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Optimization of Daylighting in a Historic Auditorium

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Abstract

A key approach to protecting historic buildings is adapting them for public use, which requires choosing suitable functions and making appropriate modifications. While exteriors should be preserved to maintain historic value, interiors must offer functional, modern spaces. Beyond design of the building and building materials, the indoor environment, especially daylighting - is crucial. Higher daylight levels reduce energy demand for artificial lighting. This paper analyzes a historic lecture hall from the last century located on the campus of the Technical University of Košice. Although the building is used daily and its space is efficiently organized, daylight in the auditorium is significantly limited. The study evaluates real measured data, later validated through simulation tools, and compares the resulting values. It further explores the benefits of improving visual comfort by enhancing daylighting. Proposed interventions include adding new openings such as windows, light guide, or skylights. Simulated variants demonstrate substantial improvement, achieving the recommended average daylight levels.

Keywords: historic buildings, daylight, light in buildings, indoor environment, skylight

1 Introduction

A building consumes a significant amount of energy during its lifetime [1]. The energy and environmental performance of buildings is strictly dependent on many factors related to the choice of building materials, HVAC equipment, design, installation, and occupancy [2]. The energy consumption of buildings in the EU accounts for approximately 40% of the total energy consumption [3-5]. Research has highlighted the need for good integration between daylight and artificial lighting as a necessary measure to reduce energy consumption in buildings and increase occupant satisfaction. The European building stock consists of 30-40% of buildings built before 1945 [2], usually with low energy performance, and which are replaced by new buildings with a renovation rate of about 1.0-3.0% per year [6]. Renovation of existing buildings represents one of the best strategies to achieve the targets set in the 2030 Climate and Energy Framework [7]. Due to the different requirement profiles and target criteria for artificial and daylighting solutions, the planning and implementation of lighting systems is an

interdisciplinary task [8]. Artificial lighting plays a crucial role in buildings, not only affecting the well-being, satisfaction and performance of building occupants, but also accounting for a significant part of energy consumption [9]. Daylight performance is one of the significant needs to provide visual comfort for users [10]. The study [11] showed that, in order to reduce the energy consumption, the best measure is the substitution of the existing luminaires with more efficient luminaires. Buildings represent a significant portion of worldwide energy use, with approximately 40 % devoted to maintaining thermal comfort indoors while global temperatures rise [12]. Adapted reuse in old historical buildings has been a real challenge since the state of deterioration is usually found severe, and suggested retrofitting is applied with high delicacy to preserve the building originality [13]. The outcomes of study [10] offer guidance for heritage adapted reuse in hot climatic conditions with minimum design interventions to meet the original design and provide potential users' comfort conditions. While new buildings continue to be constructed in the process of urbanization, historic buildings, as valuable heritage buildings carrying national historical memory, play an important role in the urban landscape [14]. Enhancing daylighting in heritage buildings is a complex challenge that requires a delicate balance between preserving architectural integrity and improving visual comfort [15].
The aim of this paper is to highlight the potential for using spaces in historic buildings for various purposes. While these spaces are often repurposed, each use requires specific minimum conditions. One of these conditions is daylighting, which is often not adapted to the intended purpose in historic buildings.

2 Methodology

For this study, a historic building located on the campus of the Technical University of Košice (TUKE) was selected. The structure originally formed part of a former distillery complex, which was gradually integrated into the university grounds as the faculties expanded. Although older than the earliest faculty buildings, it now stands centrally within the campus at Park Komenského 7, 040 01 Košice, Slovakia. Over time, the distillery facilities were demolished, leaving two preserved buildings that have since been adapted for new functions, including classrooms, lecture halls, and administrative spaces. The examined building is constructed of solid brick masonry, with preserved exposed brick elements on the façade that visually emphasize its historical character. It dates from before the 1950s and features an east–west window orientation. Among its interior spaces, the lecture hall L4 represents the most intensively used area and was therefore selected for detailed analysis. This former warehouse space was transformed into a multi-level auditorium with ascending seating rows. The lowest point of the room is the lecturer's area near the main entrance, while sanitary facilities are situated at the rear. The spatial configuration is functionally appropriate for academic instruction. In the period around the 1950s, integration of the daylight in architectural design declined due to low energy costs, increasing interest in air-conditioned environments, and the widespread adoption of modern artificial lighting systems, particularly fluorescent lamps. Consequently, many buildings from this era were constructed with minimal consideration for natural light. Renovations often focus primarily on spatial reorganization, while essential aspects of the indoor environmental quality are overlooked. However, the internal environment of any building must be adapted to its intended function. Lecture halls should meet at least the minimum daylight requirements not only for lecturers but also for students, as sufficient daylight supports visual comfort and contributes to maintaining the attention. While many factors influence alertness and cognitive performance, daylight remains a significant component of a healthy and effective learning environment. The measurements were taken in two seasons, summer and autumn. In the summer, the measurements were taken on July 11, when the sky was cloudless with direct sunlight. In the fall, measurements were carried out on October 21, when the sky was overcast with intermittent clouds, otherwise clear. Measurements were taken indoors without artificial lighting, only daylight inside the room was provided. The measurements were taken according to a control network of points at the height of visual activity – on the students' work surface (desk level). Lighting conditions should at least meet the requirements typical for standard classrooms and according to standard [17] these are at least Em = 300 lx. The simulation itself is designed for the autumn period, due to the frequent use of the room for lectures and teaching. Two simulations were created, one to verify the measured points, to allow comparison of the simulation program's deviation. The second simulation highlights the effective design of new daylighting elements. The aim of new design would improve daylight and the overall lighting comfort in the room.

2.1 Lighting measurement

Lighting measurements were conducted in the selected auditorium of the historic building under empty-room conditions to avoid interference from occupants (Figure 1). Illuminance levels were recorded using a Testo 400 luxmeter. During the measurements, all artificial lighting was switched off to ensure that only daylight contribution was evaluated. The primary objective was to assess the sufficiency and distribution of natural daylight within space. All measured values are reported in lx.

Figure 1: Photograph of the L4 lecture room during the recording of daylight illuminance values

2.2 Control point grid

Table 1 presents the illuminance values measured according to a predefined control-point grid. The grid was constructed based on the room dimensions (14.78 × 12.13 m) using a maximum spacing of 1.0 m between points for areas exceeding 10 m in length (Figure 2), following the methodological recommendations provided in [16]. In accordance with STN EN 12464-1:2023, illuminance measurements for specific visual tasks must be performed in the plane where the task occurs. Therefore, a control-point grid was selected as the appropriate measurement method:

- The grid consisted of square intervals with spacing up to 1.0 m, depending on the room's geometry.
- All measurement points were in the plane of visual activity - on the students' work surface (desk level).
- The measurement height corresponded to the height of the desks in the auditorium, which varies due to the ascending arrangement of seating.

2.3 Measured values

The measured illuminance values are low, with none approaching the levels recommended by current standards. According to STN EN 12464-1:2023, lecture theatres and lecture rooms should achieve an average maintained illuminance of Em = 500 lx, with the recommendation that lighting is adjustable to meet varying functional needs [17]. This implies that, although the upper limit may be flexible, the lighting conditions should at minimum meet the requirements typical for standard teaching spaces (E_m = 300 lx). In contrast, the values measured in the examined auditorium were significantly lower. The highest recorded illuminance was approximately E_m = 100 lx, found at a measurement point in the first row near the window on the south-facing side of the room. As expected, measurement points on the south side exhibited slightly higher values due to their proximity to available daylight, yet these values remain far below the recommended minimum.

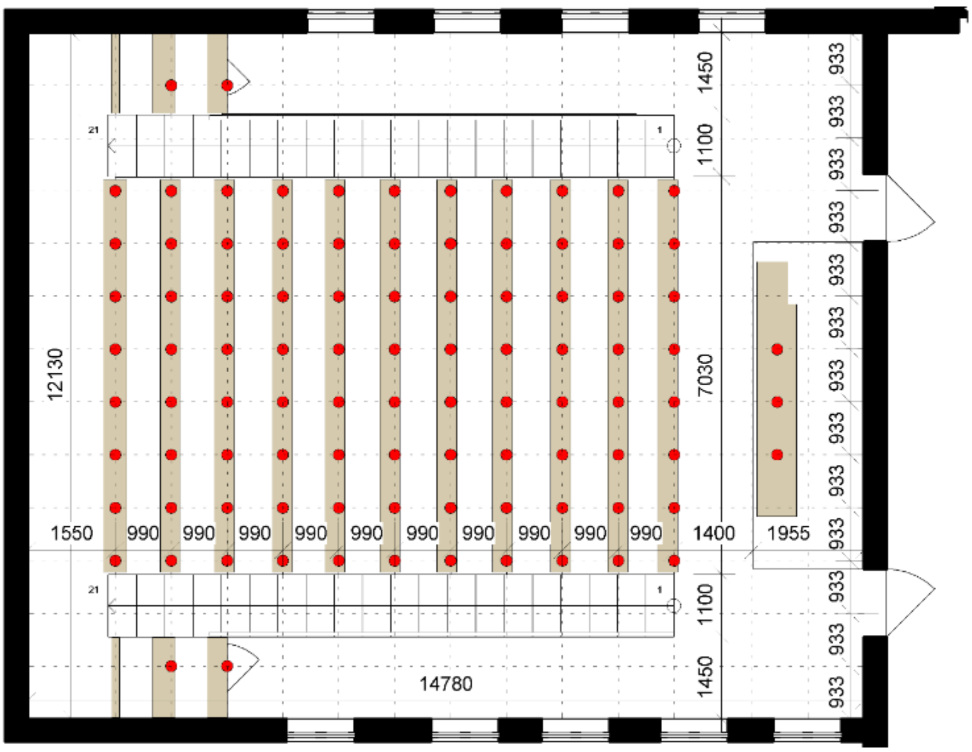


Figure 2: Floor plan of the lecture hall with the control grid of measured points

Table 1: Measured illuminance values in L4 auditorium (lx)

Desk	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**Average**
11		7.7	7.7	7.6	7.8	7.3	7.0	7.6	7.8		7.6
10	10	10.6	9.8	9.6	9.3	8.4	6.9	5.8	5.1	12.8	8.7
9	12.5	11.6	10.9	9.6	7.6	6.9	6.7	6.0	6.0	16.7	8.2
8		16.4	14.8	11.6	14,7	14.3	12.1	9.3	12.8		13.3
7		17.1	20.4	20.1	19.4	16.8	18.7	17.5	15.9		18.2
6		20.0	22.1	16.7	18.5	15.3	16.1	19.8	19.7		18.5
5		30.6	23.4	21.8	21.0	23.6	28.7	30.0	43.0		27.8
4		34.0	31.2	29.8	28.2	29.5	32.6	36.2	38.9		32.6
3		44.3	35.0	31.4	26.1	28.4	31.2	39.4	62.7		37.3
2		41.3	34.8	35.0	34.3	37.2	46.0	63.6	103.6		49.5
1		55.4	37.2	39.2	36.2	36.5	46.0	68.1	102.0		52.6
Lecturer's desk			35.5			40.3		38.8			38.2
										Average:	26.0

However, we can conclude that the values measured in autumn were slightly higher than in summer. The sun's rays were lower and penetrated directly into the room. For comparison and verification of the measured values, the measurement was repeated in summer. The measurement was taken in July, when the sun is at its highest. The values in the room were even lower than in the previous measurement in autumn. The value ranged from 4 lx to 50 lx, and the average value on the measurement grid was 18.4 lx. The illuminance measurements on site are shown in the following graph (Figure 3).

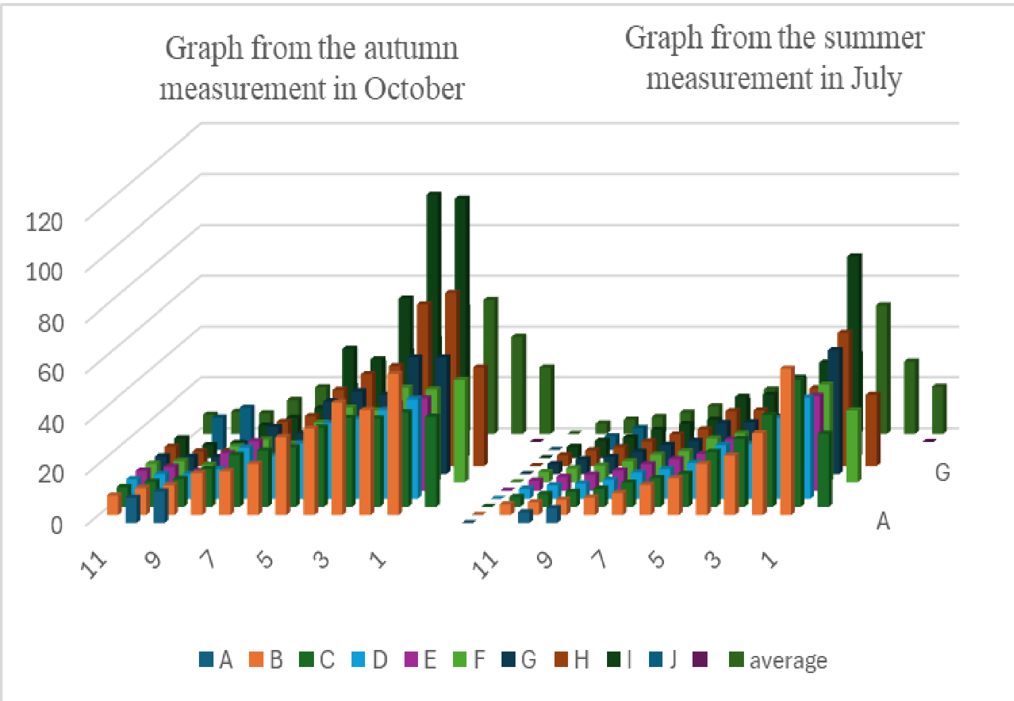


Figure 3: Graph with measured values of daylight illumination points (lx)

3 Lighting verification by simulation

The recorded measurement points were subsequently verified using a daylight simulation program to ensure the accuracy and reliability of the measured data. For this purpose, the VELUX Daylight Visualizer 3 software was selected. A detailed 3D model of the auditorium was created within the program, enabling the simulation of daylight conditions under parameters corresponding to the actual measurement setup. The 3D model of the room is shown in Figure 4.

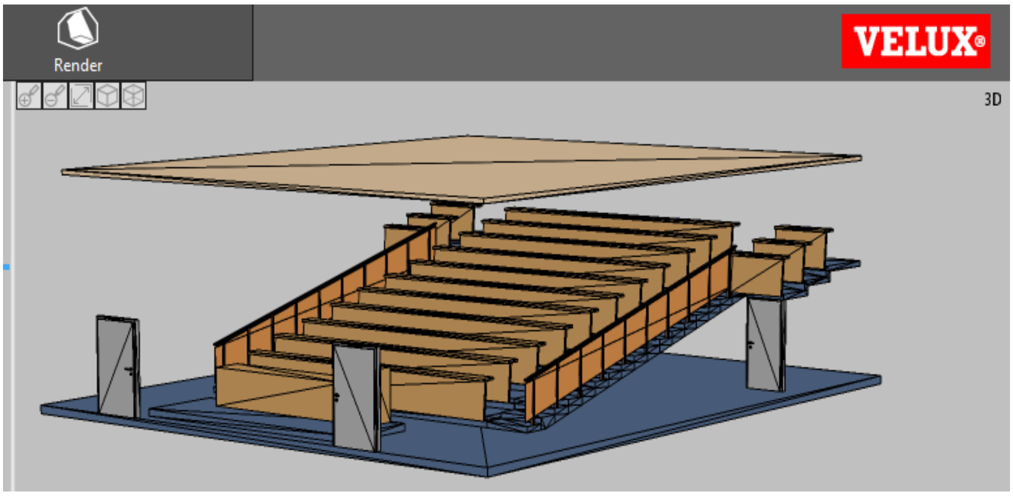


Figure 4: 3D model of the lecture room in the working environment in the simulation program (with hidden walls)

Reflectance values for individual surfaces in the room, as shown in Table 2, were used in the simulations.

Table 2: The reflectance values of the individual surfaces in the room were then entered

Type	Material	Reflectivity
Walls	indoors white	0.85
Floor	linoleum and dark marble	0.42
Staircase	linoleum	0.42
Railings	wooden filling	0.65
Ceiling	suspended wooden structure	0.85
Furniture	wood-based materials	0.66
Doors	white wood-based laminate	0.70
Windows and glazing	wooden frames, clear glass - glass transmittance	0.80

The geographic location of the building was set to coordinates [N: 48.7; W: 21.2], and a north rotation of 130° clockwise was applied. Cloudy sky conditions were selected for the simulation. Subsequently, a daylighting export was generated for the chosen date, 21 October 2024, producing a floor-plan simulation output with Isolux contours representing illuminance levels in lx.

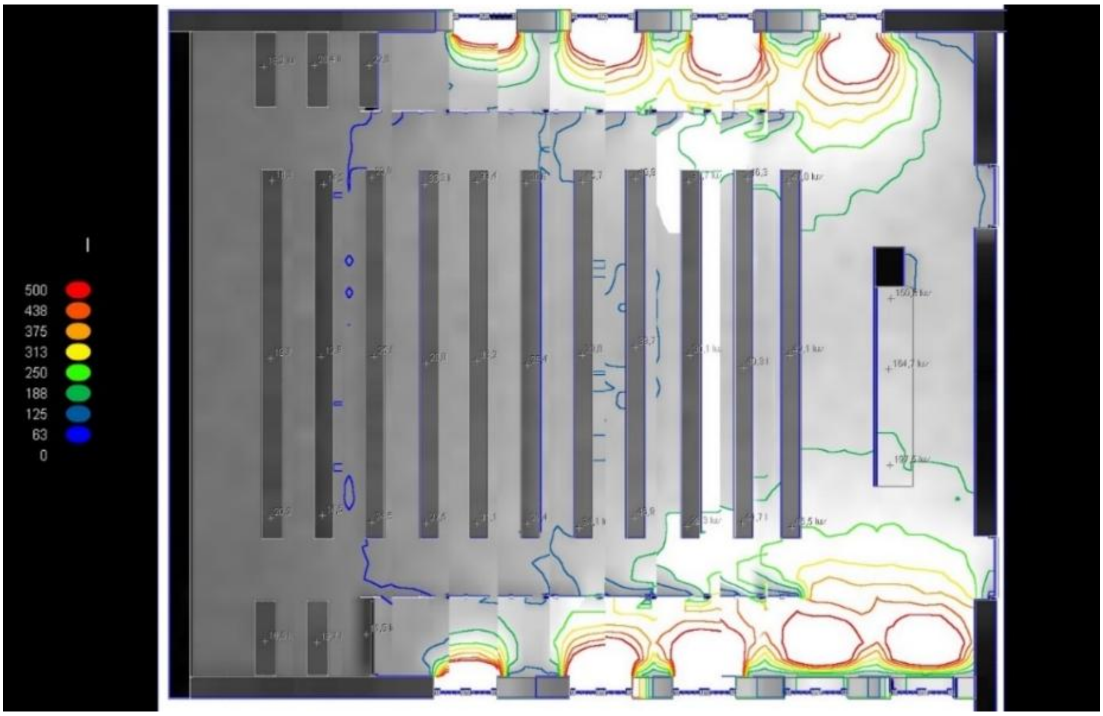


Figure 5: Exporting data from the Velux Daylight Vizualizer simulation program

The export of values can be exported (in the program) according to the specified amount. For this reason, multiple exports of data according to desk heights in space have been created. Subsequently, the exports were stitched together into a single image Figure 5, with the ISO differences of the illumination lines visible. The division of the simulation data by desk height. The values from the simulation program are presented in Table 3, which are also shown in the graph in Figure 6.

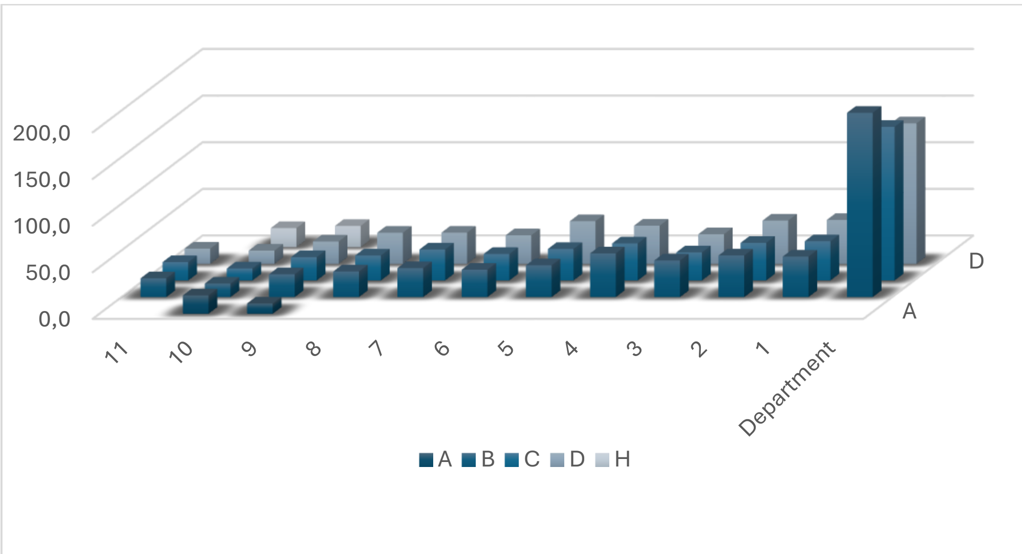


Figure 6: Graph with daylight values from the simulation program (lx)

Table 3: Illuminance values from the program, generated by simulation (lx)

Desk	A	B	C	D	H	Average
11		20.	19.7	16.3		18.7
10	19.7	14.5	12.8	14.2	20.4	16.3
9	11.0	24.5	25.0	23.9	22.8	21.4
8		27.5	26.8	33.3		29.2
7		31.1	33.2	33.4		32.6
6		29.4	28.4	30.6		29.5
5		34.1	33.8	45.7		37.9
4		46.9	39.7	40.9		42.5
3		39.3	30.1	31.7		33.7
2		44.7	40,3	46.3		43.8
1		43.5	42.1	47.0		44.2
Lecturer's desk		197.6	164.7	150.6		171.0
					Average:	43.4

With the increasing number of desk rows, the seating height also rises. While this stepped configuration ensures good visibility toward the lectern, it significantly reduces the availability of daylight. The auditorium relies solely on lateral daylight entering through the windows, as the height and distance from the windows increase, daylight penetration decreases. Consequently, illuminance levels in the uppermost rows (rows 8-11) are almost negligible. The simulation results closely correspond to the measured daylight illuminance values. Slightly higher values observed in the simulation output may be attributed to simplifications or inaccuracies in the definition of reflective surface properties and other model parameters.

4 Design of optimization options

Introducing optimized architectural openings to enhance daylight penetration can significantly improve visual comfort. When sufficient daylight is available, a well-designed daylighting strategy enables the reduction or complete shutdown of artificial lighting, thereby lowering actual electricity consumption [17]. The previous tables clearly demonstrate that the existing daylight levels are insufficient. This applies both to the measured values and to the simulation results, which mutually confirm the low illuminance in the auditorium during daytime. The space relies solely on lateral daylight from windows, and the stepped increase in desk height creates progressively darker zones. As a result, the rear portion of the auditorium approaches near-darkness under natural lighting conditions. While lecturers and occupants seated in the front rows may not perceive reduced illumination, users seated from the middle rows upward are exposed to inadequate daylight levels, which compromises visual comfort and the overall functionality of the space.

Light pipe systems improve visual comfort. The disadvantage of light pipes is their high price, which is why they are not yet commonly used for lighting interior spaces. In spaces where lighting is needed even during the day, the use of light pipes is very advantageous because when a room is lit by daylight from a light pipe, artificial lighting can be turned off. If there is sufficient daylight in the room during the day, it is not necessary to use artificial lighting [18].

4.1 Design new skylights

The introduction of additional daylight openings could further enhance the natural illumination of the interior; however, due to the building's recognized heritage value, the placement of new façade windows is strictly limited. Any newly added architectural elements must remain clearly identifiable as contemporary interventions. Given these constraints, the incorporation of additional side-wall openings is not considered feasible. A more appropriate strategy involves the installation of new daylighting elements within the roof structure. Although the roof has been recently reconstructed, its design replicates the historic appearance, thereby enabling the unobtrusive integration of modern components. The presence of skylights in the attic of the adjacent wing provides an established precedent, demonstrating that such contemporary additions can be successfully implemented without diminishing the building's cultural significance. This precedent supports the viability of integrating roof-based daylighting solutions - either full-scale skylights or smaller roof apertures - above the auditorium. The proposed design introduces eight skylights, symmetrically distributed across the roof, with four positioned along the western slope and four along the eastern slope. The light guides are shown in simulation (Figure 7) as red circles, indicating their position and approximate location. This arrangement ensures uniform daylight distribution across the interior space. Simulation analyses indicate that the proposed intervention substantially improves daylight availability (Figure 7), profitably higher illuminance levels throughout the auditorium.

4.2 Resulting graph

The resulting graph presents several datasets, including recommended illuminance values, on-site measurements, simulation outputs, and values obtained after the proposed modification. The graph (Figure 8) also displays a curve generated by the simulation program that illustrates the increase in daylighting resulting from the insertion of eight skylights into the roof structure.

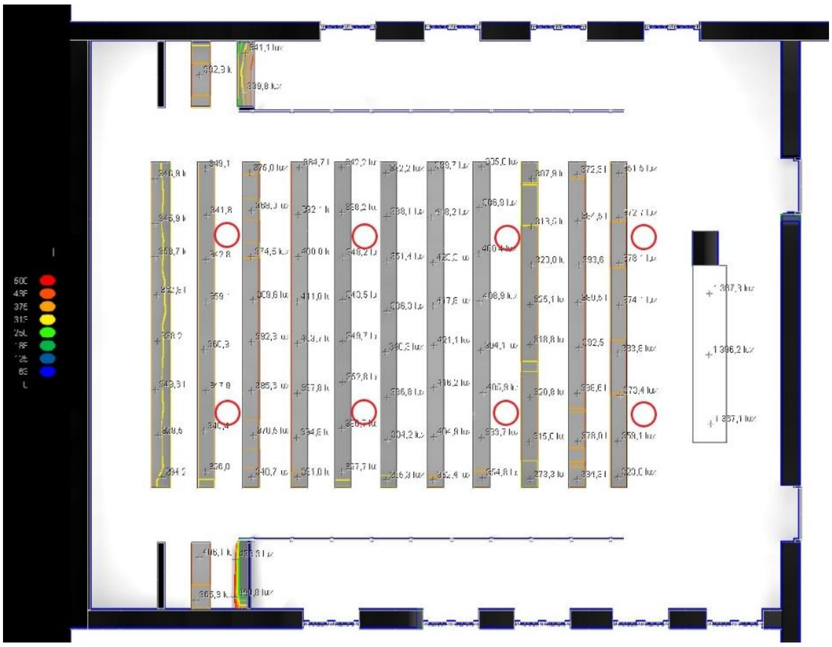
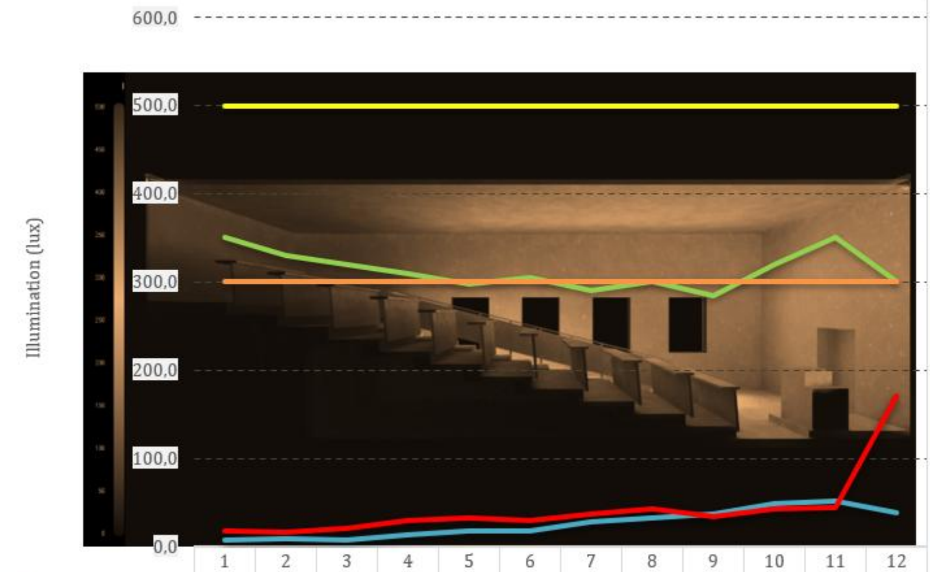


Figure 7: Floor plan from the simulation program after designing the light guides

The background image beneath the graph is a snapshot of the simulation export, showing the 3D model with a rendered daylight distribution using a lux-based color scale. All values and curves are precisely aligned with the seating arrangement, corresponding to the working plan of the evaluated surfaces.



	1	2	3	4	5	6	7	8	9	10	11	12
Measured	7,6	8,7	8,2	13,3	18,2	18,5	27,8	32,6	37,3	49,5	52,6	38,2
Simulated	18,7	16,3	21,4	29,2	32,6	29,5	37,9	42,5	33,7	43,8	44,2	171,0
Recommended	500	500	500	500	500	500	500	500	500	500	500	500
Simulated even with overhead lighting	350	330	320	310	298	305	290	300	285	320	350	300
Required	300	300	300	300	300	300	300	300	300	300	300	300

Figure 8: Graph with measured values of daylight illumination points (lx)

5 Conclusion

Slovakia possesses a large number of historic buildings that require careful protection. Preserving these structures and adapting them for new functional uses is essential for maintaining cultural heritage while ensuring their long-term relevance. Sensitive restoration must therefore balance conservation principles with contemporary spatial and environmental requirements, among which daylight availability plays a key role. This study is focused on a historic building from the early 20th century, specifically its auditorium, which is currently used as a lecture hall at the Technical University of Košice. Although the building effectively fulfills its functional purpose and is used daily, the daylight conditions in the auditorium proved to be insufficient. Lighting measurements were taken over two measurement days in the summer and autumn, under slightly cloudy sky conditions. The measurements were taken in lx and verified using the VELUX Daylight Visualizer simulation tool, with only minor deviations between the measured and simulated values. The measured results show that the current level of daylight does not meet the standard recommended average lighting values for educational spaces. In order to improve the availability of daylight and increase the visual comfort of users, it is proposed to install light guides in the flat roof above the auditorium. The auditorium is located directly under a low-pitched roof, which allows for the integration of skylights with customized light wells. The simulation was created for the period of low sunlight in autumn, and the results clearly show the effects of the proposed measures. If this simulation is valid for this period, the results can also be applied to other periods. To mitigate potential overheating during the summer months, roof windows with lower effective transmittance, less than standard roof windows, are recommended. This solution offers a balanced approach that improves daylighting while respecting the constraints of heritage protection and indoor environmental quality. Eight light skylights are designed to optimize the daylighting of this room and verified through a simulation with evident results of improved daylighting. Our future work will focus on the effective design, simulation, and verification of daylighting systems in various historic buildings with inadequate lighting, with the aim of utilizing them for various purposes.

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