04
Research paper
Doi 10.61892/STP202601089K
ISSN 2566-4484

Jelena Kljakić, University of Banja Luka, jelena.rasovic@aggf.unibl.org
Biljana Antunović, University of Banja Luka, biljana.antunovic@aggf.unibl.org
Ljubiša Preradović, University of Banja Luka, ljubisa.preradovic@aggf.unibl.org
Darija Gajić, University of Banja Luka, darija.gajic@aggf.unibl.org
Slobodan Peulić, University of Banja Luka, slobodan.peulic@aggf.unibl.org
Milan Pupčević, University of Banja Luka, milan.pupcevic@mf.unibl.org
Milovan Kotur, University of Banja Luka, milovan.kotur@mf.unibl.org

ASSESSMENT OF DAYLIGHT AVAILABILITY IN AN EDUCATIONAL BUILDING

Abstract:
This study analyses daylight availability in a faculty lecture classroom using illuminance measurements and a survey of students. The results of the measurements conducted in mid-February showed that the recommended horizontal illuminance level (300 lx) was achieved at 50% of the measurement points around midday (12:00 h and 14:00 h), while only 0–15% of the area met this requirement at 8:00 h and 16:00 h. The minimum illuminance level (100 lx) was satisfied at all measurement points around midday but decreased to 25–45% in the early morning and late afternoon. Survey results indicated that 76.7% of students reported the need for artificial lighting during the winter period. Since natural daylight is sufficient during certain periods of the day, optimisation of the lighting system and the integration of controlled sensors for supplementary lighting are recommended.

Keywords: visual comfort, educational building, daylight, illuminance

ПРОЦЈЕНА ДОСТУПНОСТИ ДНЕВНЕ СВЈЕТЛОСТИ У ЗГРАДИ ОБРАЗОВНЕ НАМЈЕНЕ

Сажетак:
У овом раду анализирана је доступност дневне свјетлости у факултетској учионици на основу мјерења освијетљености и анкете међу студентима. Резултати мјерења проведеног средином фебруара показали су да је препоручени ниво хоризонталне освијетљености (300 lx) остварен на 50% мјерних тачака око поднева (12:00 h и 14:00 h), док је у 8:00 h и 16:00 h овај услов испуњавало свега 0–15% површине. Минимални ниво освијетљености (100 lx) био је задовољен на свим мјерним тачкама око поднева, али се смањио на 25–45% у раним јутарњим и касним поподневним часовима. Резултати анкете показали су да 76.7% студената наводи потребу за коришћењем вјештачког освјетљења током зимског периода. С обзиром на то да је природна дневна свјетлост довољна у одређеним периодима дана, препоручује се оптимизација система освјетљења и интеграција контролисаних сензора за допунско освјетљење.

Кључне ријечи: визуелни комфор, образовна зграда, дневна свјетлост, освијетљеност

1. INTRODUCTION

Indoor environmental quality (IEQ) covers a broader set of factors than indoor air quality (IAQ) alone, as it also includes the overall sensory experience of occupants: what they see, hear, and feel within the indoor environment. Thermal, acoustic, and lighting comfort conditions, together with IAQ, are especially important for students since they spend around 30% of their time in universities and schools [1]. Poor IEQ in schools has been linked to illness, increased student absenteeism, adverse health effects, and a decline in learning performance [2]. Although studies are limited, systematic literature reviews indicate that the quality of indoor environmental conditions in classrooms, including air, thermal, acoustic, and lighting conditions, can positively influence students' learning and short-term academic performance [3]. Among these factors, lighting is considered one of the most important aspects of IEQ. Until the beginning of the twentieth century, natural lighting was the primary source of building illumination. With the introduction of electric lighting, natural light was supplemented in this way or even completely replaced. The current practice is such that the lighting typically combines daylight and electric light. These two light sources can be controlled independently; however, lighting quality must also be maintained in the absence of daylight [4]. For classrooms, the recommended illuminance level ranges between 300 lx and 500 lx, in order to ensure adequate visual conditions for teaching and learning activities.

Lighting quality requirement is based on satisfying three human needs: visual comfort, visual performance, and safety [5]. Since lighting has an impact on people's physical, physiological, and psychological well-being, it should be designed to enhance human well-being in addition to facilitating visual activities [6], [7]. The unique spectral qualities of daylight provide health benefits that cannot be replicated by electric lighting. Skin exposure to daylight induces the production of vitamin D. Furthermore, daylight plays a crucial role in synchronising the circadian clock, which in turn regulates blood circulation, affects metabolism, and modulates the levels of various hormones. Castilla et al. demonstrated that natural daylight produced more positive emotional responses from students than electric lighting [8]. Some findings also indicate that classroom characteristics related to daylighting significantly affect students' performance, potentially explaining over 20% of the variation in test scores [9]. Adjusting light levels, colour temperature, and spectrum throughout the day and across seasons can further enhance well-being. These effects, beyond standard lighting requirements, are linked to "non-image-forming" qualities of light.

In addition to its impact on human health, natural light plays a significant role in the energy consumption of buildings. While regulations on building energy efficiency have primarily focused on energy for heating and cooling due to their significant share of the EU's energy consumption, components like windows also impact overall energy use by reducing the need for artificial lighting through daylighting [10]. Bashir et al. have shown that when the daylighting factor increases from 3% to 6%, the average annual CO_2 emissions decrease by approximately 3% [11]. Therefore, integrating natural light into building design, particularly through skylights and daylight-responsive systems, can improve energy efficiency.

This study aimed to evaluate daylight availability in an educational building and to assess the need for electric lighting to meet visual requirements, with daylight measurements introduced as an extension of earlier research focused on IAQ. Measurements were taken in the classroom, and students were surveyed regarding the adequacy of daylight and their use of electric lighting. Other visual comfort parameters, such as glare risk, luminance distribution, and colour rendering quality, were not considered.

2. MATERIAL AND METHODS

Visual comfort is defined in the European standard EN 12665 [12] as a subjective state of visual well-being arising from the visual environment, i.e. it refers to how occupants perceive and experience the lighting conditions within a space. It is influenced by several factors, including the physiology of the human eye, the physical quantities that describe the amount of light and its spatial distribution, and the spectral characteristics of the light source. In both, research and practice, visual comfort is commonly evaluated through key parameters that describe the interaction between human visual needs and the luminous environment. These parameters typically include the quantity of light, the uniformity of its distribution, the quality of color rendering, and the potential risk of glare experienced by occupants.

The evaluation of these aspects is often guided by international lighting standards and recommendations. Documents developed by the International Commission on Illumination and the

International Organization for Standardization define criteria for appropriate illuminance levels, visual comfort, and overall lighting quality in indoor environments. The first standard, EN 17037, which exclusively focused on natural daylight, was introduced at the end of 2018 [13]. It defines the criteria for achieving an adequate subjective perception of indoor lighting using only natural light, as well as for providing an appropriate view of the outdoor environment. Before the introduction of the new standard, illuminance analysis was conducted in accordance with EN 12464 [5] and EN 15193 [14], these standards did not differentiate between artificial and daylight lighting. Although EN 12464-1 primarily addresses artificial lighting, its reference values, $\bar{E}$ and U_0, are commonly used to assess whether indoor lighting can meet the requirements of a visual task. Furthermore, the requirements for lighting of indoor workspaces, including the performance of visual tasks, are defined exclusively in EN 12464-1.

In this study, the availability and distribution of daylight were analyzed through daylight illuminance and uniformity, while light availability was further evaluated in terms of target illuminance (E_T) and minimum target illuminance (E_{TM}). To calculate these parameters, illuminance was measured at selected points within the space.

The relevant quantities and the applied methodology are described in the following sections.

2.1. PHYSICAL QUANTITIES

Daylight can be used partially or fully to illuminate indoor spaces and offers significant potential for energy savings. The amount of daylight inside a building depends on outdoor conditions, the surrounding environment, and the design of interior spaces. However, daylight alone is not consistently sufficient, since its intensity varies throughout the day and seasonally, and it is further affected by parameters such as the size, position, orientation, and material of windows, as well as the reflectivity of interior surfaces. One of the key parameters determining visual comfort is illuminance - the ratio of the luminous flux incident on a surface to the area of that surface. In the context of daylight, target illuminance E_T (lx) represents the desired level of illuminance to be achieved within the space. It defines the target lighting condition that should be provided by daylight across the relevant portion of the reference plane for a specified percentage of the annual daylight hours. The minimum target illuminance E_{TM} (lx) defines the lower acceptable limit of illuminance, below which the lighting level in the space should not fall. Although E_{TM} is lower than E_T, it is required to be achieved across almost the entire reference plane, ensuring a uniform minimum level of daylight throughout the space.

Daylight uniformity U_o is the ratio of the minimum illuminance E_{min} to the average illuminance $\bar{E}$:

$$U_o = \frac{E_{min}}{\bar{E}} \tag{1}$$

Uniformity is used to assess daylight distribution, with a higher uniformity ratio indicating a more even and therefore better distribution of daylight throughout the space.

2.2. THE EXAMINED UNIVERSITY CLASSROOM

Measurements of illuminance, along with a survey, were carried out in the building of the Faculty of Physical Education and Sport (FPES) on the University of Banja Luka campus. The building was constructed with massive masonry walls and reinforced concrete ribbed floor slabs, while its envelope lacks thermal insulation. The transparent elements, mostly windows, account for 17.25% of the total building envelope area. The windows are wooden-framed and fitted with double glazing in a single sash, providing only basic thermal performance. Illuminance measurements and a survey of 60 students were conducted in a typical north-oriented lecture room on the second floor (total area 90 m²; Figure 1), with the survey carried out in November 2024 and the measurements performed on 11 February 2025. Daylight levels were evaluated in terms of target illuminance, minimum target illuminance, and daylight uniformity, providing quantitative information on lighting conditions as well as insights into occupants' perception of visual comfort and the adequacy of views to the outdoor environment. The collected data were subsequently processed using SPSS (version 22) and Microsoft Excel to assess daylight availability, illuminance levels, and occupants' perception of lighting conditions.

The daylight can be verified through the use of appropriate simulation tools or by conducting in-situ measurements. While simulation tools are suitable for assessing daylight in both existing buildings and during the design and planning stages, in-situ measurements are mainly employed to validate the results. In this study, the measurements were carried out on 11 February, a day selected due to completely overcast sky conditions throughout the day. This enabled the observation of representative daylight conditions, given that lectures in the winter period in the analysed classroom are held in the afternoon. It should be noted that simulation results may differ significantly from the actual conditions measured in practice, with smaller discrepancies being observed under cloudy sky conditions [10].

A grid of points was created to indicate the locations where the illuminance was measured. According to EN 17037, the minimum number of measurement points is determined by the nearest whole number, d/p where d represents the longer dimension of the calculation area (m), and p is the maximum grid cell size, calculated as:

$$p = 0.5 \times 5^{\log(d)} = 2.79. \quad (2)$$

According to the previous condition, the minimum number of points was 4 x 3. U.C9.100:1962 and CIBSE Lighting Guides prescribe the grid creation in the room depending on the index of the room, that is, the number of measurement points is determined by the room index, which is calculated as $k = \frac{ab}{h_k(a+b)}$, where a and b are dimensions and h_k is the effective height. In this case, the recommendation for the number of points in the measurement grid is 18 for the accuracy ± 5%, or 9 for the accuracy ± 10 %.

To form a grid with equally sized measurement cells while considering the desks arrangement, the number of measurement points was set to 20 (Figure 1). The ratio of length to width of each grid cell was maintained between 0.5 and 2, with an actual value of 1.2, as recommended. The grid consisted of 4 points along the width and 5 points along the length of the classroom. It should be noted that a 0.5 m band from the walls was not excluded, despite common recommendations, because the desks, as primary work surfaces, are located along the walls.

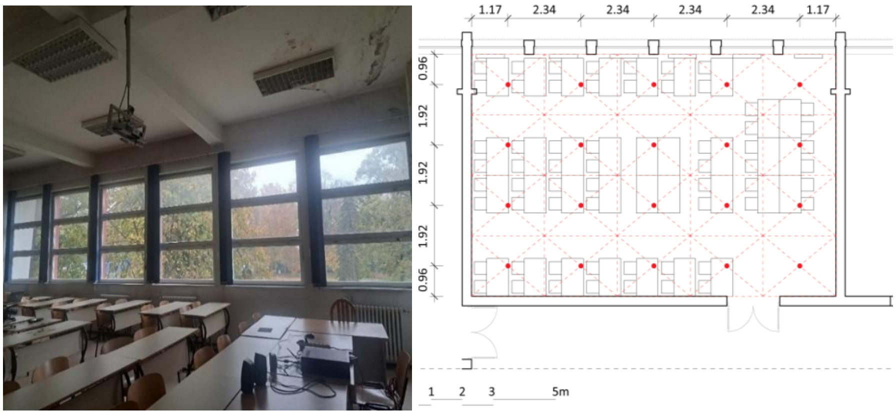

Figure 1. The classroom where measurements and surveying were conducted (created by author).

For the illuminance measurements, an Almemo Ahlborn 2690-8 data logger with a corresponding luxmeter sensor was used (Figure 2). Technical specifications of the instrument are: the illuminance measurement range (0 lx to 260.000 lx), accuracy ±5% (optional < 3%) and spectral correction.

Figure 2. Almemo Ahlborn 2690-8 (left), luxmeter (right) (photography by author).

The measurements were recorded at 20 locations within the room, over a single day at 8:00 h, 10:00 h, 12:00 h, 14:00 h, and 16:00 h. This setup allowed both the spatial and temporal variations in daylight levels.

The assessment of daylight conditions in the classroom was conducted in accordance with EN 17037, which addresses the quality and availability of natural light in indoor spaces. The visual requirements for teaching and learning activities were evaluated separately by comparing the measured illuminance values with the recommendations given in EN 12464-1, which specifies lighting requirements for indoor workplaces, including classrooms. This comparison was performed to assess the extent to which daylight alone can meet the required illuminance levels for visual tasks, without considering electric lighting.

2.3. REQUIREMENTS

The assessment methodology is based on three predefined performance levels (minimum, medium, and high), with the corresponding criteria summarised in Table 1. The criteria are applied to two spatial thresholds, requiring the target illuminance to be achieved over 50% and 95% of the reference area, respectively. In the case of the minimum performance level and spaces with vertical or inclined daylight openings, the required illuminance values are 300 lx over 50% of the space and 100 lx over 95% of the space, both sustained for a minimum of 50% of the daylight hours.

Table 1. Recommendations for daylight provision by daylight openings in vertical and inclined surfaces.

	Target illuminance (E_T) $[lx]$	Fraction of space for target level (F_{plane})[%]	Minimum target illuminance (E_{TM}) [lx]	Fraction of space for minimum target level (F_{plane}) [%]	Fraction of daylight hours (F_{time}) [%]
Minimum	300	50	100	95	50
Medium	500	50	300	95	50
High	750	50	500	95	50

3. RESULTS

Periodic measurements of daylight were conducted in a classroom used for lectures, with corresponding illuminance levels systematically recorded. Additionally, a survey was conducted among the students who attend classes in the observed classroom. The survey examined their subjective perception of the availability of natural light, as well as their perceived need for supplementary artificial lighting. This approach enabled the spatial and temporal variations of the illuminance levels in the room within the classroom, providing insights into the adequacy of daylight for teaching activities and the potential need for supplementary artificial lighting.

3.1. OBJECTIVE INDICATORS

Natural light in the classroom decreases significantly from the windows toward the interior and also varies throughout the day, peaking around 12:00 – 14:00 and declining sharply in the afternoon. Illuminance values are lower during the early morning and late afternoon hours, while peak values occur around midday, corresponding to the highest solar altitude (Figure 3). This pattern is particularly pronounced at measurement points located near the windows, indicating the strong dependence of indoor illuminance on external daylight conditions.

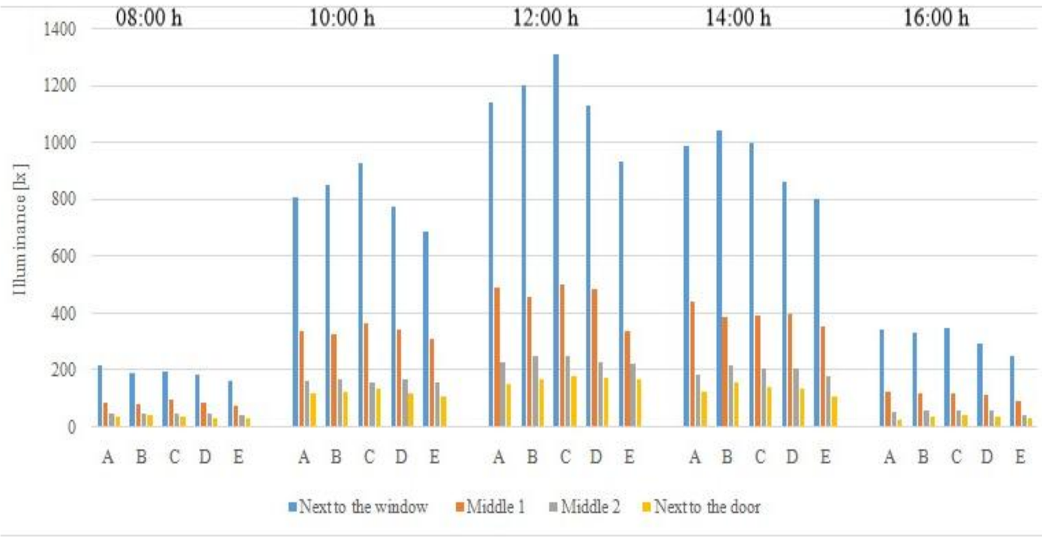

Figure 3. Temporal illuminance distribution. Zone A denotes the area in front of the board, while zone E denotes the area at the back of the classroom. The zones in between are labelled B, C, and D, respectively, from the board toward the back of the classroom (created by author).

Spatially, the highest illuminance levels are consistently recorded in the zone adjacent to the windows, where maximum values exceed 1200 lx during midday hours (Figure 4). Illuminance decreases progressively with increasing distance from the façade, further emphasising the gradient of natural light within the classroom.

In comparison to the window-adjacent zone, the central zones of the classroom have lower temporal variability and moderate illuminance levels, typically ranging between 300 lx and 500 lx during peak daylight hours. The lowest illuminance values are observed at measurement points located near the door and at the back of the classroom. In these areas, illuminance frequently remains below 200 lx, especially during the morning and afternoon periods, indicating insufficient daylight availability for visual tasks without supplementary electric lighting.

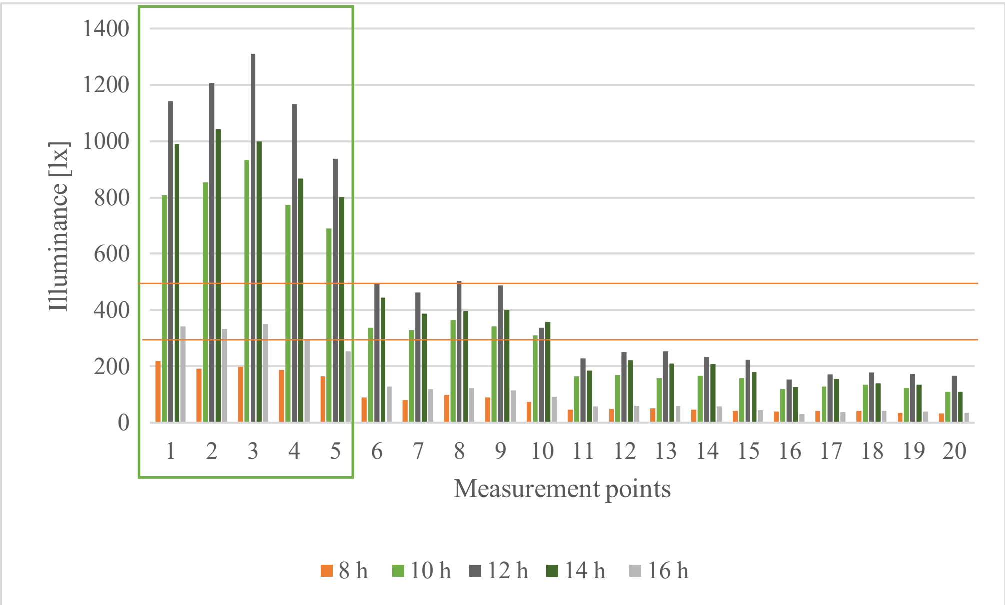

Figure 4. Spatial illuminance distribution. Points 1–5 represent the zone near the window, while points 15–20 represent the zone near the door. Points 5–10 and 10–15 are two zones along the length of the classroom, located between the window and the door (created by author).

Table 2 presents the requirements for four target illuminance levels (100 lx, 300 lx, 500 lx, and 750 lx) and three qualitative categories (minimum, medium, and high), specifying the portion of the plane and the duration of time over which the specified conditions must be met.

Table 2. Daylight provision

	E_T $[lx]$	8:00 h F_{plane} [%]	10:00 h F_{plane} [%]	12:00 h F_{plane} [%]	14:00 h F_{plane} [%]	16:00 h F_{plane} [%]	F_{time} [%]
Minimum	300	0	50	50	50	15	60%
Medium	500	0	25	25	25	0	-
High	750	0	20	25	25	0	-
	E_{TM} [lx]	8:00 h F_{plane} [%]	10:00 h F_{plane} [%]	12:00 h F_{plane} [%]	14:00 h F_{plane} [%]	16:00 h F_{plane} [%]	F_{time} [%]
Minimum	100	25	100	100	100	45	60%
Medium	300	0	50	50	50	15	-
High	500	0	25	25	25	0	-

Table 3 presents the average illuminance values in the classroom for each measurement interval, along with corresponding minimum and maximum illuminance values. The average illuminance values were evaluated against visual performance requirements, according to EN 12464-1.

Table 3. Average, maximum and minimum illuminance values, along with illuminance uniformity.

	8:00 h	10:00 h	12:00 h	14:00 h	16:00 h
$\bar{E}$	91.7	358.7	502	417.8	130.7
E_{max}	220	932	1311	1042	351
E_{min}	32	109	154	110	30
U_o	0.3	0.3	0.3	0.3	0.2

3.2. SUBJECTIVE SURVEY

A survey involving 60 students was conducted in the investigated classroom, where the measurements were also performed. Among the participants, 22 were male (36.67%), and 38 were female (63.33%), with a mean age of 21.22 years (standard deviation: 2.37). Results of the student survey related to daylight availability and the need for artificial lighting are presented in Table 4. The majority of students (55%) reported that daylight during the winter period was not sufficient for task performance, while 45% of them considered the available daylight to be adequate. Consequently, a high proportion of respondents (76.7%) indicated the need to use artificial lighting during the winter period, whereas only 23.3% of them stated that artificial lighting was not required. With respect to the perceived illuminance of the work plane, most students rated the lighting as medium (53), while fewer rated it as low (6) or high (1), indicating overall moderate lighting conditions in the classroom.

Table 4. Respondents' characteristics and assessment of daylight sufficiency

Faculty of Physical Education and Sports (FPES)		
Gender	Male	22 (36.67%)
	Female	38 (63.33%)
Age (year)	Mean	21.22
	St. Deviation	2.373
Stay in the faculty premises (years)	Mean	1.30
	St. Deviation	0.8088
Sufficiency of daylight for task performance (winter period)	Yes	27 (45%)
	No	33 (55%)
The need to use artificial lighting during the winter period	Yes	46 (76.7%)
	No	14 (23.3%)
Illuminance of the work plane	Minimum	6
	Medium	53
	High	1

It should be noted that the χ^2 test showed no statistically significant difference ($\chi^2 = 0.6$, $p = 0.439$) in respondents' answers concerning the adequacy of lighting for work in winter. In contrast, a highly statistically significant difference was observed ($\chi^2 = 17.067$, $p < 0.001$) in respondents' answers concerning the use of artificial lighting during the same period.

4. DISCUSSION

The measured daylight provision in the classroom was analysed at 20 points throughout the day (8:00 h, 10:00 h, 12:00 h, 14:00 h, and 16:00 h) and compared with the recommended illuminance levels spatial fractions. As shown in Table 1 [12] and Table 2, horizontal illuminance (E_T) reached the minimum recommended value of 300 lx in 50% of the points around midday (12:00 and 14:00), while at 8:00 and 16:00, only 0–15% of the area met the minimum requirement. These findings indicate that natural daylight itself does not provide adequate illuminance to satisfy minimum illuminance requirements in the early morning and late afternoon. Additionally, medium and high illuminance levels were generally not achieved throughout the day. Measurements also indicated that the front zone consistently achieves higher illuminance levels, while the rear zone exhibits a significant reduction, emphasising the strong daylight gradient characteristic. The reason for this is the shading effect and the presence of outdoor vegetation surrounding the rear part of the classroom.
When considering the target illuminance on work surfaces E_{TM}, the results Table 2) show that the minimum level (100 lx) was achieved at 100% of the measurement points around midday, decreasing to 25–45% in the early morning and late afternoon. The medium (300 lx) and high (500 lx) levels were only partially met, with a maximum of 50% and 25% of the surface, respectively, reaching the target between 10:00 and 12:00. These findings indicate that while natural daylight can provide sufficient illuminance for basic visual tasks during peak hours, it is generally insufficient to maintain medium or high lighting levels throughout the day, highlighting the need for supplementary artificial lighting during early morning and late afternoon periods.

In educational buildings, it is recommended that illuminance provide sufficient light for basic visual tasks during peak hours. For different types of classrooms and lecture halls, target illuminance levels should be in the range of 300–500 lx, with a uniformity of 0.6. Comparing the average illuminance (Table 3), it is evident that the recommended levels are met during the period from 10:00 to 12:00. However, when uniformity is considered, some areas still fall below the required illuminance for visual tasks. Although the average illuminance is satisfactory during certain periods of the day, the classroom uniformity is only 0.3, which explains why students report the need for additional artificial lighting even when the average illuminance appears adequate. Similar findings were reported in a study of daylight performance in an Austro-Hungarian heritage building located within a university campus, where significant spatial variations in illuminance and insufficient uniformity were also observed, indicating the need for supplementary artificial lighting during certain periods of the day [15].

5. CONCLUSION

An analysis of daylight availability in a faculty lecture classroom using illuminance measurements and a survey of students occupying the classroom was conducted in this study.

Daylight illumination in the classroom is spatially non-uniform and generally insufficient across the reference plane. The window zone frequently exceeds 500 lx, the central zone reaches 300–500 lx only around noon, while the rear zone remains almost constantly below the required illuminance levels. Objective measurements indicate insufficient light availability between 8:00 and 16:00, which aligns with students' subjective responses, as only 45% considered the available daylight to be adequate.

Considering that natural daylight is adequate during limited periods of the day, it is recommended to adjust the lighting system and integrate controlled sensors for supplementary lighting, which could enable energy savings of 20–30%.

For future studies, it will be necessary to perform year-round simulations and compare them with measurements for result validation. Additionally, measurements should also be repeated following the building renovation to assess changes in daylight availability.

ACKNOWLEDGMENT

The authors acknowledge the support of the European Research Executive Agency (REA) for funding this research under the project "ENPOWER – Enhancing Scientific Capacity for Energy Poverty (101160253 — ENPOWER — HORIZON-WIDERA-2023-ACCESS-02)" and also the authors acknowledge the support of the Ministry of Scientific and Technological Development and Higher Education, Republic of Srpska Government, for funding this research under the project "Correlation between envelope quality and indoor air quality in an educational building".

LITERATURE

[1] V. De Giuli, O. Da Pos, and M. De Carli, "Indoor environmental quality and pupil perception in Italian primary schools," *Building and Environment*, vol. 56, pp. 335–345, Oct. 2012.

[2] U. Haverinen-Shaughnessy, R. J. Shaughnessy, E. C. Cole, O. Toyinbo, and D. J. Moschandreas, "An assessment of indoor environmental quality in schools and its association with health and performance," *Building and Environment*, vol. 93, pp. 35–40, 2015.

[3] H. W. Brink, M. G. L. C. Loomans, M. P. Mobach, and H. S. M. Kort, "Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: A systematic literature review," *Indoor Air*, vol. 31, no. 2, pp. 405–425, Mar. 2021.

[4] T. Kruisselbrink, R. Dangol, and A. Rosemann, "Photometric measurements of lighting quality: An overview," *Building and Environment*, vol. 138, pp. 42–52, Jun. 2018.

[5] *Light and lighting – Lighting of work places – Part 1: Indoor work places*, EN 12464-1:2011, Brussels, 2011.

[6] L. Bellia, "Lighting in indoor environments: Visual and non-visual effects of light sources with different spectral power distributions," *Building and Environment*, vol. 46, pp. 1984–1992, 2011.

[7] N. Shishegar and M. Boubekri, "Natural light and productivity: Analyzing the impacts of daylighting on students' and workers' health and alertness," presented at *Proc. Int. Conf. Health, Biological and Life Science (HBLS-16)*, Istanbul, Turkey, Apr. 2016.

[8] N. Castilla, V. Blanca-Giménez, C. Pérez-Carramiñana, and C. Llinares, "Differences between daylighting and electric lighting in affective response," *Buildings*, vol. 14, no. 3, 2024, Art. no. 770.

[9] R. M. Baloch et al., "Daylight and school performance in European schoolchildren," *Int. J. Environ. Res. Public Health*, vol. 18, no. 1, Dec. 2020, Art. no. 258.

[10] J. Rucińska and A. Trząski, "Measurements and simulation study of daylight availability and its impact on the heating, cooling and lighting energy demand in an educational building," *Energies*, vol. 13, no. 10, 2020, Art. no. 2555. https://doi.org/10.3390/en13102555

[11] M. Arun and G. Gopan, "Effects of natural light on improving the lighting and energy efficiency of buildings: Toward low energy consumption and CO_2 emission," *Int. J. Low-Carbon Technol.*, vol. 20, pp. 1047–1056, 2025.

[12] *Light and lighting — Basic terms and criteria for specifying lighting requirements*, EN 12665:2018, CEN, Brussels, 2018.

[13] *Daylight in buildings*, EN 17037:2018, CEN, Brussels, 2018.

[14] *Energy performance of buildings — Energy requirements for lighting — Part 1: Specifications*, EN 15193-1:2017, CEN, Brussels, 2017.

[15] B. Antunović, M. Malinović, J. Rašović, and S. Petrović, "Daylight Performance in an Austrohungarian Heritage Building," *AGG+ Journal for Architecture, Civil Engineering, Geodesy, and Related Scientific Fields*, vol. 8, no. 1, pp. 8–18, Dec. 2020.