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Reconstruction of the volume-planning parameters of schools using biophilic principles and techniques

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Abstract. The aim of the study is to approve the method of evaluation of school buildings, based on the use of space-planning parameters of objects, taking into account the principles and techniques of biophilic architecture. Objectives of the study: to evaluate typical projects of schools of the Soviet period, taking into account modern standards of ecological construction, requirements of bioclimatic comfort and biophilic principles, using space-planning parameters specified in the design architectural and construction drawings; consider this method as the primary step for the diagnosis of potential biophilic properties of buildings, visual connection with the environment; make a critical analysis and provide recommendations for the use of this method of assessment. The study of domestic and foreign experience in creating biophilic learning spaces showed that preliminary analysis of volumetric and planning parameters of school buildings, can be used to diagnose the potential biophilic properties of objects, such as the efficiency of daylighting, natural ventilation, visual connection with the outside environment. The study critically analyzes the plans, facades, and cuts of typical Soviet school projects from the 1960s-1970s based on contemporary building certification standards and principles of bioclimatic, biophilic architecture. The significance of the obtained results for architects and designers is that the proposed method makes it possible to give a quick initial assessment of the potential biophilic properties of an object during the development of school reconstruction projects on the basis of the volume-planning parameters of buildings specified in the project documentation without a full-scale survey.

1 Introduction

In order to provide a high-quality learning environment that meets current and future needs in Russia, a large-scale state program of major repair of schools for 2022-2026 has been launched [1]. Thanks to the state programs, for the coming years architects and designers have expanded the opportunity to create a quality learning environment. The solution of this

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task can be achieved not only by eliminating the physical deterioration of objects and bringing their characteristics to compliance with current requirements and norms, but also by means of modernization using the principles of «green», bioclimatic and biophilic architecture, that affect students' physical well-being and academic performance.

The school environment also influences the emotional, intellectual and cultural development of children, according to some authors [2-4]. A. Butabekova in her research shows that the performance in classes with biophilic interior increased by 20-25%, the results of testing, the level of attention and attendance of pupils [5]. The relationship of people with nature in architecture, its presence and influence on humans in the space of the building, receive different assessments in the scientific research of C. Ryan, S. Kellert and some others [6-10]. Biophilic space assessment typically focuses on two main aspects: human impacts on nature and possible outcomes for human comfort. Research confirms that human interaction with nature indoors and in the natural environment helps to relieve stress and restore attention. Biophilic buildings go beyond the concept of integrating indoor and outdoor spaces, as the external environment may not always be perceived positively. For example, urban noise, the proximity of busy roads or industrial zones, etc. are seen as negative externalities in creating biophilic space. The notion of the experience of connecting people to the natural environment focuses on its immediate beneficial, physical impact on them when they observe, smell or listen to nature.

A. Butabekova and M.Hanc identify the following principles that form the inner biophilic space of the building [5, 7]:

- adoption of a project decision aimed at integrating the natural environment and human beings;
- a sense of unity, harmony with nature and responsibility to the natural community;
- maintaining people's emotional attachment to their natural habitat;
- use of the evolutionary experience of adaptation of man to the natural environment, for physical and moral recovery;
- establishment of a permanent, sustainable human contact with nature

At the initial stage of making design decisions to create a biophilic space in an educational institution, the advantages or barriers of the architectural characteristics of the building are considered for compliance with basic biophilic principles. At the next stage, a significant addition to the development of recommendations for biophilic design is a visit to the facility and surveys of students and school staff (hereinafter referred to as consumers).

Few biophilic design recommendations determine the bulk planning characteristics of buildings that contribute to an effective perception of nature. I. Akhtiamov, R. Akhtiamova describe some natural factors that need to be used in the building, discuss the manipulation of light intensity, its dissipation and shadows, without linking these empirical qualities with architectural data [8-11]. Without focusing on the parameters to be measured, architects use template solutions and rely on estimating the effects of biophilic space during the operation of the facility. To date, various methods for creating biophilic space have been proposed. Research by C. Hodson H. Sander identifies links between the object and the urban landscape using satellite or cartographic data, but their attention is limited only to the influence of the external environment [12, 13]. The works are focused on questionnaires by S. Collado, E.Cochran Hameen et al. offer results based solely on the subjective perception of the survey participants' contact with nature, their self-assessment [14, 15]. Researchers focus on changing the private parameters inside the building, such as color of walls, interior decoration, environmental views, etc. Thus, this method does not allow to provide objective indicators of quantity and quality of «nature» provided by the artificial environment. S.Vasilyeva, L. Lipanova provide data that can reveal certain aspects for the formation of biophilic space [16]. However, these methods can be time-consuming and access to the learning environment can be hampered by unwanted interference with the educational process. Note the foreign standards of certification of buildings WELL Building Standard and Living Building Challenge, which include criteria describing architectural characteristics and parameters aimed at creating a comfortable space inside buildings and structures, biophilic. Some requirements of these standards, for example, regulate the architectural solutions of window openings in a regularly occupied room, providing people with a thermal, olfactory and auditory connection to the external environment. While these requirements may not be sufficient to determine whether the architecture of a building encourages the development of deep and meaningful attachment to nature, The parameters noted are the basis of any project and can be used for biophilic compliance analysis in the early stages of the site assessment.

The principles of the bioclimatic approach to design can also give an idea of the volume-planning parameters of the building that affect the perception of nature. Certain quantitative recommendations and empirical rules in the bio-climatic design literature inform people about the perception of certain environmental factors (daylight, temperature variability, etc.) Although bioclimatic design is not always biophilic, biophilic design is not always bioclimatic. Drawing on environmental resources, M. DeKay, G. Brown's work on bioclimatic themes can raise the awareness of planners and ultimately consumers about natural factors and processes affecting health and well-being [17, 18].

The proposed method consists in using volumetric-planning parameters of an object for analysis and identification of criteria allowing to organize biophilic training space. The study shows that the main characteristics of buildings, dimensions of plans, facades and sections allow the designers to determine the parameters necessary for harmonious integration of the natural environment into the space of reconstructed schools. Analysis of the object by drawings found in some works allows to present graphical and numerical parameters of the concept of reconstruction of the building taking into account requirements of environmental standards and principles of bioclimatic, biophilic design [19-21]. Research objectives:

– to evaluate typical projects (t.p.hereinafter) of schools of the Soviet period, taking into account modern standards of ecological construction, requirements of bioclimatic comfort and biophilic principles, using bulk planning parameters specified in the design architectural and planning parameters construction drawings;
– to consider this method as a first step to diagnose the potential biophilic properties of buildings such as: the effectiveness of the use of daylight, natural ventilation, visual communication with the external environment;
– to analyse and recommend the use of the method in the reconstruction of school buildings.

2 Methods

The presented method of estimation, based on indicators of geometric characteristics of the building, such as the configuration, proportions, size of rooms and window openings, etc. It provides a preliminary assessment of the potential for changes based on biophilic architecture. Based on the data obtained, designers and architects will create conditions that allow students to feel closer to a natural habitat that promotes a positive visual, olfactory or auditory perception of nature. The proposed method facilitates the decision-making process for the reconstruction and modernization of the existing stock of various school buildings in Russia, understanding the state taking into account modern regulatory requirements, principles of bioclimatic and biophilic architecture. The authors, for testing of the method, selected model projects of general education schools of mass application of the Soviet period with various widely distributed volumetric planning and design solutions of the 1960-1970s (table 1).

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Table 1. The main characteristics of the studied typical projects of school buildings of the Soviet period

Number of a typical project	Scheme of plan	Year of approval	Capacity, st./ Number of classes	Structural concept	Dimensions in axes, m	Building volume, m3	Building area, m²	Usable area, m²	Window area, m²
2C-02-8		1964	1000/24	frameless, brick	66 x 53,2	17743	2110	4038	1102
221-1-179		1973	624/16	frameless, brick	75,2x44,88	12917	1714	3212	920

(Source: Scientific and technical, methodological and design recommendations for energy supply in Russian school buildings. Volume 2.)

In most modern domestic projects of educational institutions, the model of the educational space of the Soviet period is borrowed, based on the unification of architectural and engineering solutions. When developing standard projects of Soviet schools, the need to increase the usable area was taken into account, which led to a decrease in public spaces and areas for additional classes. This concept prevails today in the domestic practice of designing schools.

The typical project 2C-02-8 (hereinafter 2C-02-8) was developed in accordance with the requirements SNiP (National Codes and Standards of Russia)- P.L.4-62. The composite scheme of the building is linear, consisting of two parallel buildings - a 2-storey general school on the side of the main entrance and a 3-storey school building connected by a 2-storey transition, which includes classrooms, administration and lobby. The size of window openings on the facade - 2100 x 2400 mm, prosthetic/ step - 770 mm. Educational and school premises are illuminated equally. The sports hall, 12 m wide, has two-sided lighting windows measuring 5900 x 4800 mm and 2100 x 4300 mm. Window openings of staircases are filled with glass blocks. The structural solution is a frameless building with porous brick walls. Coatings and floors - prefabricated reinforced concrete multi-level slabs. Roof solution - combined, unventilated, roll.

The drawings of two typical projects were analyzed using the ArchiCad program (v. 23.0 7000, developer Graphisoft SE). The program included measurements of plans, facades and object sections to obtain values such as the ratio of floor area to window openings (fig. 1,2).

Then these data were compared with threshold values, according to biophilic, bioclimatic recommendations and certification requirements. This analysis helps to identify problem areas in the reconstruction and modernization of the existing stock of school buildings in accordance with modern operational requirements.

The use of objective criteria and measurements revealed relative differences between the model projects of Soviet schools in the 1960s and 1970s from the point of view of potential biophilic qualities and related problems for comfortable stay of consumers. Analysis of the proportions of the building and premises, as well as window glazing and openings, revealed possible problems.

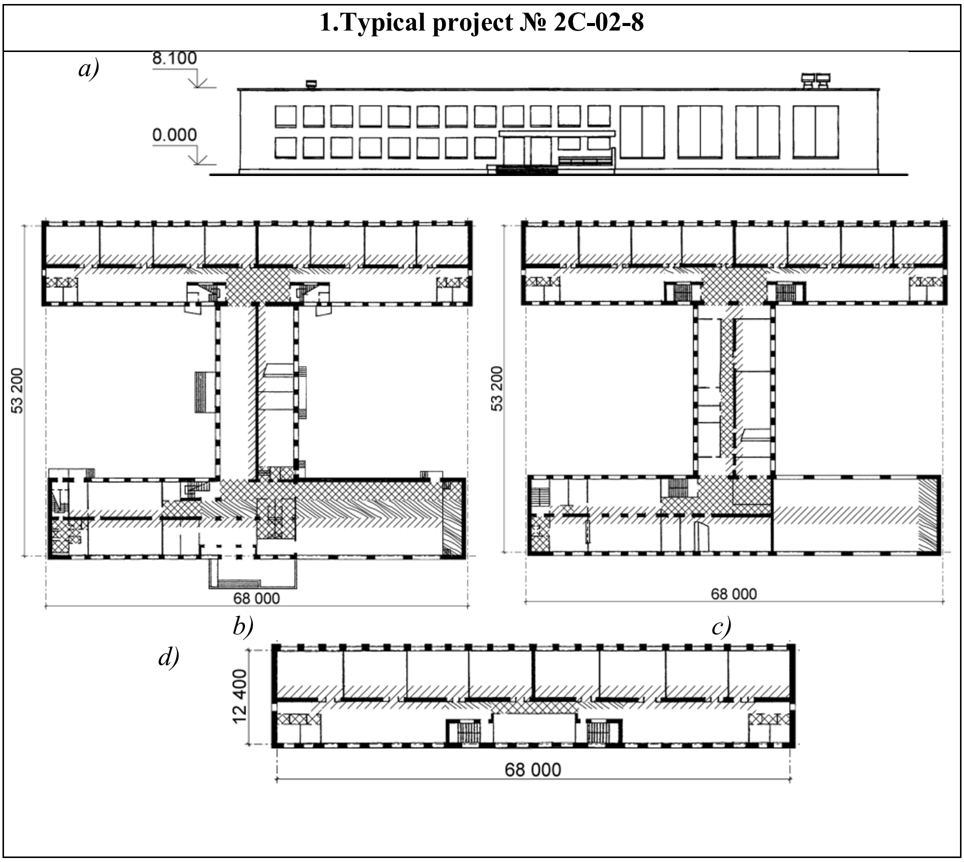

Fig. 1. Typical projects of secondary schools: typical project No 2C-02-8 : *a)* scheme of the main facade; *b)* plan of the 1st floor; *c)* plan of the 2nd floor; *d)* plan of the 3rd floor. Areas of the floor surface of the usable area away from the outer wall with window openings:

– over 4.5 m; – over 6 m. – areas without natural light

(Illustration by the authors)

3 Results and discussion

The same type of classroom in the typical projects under study have different indicators of daylight, natural ventilation and the possibility of viewing the outside. The ceiling of classes and other classrooms in all submitted projects is about 3 m, which corresponds to the normative requirements of the time SNiP P-L.4-62 (t.p. 3.2) and SNiP II-65-73 (t.p. 3.4), are typical for Soviet schools of the 1960-1970s. The typical eye height of primary school children sitting behind a desk is approaching one meter. The height of the window sills, in the classes of the three model designs, varies from 0.7 m to 0.8 m (Fig. 3), which is sufficient for visual perception of the external environment.

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2. Typical project № 221-1-179

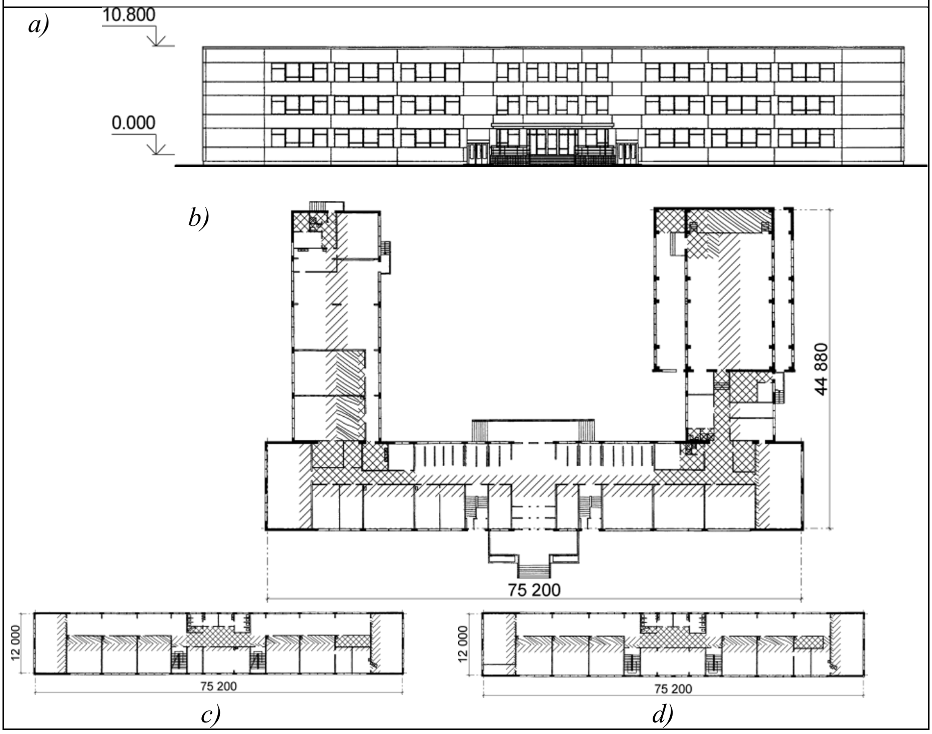
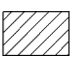
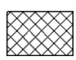


Fig. 2. Typical projects of secondary schools: typical project No 221-1-179: *a)* scheme of the main facade; *b)* plan of the 1st floor; *c)* plan of the 2nd floor; *d)* plan of the 3rd floor. Areas of the floor surface of the usable area away from the outer wall with window openings:

 – over 4.5 m;  – over 6 m.  – areas without natural light

(Illustration by the authors)

Based on bioclimatic recommendations in classes 2C-02-8 the largest area illuminated by natural light and allowing more active visual contact with the external environment (75.0%), incl 221-1-179 the lowest indicators (60.4%) (Table 2). But this figure 221-1-179 is partially offset by an acceptable luminous coefficient (1:4.4). In the classes of the model projects under study, partially illuminated areas are 20.1 (t..p.. 221-1-179) and 25% (t.p. 2C-02-8). The classroom 221-1-179 has the highest distance of the floor area from the window more than 6 m (19.5%). According to SanPiN (Sanitary Regulations and Standards) 2.4.2.2821-10, during classes will need to constantly illuminate this area with artificial light, which is a negative indicator, including in terms of energy savings.

Classrooms, longer and less deep, offer the potential to increase multisensory impressions of the external environment, provided that the windows cover the entire length of the facade. A positive example would be 2C-02-8, where the ratio of class proportions is 1.4 and the best luminous coefficient (1:3.9). Conversely, classes that are deeper relative to length, such as 221-1-179 (ratio 0.9), may lead to student inequality, as those sitting by the windows have more opportunities to perceive the environment than those sitting in the back.

Considering the initial measurable parameters of classrooms, such as the plan, height, proportion of the room to conform to biophilic and bioclimatic recommendations, the class in the 2C-02-8 has a higher potential than the 221-1-179.

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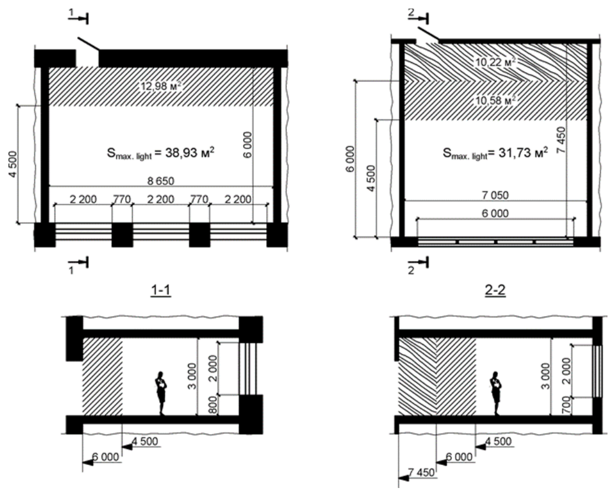
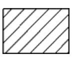


Fig. 3. Classrooms: a) typical project No 2C-02-8; b) typical project No 221-1-179. Areas of the floor surface away from the exterior wall with window openings:

 – over 4.5 m;  – over 6 m

(Illustration by the authors)

Table 2. Comparative indicators of typical projects under study

Typical school projects	Classroom				Surface of the floor according to the distance from the exterior wall with window openings or requiring illumination, %					
					Classrooms			School-wide premises		
	Room area m²	Window opening area m²	Light coefficient	Aspect ratio length/ depth	4.5 m	4.5-6 m	> 6 m*	4.5 m	4.5-9 m	> 9 m**
№ 2C-02-8	51.9	13.2	1:3.9	1.4	75.0	25	–	53.2	20.9	19.2
№ 221-1-179	52.5	12	1:4.4	0.9	60.4	20.1	19.5	65.6	15.7	16.1

Note:* According to SanPiN 2.4.2.2821-10, a continuous illumination with artificial light is required during the training.
** According to the foreign standards of ASHRAE, IES, USGBC (LEED), Living Building Challenge, WELL Building Standard, continuous illumination with artificial light is required during operation.

The ceiling height of general school premises in all the projects presented is about 3 m, except gymnastics halls (about 6 m). The areas with the highest average natural light illumination and allowing consumers to observe outdoor species are represented in the 221-1-179 (65.6%) with the smallest in the 2C-02-8 (53.2%). In general school buildings, the indicators of partially illuminated areas are 15.7% (t.p. 221-1-179) and 20.9% (t.p. 2C-02-8). The highest average distance between the floor area and the window or requiring constant illumination during the operation of general school areas is observed in the 2C-02-8

(19.2%). When making design decisions for the reconstruction of schools, based on these indicators, the redevelopment of school-wide areas will require an individual approach. Potential problems for the implementation of biophilic principles in the school reconstruction project can be identified by identifying regularly occupied areas remote from window openings and requiring permanent illumination during operation, Over 6 m in the classroom and 9 m in the general school. It is necessary to take into account the luminous coefficients of the premises. The quantitative data collected facilitate the diagnosis of potential bioclimatic properties of buildings. Systematization of the obtained results and comparison of them with thresholds, recommended systems of certification of buildings will allow to create in an educational institution biophilic spaces that provide a comfortable connection with the external environment. Spatial planning solutions for buildings can reveal problems and opportunities for biophilic relationships with the external environment. In narrow buildings it is easier to provide good lighting and circulation of fresh air inside the premises than in wide buildings [23]. The location of students' desks away from windows in wide spaces may limit access to ambient view, natural light and natural air movement. The dimensions of the plans and sections of the building in the architectural and construction drawings allow to determine the degree of penetration of daylight into the premises, one of the important attributes of creating a connection with the external environment. In Russia, to ensure regulatory levels of insolation, natural and artificial lighting, it is necessary to take into account the requirements of SanPiN 2.4.2.2821-10 «Sanitary and epidemiological requirements to the conditions and organization of education in general educational institutions» (further SanPiN). According to the requirements of SanPiN for natural lighting in general education institutions, the ratio of the area of glazing to the floor area (light coefficient) should be at least 1:6; if the depth of the educational premises exceeds 6 m, Illumination is required on the right side, at least 2.2 m high from the floor level. In the bioclimatic literature, the most illuminated area in a building is typically 4.5 m deep, perimeter-wise from the outer wall with window openings. The next 4.5-9 m form a partially illuminated area. In an area more than 9 m from the facade, continuous illumination with artificial light is required when operating [24]. According to the WELL Building Standard, less than 70% of the floor area must be within 6 m of the outer wall and less than 30% of the floor area must be 7 m away.

In the interior, high windows and ceilings, in addition to aesthetic appeal, contribute to a greater penetration of daylight into the room. In addition, in educational institutions with high ceilings it is possible to organize variations in height, which are an attribute of biophilic design built on complementary contrasts. By changing the structure of daylight, multi-level ceilings can cause the sensation of high and low, open and closed, which affects the thermal and auditory sensations in the premises. However, high ceilings should prevail in classrooms [25]. It should be borne in mind that, according to Russian regulatory requirements, the height of the classrooms in cleanliness should be at least 3 m. The height of horizontal communications in educational buildings is allowed at least 2.6 m. The presence of windows in regularly used premises is perhaps the simplest and most important indicator of consumers' contact with the external environment. Windows are a key element in the design of biophilic buildings to create a favorable, comfortable environment inside the facility. The intensity of natural light in the room directly affects the health, positive attitude, activity and academic performance of students [26]. The height of the windows determines the degree of penetration of natural light into the interior of the building. The higher the placement of the window from the floor level, the more evenly the distribution of daylight and its penetration into the room. As a rule, daylight penetrates the room to a depth of about 1.5-2 times the height of the window. In addition, the height of the window sills affects the field of view of the external environment. The field of vision varies depending on the depth of the building, and students sitting further away from the exterior wall with windows will have a more limited view of the sky and may be less exposed to melanopic light, which is an indicator of circadian rhythm (cyclical fluctuations in the intensity of all possible biological processes) provided by the sun.

Window openings can serve as an indicator of potential problems and opportunities for the use of daylight and natural ventilation prior to site visits and more detailed analysis of schools with obvious defects in reconstruction.

The effectiveness of the method for evaluating the diagnostics of potential bioclimatic qualities of a building based on geometric characteristics selected from the design documentation lies in its accessibility and ease of use. The proposed method allows architects to quickly estimate a large sample of buildings and identify those that have a limited connection with the natural environment (e.g., daylight, natural ventilation and outdoor species, including street vegetation). Studies have shown that the quantitative information contained in the design drawings allows a relative comparison of a sample of schools based on regulatory requirements and biophilic criteria. This will allow architects and designers to determine without visiting the facility which parameters are below the recommended thresholds, and which premises or characteristics require more detailed field research and adjustments using post-operational assessment tools. During the inspection of the building, adjustments can be made to the identified individual features and problems, additional biophilic design solutions are made. Project teams need to move beyond simple quantitative indicators and to be more proactive in using a multidisciplinary approach to produce representative results. This method of architectural evaluation of the schools being reconstructed is proposed as a first step to understand the potential biophilic properties of buildings before making final decisions when developing design documents. The presented components are additional tools in the design, and to achieve effective results it is necessary to combine them with personal experience, knowledge of modern research, trends and current regulatory requirements related to biophilic design.

4 Conclusion

Based on the results of the study the following conclusions can be drawn:

1. The proposed method, based on the use of volumetric planning parameters specified in the architectural and construction drawings, allows to evaluate schools based on the standards of environmental construction, Bioclimatic comfort requirements and biophilic principles to identify problems that impede human connection with nature.
2. The method of architectural evaluation of reconstructed schools is proposed as a first step for diagnosing potential biophilic properties of buildings, such as the efficiency of use of daylight, natural ventilation, visual connection with the environment.
3. The advantage of this method is that it is quick, there is no need for a field survey of the object and its use is clear.
4. This work can serve as a basis for testing the method of architectural evaluation, based on volumetric-planning parameters for diagnostics of potential biophilic properties of civil buildings of various purposes.

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