21th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Lighting characterization of an Italian beginning twentieth-century school building

A. Moschella[1], D. Amato[2] A. Gagliano[3]
[1] Department of Civil Engineering and Architecture
University of Catania, viale Andrea Doria, 6 95125 Catania (Italy)
Phone/Fax number:+0039 0957382532, e-mail: angela.moschella@unict.it
[2] Freelance amatodaniele92@hotmail.it
[3]Department of Electrical, Electronic and Computer Engineering
University of Catania, viale Andrea Doria, 6 95125 Catania (Italy)
Phone/Fax number:+0039 0957382451, e-mail: antonio.gagliano@unict.it

Abstract. Nowadays, visual comfort in classrooms is considered crucial for the quality of students' learning processes. In Italy (1888 and 1901), many educational buildings, which constitute a cluster of historic school buildings, were built following specific national regulations.
These buildings are characterized by the careful design of the classrooms both in relation to the orientation and their size.
Among the design criteria, educational buildings structures had taken into account the orientation of the facades, as well as the arrangement and size of windows and other light inputs
The study presented in this paper is aimed at evaluating if these educational buildings, designed according to ancient rules, are able to meet today's standards of visual comfort. With this purpose, the assessment of lighting levels, luminance distribution, average daylight factor, and daylight autonomy (DA) was carried out for all classrooms for a case study, typologically representative of this school buildings' cluster.
The daylight analysis showed that most classrooms were subject to glare and lack of uniformity of illumination, while in other environments low values of illuminance levels were found. However, it is believed that a lighting refurbishment, respectful of the cultural value of these historic school buildings, can be considered.

Key words. Historic School Building, Classroom, Visual Comfort, Daylighting, Simulation.

1. Introduction

From the end of the 19th century to the beginning of the 20th century, the Italian state issued laws on the granting of low-interest loans for the construction of school buildings. The regulations issued in the implementation of these laws also contain precise design instructions [1, 2, 3]. Only with the 1925 law do these instructions become regulations, thus acquiring the character of cogency [4]. During this period, the Ministry of Education reformed the organization of teaching while it still considered the criteria for the design of school buildings to be valid and current [4]. In fact, from 1888 onwards, the subject of school buildings was tackled organically and comprehensively, defining criteria for the choice of area, thermal comfort, furnishings, etc.

The building is thought of as isolated and with a maximum of three levels of elevation; the distance between facing walls had to be at least 10 m. Other specifications concerned the shape of the building, the orientation of the classrooms, and the size of the windows. As far as the shape of the building was concerned, closed courtyards were to be avoided and one-sided shapes were to be preferred.
Classrooms were to be oriented to the south or southeast, while corridors and all other rooms were to be oriented to the north; this allowed them to draw on free sunlight in winter. They were also to be rectangular in shape and no longer than 8-10 meters in length [1] and 6.40 to 7 m wide or 4.80 to 5.4 depending on the arrangement of 4 rows or 3 rows of desks respectively [2]. Particular attention is paid to the arrangement of the desks in relation to the position of the windows with the aim of optimizing visual comfort; in this case, it is required that pupils should receive light from the left and never from the front [1]. The sizing of the windows, referring to buildings free of all surroundings, should be done in relation to the floor area, i.e. 1/6.
We can observe that school buildings of the early 20th century are characterized by careful design of the classrooms both in relation to the exposure and their size and so can be considered a typological cluster [5].
School buildings (pre-school, primary, and secondary schools) built in the early 20th century (up to 1940) account for 23.8% of the total, according to the Legambiente report [6].
This paper discusses the results of research conducted on the current lighting in Italian beginning twentieth-century school buildings. To this end, this study was carried out through an accurate geometric survey of the building and subsequent simulation for the evaluation of daylight.

2. Material and Methods

The importance of appropriate lighting conditions at academic institutions has been widely analysed as it has important effects on learning [7]. Visual performance is the ability to perceive and identify objects or small details

and visual tasks which have low contrast to the surroundings. Guaranteeing students and teachers a pleasant and stimulating environment encourages learning, avoid visual effort and reduces fatigue [8].
In the classrooms, attention needs to be paid to achieving adequate light levels, including the lighting of teachers' and pupils' faces for good visual communication.
The norm UNI EN 12464-1:2021 "Light and lighting - Lighting of workplaces " specifies the lighting requirements for people, in indoor workplaces, which correspond to the visual comfort and visual performance needs of people with normal or corrected ophthalmic (vision) abilities. Different parameters are established to achieve these objectives, which are: luminance contrast, specific area light (lux) levels, uniformity ratios, glare ratings (UGR), and colour rendition (Ra).
Daylighting, which involves the illumination of interior spaces by natural light, is an established practice of building design that improves the health and performance of building occupants. Natural light and views are important design elements that are addressed in many building design assessment programs. The appropriate use of daylight in educational environments has myriad benefits: healthier students and fewer sick days, as well as improved moods, learning aptitudes, and attention spans [9]. The European standard EN 17037, published in 2018, provides requirements for daylight in buildings [10]. It defines four daylighting design criteria: daylighting, views, access, and glare. These criteria establish a minimum acceptable daylighting environment for building occupants and address health, comfort, and productivity.
The CIBSE "Lighting Guide LG5: Lighting for education" is exhaustive and detailed on the lighting of all school spaces including teaching rooms, conference rooms, and special-purpose rooms [11].
School lighting to be suitable attention needs to be paid to:
- giving priority to daylight in all teaching spaces, circulation, staff offices, and social areas
- providing adequate views to the outside or into the distance to ensure visual comfort and help avoid eye strain
- providing means to control daylight and sunlight, to avoid glare, excessive internal illuminance and summertime overheating.

A. Daylighting provision

The EN 17037 provision requires that 300 lux of natural light, should be present for building occupants to be able to perform regular tasks. A space is deemed compliant if it achieves a minimum of 300 lux over 50% of the space for more than half the daylight hours in the year without artificial lighting [10].
CIBSE and BREEAM [11, 12] recommend that the room depth criterion, expressed by eq. 1, have to be satisfied in side-lit classroom for guarantying acceptable illuminance uniformity.

$$\boldsymbol{L/W + L/H \leq 2/(1-\rho)} \qquad (1)$$

L is the room depth, W is the room width, H is the window head height from the floor level, and ρ is the average visible reflectance of the surfaces in the half of the room far from the window. As a uniformity ratio of 0.6 is difficult to accomplish by daylight only in side-lit classrooms, lower values can be accepted, as in the BREEAM rating scheme (U > 0.3) [12].

The daylight availability is expressed by the Daylight Factor (DF), which is defined as the ratio of the daylight illuminance at a given point inside a room (E_{in}) to the daylight illuminance measured at the same time under an unobstructed horizontal plane (E_{out}).

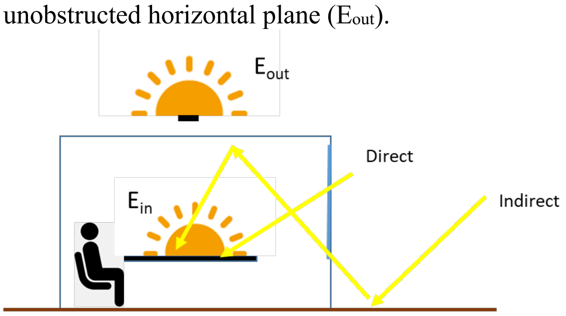


Fig. 1. Daylight Factor

$$\boldsymbol{DF = \frac{E_{in}}{E_{out}}} \qquad (2)$$

DF must be calculated under CIE (Commission Internationale de l'Eclairage) overcast sky conditions; hence, it does not account for the effects of direct sun light. Italian norm UNI EN 10840 recommended threshold values for the average DF_{avg}>3% and the ratio DF_{min}/DF_{max} > 0.16 in classrooms [13].
Assuming that, under overcast sky conditions, the outside illuminance lies around 10,000 lux: hence, an average DF=3% means that, even in the absence of direct solar irradiance, a minimum of 300 lux is guaranteed on average over the working plane [13]. In order to overcome the several limitations of the Daylight Factor, (e.g., it makes no difference among different window exposures, and does not describe the—often negative—effects of direct sunlight) other daylighting metrics have been recently introduced, called climate-based metrics, as they derive from dynamic calculations over a large time-span and on actual variable sky conditions.
Daylight Autonomy (DA) is defined as the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylight only [15]. The spatial Daylight Autonomy (sDA) provides the percentage of floor area that exceeds a specified illuminance level for a specified amount of annual hours (e.g sDA 300/50% means that the threshold of 300 lux is overpassed for 50% of the time.). Hence, it shows a single value for each room. sDA calculation should be supplemented with the evaluation of the Annual Sunlight Exposure (ASE), which is the percentage of the occupied area where direct sunlight illuminance exceeds a certain value (usually, 1000 lux) for a specified number of hours per year (usually, 250) [16]. Blinds and shadings must not be taken into account when calculating ASE.
Useful Daylight Illuminance (UDI) represents the percentage of time in which daylight levels fall within a lower and an upper illuminance threshold, which is subdivided into a certain number of bins. The upper bin represents the percentage of time when excessive daylight illuminance occurs, which might lead to visual discomfort; on the other hand, the lower bin represents the percentage of time when daylight illuminance alone is too scarce [17]. Finally, the intermediate bin is the percentage of time when appropriate daylight illuminance is attained.

According to the original UDI definition [18], the lower and upper thresholds are set to 100 and 2000 lux respectively proposed.

3 Description of the Case Study

The Marconi School Building, sited in Biancavilla (LAT 37◦030 N, LON 17◦ E), built in 1934, has two elevation floors, and a C-shaped floor plan, which defines an open inner courtyard (Fig.2). The façades on the public streets face southwest (main façade), southeast and northwest (side façades).

Fig.2 Case study building: aerial overview, 3D view, main façade facing Vittorio Emanuele street (photo plan) and side façades facing Meli and Dusmet streets.

The building is used for pre-school on the ground floor and for primary school both on the first floor and partially on the ground floor. All the classrooms, as shown in Fig.3, are oriented southwest and southeast, in order to guarantee the best conditions of sunshine and to be able to enjoy the free solar gains in the winter period; the classrooms are of various sizes, ranging from a minimum of 31.1 m^2 to a maximum of 67.9 m^2.
There are 3 types of windows, as shown in Figure 4; they are surrounded by a stone frame and have a fixed fanlight and an openable part. In particular, the type B windows, due to architectural choices, are located in biforas and therefore consist of 2 single-hung frames separated by a stone column.

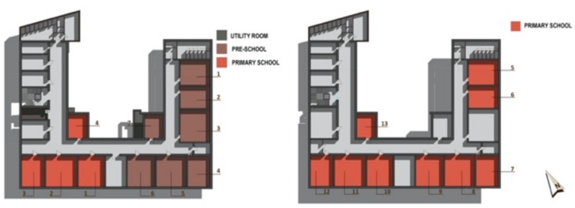


Fig. 3. Plan of the ground and first floor (in brown pre-school and in red primary school).

In accordance with the SINPHONIE study approach, the variables considered to have a possible influence on the amount of light inside the classrooms are the following: type of lighting (natural, artificial, or mixed), window size, presence of direct sunlight, type of window glazing, type of shading, latitude, percentage of windows facing south, and openable windows.

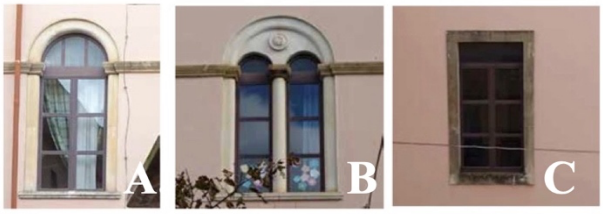


Fig.4 Case study: type of windows

All the classrooms have direct sunlight and openable windows. There are no shutters or other shading systems.
Table 1 provides the above-mentioned data for each classroom. It is possible to notice that in many rooms the Window-to Floor Ratio (WFR) is lower than 12.5%, thus this ratio is not fulfilled. It is possible to notice that in many rooms the Window-to Floor Ratio (WFR) is lower than 8.0%, thus the requisite WFR of 12.5% is not fulfilled.

3. Analyses and Results

The 3D representation of the building and of the adjacent built up was carried out by the Autodesk Revit 2018 software The lighting analysis was conducted using the Insight lighting Analysis plug-in. Such tool allows to carry out lighting simulations at the various hours of the day and different days of the year, to evaluate the contribution of light natural. It is possible to define the type of analysis to be performed (e.g Illuminance Analysis, Daylight Autonomy, LEED 2009 IEQc8 opt1, LEED v4 EQc7 opt 2, Solar Access).
Fig. 5 shows the representation of the building school through REVIT.

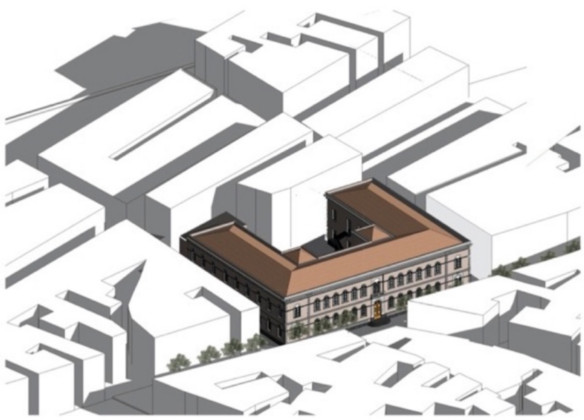


Fig. 5. 3D view of the building school

The diagrams that define the solar route and the realistic views carried out on the main elevation placed on Vittorio Emanuele street are shown below. The shadow study, shown in figures 6 and 7, was carried out: at 8:00, and 12:00 a.m., on 21 December and 21 June.
The comparison between the photos taken at the same hours as the 3D simulation has allowed verifying that the simulation of shadows was faithful.

A. Daylight analysis

Figure 8 shows the illuminance on 21 December at 10:00, 12:00, and 15:00 hours, at the ground (a,b,c) and first floor (d,e,f) Figure 9 shows the illuminance on 22 March at 10:00, 12:00, and 15:00 hours, at the ground (a,b,c) and first floor (d,e,f). Observing the levels of natural lighting, important differences are observed according to the day of the year, the time of day, the orientation of the classrooms, and the floor of the building. On 21 December, which is the most critical day for daylight, the classrooms facing southeast (side façade on Meli street), on the ground floor, receive modest natural lighting due to the shading caused by the facing buildings. An exception is a classroom overlooking a side street that receives direct solar radiation at 10:00, a condition which however could give rise to risks of glare. Comparable lighting levels are observed on the first floor, with the exception of the classroom with double exposure located in the corner of the building. Also on this floor, the room facing the side street, at 10.00, will reach high levels of illumination and risks of glare. The classrooms with a southwest orientation (Vittorio Emanuele street), on the ground floor, are poorly lit until 10:00, after which the lighting levels increase significantly. Classrooms on the first floor have illuminances similar to those on the ground floor. At 15:00 very high illuminances are observed in all classes with potential risks of glare. The corridors and rooms facing northwest all receive modest natural lighting.

On 22 March, almost all of the classrooms reach good lighting levels, with the exception of the classrooms facing southeast which are poorly lit in the afternoon. On the other hand, in classrooms with a southwest orientation, there is the risk of glare and therefore the need to use shading systems.

Fig. 6. Building shadow on 21 December at 8:00 (left side) and 12:00 (right side)

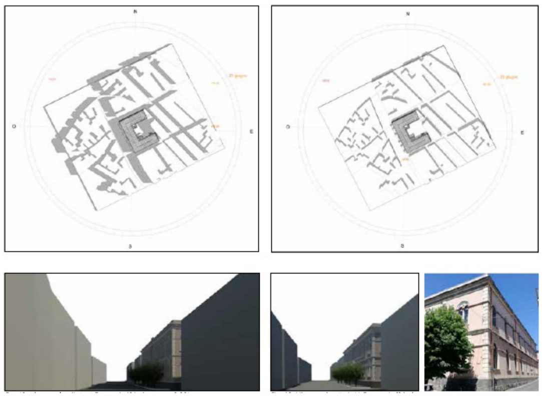
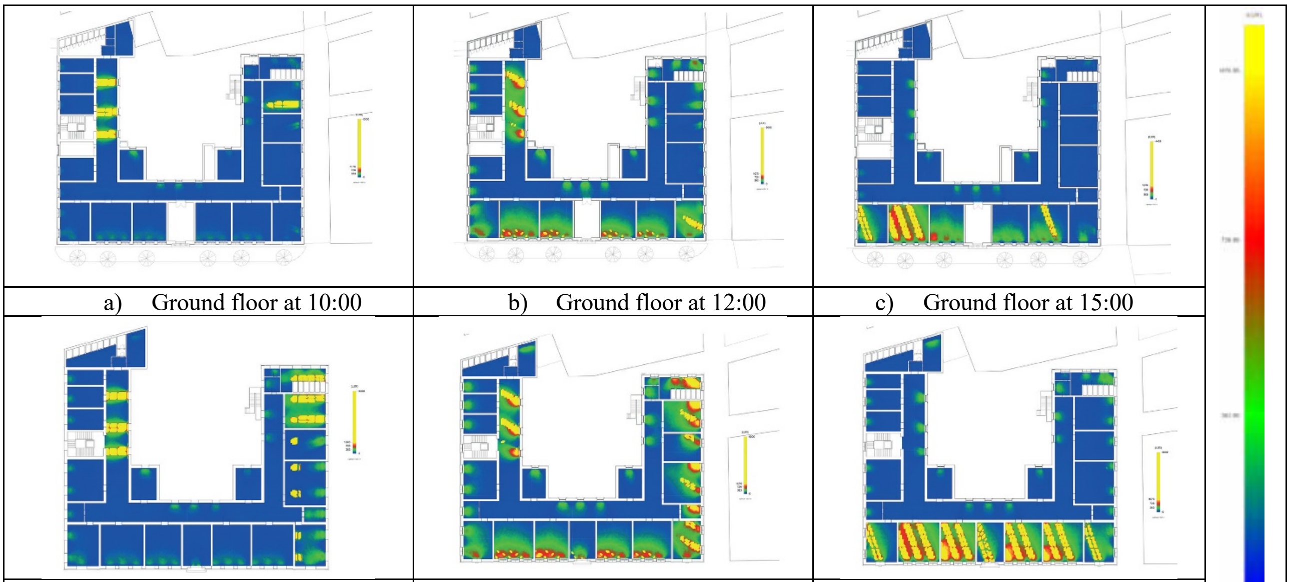


Fig. 7. Building shadow on 21 June at 8:00 (left side) and 12:00 (right side)

Table I. – Classroom lighting classification (pre-school classrooms I-VII and primary school classrooms 1-13);

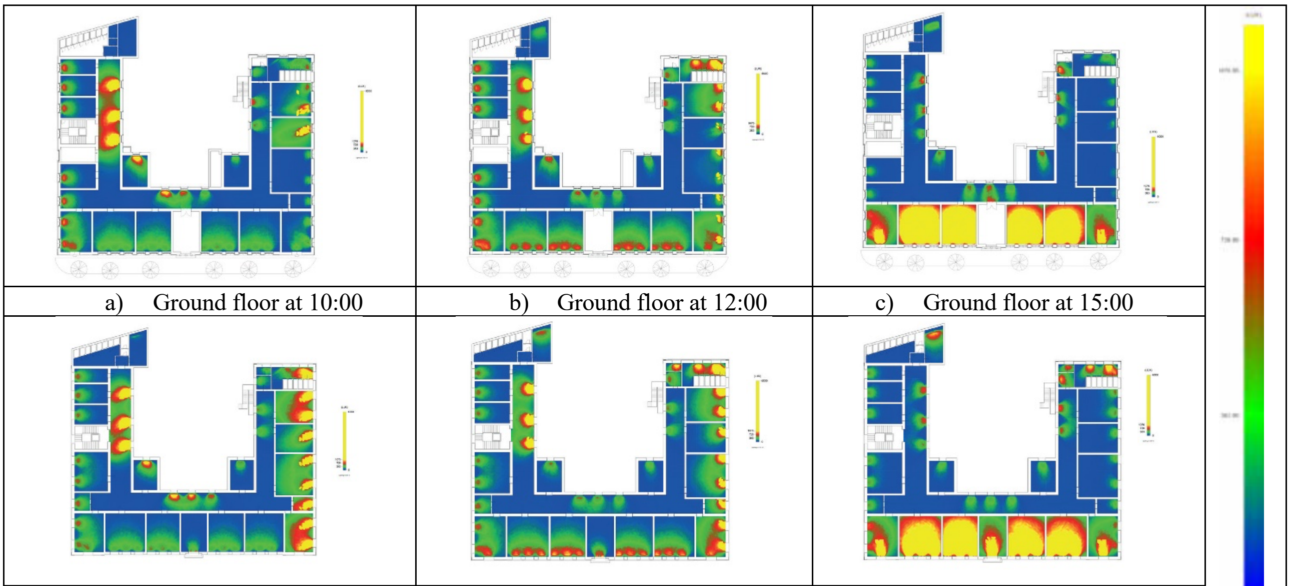
	classroom	floor	surface (m^2)	window type	orientation	window size (m)	window glazing	(WFR)
Pre-school	I II III	ground	52.6 46.3 68.3	A	S-E	1.25x3.00	double glazing	7.1% 8.1% 5.5%
	IV	ground	48.8	A; B	S-E; S-W	1.25x3.00; 2x (0.65x 2.6)	double glazing	14.6%
	V VI	ground	65.5 60.2	A	S-W	1.25x3.00	double glazing	5.7% 6.2%
	VII	ground	31.1	C	N-E	1.4 x 2.66	double glazing	12.0%
Primary school	1 2	ground	57.0 67.9	A	S-W	1.25x3.00	double glazing	6.6% 5.5%
	3	ground	49.8	A B	S-W N-W	1.25x3.00 2x (0.65x2.6)	double glazing	14.3%
	4	ground	31.1	C	N-E	1.4x 2.66	double glazing	12.0%
	5 6	first	52.6 46.3	A	S-E	1.25x3.00	double glazing	7.1% 8.1%
	7	first	48.8	A B	S-E S-W	1.25x3.00 2x (0.65x 2.6)	double glazing	14.6%
	8 9 10 11	first	65.5 60.2 57.0 67.9	A	S-W	1.25x3.00	double glazing	5.7% 6.2% 6.6% 5.5%
	12	first	49.8	A B	N-W S-W	1.25x3.00 2x (0.65x 2.6)	double glazing	14.3%
	13	first	31.1	C	N-E	1.4 x 2.66	double glazing	12.0%



a) Ground floor at 10:00 b) Ground floor at 12:00 c) Ground floor at 15:00

d) First floor at 10:00 e) First floor at 12:00 f) First floor at 15:00

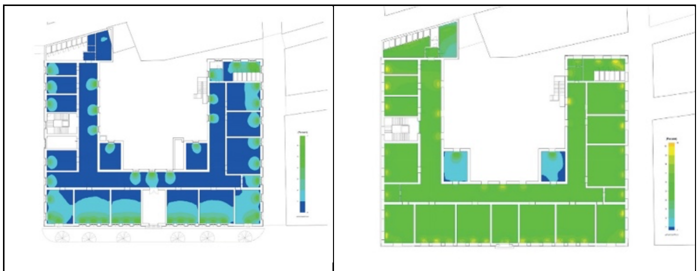
Fig. 8. Ground and first-floor illuminance at 10:00. 12:00. and 15:00 on 21 December



a) Ground floor at 10:00 b) Ground floor at 12:00 c) Ground floor at 15:00

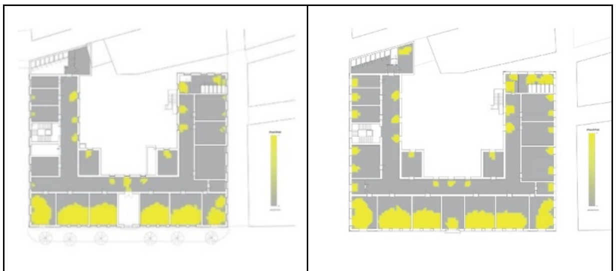
d) First floor at 10:00 e) First floor at 12:00 f) First floor at 15:00

Fig. 9. Ground and first-floor illuminance at 10:00. 12:00. and 15:00 on 22 March



a) Ground floor b) First floor

Fig. 10. Average Day Light factor



a) Ground floor b) First floor

Fig. 11. Daylight Autonomy (DA)

Table II. – Classroom lighting results

Floor	Class	Orientation	FWR	DF(%)	DA (%)
ground	I	S-E	7.1%	1.2	1
	II	S-E	8.1%	0.70	2
	III	S-E	5.5%	0.80	2
	IV	S-E/S-W	14.6%	2.10	38
	V	S-W	5.7%	2.10	44
	VI	S-W	6.2%	2.30	56
	VII	N-E	12.0%	0.60	3
	1	S-W	6.6%	2.10	59
	2	S-W	5.5%	1.90	44
	3	S-W/N-W	14.3%	1.70	50
	4	N-E	12.0%	0.60	5
first	5	S-E	7.1%	4.90	9
	6	S-E	8.1%	4.80	30
	7	S-E/S-W	14.6%	5.40	48
	8	S-W	5.7%	5.00	41
	9	S-W	6.2%	5.10	47
	10	S-W	6.6%	5.00	52
	11	S-W	5.5%	5.10	50
	12	S-W/N-W	6.6%	5.00	58
	13	N-E	5.5%	1.70	5

Figure 10 shows the average daylight factor. It can be observed that the DF of the classrooms at the ground is always lower than 3%, vice versa at the first floor it is higher than 3% with the exception of room 13.

Figure 11 shows the Daylight Autonomy (DA). It can be observed that the classrooms facing southwest have the highest DA for both the ground and the first floor.

Table II presents a synthesis of the results obtained.

5 Conclusion

This study has evaluated the lighting levels, luminance distribution, average daylight factor, and daylight autonomy for the classrooms of an Italian building school built in the first middle of the last century. The daylight analysis reveals that most classrooms suffer from glare and lack of uniform illumination, while some have insufficient levels of illuminance, especially that at ground floor.

Starting from these analyses it is necessary to design measures of light refurbishment to guaranty lighting comforts within the classrooms, without compromising the distinctive features of this historical building.

Thus the following measures could be proposed:

(i) Improving the daylight uniformity by using orientable light shelves installed on the clerestory of windows;

(ii) installation of a highly-reflective diffuse ceiling which allows the increase of the lighting levels in the room by redirecting towards the floor the solar light;

(iii) renovation of the artificial lighting system;

(iv) installation of a control system, which allow the movement of the light shelves as a function of the lighting levels.

It is very important to observe that the proposed refurbished intervention must be also taken into account of the acoustic of the room, which is another important task required in classroom. [19]

References

[1] Regolamento e istruzioni tecnico igieniche per l'esecuzione della legge 8 luglio 1888 sugli edifici scolastici, Italy (In Italian).

[2] Regio Decreto 15 novembre 1900. n. 484. "Nuove istruzioni governative intorno alla compilazione di progetti per la costruzione degli edifici moderni" (In Italian).

[3] Regio Decreto 1 maggio 1925 n.1432, "Approvazione del regolamento per la costruzione di edifici scolastici".

[4] D. Giaccone, Gli edifici scolastici in Italia dall'unità nazionale alla seconda guerra mondiale. Aracne editrice. Italy. 2017.

[5] A. Gagliano, A. Moschella, D. Giaccone, "Strategie per la riqualificazione energetica degli edifici scolastici di epoca fascista", Il progetto sostenibile (2016). 18 Edicom edizioni.

[6] Ecosistema Scuola. XIX rapporto di Legambiente sulla qualità dell'edilizia scolastica, delle strutture e dei servizi. Rome. Italy. 2018. (Available online: https://www.legambiente.it/wp-content/uploads/ecosistema_scuola_2018.pdf)

[7] P. Barrett, F. Davies, Y. Zhang, L. Barrett, "The impact of classroom design on pupils' learning: Final results of a holistic. multi-level analysis" Build. Environ (2015), 89 pp.118–13.

[8] P.M. Bluyssen, D. Zhang, S. Kurvers, M. Overtoom, "Ortiz-Sanchez. M. Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings" Build. Environ. (2018), 138 pp.106–123.

[9] RM Baloch, CN Maesano, J Christoffersen, C. Mandin, E. Csobod, EO Fernandes, I Annesi-Maesano, Consortium OBOTS. "Daylight and School Performance in European Schoolchildren" Int J Environ Res Public Health (2020 Dec 31); 18(1):258.

[10]https://orf.od.nih.gov/TechnicalResources/Documents/Technical%20Bulletins/19TB/Daylighting%20%E2%80%93%20European%20Standard%20EN%2017037%20October%202019-Technical%20Bulletin_508.pdf

[11] CIBSE. Lighting Guide 5: Lighting for Education; The Chartered Institution of Building Services Engineer: London. UK. 2011; https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7kGAAS

[12] BRE Global Ltd. BREEAM UK—New Construction. Non-Domestic Buildings. Technical Manual; BRE Global Ltd.: Watford. UK. 2014.

[13] UNI EN 10840. Luce e Illuminazione—Locali Scolastici—Criteri Generali per l'illuminazione Artificiale e Naturale; Ente Italiano di Normazione: Milan. Italy. 2011. (In Italian)]

[14] V. Costanzo, G. Evola, L. Marletta, "A Review of Daylighting Strategies in Schools: State of the Art and Expected Future Trends". Buildings (2017).

[15] C.F. Reinhart, O. Walkenhorst, "Radiance-based daylight simulations for a full-scale test office with outervenetian blinds" Energy Build. (2001) 33. 683–697.

[16] Standard IES LM-83–1. Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), New York. NY. USA. 2012.

[17] A. Nabil, J. Mardaljevic, "Useful daylight illuminances: A replacement for daylight factors" Energy Build. (2006) 905–913.

[18] C.F. Reinhart, D.A. Weissman, "The daylight area-correlating architectural student assessments with current and emerging daylight availability metrics", Build. Environ. (2011) 50. 155–164.

[19] F. Nocera, A. Gagliano, G. Evola, MC Gioia, "Acoustic quality of a tensile membrane structure used as a lecture hall, and proposals for its improvement", Building Acoustics (2014) 21 (4), 287-304.