Comparison of different roof types in terms of lighting conditions in an industrial hall

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Abstract:
The indoor climate of industrial buildings is a function of production technology and requirements for the creation of an optimal artificial material environment. Currently, we consider daylight not only as a source of illumination, but also as an aesthetic element of a building or a way of reducing energy consumption. Light in a closed space allows a person to obtain basic visual information (perception) and perform visual tasks. Top lighting schemes can provide increasingly more useful illumination from smaller apertures than side lighting when they capture and diffuse sunlight. Sunlight is roughly 10 times brighter than light from the sky or clouds. A combined lighting system (top lighting and side lighting) ensures a better light distribution in industrial buildings. In this study, we present a comparison of daylight factors for different types of skylights. Specifically, a saddle skylight in the hall and three other types of skylights were created and simulated. In all the cases, the models of skylights were prepared and simulated using RADIANCE. Additionally, a comparison of simulation results obtained with RADIANCE was conducted to quantify the lighting climate. Overall, saddle roof was considered as the best choice for daylight in an industrial hall.

Keywords:
skylights; industry; daylight simulation; daylight factor; indoor environment

1 Introduction

An industrial building is a large-spaced building that operates with exhaustive power for running heavy-operated machines. Illumination provided by artificial lighting is costly. Daylighting has been proposed as an alternative to the lighting process in industrial spaces via renewable means [1].

Top lighting systems represent an optimum source of natural light for building interiors. These systems provide abundant illuminance levels from small openings, and thereby, reducing artificial lighting and minimizing glazing areas [2]. Top lighting provides daylight from above and can generally provide the most uniform illumination throughout a space. Top lighting reduces the likelihood of glare and allows for a more even distribution of daylight within the space. Combinations of side lighting with top lighting can also be successful in providing uniform illumination levels [2, 3].

Daylighting is a sustainable method for controlling the flow of natural light into the interior surfaces of buildings. The integration of light into a building is a fundamental part of creating space. Daylight provides the highest-quality light source for visual tasks. It enhances the color and visual appearance of objects and aids students in observing small details with better clarity. In previous studies, daylighting has been analyzed via simulation tools owing to consistent and precise predictions. Hence, by improving the design of buildings for efficient daylighting, the annual energy cost of investing in artificial lighting and for industrial operation in a certain period can be restricted [2, 3].

The quantity of illumination in interior spaces is precisely measured using different metrics, whereas the quality is subjective and involves human requirements. The variability of daylight with the alternation of day and night improves the circadian rhythm of the occupants, and it is beneficial for their health. Furthermore, daylighting has numerous psychological and physiological effects on building occupants. However, it can adversely affect (i.e., glare and overheating) indoor environmental quality of a space if daylighting design is not performed with special care [4, 5].

2 Analyzed daylighting factor

The quantitative level of daylight is expressed by the daylight factor (DF). The following equation can be used to evaluate the daylight factor of an industrial building [6]:

$$DF = \frac{Indoor\ illumunance\ from\ light}{Horizontal\ Unobstructed\ Outdoor\ Illuminance} \cdot 100\% \quad (1)$$

The daylight factor includes light from (see Figure 1) [6]:

- Sky component – light received directly from the sky, excluding direct sunlight (SC).
- External reflected component – light received from exterior reflecting surfaces (ERC).
- Internal reflected component – light received from internal reflecting surfaces (IRC).

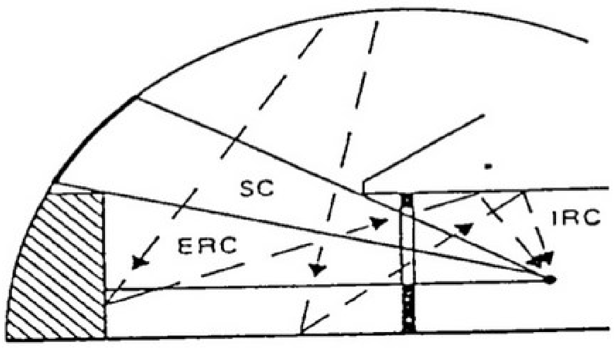


Figure 1. Daylight factor [4]

The sum of the three components corresponds to the daylight factor:

$$DF = SC + ERC + IRC \qquad (2)$$

The classification of the internal daylighting of an indoor environment, according to Slovak and Czech technical standards, is based on the work, its complexity, and the basic requirements that are placed on the complexity of the visual activity [6, 7].
The lighting technical requirements for daylight are specified based on standard STN 73 0580-1, Daylighting of buildings; Part 1: Essential requirements [8, 9].

3 Building case study

The building used in this study has a single-floor hall of 60 m × 15 located in Kosice. The orientation of the hall is as follows: the long axis of the building is aligned east–west. The roof consists of a saddle with a maximum internal ridge of 8.4 m. The required target illuminance is 300 lx at the floor level. The operating hours of the building are from 7:00 to 15:00 from Monday to Friday. The reflectance values and material properties used in the calculations are listed in Table 1.

Table 1. Material properties

	Visible transmittance (%)	Coefficient of pollution (%)	Reflectance (%)
Glazing - saddle	61	74	-
Glazing - windows	36	52	-
Polycarbonate-roof	35	-	-
Floor	-	-	10
Walls	-	-	55
Ceiling	-	-	70

The hall consists of two types of natural light sources: side windows (sidelighting) and roof skylights (toplighting) (see Figure 2).

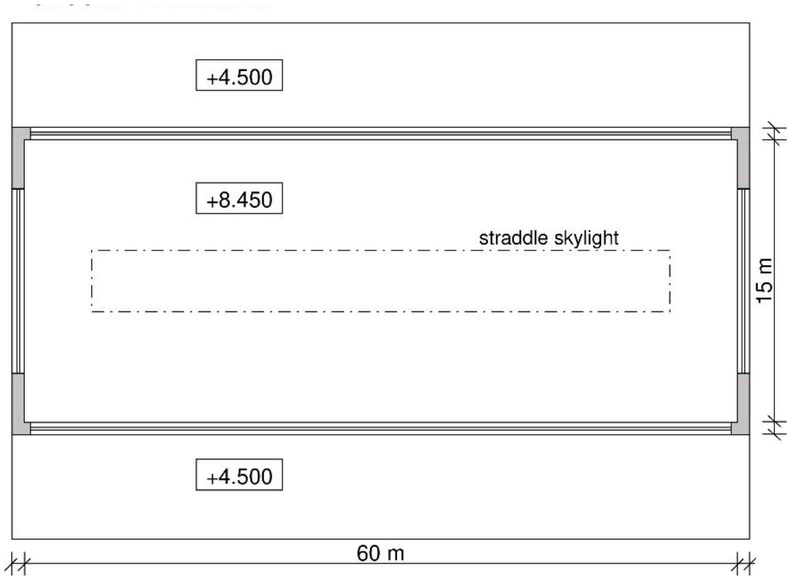


Figure 2. Floor plane of the production hall with saddle skylight

The window height is 1800 mm, and the widths are 5600 mm and 3000 mm. For all window cases, we use wired glazing with a visible transmittance of 36 % wired glass (measured at the saddle roof and then used in the simulation at other roof lights). The dimensions of the roof lights are as follows:

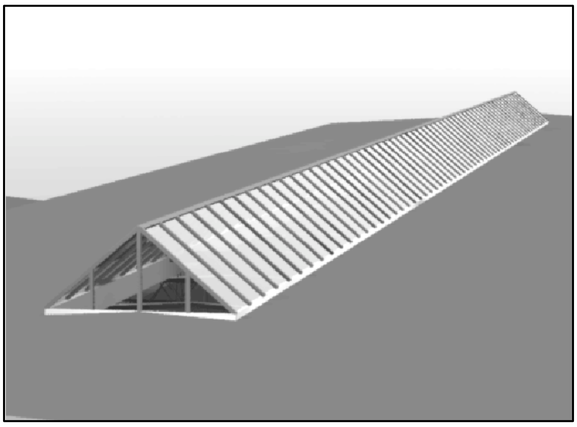
- Saddle roof – 2.4 x 48 x 1.1 m (located in the hall).
- Monitor roof – 2.4 x 48 x 1.9 m.
- Lantern roof – 2.4 x 2.4 x 1.9 m – 5 pieces.
- Sawtooth roof – 2.4 x 48 x 1.65 m – glazing oriented north at an angle of 60°.

The roof light is placed at the peak of the building bay throughout the length of the hall, i.e., 48 m. Two different materials are analyzed for skylight: wired glazing and diffused polycarbonate (visible transmittance of 35 is considered in the simulation).
The hall is used for medium-precision production with various types of work, and thus the hall is classified as a III – IV light – technical class. With the given lighting system at the critical point of the functional place on the horizontal plane, the following values are required: minimum standard value of daylight factor DF_{min} = 1.5 – 2 % and average daylight factor $DF_{average}$ = 5 – 6 % [8, 9]. Illuminance uniformity (U_0 > 0.2-0.3) is defined as the quotient of minimum and average illuminance in the visual task area given that the minimum value must be maintained at any time.

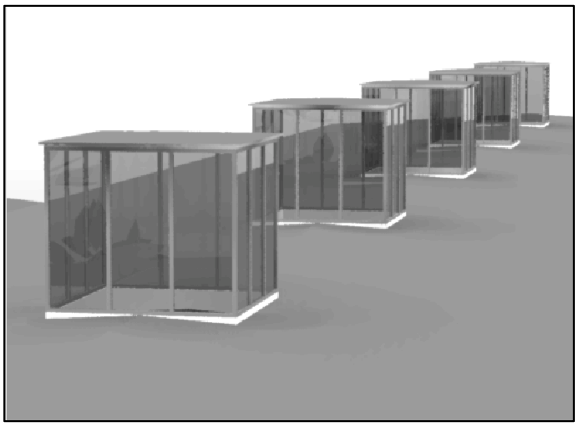
3.1 Analyzed cases

Alternatives to hall models in the simulations are considered as follows (see Figure 3):

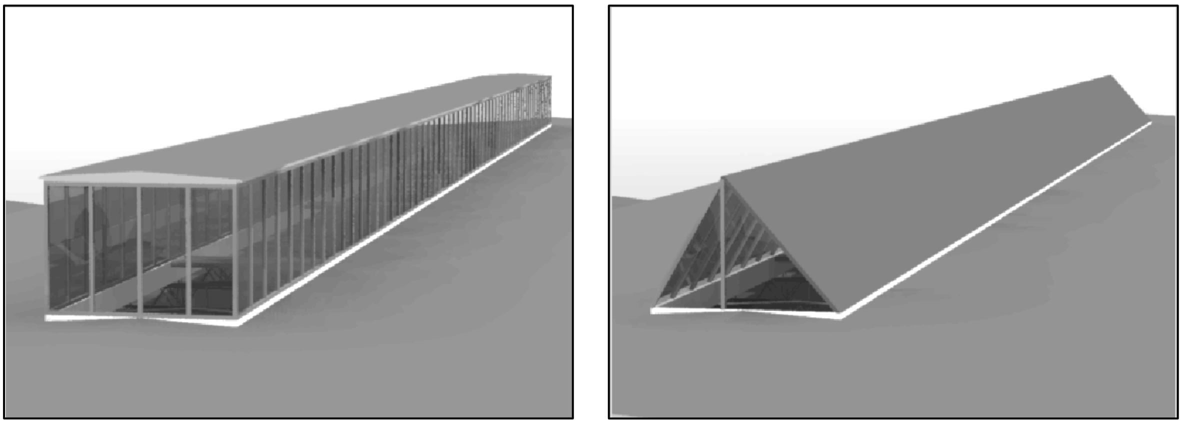
1. Hall – original saddle roof.
2. Models of roof lights:
    a. saddle roof,
    b. lantern roof,
    c. monitor roof,
    d. sawtooth roof.
3. Two types of glazing – wired and polycarbonate.
4. Effect of top lighting for all selected types of roofs - hall without side windows.



Saddle roof



Lantern roof



Monitor roof Sawtooth roof

Figure 3. Models of skylights

3.2 Results and Discussion

From the simulations, daylight factor values (DF%) are calculated for each roof alternative and for both types of glazing (see Tables 2 and 3). A hall without side lighting in the simulations is considered to evaluate the impact of top lighting on the lighting climate. The daylight factor (DF%) values are listed in Table 4. The daylight factor curves are shown in Figures 4 and 5.

Table 2. Calculated daylight factor (%) – wired glazing

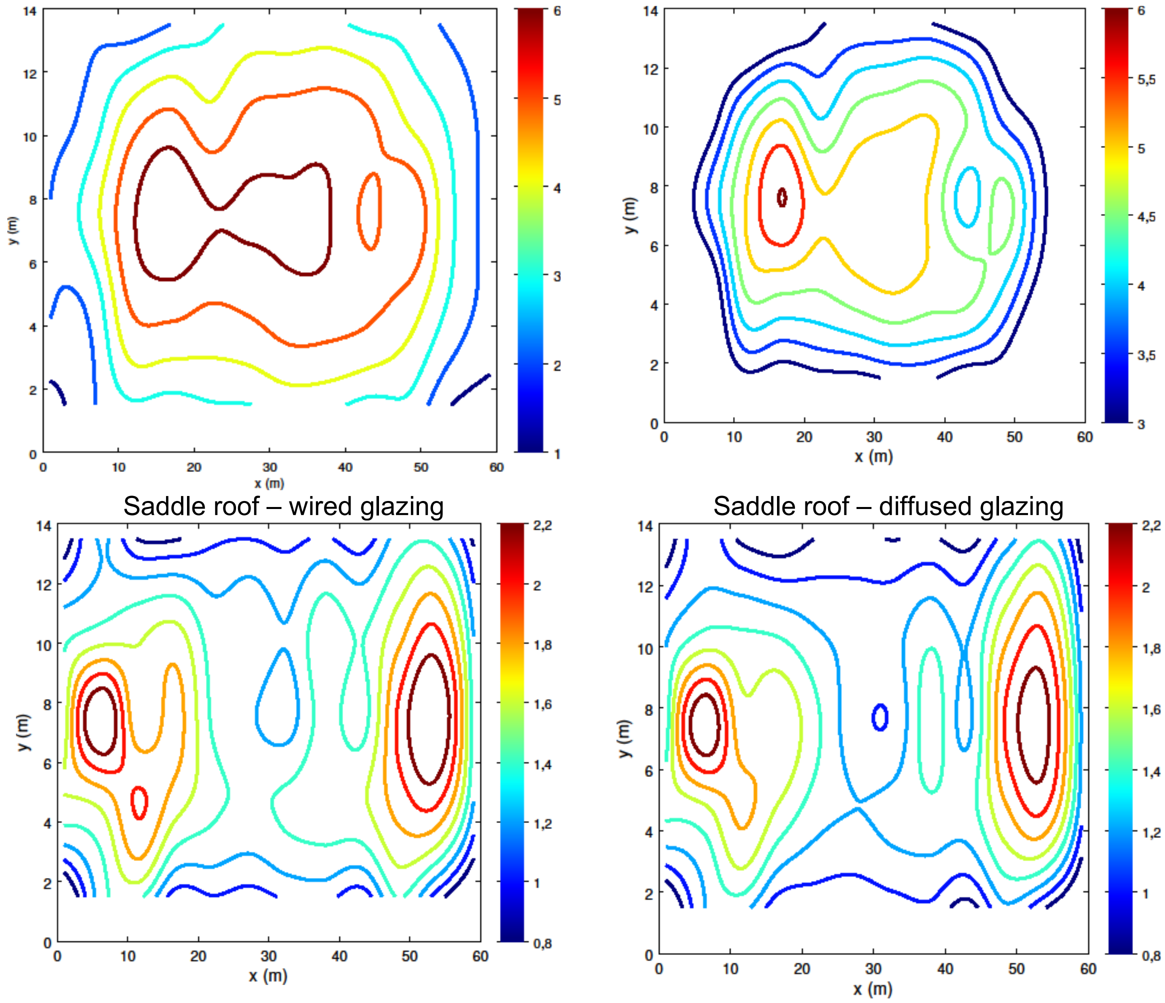
	Wired glazing			
	DF_{min} (%)	DF_{max} (%)	$DF_{average}$ (%)	U_o (-)
Saddle	2,18	6,96	4,83	-
Monitor	1,03	2,38	-	0,43
Lantern	1,12	2,43	-	0,46
Sawtooth	1,27	3,95	2,69	-

Table 3. Calculated daylight factor (%) – diffused glazing

	Diffused glazing			
	DF_{min} (%)	DF_{max} (%)	$DF_{average}$ (%)	U_o (-)
Saddle	2,38	6,01	4,30	-
Monitor	1,40	2,55	-	0,55
Lantern	1,03	2,39	-	0,43
Sawtooth	1,47	3,54	2,58	-

Table 4. Calculated daylight factor (%) – top lighting (without side windows)

	Wired glazing			
	DF_{min} (%)	DF_{max} (%)	$DF_{average}$ (%)	U_o (-)
Saddle	0,94	5,77	3,69	-
Monitor	0,16	1,21	0,74	0,13
Lantern	0,28	0,62	0,47	0,45
Sawtooth	0,23	3,13	1,56	-



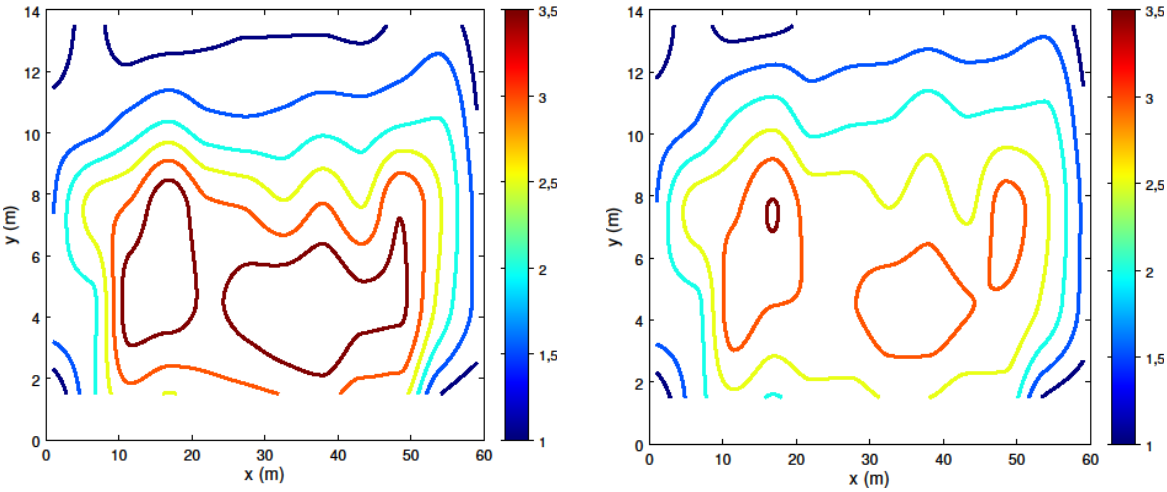
Saddle roof – wired glazing

Saddle roof – diffused glazing

Lantern roof – wired glazing

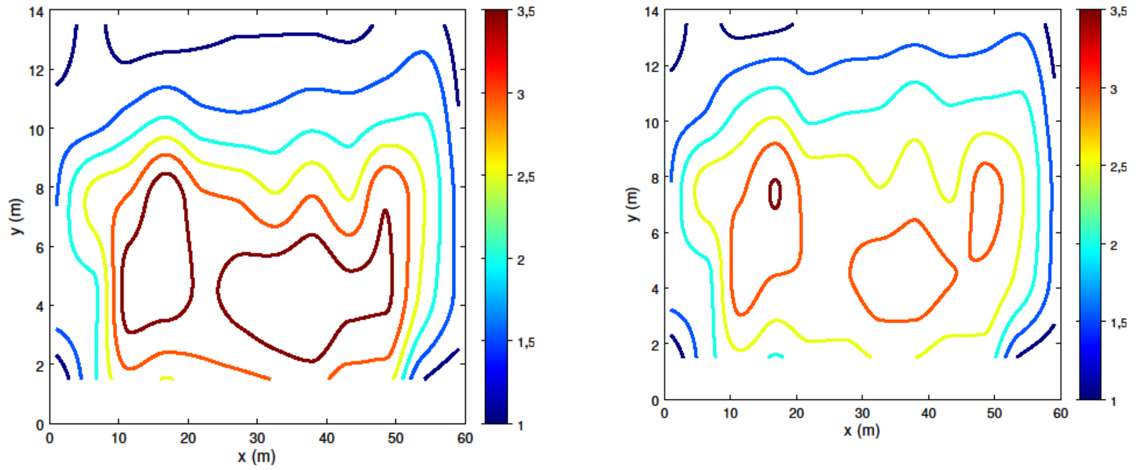
Lantern roof – diffused glazing

Figure 4. Plot of daylight factor



Monitor roof – wired glazing

Monitor roof – diffused glazing



Sawtooth roof – wired glazing   Sawtooth roof – diffused glazing

Figure 5. Plot of daylighting factor

Table 5. Evaluation of roof types based on required values of daylight factor

	DF_{min}	$DF_{average}$	U_o
Saddle	✓	– it is considered that the share of the top lighting in the average value of DF is 76% (more than 50% - standard); however, it is not appropriate	x
Monitor	x	– it is not considered that the share of the top lighting in the average value of DF is 39% (less than 50% - standard)	✓
Lantern	x	– it is not considered that the share of the top lighting in the average value of DF is 29% (less than 50% - standard)	✓
Sawtooth	x	– it is considered that the share of the top lighting in the average value of DF is 58% (more than 50% - standard); however, it is not appropriate	x

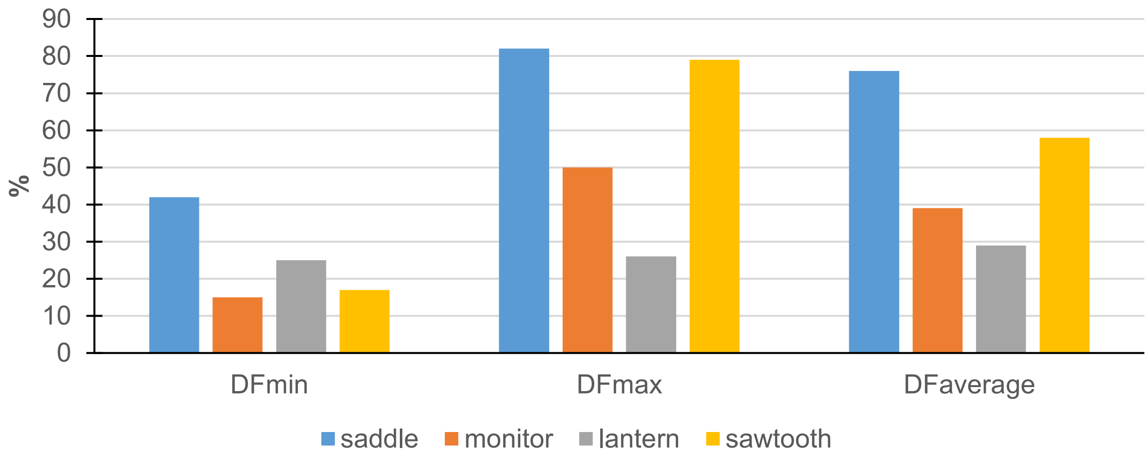


Figure 6. Percentage of toplighting in the combined illumination

The graphs (Figures 4 and 5) and tables (Tables 2 and 3) show that the minimum value of the daylight factor is only suitable for the saddle roof, and the average value of the daylight factor is assessed only for the saddle and sawtooth roofs although it is not suitable in either case. In the case of lantern and monitor roofs, the average value is not assessed. Only the lantern and monitor roof satisfy uniformity requirements. The alternative for overhead lighting (minimum DF) is not satisfied in all skylight alternatives. For saddle and sawtooth roofs, the average DF value is not satisfied. With respect to uniform skylight, uniformity of illumination is not satisfied (0.13 < 0.2 - 0.3), whereas uniformity is satisfied for lantern skylight lighting (0.45 < 0.2 - 0.3). Table 5 and Figure 6 provide a summary of the satisfactory daylight factor values.
The curves of the same illumination for diffuse glazing for all types of roof lights (see Figures 4 and 5) are evaluated, and they indicate that the use of diffuse glazing leads to better lighting uniformity in the hall with the exception for the alternative with a lantern roof.

4 Conclusion

In industrial buildings, the characteristics of a top lighting system can offer an efficient quantity and quality of daylight with a combination of sunlight and sky light. Rooflighting is more efficient when compared to windows in terms of lighting level and uniformity. Thus, the study discusses toplighting systems in an industrial hall for different roof types.
There are several different roof types. Hence, one roof type was selected from each group of roof lights in the study because it was not possible to perform simulations for all roof types. Original skylight glazing, wired glazing, and diffuse glazing were considered to evaluate and compare the uniformity of illumination. The results indicated that side lighting does not provide a sufficient amount of lighting in the middle zone of the hall in the absence of top lighting with a saddle roof, which corresponds to 76 % of lighting. In the case of a lantern and monitor roof, the side lighting constitutes a larger share of the average daylight factor value (more than 80 %). Under top lighting, the skylight constitutes 58 % of the side lighting. Thus, the most advantageous type of skylight among the four variants corresponds to the use of a saddle roof (closest to the required minimum DF value) in diffuse glazing. The most disadvantageous type corresponds to the lantern roof although the minimum daylight factor value is lower than that with the monitor roof when using diffuse glazing in this type of roof.

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