Architectural Studies
International Journal about Architecture

Volume 12, No. 2

UDC 721:727.05
DOI: 10.56318/as/2.2026.01

ISSN: 2411-801X
e-ISSN: 2786-7374

Viktoriia Dukhina
Student
Odesa State Academy of Civil Engineering and Architecture
65029, 4 Didrikhson Str., Odesa, Ukraine
https://orcid.org/0000-0002-5560-2434

Halyna Burlak*
PhD in Physics and Mathematics, Associate Professor
Odesa State Academy of Civil Engineering and Architecture
65029, 4 Didrikhson Str., Odesa, Ukraine
https://orcid.org/0000-0002-3259-1568

Liudmyla Vilinska
PhD in Physics and Mathematics, Associate Professor
Odesa State Academy of Civil Engineering and Architecture
65029, 4 Didrikhson Str., Odesa, Ukraine
https://orcid.org/0000-0003-4597-2527

Biophilic design elements in protective structures for educational institutions

Abstract. This study addressed the relevance of biophilic design principles in artificial lighting systems for educational shelters, where the absence of natural light and the confined spatial conditions can intensify stress and anxiety among occupants. The purpose of the research was to identify and substantiate lighting strategies that replicated qualities of natural illumination and enhanced user comfort in protective learning environments. The methodological approach included comparative analysis of sensory responses to various artificial lighting scenarios, evaluation of lighting parameters that emulated natural conditions, and examination of design techniques used in controlled, windowless environments. Special attention was given to the role of light intensity, colour temperature, distribution, and temporal dynamics in shaping spatial perception and emotional stability. It was analysed educational shelters in Mykolaiv Lyceum No. 55, Bilohorodka Lyceum No. 2, and the supporting gymnasium in Nizhyn, which were selected for their operational status and representative spatial characteristics. While these facilities demonstrated a comparatively high level of technical organisation and regulatory compliance, analysis revealed deficiencies attributable to the complete absence of natural daylight, limited visual connectivity with the exterior, and the spatial dominance of reinforced concrete enclosures. The research results demonstrated that artificial lighting systems incorporating soft diffusion, gradual transitions, and circadian-inspired dynamics significantly improved spatial perception, reduced psychological discomfort, and promoted a sense of safety in enclosed shelters. Systems that simulated daylight patterns through controlled brightness shifts and natural-tone spectra were found to be particularly effective in lowering stress indicators and maintaining cognitive performance during prolonged occupancy. Integration of biophilic lighting elements contributed to the functional transformation of protective structures, making them suitable not only for emergency use but also for extended educational activities. The practical value of this study lain in developing design guidelines for

Suggested Citation:
Dukhina, V., Burlak, H., & Vilinska, L. (2026). Biophilic design elements in protective structures for educational institutions. *Architectural Studies*, 12(2), 9-18. doi: 10.56318/as/2.2026.01.

Journal homepage: https://arch-studies.com.ua/en
Architectural Studies, 12(2), 9-18
Received: 19.01.2026 Revised: 13.04.2026 Accepted: 02.06.2026 Published: 22.06.2026

*Corresponding author (*demiga89@gmail.com*)

integrating biophilic lighting into educational shelters, thereby enhancing their functional resilience and supporting users' psychological well-being

Keywords: natural daylight; artificial lighting; psychological comfort; shelter architecture; safety; dynamic lighting

INTRODUCTION

The creation of comfortable, psychologically supportive environments in protective structures for educational institutions had become an increasingly urgent challenge in contemporary architectural research. During emergencies, students and staff may spend extended periods in confined shelters, where the absence of natural light, restricted spatial configurations and limited sensory stimuli can lead to elevated anxiety, perceptual discomfort, and overall psychophysiological stress. Scientific studies confirmed that traditional approaches to the design of lighting and spatial layouts in protective facilities remained predominantly technical and frequently overlook human-centred and restorative principles. K. Husar (2023) noted that the prevailing engineering-oriented design paradigm in civil protection structures insufficiently addressed users' psychological needs. Researchers noted that simulation of natural lighting, by imitating the spectral and dynamic properties of natural light, had the effect of increasing attention and concentration, and improving social interaction. Similarly, N. Semyroz (2022) emphasised the limited integration of well-being-oriented criteria into the spatial planning of protective environments. This gap highlighted the necessity of exploring biophilic design strategies capable of enhancing comfort and resilience in enclosed spaces. Between 2020 and 2025 years, the integration of biophilic design into educational and underground environments had gained significant international attention. J. Deol *et al.* (2022) demonstrated that biophilic lighting interventions can measurably improve student comfort and productivity. Using an online Qualtrics survey, scientists found that both natural daylight and lighting elements that mimic circadian rhythms increased the level of comfort and productivity compared to artificial lighting in a basement workspace. The developers of CoeLux. Experience the sky (n.d.) presented Artificial Skylight technologies that simulated natural daylight conditions and mitigate the psychological burden of windowless environments. E.-N.D. Madias *et al.* (2023) further substantiated the effectiveness of advanced artificial daylight systems in supporting emotional stability in enclosed spaces.

K. Poimanova (2024) analysed the influence of biophilic elements in educational interiors and identified their role in attention recovery and stress reduction. L. Mengqi *et al.* (2025) highlighted the contribution of nature-inspired design strategies to environmental satisfaction and cognitive engagement in learning settings. The authors showed that the influence of curvilinear forms contributed to greater improvement in cognitive functions and stress reduction, while non-biophilic forms provided better protection against stress. Learning environments with non-biophilic design may be more suitable for stressful tasks (such as lessons and exams), while environments with curvilinear biophilic forms were better suited for relaxation, creativity and attention. Additionally, S. Incesakal & M.S. Venice (2020) investigated biophilic approaches in earth-sheltered and underground structures, revealing their potential to improve spatial perception and user orientation in windowless conditions. W. Browning *et al.* (2014) classified 14 biophilic design patterns into nature in the space, natural analogues, and nature of the space. In Ukraine, the urgency of this issue was reinforced by the need to adapt civil protection facilities in educational institutions to updated safety requirements and extended periods of occupancy. The national regulation SCN V.2.2-5:2023 (2023) established contemporary standards for the design of protective structures, including requirements for functional and environmental quality. T. Zhydkova & N. Pylypenko (2023) identified persistent deficiencies in lighting quality, spatial organisation, and psychological comfort in preschool, underlining the necessity of integrating human-centred and biophilic design principles into their architectural transformation. Also, the authors proposed variants of murals in shelters of children's institutions. So, study aimed to examine the potential of biophilic design, particularly biophilic lighting principles, to improve the environmental quality of protective structures in educational institutions. The objectives included: 1) identifying relevant biophilic design elements applicable to enclosed protective spaces; 2) analysing their functional, perceptual, and psychological effects in the context of shelter use; 3) developing a set of evidence-based design recommendations for educational facilities.

MATERIALS AND METHODS

This study applied a mixed-method research design that combined systematic literature analysis, comparative architectural review, and project-based experimentation to identify biophilic design elements appropriate for protective structures in educational institutions. The methodological framework was developed to ensure a transparent and fully replicable research process so that other scholars can reproduce the study using equivalent materials and procedures. The empirical part of the study relied on a purposive sampling of architectural case studies of protective spaces in educational institutions, specifically: Mykolaiv Lyceum No. 55 (Mykolaiv, Ukraine) (Rohalevych, 2024), a newly implemented reinforced-concrete underground shelter equipped with modern engineering systems and organised learning and play zones. Bilohorodka Lyceum No. 2 (Bilohorodka, Kyiv region, Ukraine) (Kyiv Regional

Military Administration, 2023), a contemporary school shelter developed under regional reconstruction initiatives with improved spatial zoning and technical infrastructure. Supporting gymnasium in Nizhyn (Chernihiv region) (KSE Foundation, n.d.), where adapted protective space integrated updated safety infrastructure within an existing educational building. Case selection criteria included operational status and sufficient descriptive and visual materials for detailed spatial assessment. Given the absence of publicly available architectural documentation for these facilities, the analysis was conducted on the basis of materials accessible through open sources. Each case was considered within the spatial configuration, lighting conditions, material characteristics and the possibility of integrating biophilic elements under safety restrictions.

A project-based methodological component was incorporated to test the applicability of biophilic principles in real design scenarios. An interior design concept was developed for an educational institution shelter using biophilic artificial lighting as the primary intervention tool. The design process involved several iterative stages: establishing functional and safety requirements in compliance with civil protection regulations including such documents as Civil Protection Code of Ukraine No. 5403-VI (2012), Law of Ukraine 2145-VIII (2017) and SCN V.2.2-5:2023 (2023); analysing the spatial layout to determine optimal lighting distribution; selecting lighting typologies capable of simulating natural rhythms; and modelling visual, perceptual, and psychological effects through digital prototyping. Artificial luminaires with biophilic characteristics, such as variable correlated colour temperature, dynamic intensity patterns, and diffused forms inspired by natural analogues, were tested virtually to evaluate their impact on atmosphere, visual comfort, and perceived spaciousness. Each design iteration was documented and assessed using predefined performance indicators, including correlated colour temperature range and spectral variability, contrast ratios, spatial zoning clarity, perceived openness (based on visual simulation), and compliance with minimum sanitary to ensure methodological consistency and replicability. The final research stage synthesised findings from the literature review, case-study analysis, and project-based experimentation. Biophilic elements were grouped according to their functional contribution, perceptual impact, and psychological relevance for protective structures.

RESULTS AND DISCUSSION

Protective structures (shelters) in educational institutions must integrate safety, functionality, and a comfortable environment suitable for prolonged occupancy, addressing both physical protection and the psychological well-being of students and staff. Beyond fulfilling their primary protective function, these facilities should provide conditions that allowed educational activities to continue uninterrupted and minimise stress, anxiety, and other negative psychological effects associated with prolonged stays in enclosed spaces. The necessity for such an integrated approach had been underscored by the ongoing experience in Ukraine, where the full-scale military aggression and the persistent threat of missile strikes, aerial bombardments, and explosive damage to civilian infrastructure have significantly heightened the demand for high-quality protective shelters within schools (Malik *et al.*, 2023). The design and functional organisation of protective structures in educational institutions must comply with the current Ukrainian regulatory framework, which defined safety, operational, and environmental requirements for such facilities. In particular, SCN V.2.2-5:2023 (2023) established mandatory standards for spatial planning, engineering systems, lighting parameters, and sanitary conditions in civil protection shelters. These provisions ensured structural resilience, minimum luminance levels, ventilation performance, and safe evacuation routes, forming the technical basis for the architectural adaptation of educational shelters.

Lighting requirements were further specified by SCN V.2.5-28:2018 (2019), which defined normative illuminance levels, uniformity ratios, and colour rendering indices for educational and public spaces. While this standard ensured baseline visual comfort and task-oriented performance, it addressed lighting exclusively in static, quantitative terms and does not account for spectral variability, circadian dynamics, or the psychological effects of light on occupants in enclosed, windowless environments. The absence of such qualitative criteria within the existing normative framework represented a significant gap, as the conditions of prolonged shelter occupancy, particularly among children, demand considerably higher environmental standards than minimum compliance can provide. This limitation underscored the need to supplement current regulatory requirements with evidence-based biophilic lighting guidelines developed specifically for the context of educational protective structures. At the institutional level, the Law of Ukraine 2145-VIII (2017) guaranteed the right to safe and accessible learning environments and required educational institutions to provide conditions that protected the life, health, and well-being of students and staff. This legislative framework reinforced the necessity of integrating protective shelters into school infrastructure not merely as emergency facilities, but as spaces capable of supporting continuous educational processes under extraordinary circumstances. Civil Protection Code of Ukraine No. 5403-VI (2012) defined the legal and organisational principles of civil protection, including the responsibilities of public authorities and institutions in ensuring population safety during emergencies and armed conflict. The Civil Protection Code of Ukraine No. 5403-VI (2012) regulated the creation, maintenance, and operational readiness of protective structures, thereby providing the legal foundation for their implementation in educational settings.

Case studies examined in this research represented a contemporary stage in the development of educational protective structures in Ukraine, each of them demonstrating distinct architectural characteristics with direct implications for biophilic lighting integration. Mykolaiv

Lyceum No. 55 (Rohalevych, 2024) accommodated up to 600 occupants in a newly constructed reinforced-concrete underground shelter located beneath the school building. The shelter comprised a series of interconnected rooms arranged along a linear corridor, with clearly defined functional zones for learning, play, and sanitary facilities. The ceiling height was approximately 2.4 m, and the spatial configuration was characterised by a uniform rectangular layout without natural light apertures. The structural envelope consisted of exposed and plastered reinforced concrete, with no significant use of transparent or light-scattering materials. Artificial lighting was provided by standard fluorescent ceiling fixtures offering static, uniform illumination without dynamic or circadian adjustment. The absence of windows, the monotony of the concrete surfaces, and the fixed lighting regime result in a spatially undifferentiated environment that offered limited perceptual variation across zones. Bilohorodka Lyceum No. 2 (Kyiv Regional Military Administration, 2023) presented a more architecturally developed solution, realised as part of a regional reconstruction initiative in Kyiv oblast. The shelter was integrated into the basement level of the school building and features improved spatial zoning, with separate areas designated for educational activities, rest, and service functions. The interior finish employed painted masonry and partial use of acoustic panels, contributing to a more controlled acoustic environment. Lighting was delivered through LED ceiling fixtures, though colour temperature and intensity remained fixed. The spatial organisation followed a branching corridor system with slightly greater ceiling heights than in the Mykolaiv case, yet the perimeter walls remained fully opaque and windowless, and no biophilic or nature-referencing design elements were incorporated into the existing installation.

The supporting gymnasium shelter in Nizhyn (Chernihiv region) was adapted within an existing building as part of an initiative by the Olena Zelenska Foundation and KSE Foundation, which equipped the space as an inclusive protective environment for approximately 800 students (KSE Foundation, n.d.). The adapted space occupied a ground-floor or semi-basement level and integrated updated safety infrastructure, including reinforced structural elements, ventilation, and emergency systems, into the pre-existing architectural shell. The interior was organised with attention to inclusivity, incorporating accessible pathways and spatial flexibility. Lighting was provided through modern LED fixtures, and the interior palette employed lighter tones to counteract the visual heaviness of the enclosed setting. Despite these improvements, the space retained the fundamental constraint of full enclosure with no direct daylight access, confirming the systemic challenge shared across all three case studies: the need for purposeful artificial lighting strategies capable of compensating for the complete absence of natural light, the dominance of hard structural surfaces, and the limited visual connectivity with the external environment. Analysis revealed a shared structural constraint critical to the implementation of the lighting systems proposed in this study. Artificial Skylight technologies required minimum ceiling height and sufficient plenum depth that cannot be achieved through retrofitting of existing protective structures, where spatial dimensions were fixed by the original construction. Integration of sky-simulating lighting systems was therefore feasible exclusively within new construction, where the relevant parameters can be designed from the outset. The examined cases thus highlighted the gap between existing shelter infrastructure and the design standards proposed in this research.

Natural possessed a strong aesthetic function: it created dynamic interactions of light and shadow, emphasised volumetric qualities of space, and established visual depth and texture, thereby enhancing the perceived quality of interior environments (Katrichenko *et al.*, 2020). Such effects were crucial in educational settings, where both cognitive performance and emotional stability were closely linked to environmental quality. However, in protective structures or shelters, access to natural daylight was often limited or entirely absent due to architectural constraints, underground locations, or safety requirements. In these conditions, daylight must be effectively substituted by artificial lighting systems designed in accordance with biophilic principles. Key factors included: spectral composition (light with a high level of blue spectrum during daytime promoted cognitive activation and supported circadian rhythms, whereas warm light reduced stress in the evening); lighting intensity (excessive or insufficient brightness disrupts visual comfort); colour temperature (regulating lighting according to time of day supports harmonious psychophysiological processes – cool light stimulates activity, while warm light promoted relaxation); uniformity and quality of light distribution (harsh contrasts, shadows, or glare increase eye strain and cause discomfort) (Poimanova, 2024). Biophilic lighting strategies in protective educational shelters were implemented through integrated LED-based systems, including light wells, Virtual Sky ceilings, luminous virtual windows, video panels with natural imagery Artificial Skylights. These solutions improved cognitive performance and contributed to emotional stability by recreating perceptual physiological characteristics of natural daylight within enclosed environments. Realistic “sky” views on ceilings and upper wall planes mitigated the sense of confinement typical of underground shelters, while luminous virtual windows recessed flush with wall surfaces created the illusion of spatial depth. The introduction of elongated horizontal luminous openings further enhances the perception of openness by stimulating interior beyond its physical boundaries. The technological basis of such systems lain in programmable LED luminaires with adjustable spectral output and intensity. Through digital control units, lighting scenarios can simulate diurnal cycles, ensuring smooth transitions from warm morning light to brighter neutral daylight and subsequently to warmer evening tones (Deol *et al.*, 2022). Lighting regulation was calibrated in accordance with the duration of occupancy and the functional zoning of the shelter, allowing differentiated illumination for study, rest, and circulation areas.

To achieve visual comfort, it was essential to avoid harsh contrasts and ensure uniform luminance distribution. This was accomplished through the combination of diffuse and accent lighting. Diffuse illumination was provided by LED panels with optical diffusers or continuous light lines integrated into ceilings and walls, creating a soft daylight-like background. Accent lighting was applied in learning or relaxation zones to establish functional differentiation without disrupting overall visual balance. Cool light above 5000 K may increased anxiety, whereas warm-to-neutral light within the range of 2700-3000 K promoted psychological stability and relaxation, particularly during prolonged shelter use (Incesakal & Venice, 2020). Insufficient illumination led to drowsiness and decreased cognitive efficiency, while excessive brightness caused visual strain; therefore, adaptive, dimmable systems were recommended. To strengthen the perception of natural presence, LED panels and projection-based systems can display dynamic visualisations of foliage, clouds, or filtered sunlight, reinforcing sensory connections to natural analogues (Browning *et al.*, 2014). Among advanced daylight-mimicking technologies, Artificial Skylights represented a particularly effective solution. Designed to reproduce the spectral, chromatic, and intensity characteristics of natural light, it simulated the visual effect of blue sky and solar penetration even in windowless spaces (CoeLux. Experience the sky, n.d.). The application of technologies reproducing the daylight spectrum and visual sky effects ensured a comprehensive positive impact on the well-being of individuals within shelters. Realistic imitation of an "open sky" on the ceiling transformed the architectural perception of the space, neutralising the sense of isolation and confinement typical of underground structures. The use of such systems in educational institutions had been shown to increase student productivity and reduce fatigue. Table 1 summarised a comparison of the effects of artificial daylight and conventional artificial lighting on the psychophysiological state of humans.

Table 1. The impact of artificial lighting on human psychophysiological state

No.	Parameter	Artificial lighting simulating the sky (Artificial Skylight)	Conventional artificial lighting
1	Visual comfort	High; simulates natural sky, reducing visual fatigue	Moderate; uniform but may cause visual fatigue due to monotony
2	Anxiety level	Reduced; natural visual cues help lower anxiety	Elevated; standard light may create a sense of confinement and increase anxiety
3	Attention stimulation	High; natural light simulation supports activity and concentration	Moderate; bright light promotes focus but effectiveness decreases due to lack of variation
4	Emotional state	Improved; daylight simulation creates comfort and sense of security	Neutral or negative; artificial light may contribute to feelings of fatigue
5	Physiological response	Positive; regulates circadian rhythm, reduces stress	Neutral or negative; does not support biorhythm regulation, may increase stress
6	Learning quality	Enhanced; better perception and retention of information	Neutral; does not improve cognitive performance
7	Light intensity and distribution	Dynamic, natural changes throughout the day; even spatial illumination	Fixed, static, often uneven distribution
8	Effect on biorhythms	Positive; supports natural circadian rhythms and adaptation to time of day	Absent; fixed intensity disrupts natural biorhythms
9	Spatial perception	Creates a sense of open space, expanding room boundaries	Creates a sense of confinement, potentially contributing to psychological discomfort

Source: developed by the authors

The implementation of lighting panels that simulated a sky dome provided a transformative approach to interior illumination in protective structures, creating the perceptual illusion of open space and expansive ceilings. This effect was particularly effective in mitigating feelings of confinement and claustrophobia, which were common stressors in enclosed or underground shelter environments. For younger school-age children, such perceptual interventions were of critical importance, as a sense of safety and spatial freedom directly influenced emotional stability, cognitive functioning, and the ability to engage in learning and play during prolonged shelter occupancy. Retrofitting of existing protective structures with Artificial Skylight systems was constrained by fixed ceiling heights and structural configurations that precluded the installation depth such technologies required. The biophilic interior design project for an educational shelter at 129 Stryiska Str., Lviv, developed by Viktoriia Dukhina within the framework of the Steel Freedom 2024 architectural competition, addressed this limitation directly by proposing a purpose-designed shelter conceived as part of a new-construction school, where spatial parameters were determined from the outset to accommodate advanced biophilic lighting solutions (Steel Freedom, n.d.). This approach allowed the full implementation of the lighting strategies examined in this study, including Artificial Skylight systems, dynamic LED configurations, and circadian-responsive control, without the dimensional and structural constraints inherent to reconstruction. The design solutions presented were conceived as modular:

while developed for this specific facility, it established a replicable framework of lighting typologies, spatial zoning principles, and technical configurations that can be adapted to any new-construction educational shelter regardless of institution or location. The project thus served not as a site-specific proposal but as an evidence-based design model demonstrating how biophilic lighting principles can be systematically integrated into the standard practice of educational shelter design in Ukraine.

The project's primary objective was to safeguard the well-being, cognitive performance, and emotional stability of children and staff during prolonged occupancy, while maintaining functional flexibility for both educational and recreational activities. The shelter was designed to serve a dual purpose: as a protective structure ensuring physical safety and as a supportive educational space promoting comfort and engagement. The interior layout was carefully structured into clearly defined zones: classrooms, group activity areas, rest and nap spaces for preschool children, dining facilities, and recreational areas. Circulation paths were wide and fully accessible, allowing children with limited mobility to move freely and ensuring rapid and safe evacuation in emergency situations. All materials used in the shelter were durable, non-toxic, and easy to maintain, with special attention to acoustic performance and visual clarity. Furniture and spatial arrangements were modular, enabling flexible adaptation for varying group sizes and diverse activity types. Spatial zoning also incorporated visual and acoustic separation to minimise distractions, promote concentration. The primary school classroom represented the basic learning scenario (Fig. 1). Its colour palette and wall graphics followed the principles of the New Ukrainian School, creating a supportive and development-oriented environment (Order of the Cabinet of Ministers of Ukraine No. 988-r, 2016). A single central Artificial Skylight lamp was integrated into the ceiling, generating the perceptual effect of an atrium and visually increasing the vertical dimension of the room. Uniform task illumination was ensured by recessed LED luminaires arranged according to normative illuminance requirements (Order of the Ministry of Health of Ukraine No. 2205, 2020). The combination of diffuse skylight simulation and functional LED lighting provided balanced luminance distribution, reduced glare, and improved visual comfort.

Figure 1. Primary school classroom in shelter. View from the entrance (the basic scenario)
Source: developed by the authors

The corridor was designed in a more neutral chromatic range to maintain calmness and spatial continuity (Fig. 2). Instead of one dominant element, a sequence of smaller Artificial Skylight lamps was rhythmically arranged along the ceiling and alternated with linear LED fixtures. This modular system created distributed zones of perceived daylight, broke the monotony of an elongated underground passage, and enhanced spatial orientation. Through this integrated approach, Artificial Skylights operated as architectural instruments that improved perceptual openness and psychological comfort in protective educational environments. Central to the shelter design was the lighting system, which integrated biophilic principles to support both psychological comfort and cognitive efficiency. The main ambient lighting was provided through LED panels with adjustable colour temperature ranging from 2700 K to 6500 K. This allowed the creation of a baseline illumination level sufficient for educational activities, while closely simulating natural daylight enhancing overall visual comfort. For a classroom of approximately 70 m^2, the recommended configuration included 6-8 ceiling-mounted LED panels, strategically positioned to ensure uniform light distribution and accommodate furniture layout and activity zones. The luminaires were designed to reduce glare, prevent harsh shadows, and maintain a high level of visual clarity, all of which were essential for prolonged work and learning periods in confined spaces.

Figure 2. Primary school classroom in shelter. Corridor view (daylight)
Source: developed by the authors

In addition to primary lighting, three biophilic accent luminaires were integrated into the ceiling to simulate windows revealing blue skies or drifting clouds. These luminaires dynamically adjusted their spectral output throughout the day, transitioning from warm morning light to cooler midday illumination, thus replicating natural daylight cycles. Their architectural placement, centred within the ceiling plane and oriented to maximise upward luminous diffusion, reinforced the spatial impression of overhead openness and contributed to the visual differentiation of the learning zone from adjacent circulation and rest areas. Task-specific lighting was incorporated into learning and group activity areas through localised light sources, such as wall-mounted or desk lamps with a warm spectrum around 3000 K. These luminaires provided focused illumination optimised for reading, writing, and group work, enhancing visual performance and comfort, while reinforcing functional zoning within the shelter. The placement of localised lighting considered ergonomic principles and sightlines, ensuring that users received sufficient illumination without creating excessive contrast or glare, which could increase visual fatigue or stress. Safety considerations were integral to the lighting strategy. Emergency luminaires with autonomous power supply were incorporated to guarantee a minimum illumination level during power outages and to act as orientation markers within the shelter. It was recommended to install 1-2 emergency luminaires per classroom to maintain visibility and support safe navigation under critical conditions. The combination of primary, accent, localised, and emergency lighting created a multi-layered illumination system that was both functionally robust and psychologically supportive. The proposed design also addressed visual perception and spatial cognition through biophilic strategies. By integrating dynamic lighting that emulated natural light variations and incorporating visual connections to natural elements such as sky and clouds, the design reduces the psychological impact of confinement typically associated with underground or enclosed shelters. Additionally, the integration of modular furniture and spatial organisation allowed the shelter to adapt to different group sizes, activities, and operational scenarios, further enhancing both functional efficiency and user comfort. This combination of spatial and lighting strategies supported a dual-purpose approach: ensuring physical protection, while simultaneously providing a psychologically restorative and educationally productive environment.

The primary biophilic lighting principles implemented in this project aimed to establish a naturalistic and psychologically supportive environment within the enclosed conditions of a school shelter. First, a perceptual connection with nature was achieved through dynamic adjustment of lighting parameters, allowing intensity and correlated colour temperature to vary according to time of day and user activity, thereby enhancing comfort and functional efficiency. The incorporation of Artificial Skylight technologies further reinforced this connection by simulating an open sky and providing diffuse light with high spectral fidelity. Second, the integration of natural elements and materials was ensured through a synergistic design approach, in which lighting interacts with biophilic components such as natural textures, vegetation, and environmentally inspired colour schemes to produce a coherent spatial experience. Localised directional lighting was used to emulate sunlight penetration or daylight patches, strengthening associative links to outdoor environments and enhancing perceived environmental connectedness. Third, the project applied health-supportive artificial lighting strategies based on uniform light distribution and daylight simulation. Even illumination was achieved through indirect lighting systems and luminaires with diffusing elements that eliminated harsh contrasts and glare. Artificial light sources reproduced the spectral characteristics and dynamic variability of natural daylight, while Human-Centric Lighting systems supported circadian rhythm regulation, improved concentration, reduced stress levels during prolonged shelter occupancy. Based on the findings of the analysed case study on shelter design, it is worth proposing changes for Mykolaiv Lyceum No. 55, Bilohorodka Lyceum No. 2, and supporting gymnasium in Nizhyn. To improve the conditions, it would be advisable to install artificial skylight systems and dynamic LED lighting, which could enhance pupils' psychological comfort and provide the necessary lighting for learning.

Studies on energy-efficient and biophilic lighting confirmed that integrated lighting strategies enhanced cognitive engagement and user comfort. O.C. Dewi *et al.* (2020) demonstrated that biophilic lighting increased spatial attractiveness and reading interest in social facilities, supporting the broader premise that lighting performed both technical and psychological functions simultaneously. The authors findings were particularly relevant to shelter design, where the absence of natural stimuli places the entire affective burden of the environment on the artificial lighting system. N. Natsir *et al.* (2021) and D.T. Miranda *et al.* (2024) established quantitative criteria for visual comfort in educational spaces, providing a normative reference against, which the lighting configurations proposed in this study can be evaluated. Y. Bian *et al.* (2023) further demonstrated the importance of adaptive daylight systems for maintaining visual comfort and view clarity in classrooms, reinforcing the argument that static illumination was insufficient for environments intended to support sustained cognitive activity. Empirical research substantiated the restorative effects of biophilic design on the psychological and physiological condition of users. L. Mengqi *et al.* (2025) demonstrated measurable stress reduction and improved cognitive performance in high school interiors incorporating biophilic elements, and notably identified curvilinear forms and nature-referencing materials as the primary drivers of restorative response, a finding that broadened the scope of biophilic intervention beyond lighting alone. J.-Y. Kim & S.-J. Park (2025) identified statistically significant correlations between biophilic design interventions in school common areas and reduced indicators of adolescent depression, underscoring the particular importance of such strategies in environments occupied by children under conditions of prolonged stress. F. Favero *et al.* (2026) confirmed that daylight-mimicking systems positively influenced mood and alertness during extended indoor occupancy, providing direct empirical support for the Artificial Skylight configurations proposed in the project component of this study. P. Creati *et al.* (2025) conceptualised lighting design as an active architectural instrument capable of shaping behavioural and cognitive outcomes in training environments, thereby framing it not as a secondary technical consideration, but as a primary design decision with measurable consequences. A.M. Obeidat *et al.* (2025) extended the discussion beyond institutional settings, demonstrating that biophilic integration in residential environments significantly enhanced comfort, emotional stability, and perceived well-being; the transferability of these effects across building typologies reinforced the universal restorative potential of nature-inspired spatial strategies and supported their applicability to the high-stress conditions of shelter occupancy. Conversely, research specifically addressing protective structures continued to prioritise structural resilience and regulatory compliance over environmental quality. T. Malik *et al.* (2023) proposed multi-criteria optimisation models for civil shelter design in Ukraine, drawing on international precedents. While researcher's framework advanced the technical performance of protective facilities, psychological comfort and spatial quality were treated as secondary considerations subordinate to structural and logistical parameters. A. Jörgen *et al.* (2025) outlined contemporary design guidelines for civilian shelters in contexts of armed conflict, offering a rare systematic treatment of shelter architecture at the intersection of safety and habitability; yet biophilic integration was not addressed within their framework, and the qualitative dimensions of the interior environment remain outside the scope of their recommendations. This persistent gap between the technical and the human-centred dimensions of shelter design confirmed that the present study addressed a genuinely underexplored area, and that the development of evidence-based biophilic lighting guidelines for educational protective structures constituted a necessary contribution to both architectural research and design practice.

CONCLUSIONS

The integration of biophilic design principles into the development of artificial lighting for protective structures in educational institutions demonstrably enhanced psychological comfort, emotional stability, and perceived safety for both students and staff. Case-study analysis of Mykolaiv Lyceum No. 55, Bilohorodka Lyceum No. 2, and the supporting gymnasium shelter in Nizhyn confirmed that existing facilities, despite their regulatory compliance and functional adequacy, shared a common set of spatial deficiencies: fixed low ceiling heights, fully opaque enclosures, static artificial lighting, and the absence of any nature-referencing design elements, that collectively produced an environment ill-suited to prolonged educational occupancy. The design analysed in the study effectively reduced anxiety, alleviated feelings of confinement and created an environment conducive to learning, relaxation and extended stays, by mimicking natural lighting conditions using biophilic lighting fixtures that replicated daylight cycles and sky patterns. The adoption of a multi-layered lighting strategy, including primary, accent, localised, and emergency sources, ensured that spaces can adapt flexibly to varying functional requirements, activity types, and occupancy durations.

Biophilic artificial lighting contributed not only to the functional and safety performance of protective structures but also transformed these spaces into dual-purpose environments that actively supported educational activities and the well-being of occupants. The results of the comparative analysis, case-study evaluation, and project-based experimentation demonstrated that dynamic lighting scenarios with adjustable correlated colour temperature (2700-6500 K), uniform luminance distribution, and daylight-inspired temporal modulation contributed to improved concentration, emotional stability, and perceived safety among users. The application of Artificial Skylight technologies and diffused LED systems was found to expand perceived spatial boundaries, reduced the sense of confinement typical of underground facilities, and supported circadian rhythm synchronisation, thereby strengthening both cognitive performance and psychophysiological resilience. Further research should concentrate on refining adaptive lighting algorithms and conducting longitudinal performance assessments to develop comprehensive, evidence-based guidelines for the design of multifunctional educational shelters grounded in biophilic and human-centred principles.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Bian, Y., Chen, Y., Sun, Y., Ma, Y., Yu, D., & Leng, T. (2023). Simulation of daylight availability, visual comfort and view clarity for a novel window system with switchable blinds in classrooms. *Building and Environment*, 235, article number 110243. doi: 10.1016/j.buildenv.2023.110243.

[2] Browning, W., Ryan, K., & Clancy, J. (2014). *14 patterns of biophilic design: Improving health & well-being in the built environment*. New York: Terrapin Bright Green, LLC.

[3] Civil Protection Code of Ukraine No. 5403-VI. (2012, October). Retrieved from https://zakon.rada.gov.ua/laws/show/5403-17#Text.

[4] CoeLux. Experience the sky. (n.d.). Retrieved from https://www.coelux.com/.

[5] Creati, P., Cuccaro, A., & Gentilozzi, Ch. (2025). Lighting design as a possibility for the design of training and work spaces: A research proposal. *Form@re – Open Journal for Training in Network*, 25(1), 511-524. doi: 10.36253/form-17107.

[6] Deol, J., Lee, H., Kwok, A., Pappo, J., & Zhou, R. (2022). *The effects of biophilic lighting on student comfort and productivity*. (Report, University of British Columbia, Vancouver, Canada). doi: 10.14288/1.0421557.

[7] Dewi, O.C., Ismoyo, A.D., Felly, R., Aisyah, & Yohardi, L. (2020). Energy-efficient lighting and biophilic design concept to boost reading interest in social facilities' library. *IOP Conference Series: Earth and Environmental Science*, 505, article number 012008. doi: 10.1088/1755-1315/505/1/012008.
[8] Favero, F., Bresin, R., Lowden, A., & Muro, R. (2026). Light and perception: Study of the effects of daylight and artificial light on affect, mood, and sleepiness under a sky-lighting machine. *LEUKOS*, 22(3), 370-393. doi: 10.1080/15502724.2025.2609621.
[9] Husar, K. (2023). Biophilic design – application in the architectural environment. In *Proceedings of the all-Ukrainian scientific and practical conference "Traditions and innovations in modern design"* (pp. 15-18). Ivano-Frankivsk: King Danylo University.
[10] İncesakal, Ş., & Yenice, M.S. (2020). Effects of earthshelter's on urban space in context of biophilic design: A case of Meydan İstanbul Mall, Turkey. *Proceedings of the International Conference of Contemporary Affairs in Architecture and Urbanism*, 3(1), 130-143. doi: 10.38027/N132020ICCAUA316285.
[11] Jörgen, A., Łątka, J.F., Tarczewski, R., Szcześniak, Z., Pieńko, B., Morales-Beltran, M., Gromek, D., & Kosztołowicz, L. (2025). Design of shelters for civilians in the event of armed conflict: State of the art and contemporary design guidelines. *Housing Environment*, 52(3), 91-105. doi: 10.2478/he-2025-0019.
[12] Katrichenko, K., Vasina, H., & Kryvuts, S. (2020). Harmonization of secondary school inclusive environment based on the concept of "biophilic design". *Bulletin of Kharkiv State Academy of Design and Arts*, 3, 21-29. doi: 10.33625/visnik2020.03.021.
[13] Kim, J.-Y., & Park, S.-J. (2025). Biophilic design application in school common areas: Exploring the potential to alleviate adolescent depression. *Buildings*, 15(11), article number 1863. doi: 10.3390/buildings15111863.
[14] KSE Foundation. (n.d.). *800 children in Nizhyn returned to offline learning: Olena Zelenska Foundation and KSE Foundation equipped an inclusive shelter*. Retrieved from https://foundation.kse.ua/800-ditej-nizhyna-povernulys-do-oflajn-navchannia-fundatsiia-oleny-zelenskoi-ta-kse-foundation-obladnaly-inkliuzyvne-ukryttia/.
[15] Kyiv Regional Military Administration. (2023). *Shelter in Bilohorodka Lyceum underwent major renovation*. Retrieved from https://koda.gov.ua/u-bilogorodskomu-liczeyi-kapitalno-vidremontuvaly-ukryttya/.
[16] Law of Ukraine No. 2145-VIII "On Education". (2017, September). Retrieved from https://zakon.rada.gov.ua/laws/show/2145-19#Text.
[17] Madias, E.-N.D., Christodoulou, K., Androvitsaneas, V.P., Skalkou, A., Sotiropoulou, S., Zervas, E., & Doulos, L.T. (2023). The effect of artificial lighting on both biophilic and human-centric design. *Journal of Building Engineering*, 76, Article 107292. doi: 10.1016/j.jobe.2023.107292.
[18] Malik, T., Kovalov, Yu., Kalashnikova, V., & Nerusheva, V. (2023). Multi-criteria optimization of civil shelters design in Ukraine taking into account Israeli experience. *Art and Design*, 6(2), 170-178. doi: 10.30857/2617-0272.2023.2.15.
[19] Mengqi, L., Jie, Y., & Leiqing, X. (2025). Protective and restorative effects of biophilic design in high school indoor environments on stress and cognitive function. *Indoor Air*, article number 8696488. doi: 10.1155/ina/8696488.
[20] Miranda, D.T., Barreto, D., & Flores-Colen, I. (2024). An evaluation of the luminous performance of a school environment integrating artificial lighting and daylight. *Sustainability*, 16(4), article number 1426. doi: 10.3390/su16041426.
[21] Natsir, N., Jamala, N., & Kusno, A. (2021). The artificial lighting analysis of study rooms in dormitories and classrooms of the Islamic Boarding School of Lil Banat Parepare. *EPI International Journal of Engineering*, 4(1), 81-92. doi: 10.25042/epi-ije.022021.12.
[22] Obeidat, A.M., Obeidat, A.M., Obeidat, M.O., Maghairh, Z.N., Salman, L.B., & Momani, R.K. (2025). Biophilic design in homes: Integrating nature for comfort & well-being. *Periodicals of Engineering and Natural Sciences*, 13(3), 597-608. doi: 10.21533/pen.v13.i3.513.
[23] Order of the Cabinet of Ministers of Ukraine No. 988-r "On the Approval of the Concept for the Implementation of State Policy on the Reform of General Secondary Education, "New Ukrainian School", for the period up to 2029". (2016, December). Retrieved from https://zakon.rada.gov.ua/laws/show/988-2016-%D1%80#Text.
[24] Order of the Ministry of Health of Ukraine No. 2205 "Sanitary Regulations for General Secondary Education Institutions". (2020, September). Retrieved from https://moz.gov.ua/uploads/5/27593-dn_2205_25_09_2020_dod_1.pdf.
[25] Poimanova, K. (2024). Biophilic design as a basic concept in forming the learning space of a secondary school. *Ukrainian Art Discourse*, 1, 154-159. doi:10.32782/uad.2024.1.20.
[26] Rohalevych, D. (2024). A new shelter opened in Mykolaiv school, renovated with fundraising support from "Ukrainska Pravda". *MykVisti*. Retrieved from https://nikvesti.com/ua/news/public/v-mikolayivskomu-liceyi-vidkrili-ukryttia-naibilshu-vmistiti-600-lyudey.
[27] SCN V.2.2-5:2023. (2023). *Protective structures of civil protection*. Retrieved from https://e-construction.gov.ua/laws_detail/3225773063500990463?doc_type=2.
[28] SCN V.2.5-28:2018. (2019). *Natural and artificial lighting*. Retrieved from https://e-construction.gov.ua/laws_detail/3074958732556240833?doc_type=2.

[29] Semyroz, N. (2022). Interior design for civil defense shelters. *Theory and Practice of Design*, 26, 210-215. doi: 10.32782/2415-8151.2022.26.25.
[30] Steel Freedom. (n.d.). *Results of the Steel Freedom 2024 competition*. Retrieved from https://steelfreedom.ua/steel-freedom-result-2024.html.
[31] Zhydkova, T., & Pylypenko, N. (2023). Design for premises of protective structures in preschool education institutions *Ukrainian Journal of Civil Engineering and Architecture*, 4, 77-84. doi: 10.30838/J.BPSACEA.2312.290823.77.973.

Вікторія Духіна
Студент
Одеська державна академія будівництва та архітектури
65029, вул. Дідріхсона, 4, м. Одеса, Україна
https://orcid.org/0000-0002-5560-2434
Галина Бурлак
Кандидат фізико-математичних наук, доцент
Одеська державна академія будівництва та архітектури
65029, вул. Дідріхсона, 4, м. Одеса, Україна
https://orcid.org/0000-0002-3259-1568
Людмила Вілінська
Кандидат фізико-математичних наук, доцент
Одеська державна академія будівництва та архітектури
65029, вул. Дідріхсона, 4, м. Одеса, Україна
https://orcid.org/0000-0003-4597-2527

Елементи біофільного дизайну в захисних спорудах для освітніх установ

Анотація. Це дослідження розглядало актуальність принципів біофільного дизайну в системах штучного освітлення для освітніх сховищ, де відсутність природного світла та обмежені просторові умови можуть посилювати стрес і тривожність серед мешканців. Метою дослідження було виявити та обґрунтувати стратегії освітлення, що імітують властивості природного освітлення та підвищують комфорт користувачів у захисних навчальних середовищах. Методологічний підхід включав порівняльний аналіз сенсорних реакцій на різні сценарії штучного освітлення, оцінку параметрів освітлення, які відтворюють природні умови, а також вивчення дизайнерських технік, що застосовуються в контрольованих, безвіконних середовищах. Особлива увага приділялася ролі інтенсивності світла, кольорової температури, розподілу та часової динаміки в формуванні просторового сприйняття та емоційної стабільності. Було проаналізовано освітні сховища в Миколаївському ліцеї № 55, Білогородському ліцеї № 2 та спортивній залі в Ніжині, які були обрані через їх експлуатаційний стан та характерні просторові особливості. Хоча ці об’єкти демонстрували порівняно високий рівень технічної організації та дотримання нормативних вимог, аналіз виявив дефіцити, пов’язані з повною відсутністю природного денного світла, обмеженою візуальною взаємодією з зовнішнім середовищем та просторовою домінантою армованих бетонних конструкцій. Результати дослідження показали, що системи штучного освітлення, що включають м’яке дифузне світло, поступові переходи та динаміку, натхненну циркадними ритмами, значно покращували просторове сприйняття, знижували психологічний дискомфорт та сприяли відчуттю безпеки в закритих сховищах. Системи, що імітують денні коливання через контрольовані зміни яскравості та природні спектри кольорів, виявилися особливо ефективними у зниженні стресових показників та підтриманні когнітивної працездатності під час тривалого перебування. Інтеграція біофільних елементів освітлення сприяла функціональній трансформації захисних споруд, роблячи їх придатними не лише для надзвичайних ситуацій, але й для тривалих освітніх заходів. Практична цінність цього дослідження полягає у розробці дизайнерських настанов для інтеграції біофільного освітлення в освітні сховища, що підвищить їх функціональну стійкість та підтримуватиме психологічне благополуччя користувачів

Ключові слова: природне денне світло; штучне освітлення; психологічний комфорт; архітектура сховищ; безпека; динамічне освітлення