on the solar chart yielded the angles $\alpha = 75^\circ$, $\beta = 15^\circ$, $\gamma = 50^\circ$ (northeast façade) and $\alpha = 40^\circ$, $\beta = 30^\circ$, $\gamma = 25^\circ$ (southwest façade). Accordingly, shading devices were designed to account for the needed shading effect. In the NE façade, the already existent 90 cm overhang will be sufficient as a shading strategy. In the SW façade, three fixed horizontal louvers were adopted. The color used for these shading devices was light-gray of unfinished concrete (Fig. 8).

After adding shading devices to individual façades, simulations were run for the same configurations considered before. Fig. 9 presents results of both the totals of daily percentages of adequate workplaces in winter and in summer and the daylight distribution in both classrooms

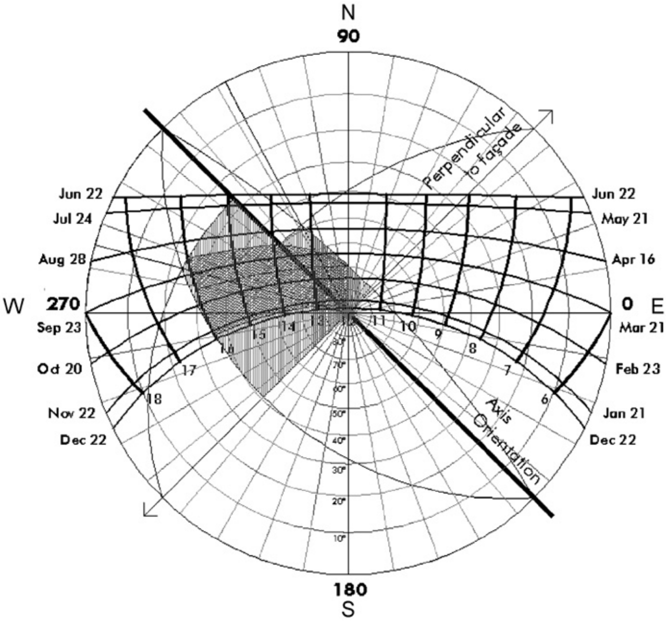

Fig. 7. Periods of possible overheating and resulting shading mask for an NW–SE axis.

Table 2
Identification of periods of possible overheating

	January	February	March	April	May	June	July	August	September	October	November	December
0–2 a.m.	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 a.m.	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 a.m.	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 a.m.	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 a.m.	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 p.m.	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 p.m.	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 p.m.	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 p.m.	24.3[a]	24.2[a]	23.9[a]	19.5	19.2	16.8	17.5	18.4	19.8	17.2	21.2	21.1
6–8 p.m.	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 p.m.	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 a.m.	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 operative 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

[a] Considered irrelevant.

(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 daylight. Also, 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 useful to know how the use of shading devices would affect the luminic performance of such classrooms under overcast sky 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 (Fig. 8a exemplifies a condition where the use of a shading device would be unnecessary). For overcast conditions, as expected, lighting levels are greatly reduced, especially in winter. Luminic performance in classrooms without shading devices (those oriented to S, E, NE, SE) is generally higher than in classrooms with shading elements (façades oriented to N, W, SW and NW), where overall lighting levels are lower than recommended (Fig. 10).

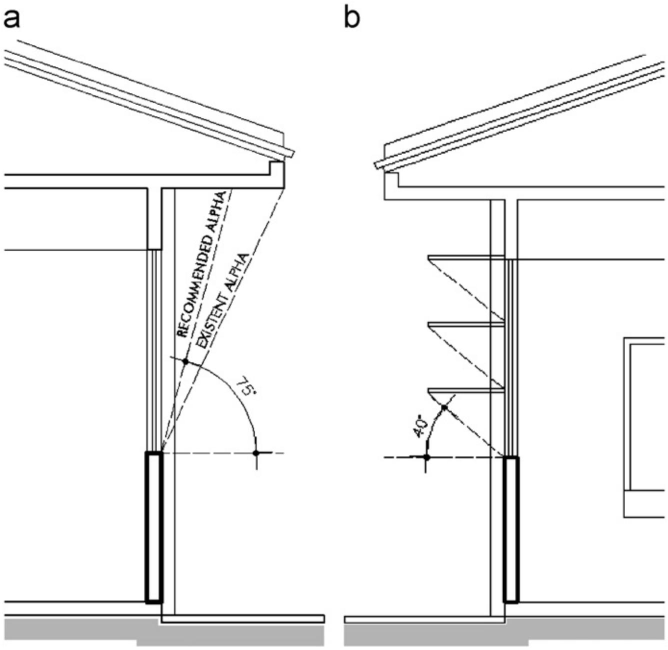

Fig. 8. Shading device: (a) NE façade and (b) SW façade.

As a measure of checking and comparing daylight distribution among 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 closest such index nears "1", the more daylight is distributed in both spaces.

Results from the use of the daylight distribution index showed that although providing only one classroom on one side of the building with shading devices may increase daylighting (in our case, reducing glare) and have a positive effect on the thermal quality of the space, daylight distribution may diminish. This happens as a consequence that the unshaded classroom will keep the previous performance whereas the shaded one will show an improvement (Table 3).

The reduction in daylighting levels due to the consideration of shading devices can be observed more strikingly in the graphs for each separate season (winter and summer) (Figs. 11 and 12).

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

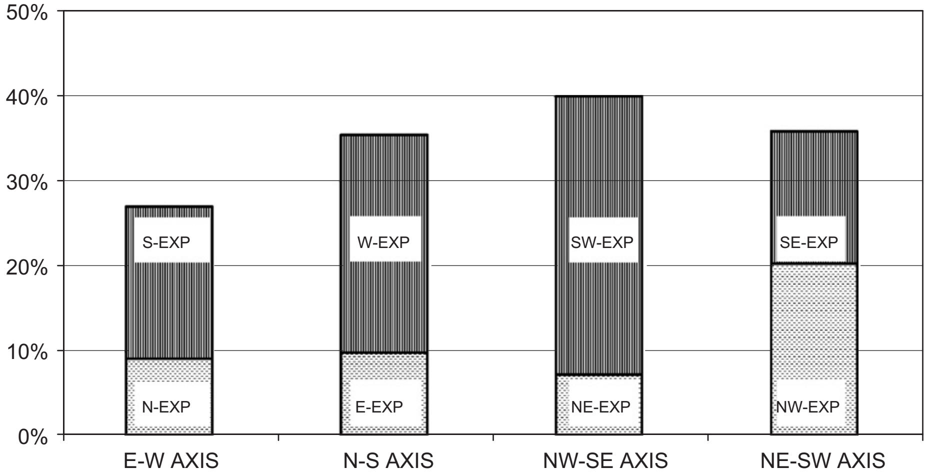

Fig. 9. Daily percentages of adequate workplaces and daylight distribution—clear sky conditions, with shading devices (columns show totals for both opposing exposures).

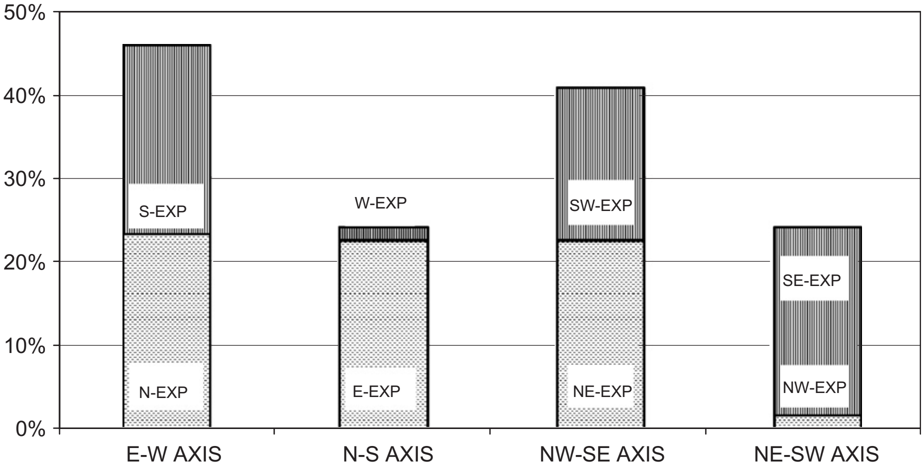

Fig. 10. Daily percentage of adequate workplaces and daylight distribution—overcast sky conditions, with shading devices (columns show totals for both opposing exposures).

Table 3
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

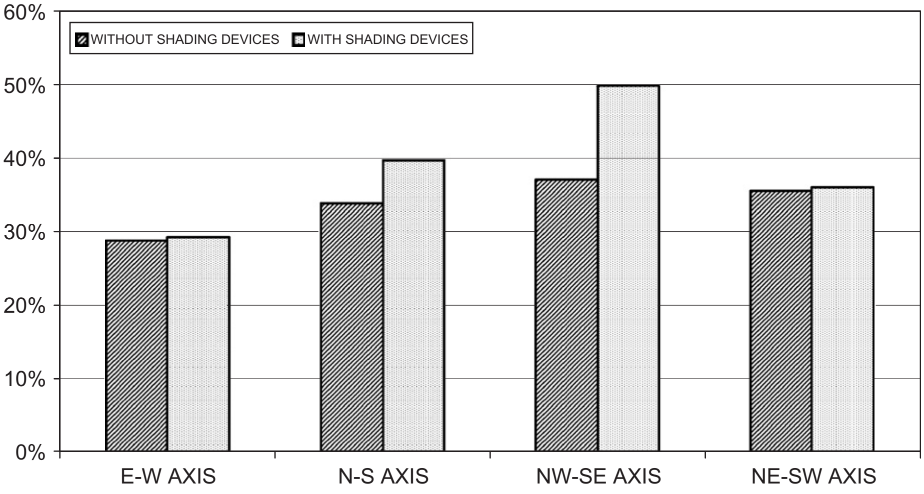

Fig. 11. Total daily percentages of adequate workplaces in both classrooms—clear sky conditions, with and without shading devices (winter).

7. Conclusions

The evaluation of daylighting levels indicated that all possible orientations of the central building axis, defined by the central corridor, were substantially high. This happens as a direct consequence of the high WWR of 0.40. As excess daylight may be associated to an increase in thermal loads within the building due to direct solar gain, shading devices were designed for each individual façade according to a procedure suggested by Olgyay and Olgyay [14].

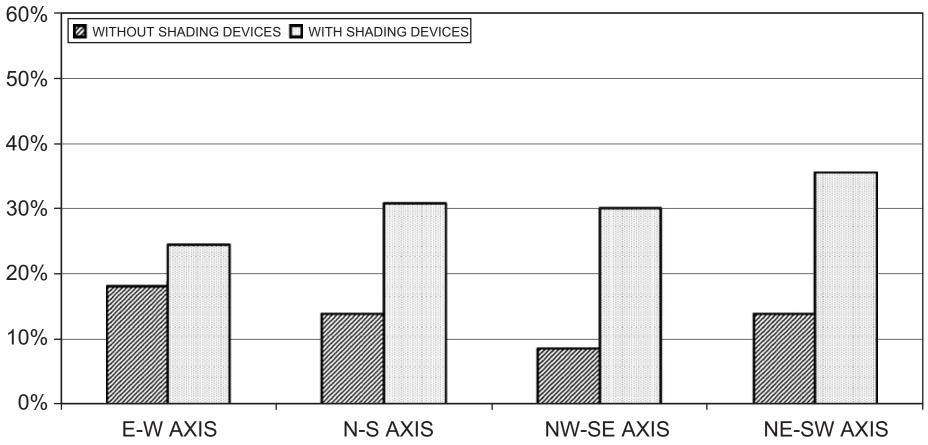

Fig. 12. Total daily percentages of adequate workplaces in both classrooms—clear sky conditions, with and without shading devices (summer).

For Curitiba, this meant providing some of the school building façades with shading elements.

As a consequence of using such elements, the luminic performance of the building as a whole was increased for all axis orientations and for both seasons. 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 analyzed project (school building type Standard 023) was favored with large window areas, the method presented in this paper can support the choice of siting and the design of shading strategies in buildings with definite constraints, such as existent noise sources, obstacles to direct solar gains, etc.

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