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Original
Daylighting for Green Schools: A Resource for Indoor Quality and Energy Efficiency in Educational Environments / Pellegrino, Anna; Cammarano, Silvia; Savio, Valeria. - In: ENERGY PROCEDIA. - ISSN 1876-6102. - 78(2015), pp. 3162-3167.

Availability:
This version is available at: 11583/2628997 since: 2016-01-22T18:53:32Z

Publisher:
Elsevier

Published
DOI:10.1016/j.egypro.2015.11.774

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 3162 – 3167

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Daylighting for Green schools: a resource for indoor quality and energy efficiency in educational environments

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Abstract

Daylight is a fundamental resource to achieve indoor quality and energy efficiency in educational buildings and therefore to improve their sustainability. The study presented in this paper is aimed at defining and testing a method to assess daylighting in classrooms based on performance indicators drawn from literature, standards and green building rating protocols (LEED), and intended as a tool to assess lighting sustainability and drive the retrofit of existing schools into comfortable and energy efficient buildings. The assessment approach is based on both in field analysis and dynamic climate-based simulations. In the paper the results obtained from the application of the method to a case study are presented.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: green schools, green audit, daylighting assessment, visual comfort

1. Introduction

Daylighting is considered a resource of primary importance in Schools: it's a key factor for occupants' health and well-being, to enhance the indoor environmental quality and to reduce the energy consumption for electric lighting.

The impact of daylight on the performance of students has been a subject of interest for many years [1]. It has been demonstrated a direct link between the presence of daylight and the performance of students, as it is well known that human health and mental functions are set by circadian rhythm, which is influenced by the duration and the intensity of light exposure during the day. Furthermore some criteria, such as the daylight availability and

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.774

distribution, the presence of glare sources, the direct sunlight penetration and the view out of the window have to be taken into account to achieve visual comfort and optimize the use of electric lighting in an energy saving perspective.

The topic of daylighting in educational buildings is part of a research project carried out at the Politecnico di Torino, named “Green School”. Green School is born from a collaboration between the Politecnico di Torino and the Province of Turin and it has the aim of developing methods and tools to facilitate the transformation of existing school buildings in “green” schools, i.e. buildings that offer healthy and comfortable environments for students and teachers, which reduce the consumption of water and energy resources in the operating phase and which are managed and maintained according to criteria of environmental, economic and social sustainability.

This paper focuses on lighting aspects: in particular the study is based on the assessment of the existing lighting conditions in the perspective of defining the “level of sustainability” and therefore, in a future step of the research activity, the best retrofit solutions for both daylighting systems, lighting plants and lighting controls.

This paper presents the approach adopted to assess daylighting in classrooms and the results obtained from the analysis carried out in one of the School chosen as case study.

The research project is still in progress and future work will be focused on other in-field measurements and subjective surveys of the perceived lighting quality.

2. Methodology

During a first phase of the project a research on current standards, design guidelines and certification protocols has been carried out, so as to outline the whole set of metrics and criteria that can be found in the literature to asses lighting in Schools and the whole lighting requirements that have to be verified for both visual comfort and energy purpose. At the end of this phase a protocol to assess the lighting condition in Schools has been outlined, based on in field analysis and measurements, on lighting and energy simulations and on subjective surveys (the subjective survey was carried out in a later stage of the project and therefore it’s not part of this paper).

A second phase of the project consisted in the survey of the daylighting and electric lighting systems which exist in the School and the last phase is the application of the previously defined evaluation protocol.

2.1. Literature analysis and definition of the assessment protocol

Three different references from the current literature have been mainly taken into account to define the protocol to assess daylighting.

The first one is the Italian Standard UNI 10840:2000 [2], which specifies the general criteria for daylighting in educational buildings. The Daylight Factor is the metric adopted to define the minimum required daylight level. The Standard requires a DF $\geq$ 3% for all types of classrooms and laboratories and a DF $\geq$ 1% for offices.

The second reference is the LEED Reference Guide for Building Design and Construction [3]. Both the LEED v4 and the LEED 2009 for Schools have been taken into account. The LEED green buildings certification program is based on reaching a number of credits aiming to define the level of sustainability of a building. The credits related to daylight are included in the *Indoor environmental quality* category and have the intent to evaluate the occupants comfort by checking the daylight availability, the potential glare and the visual connection to the outdoor.

The last LEED version (v4) provides three options to get credits from daylight. The first option requires calculating the spatial Daylight Autonomy ($sDA_{300/50\%}$) and Annual Sunlight Exposure ($ASE_{1000/250h}$), two new daylight metrics recently proposed by the Illuminating Engineering Society of North America [4]. $sDA_{300/50\%}$ has to be achieved for at least 55%, 75% or 90% of the regularly occupied floor area. The second option provides the calculation of illuminance levels, demonstrating that illuminance levels will be between 300 lux and 3000 lux for 9 a.m. and 3 p.m., both on a clear-sky day at the equinox, for at least 75% or 90% of the regularly occupied floor area. The third option requires the measurement of illuminances two times during the year. The measurement has to demonstrate that illuminance levels between 300 lx and 3000 lx of at least 75% or 90% of the regularly occupied floor area are achieved. The LEED 2009 for School proposes the same method of LEED v4 to get credits from daylight including also a prescriptive option, which is based on the calculation of the product of the glazing visible transmittance (τ_{vis}) and Window-to-Floor area Ratio (WFR). This product has to be between 0.15 and 0.18.

The last main reference considered in the project for daylighting is the English guideline “Baseline designs and strategies for schools” elaborated within the Priority School Building Programme (PSBP). The aim of the baseline designs was to ensure sufficient levels of balanced glare-free light to all teaching spaces. The guideline is based on the Useful Daylight Illuminance achieved (UDI-a) metric [5] to assess the dynamic variation of daylight within spaces. The minimum target for UDI-a was set to 80% for each learning space.

Taking into account the criteria and methods proposed in the literature, a specific protocol to assess daylighting was developed for the Green School project. Both in field measurements and simulations were included to assess the effectiveness of daylighting during the whole year and in particular it was defined to measure in field the Daylight Factor and to calculate, through climate-based simulation, the spatial Daylight Autonomy and the UDI-a metrics.

Furthermore the product of τ_{vis} and WFR was considered and calculated during the first inspection at the school.

Measurements and simulations were carried for six classrooms taken into account as representative of the whole regularly occupied floor area.

3. Case study

One of the case studies of the Green School project is the J.C. Maxwell School located in Nichelino, a small town belonging to the Turin province, in Italy. The building has a typical imprinting of the time ’70 architecture: it’s a linear construction with a central hallway and all classrooms are facing East and West. The structure of the building is made of a concrete prefabricated frame of pillars, beams and slabs. An image of the building is shown in Figure 1.

Fig. 1. J.C.Maxwell building: East and West façades

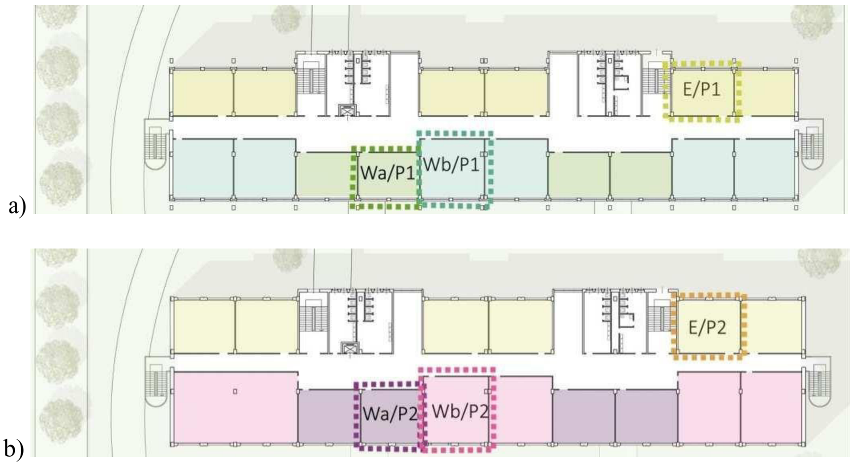

Fig. 2. J.C.Maxwell building: 1st floor (a); 2nd floor (b).

Classrooms are all located at 1st and 2nd floor. They are continuously occupied Monday through Friday from 8:10 a.m. to 12:50 a.m. Sometimes there are lessons during the afternoon.

The first analysis was based on the investigation of the classrooms' characteristics in terms of daylighting and electric lighting systems so as to define which are the most representative of the overall regularly occupied area. At each floor they were divided according to their features in terms of orientation, external obstruction, dimensions, window area, room depth, shading devices, reflectance properties and view to the outside. For each floor three types of classrooms were identified: E/P1, Wa/P1 and Wb/P1 are the classrooms located at 1st floor facing East and West, respectively. E/P2, Wa/P2 and Wb/P2 are the classrooms located at 2nd floor facing East and West, respectively. At each floor two types of West-facing classrooms were identified because of their different dimensions.

The spaces which were selected are all shown in Figure 2 and classrooms belonging to the same type are indicated with the same color background.

3.1. Survey on the existing daylighting systems

As far as daylighting systems are concerned, the infield survey has highlighted different window areas, shading devices and surfaces reflectance properties. Windows are double-glazed with a glazing visible transmittance of about 75% (measured in field). The West façade is obstructed by a barrier of trees (as shown in Figure 3) while the East façade has a lower level of external obstruction since there are some low buildings quite far from the façade.

At first floor classrooms belonging to the type of E/P1 and Wa/P1 (A_{floor}=50.4 m^2) fulfill the credit required by the LEED 2009 for Schools: the product of τ_{vis} and WFR is 0.16. On the other hand classrooms belonging to the type of Wb/P1 (A_{floor}=62 m^2) have a product of τ_{vis} and WFR equal to 0.13. This is due to the different floor area since all classrooms at first floor have the same window area (A_{window}=10.6 m^2). Furthermore all spaces are equipped with venetian blinds which should be manually operated. Because of the poor maintenance they result as fixed shadings (lowered and with horizontal slats). Walls, floors and ceilings have a diffuse reflectance of 50%, 45% and 60% respectively (Figure 3a).

a) b)

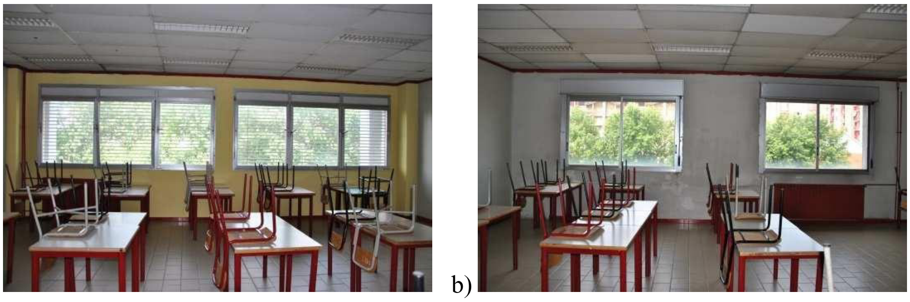

Fig. 3. Daylighting systems for classrooms at 1st floor (a) and 2nd floor (b)

At second floor all classrooms don't satisfy the credit required by the LEED 2009 for Schools: the product of τ_{vis} and WFR is below 0.14 because of the smaller window area (A_{window}=8.8 m^2). Furthermore all spaces are equipped with manually operated rolling shutters. Walls, floors and ceilings have a diffuse reflectance of 50%, 45% and 60% respectively (Figure 3b).

4. Daylighting evaluation

4.1. Measurements and results

The DF has been calculated according to the measurement performed in field in each of the classrooms identified as representative. Indoor and outdoor illuminance measurements were performed at the same time during a day with an overcast sky condition. Indoor illuminances were measured according to a 1 m * 1 m grid over the whole horizontal working plane.

As shown in Figure 4 none of the classrooms satisfies the target of DF ≥ 3% requested by the Italian Standard UNI 10840:2000. In general it could be said that West-facing classrooms at first floor (Wa/P1 and Wb/P1) can benefit of a very low amount of daylight. This is mainly due to the presence of an outdoor barrier of trees which, on the contrary, does not have the same influence on the daylight availability for West-facing classrooms at second floor (Wa/P2 and Wb/P2). Furthermore all classrooms at first floor are equipped with fixed shadings which represent a heavy obstruction for the incoming daylight, in particular in presence of an overcast sky condition.

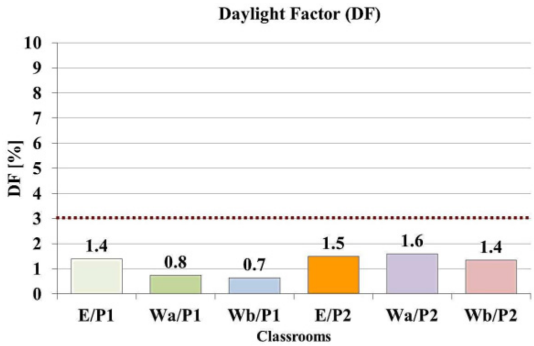

Fig. 4. Daylight Factor values for the six types of classrooms which have been analyzed

4.2. Simulations and results

The simulations to calculate the $sDA_{300/50\%}$ and the UDI-a were performed using Daysim [6], a validated dynamic daylight program specifically developed for the analysis and visualization of lighting in a space. The daylight illuminances were calculated according to a 50 cm * 50 cm calculation grid over the working plane area, set at a distance of 0.8m from the floor. The target task illuminance was set to 300lx, a typical value for schools activities according to European standard EN 12464:1-2011 [7]. For all classrooms at second floor two different rolling shutters' positions during occupancy hours were simulated: totally opened and partly closed. The latter shading control strategy is based on the algorithm implemented in Daysim, which assumes the presence of active users. Active users open the blinds in the morning and partly close them to avoid visual discomfort when direct sunlight above 50 W/m^2 is incident on the work plane calculation greed points [6].

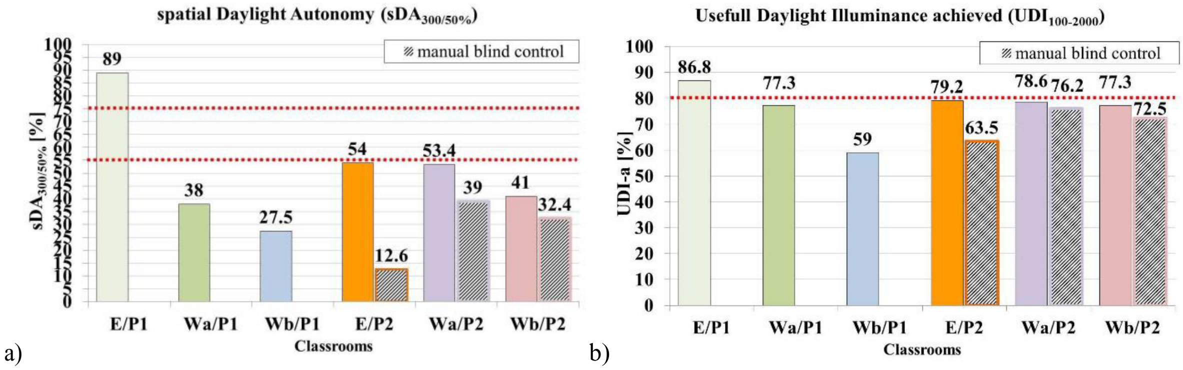

Fig. 5 $sDA_{300/50\%}$ (a) and UDI-a (b) values for the six types of classrooms which have been analyzed

Figure 5 shows the $sDA_{300/50\%}$ and UDI-a results for the six types of classrooms which have been analyzed. It could be noted that only one type of classroom (E/P1) fulfills both the requirements of the LEED rating system v4 and the PSBP guideline. Classrooms at second floor (E/P2-Wa/P2-Wb/P2) can benefit of a quite good level of daylight according to UDI-a results but in presence of a manually operated shutter, which could be sometimes pulled down during occupancy hours, the daylight amount decreases, in particular $sDA_{300/50\%}$ values and in particular for East classrooms (where the use of blinds to control glare in the morning is highly probable and frequent).

For West-facing classrooms at first floor (Wa/P1-Wb/P1) $sDA_{300/50\%}$ values are very low mainly because of the presence of the outdoor barrier of trees and a fixed shading system always pulled down which partially block the incoming daylight. Despite of a lower WFR for West-facing classrooms at second floor $sDA_{300/50\%}$ values result higher than West-facing classroom at first floor because they are less influenced by the barrier of trees.

4. Discussions and conclusions

The aim of the study was to evaluate daylighting in the classrooms of one of the Schools of the "Green School" project, a research activity aimed at developing methods and tools to drive the retrofit of existing schools into buildings that can offer comfortable environments and reduce their energy demand.

As far as daylighting investigation is concerned, both in field analysis and dynamic climate-based simulations were performed. The results obtained from the study showed some critical situations:

- very low DF and $sDA_{300/50\%}$ values for West-facing classrooms at first floor due to fixed lowered shadings and external obstructions;
- low WFR at second floor, that limits the quantity of incoming daylight, in particular if the rolling shutters are manually pulled down.
- poor maintenance and building management.

According to these considerations the level of sustainability in terms of daylight availability and view to the outside is very low since only East-facing spaces at first floor can reach both the requirements of the LEED rating system v4 and the PSBP guideline. The high $sDA_{300/50\%}$ and UDI-a results obtained for these classrooms are also due to the fact that the fixed shading is a venetian blind with horizontal lamellas and therefore during the early morning hours, when the solar elevation angle is still low, sunlight is not completely blocked by the shading device. Furthermore the target of DF $\geq$ 3% requested by the Italian Standard UNI 10840:2000 is never obtained.

Since the object of the study is an existing building, suitable solutions to improve the daylight availability within classrooms are strictly related to maintenance programs for interiors and daylighting systems (e.g. window cleaning, proper operation of movable shading devices, painting of interior surfaces with light color to increase the diffuse reflectance of light, etc.) and in the reduction of the external obstruction produced by the trees on the West side.

Besides a more expensive solution to improve the daylight availability could be found in a redesign of shading device systems for all classrooms.

The research project is still in progress and future work will be focused on other in-field measurements and subjective surveys of the perceived lighting quality.

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