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Article

The Selection of Skylight Type for a Certain Building Using Evaluation Criteria and the Multi-Criteria Decision-Making Method

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Abstract: The article is focused on the selection of the rational skylight from the examined alternatives using quantitative and qualitative evaluation criteria, which are based on skylight performance and the multi-criteria decision-making method. A non-residential building, namely, a car service shop, was chosen for the research in order to offer good lighting in the large hall where the car repair work is performed every workday. Three alternatives of skylights with glazing material of spherical shape or dome were chosen for the study, skylight domes, longitudinal skylights, and tubular skylights, whose selection was based on the technical parameters of the product and the calculated amount of natural light entering through three different types of skylights. The skylight alternatives were evaluated according to seven criteria whose priority ranking and importance were determined by the survey questionnaire, while the theoretical and complex importance was determined using the Entropy Method. The most rational type of skylight was determined by the TOPSIS method. The analysis based on the offered method showed that skylight domes are a rational solution for the choice of skylight type for the tested building. The main criterion for choosing the roof daylighting system according to the survey was heat transfer coefficient, while skylight cost and installation cost were the criteria chosen by Entropy Method. In both cases, when alternative solutions were compared using the theoretical and complex importance of evaluation criteria, the most rational type of skylight selected using the TOPSIS method was the same alternative, namely the skylight dome.

Keywords: skylight domes; longitudinal skylights; tubular skylights; illuminance; Entropy method; TOPSIS method

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1. Introduction

Today skylights are used to bring natural light into a building through openings in the roof. Natural light in domestic and commercial spaces improves human health, well-being and productivity and employee satisfaction in workplace environments [1–3]. Daylighting can be beneficial both economically and environmentally. From the economic point of view, daylighting reduces the energy consumption for artificial lighting [4], can increase the rental price of office spaces [5] and can increase the property's value due to high visual comfort that attracts more visitors [6]. From the environmental point of view, the use of daylighting reduces CO_2 emissions [7] and cooling loads and creates a potential for smaller sizes of heating, ventilating and air-conditioning equipment [8–10]. The design of natural lighting in the interior requires careful consideration of the skylight type as well as environmental aspects [6]. The above-mentioned investigations showed the benefit of skylight utilisation as a roof daylighting system for human health and well-being. Moreover, economic and environmental points of view were likewise significant.

Today, the choice of skylight type for certain buildings depends not only on the characteristics of skylights (such as cost, U value, transmittance, size and shape) but also on other factors such as purpose, orientation and placement, operability, compliance, size and shape of specific area/room, etc. [9–18]. It should be noted that indoor lighting conditions in a building also depend on other factors, such as the time of the year, outdoor sky conditions, position, quantity and characteristics of the chosen skylights [17–19]. That is why even scientific methods that could help to summarize all these factors and choose the right skylight type are offered [6,20–25]. The above-mentioned factors show that the choice of the appropriate skylight type for a certain building is not an easy task. Therefore, the authors of this study would like to suggest a method based on evaluation criteria of the alternatives of the types of skylights offering a rational solution for the choice of skylight type.

1.1. The Types of Skylights

The type of skylight mainly depends on the materials used, the mode of their use (for illumination, ventilation, smoke or heat extraction, roof access, etc.), roof types (flat or pitched) and the types of specific premises (size or shape). Today, the Lithuanian market offers skylights with dome-shaped glazing made of acrylic (PMMA) or polycarbonate (PC). Acrylic domes are available in one, two or three layers, while the thickness of polycarbonate domes can vary from 10 to 32 mm, depending on a customer. The light transfer efficiency and thermal performance of skylights differ depending on the number of acrylic layers or the thickness of the polycarbonate. Polycarbonate and acrylic domes can be transparent or matte. An overview of most commonly used skylights in Lithuania is presented in Table 1. By conducting the proposed economic–technical analysis, these skylights were chosen as skylight alternatives for a certain building.

Table 1. The most commonly used skylights in Lithuania.

	Skylight Domes	**Longitudinal Skylights**	**Tubular Skylights**
Description	Dome skylights (also known as skylight domes). This product can improve the energy efficiency of a building due to its high thermal values and high levels of light transmission and diffusion. There are two main types of skylight domes: fixed and ventilated. They also can be active and passive [16]. Active skylights contain moving components such as louvres, reflectors, mirrors or other mechanical devices to assist the delivery of natural light into interior spaces [26], while passive skylights do not utilise any moving or other mechanical components.	Longitudinal skylights (also known as arcade rooflight systems). The longitudinal skylight is a system for industrial flat roofs with standard requirements and is an ideal solution for pure daylighting, ventilation or complex smoke and heat extraction systems. Longitudinal skylights can be fixed or ventilated, active or passive. This type of skylight has some limitations due to the length of its frame [27].	Tubular skylights (also known as a light pipe or sun pipe systems). The light pipe system with a reflective tube extends through adjustable ends and has an internal mirror finish that intensifies and reflects natural daylight, delivering outdoor light to a room or area below, where the light is evenly diffused by a translucent ceiling fixture [20,28]. This type of skylight has a potential to reduce the lighting energy used [29] and can provide adequate visual comfort [30] and light at different floor levels with a single light pipe, or, through innovative layout planning, light pipes can provide natural light for multiple workspaces [2].
View of skylight			

Table 1. *Cont.*

	Skylight Domes	Longitudinal Skylights	Tubular Skylights
Technical data of the main skylight components			
Frames	-aminated wood (1) -polyvinyl chloride (PVC) profile (2) -aluminium profile (3)	-aluminium profile	-aluminium profile -polyvinyl chloride (PVC) profile
Frame shape	-square, rectangle, round	-square, rectangle	-round
Glazing variant	-glass units with optional argon gas filling (1) -polycarbonate (PC) or acrylic (PMMA) (2)	-glass -polycarbonate (PC) sheets	-organic glass
Glazing form	-flat elements are glazed with single- or double-glazing units or polycarbonate sheets -spherical elements are domes formed from PMMA sheets	-arch shaped -pyramid shaped	-dome or round shaped
Glazing material	-transparent -matte	-transparent -matte	-matte
Thermal insulation	-frame insulated with mineral wool	-frame insulated with mineral wool	-trim ring insulated -not insulated
Thermal performance	-U value: $1.1 \div 0.6$ W/(m^2 − K) (1) -U value: $1.3 \div 0.5$ W/(m^2 − K) (2) -U value: $2.7 \div 0.9$ W/(m^2 − K) (3)	-U value: $3.0 \div 1.1$ W/(m^2 − K)	-U value: $2.9 \div 1.8$ W/(m^2 − K)
Installation locations	-used in pitched roofs and in the roof structure of detached houses and apartment buildings (1) -used in flat roof structures of industrial, and commercial buildings, warehouses (2)	-used in industrial, and commercial buildings, warehouses, shopping centres	-used in the areas where skylights cannot be installed due to the roof structure, attic, etc. Mainly are used in residential and commercial buildings

Skylight domes and longitudinal skylights consist of a glazing, frame, a base and additional equipment (moving or other mechanical components), while a tubular skylight consists of a roof-mounted light collector, a highly reflective tube and an interior fixture. Skylight glazing material and frame are the components that affect the thermal performance of the product. Different levels of cooling and insulation in the room below the skylight can be achieved by filling a skylight with participating gas and by optimizing the skylight design [11,12]. The type of glazing can help to avoid glare and reduce heat gaining; it can also save energy for cooling and heating requirements [13–15].

Lightscoop skylights and other innovative daylighting systems can also be used to provide natural light to indoor spaces [31–34].

1.2. Factors That Help to Consider which Skylight Type to Choose

From the practical point of view, there are several factors to consider which skylight type to choose [18]:

- Purpose. Skylights may have different primary and secondary purposes, such as to increase the amount of natural light entering the building, provide ventilation or complex smoke and heat extraction, access the roof or, perhaps, increase the aesthetic value of the room. Usually, the primary purpose of the skylight is to increase the amount of natural light in the specific area. It should be noted that a skylight would bring more light than a vertical window of the same size. The required amount of light in a specific area depends on the activities performed there. Therefore, specific areas require different levels of illuminance; for offices and workspaces, for instance, the level of light varies in the range from 300 to 400 lux. It means that, at first, the area where the amount of natural light has to be increased is chosen, and the amount of light in lux is calculated according to the requirements. The secondary purposes of choosing the skylight can be ventilation, smoke and heat extraction, aesthetics, access, etc.

- Orientation and placement. The orientation of the skylight on the roof has an influence on the amount of natural light captured. The size and the number of skylights depend on their orientation. The placement of the skylight has an impact on the distribution of the natural light inside the specific area. The natural light will be more evenly distributed throughout the specific area if the skylight is placed close to the centre of the specific area.
- Size and shape of the room. The amount of natural light entering the specific area directly depends on the size of the chosen skylight. It should be noted that the spacing between the roof trusses for a certain building could be the main factor that limits the size and shape of a skylight. The size of a skylight should be 3–5% bigger than the specific area needing to be illuminated. Therefore, the choice of a skylight depends on the size and shape of the specific area.
- Shape and glazing. The shape of the skylight has an effect on the amount of natural light entering the building, e.g., some shapes are more efficient in delivering daylight. Currently, producers can offer square, rectangle and round-shaped skylights and different type of glazing from single- or multi-paned glass to innovative plastics, with or without insulation, as well as coatings to control such variables as heat and UV radiation. Not only will the choice of glazing influence the visual light transmission but also the heat transfer coefficient and the fire performance of a skylight. These parameters are declared by manufacturers. In addition, skylights with curved glass on flat roofs do not have an issue with rainwater collecting on top.
- Operability. There are two main categories of skylights, namely, fixed and vented. Additional equipment, e.g., moving components such as louvres, reflectors, mirrors or other mechanical devices, are used to assist the delivery of natural light into interior spaces, control ventilation or complete complex smoke and heat extraction systems.
- Compliance. This factor mainly relates to the energy efficiency requirements of the building. Skylight glazing material and frame are the components that affect the thermal performance of the product.
- Cost and installation. The cost of skylight depends on the materials it is made of. Innovative materials and solutions and accessories usually increase the cost of skylight. The shape of the roof slope of certain buildings may require special installation techniques and thus increase the total cost. The choice of materials used to produce a skylight and proper installation will influence the warranty term. To ensure a watertight installation, the professional installer should use the roofing material to flash the curb before fastening the skylight to the curb. The waterproofing is achieved by installing a continuous self-adhesive waterproof membrane beneath the roofing material and flashing material.

Considering the potential application of skylights in a specific building and by conducting the offered analysis, some of the above-mentioned factors were used as the quantitative and qualitative evaluation criteria, such as skylight cost, installation costs, heat transfer coefficient, the amount of natural light in the test object, the warranty period and the fire performance class of the glass products.

1.3. Scientific Methods That Help to Choose the Right Skylight

Scientific methods, such as parametric design, modelling and multi-criteria decision-making help to choose the right skylight type for a certain building. Currently, different simulation software used to design, calculate and visualise the illuminance in the tested building helps to select the right skylight. The lighting simulation and illuminance distribution below the ceiling level for different types of skylights were performed using DesignBuilder, Diva (Rhinoceros), Lightscape 3.2, DaySim 3.1, HOLIGILM, DIAlux evo, RADIANCE, DELight, RELUX Desktop, an interactive rendering engine based on the hybrid radiosity/shadow volumes rendering method and other simulation tools [13,14,28,32,33,35–41]. Some innovative designers use computer-generated building models with various input parameters for early planning of daylighting [16]. The full-scale models are the most effective but are also the most expensive when studying daylight performance [21]. Computer-based simulation can also offer cost-effective solutions and accurate predictions of daylighting performance, i.e., early considerations in the skylight and interior design could reduce overlighting by more than 50% [6]. Prediction methods for light pipes can estimate the amount of light exiting the pipe system and the distribution of this light within the installation [22] or allow designers to approximate a bulb or bulbs of given wattage with that of a light pipe or light pipes of a given size [23]. Sophisticated models showed that solar altitude, sky clearness index and the distance between the point of illuminance measurement and the light pipe diameter have an impact on the daylight penetration factor of the light pipe [20]. A performance prediction method of a light pipe system based on the amount of daylight admitted and energy saved by not needing electric lighting was offered in [29]. The authors of [24] developed a tool that integrates GIS site data, parametric modelling of multi-level building forms and multi-spectral lighting simulation that is capable of automatically performing hourly time-series evaluations over selected days throughout the year. Not only can a parametric design system be used for the generation of skylight configurations but also for a heuristics search [25]. Functional and environmental criteria (use and lighting) were considered using the heuristic search, while aesthetic criteria presented aesthetically pleasing configurations. The exhibition space was modelled and simulated to calculate the daylighting parameters, such as the daylight factor, uniformity of daylighting, luminance distribution and daylight glare index of the natural lighting environment with different daylighting schemes [42]. The authors of [17] shortlisted the following indices used to assess the indoor conditions/availability of natural lighting: building simulation, lighting uniformity assessment, Daylight Factor improvement, daylight metrics improvement, glare evaluation, visual comfort, solar radiation control, sustainable building design, energy-saving ability and weather data use. Glare is recognised as an important factor in providing visual comfort and must be evaluated and prevented when it occurs within a daylit space [19].

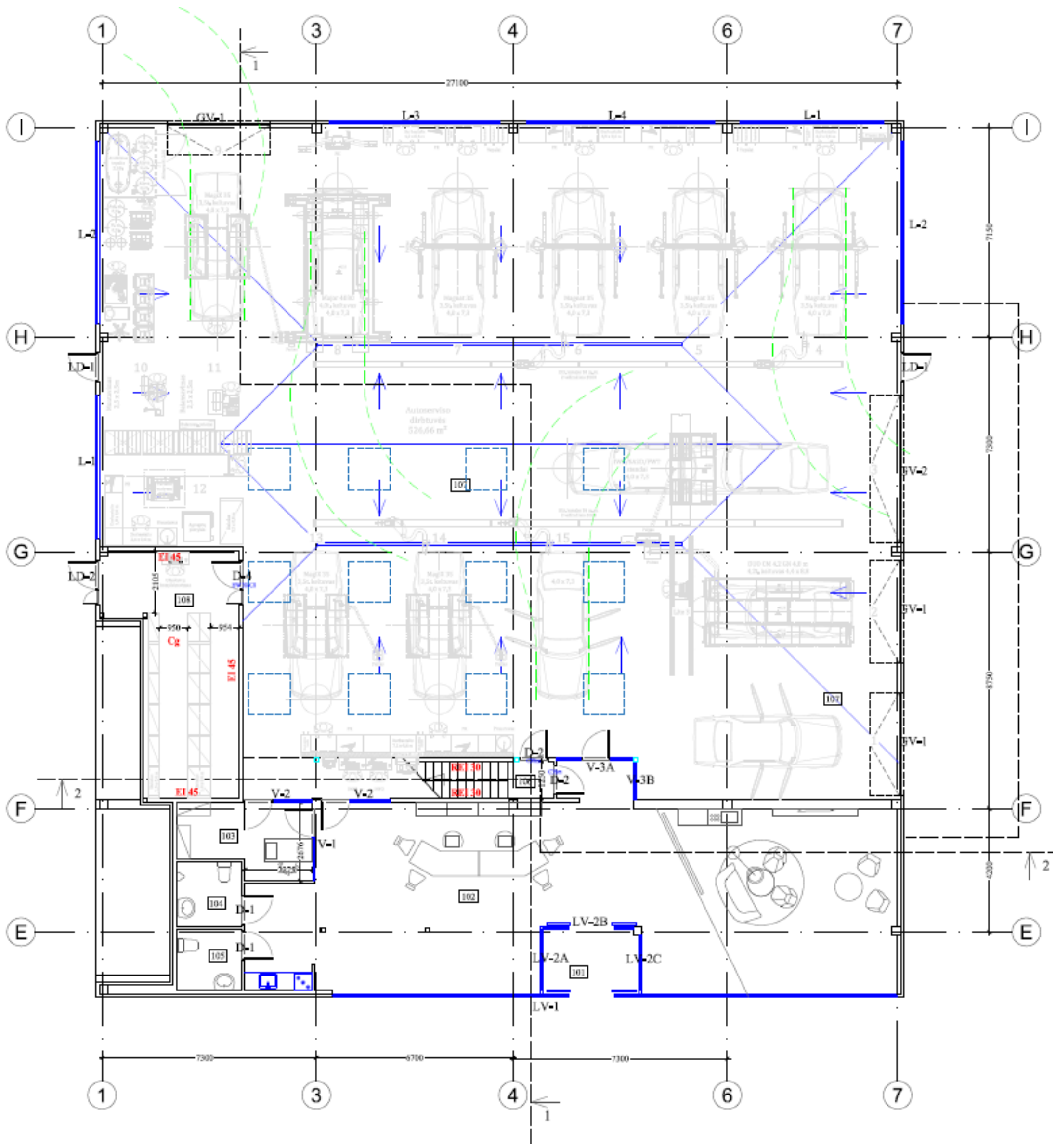
Practical examples mentioned in literature sources show that simulation software used to design, calculate and visualise the illuminance in the tested building and the multi-criteria decision-making method with various input evaluation criteria could help to select the right skylight. By conducting the proposed analysis to design, calculate and visualise the illuminance, the DIAlux evo computer software was chosen. The criteria priority order was developed referring to the importance of the evaluation criteria ranked by the respondents of the survey. To avoid the subjective opinion of the respondents only, the theoretical and complex importance of the criteria were also determined by using the Entropy Method. The most rational option of the alternative solutions analysed according to chosen evaluation criteria was determined using the Technique for Order Preference by Similarity to an Ideal Solution.

This work seeks to describe the selection of the rational skylight from the examined alternatives using quantitative and qualitative evaluation criteria, which are based on the performance of skylights and the multi-criteria decision-making method.

2. Materials and Methods

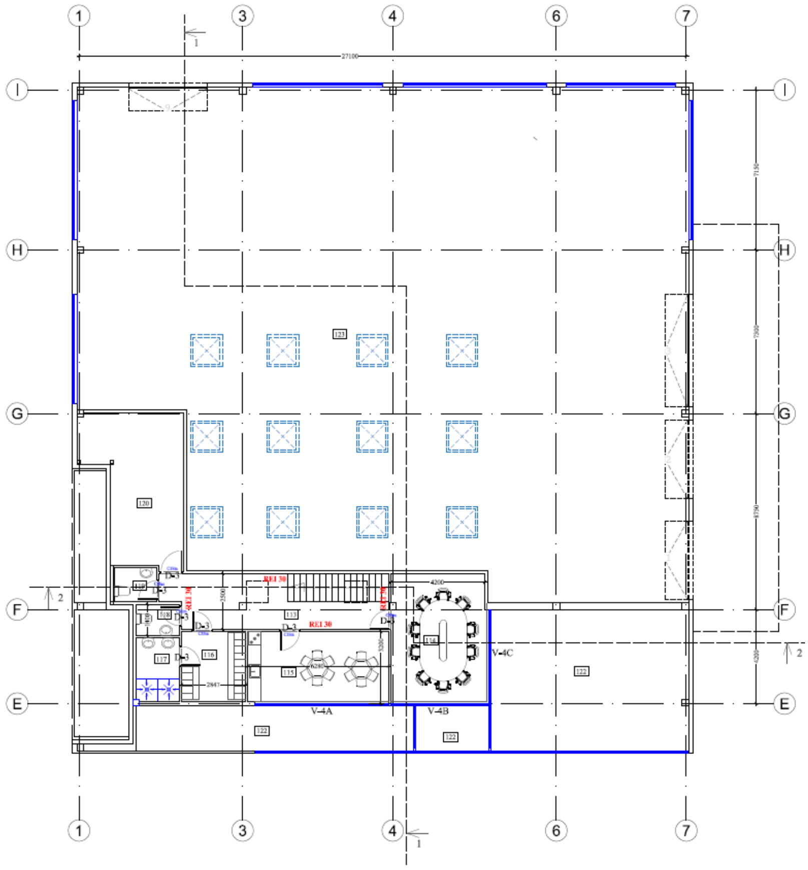
2.1. The Selection of the Specific Building

A non-residential building, namely, a car service shop, was chosen for the research for the three main reasons. The first reason was good lighting required in the large hall where the car repair work is performed. The second reason was the layout of the building being suitable for the modelling of natural lighting. The third reason was the service shop owner's willingness to compare different roof daylight systems. The requirement for the chosen daylighting system was to reduce the lighting cost and have a more sustainable business. At the owner's request, the glazing material of the roof daylighting system had to be of a spherical shape or dome. The commercial building with the service shop is located at Tilžės g. 62, Klaipėda, Lithuania. The gross floor area of the building is 873.39 m^2, the usable floor area is 761.55 m^2 and the building volume is 4998 m^3. The roof of the building is flat and is suitable for the installation of roof daylighting systems. The highest elevation of the building is +6.40 (Figure 1). Windows in the sidewalls and overhead garage door provide lighting in the nearby areas only, while the middle of the workshop is not naturally lit. The quality of natural lighting in the central part of the workshop was modelled by comparing the skylight alternatives selected.

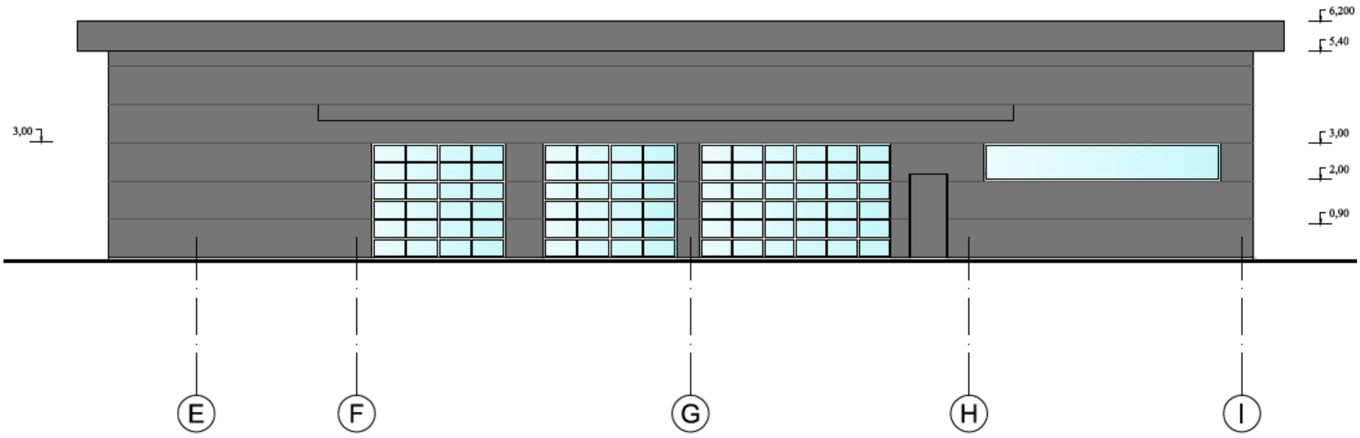


(a)

Figure 1. *Cont.*

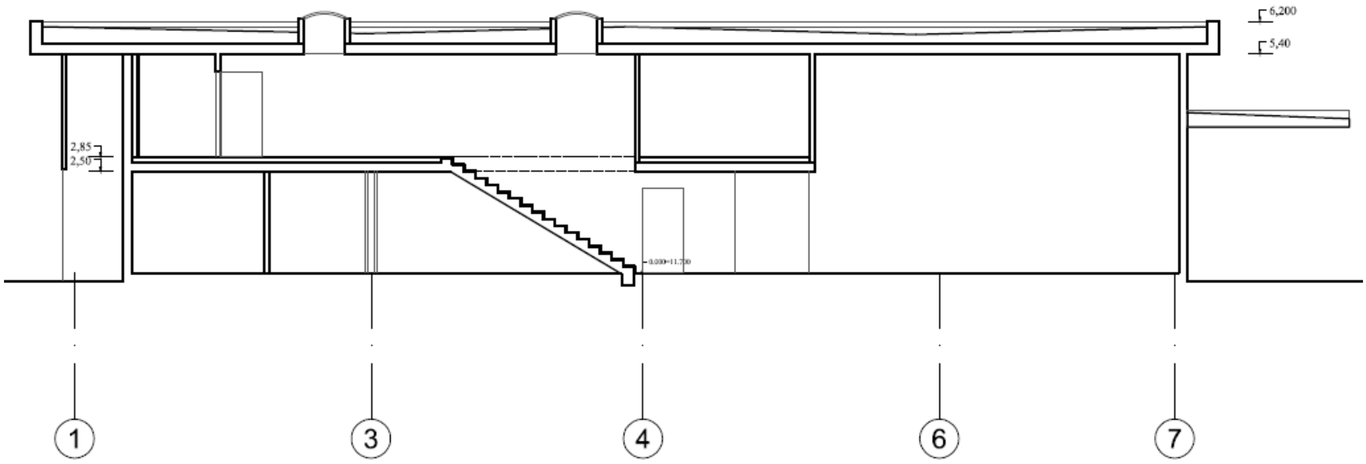


(**b**)



(**c**)

Figure 1. *Cont.*



(**d**)

Figure 1. First-floor plan of the analysed building (**a**); second-floor plan (**b**); facade (**c**) and section drawings (**d**). Where: the numbers indicate the coordination axes along the side of the building, while the letters indicate the coordination axes across the side of the building. The extension lines marked with a sign, which is an arrow with a shelf indicate elevation marks of levels (heights) of the building.

2.2. The Selection of the Skylight Alternatives

The selection of the skylight alternatives for the car service shop was based on the technical parameters of the product and on the hygiene norms that specify the illuminance of specific workplaces. Three alternatives of skylights were chosen for the research from the widely used roof daylighting systems: skylights domes—A_1, longitudinal skylights—A_2 and tubular skylights—A_3. The main purpose of the skylights chosen was to increase the amount of natural light entering the building. The chosen skylight alternatives were rational options to install on a flat roof and to illuminate the central part of the car service workshop, and at the owner's request, the glazing material of the chosen roof daylighting systems was to be of a spherical shape or dome. As an advantage, the first (A_1) and the second (A_2) alternatives can also be used for ventilation or complex smoke and heat extraction systems. In this case, active skylight systems have to contain some mechanical devices. The third alternative, namely tubular skylights (A_3), is a less rational option due to higher installation cost because a reflective tube system and suspended ceiling must be installed according to the requirements. The detailed view and some technical data of the selected skylight alternatives are given in Table 2. In addition, Table 2 presented skylight sealing assemblies.

According to the proposed evaluation system, the skylight price (in EUR/m^2) is taken from the suppliers' commercial offers, and the installation cost (in EUR/m^2) is taken from the commercial offers of installation company, while the visual light transmission (in %), the heat transfer coefficient (U value, W/m^{2}K) and the warranty period (in months) are declared by manufacturers. The fire performance class of glass products used in skylights is a qualitative indicator that is also declared by manufacturers. Only one evaluation criterion, namely, the amount of natural light (in lux) indicating the average natural illumination (lux) in the tested object, has to be calculated. Specialised computer software that models the spaces of the building and selects façade windows and skylights with appropriate light transmission parameters is used to make more accurate calculations. The natural lighting design helps to find the optimal products in order to achieve the desired result. In this study, software DIAlux evo 10.1 was used to calculate the amount of natural light entering through three different types of skylights in the tested object. This software was chosen for three main reasons. First of all, DIAlux is an open-source lighting design software that can be used to design, calculate and visualise light for single rooms, entire buildings, streets, outdoor areas, emergency lighting and daylighting [46]. Secondly, this program does not require much additional knowledge or special preparation to work with it. Thirdly, the usability of this software was proved by other authors [36,37]. In addition, this program has the declaration of conformity of the lighting calculation and visualisation software in accordance with ISO/IEC 17050-1:2010 [46]. It should be noted that to prove that the results are representative of the actual situation, lighting in real conditions in the as-built building is needed. This work was carried out when the analysed building was not built yet and there were no possibilities of doing that.

Table 2. The detailed view and some technical data of the selected skylight alternatives.

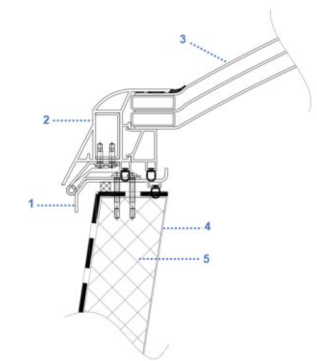
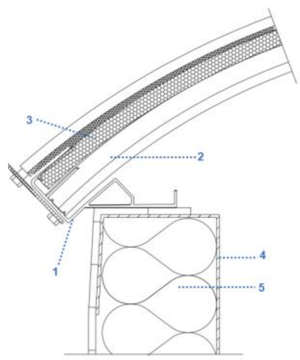
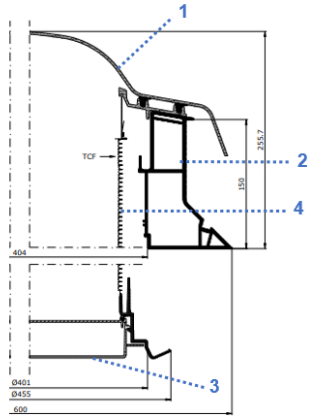
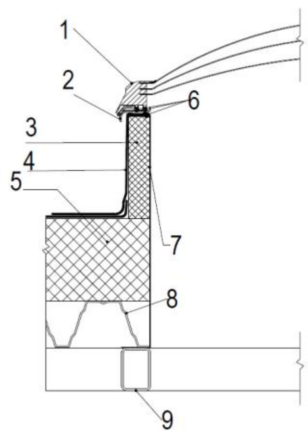
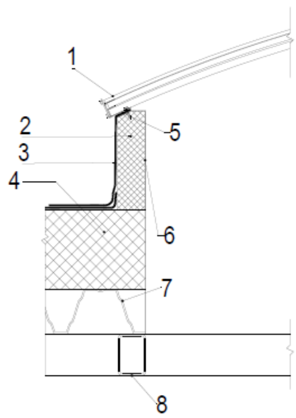
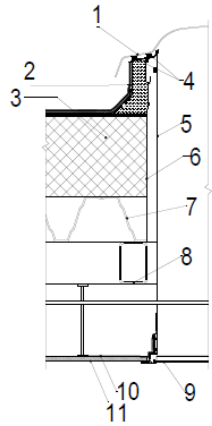
Option/Alternative	Skylight Dome (A_1)	Longitudinal Skylight (A_2)	Tubular Skylight (A_3)
Type of skylight	SOLIDM 3 Skin with dimensions of 140 × 140 cm [43]	KINGSPAN ESSMANN PC16/7 + PC10/4 with dimensions of 200 × 588 cm [44]	VELUX TCF-0K14 [45]
Detailed view	 where (1) protective frame; (2) skylight frame.; (3) round-shaped glazing; (4) base; (5) thermal insulation.	 where (1) skylight frame (2) ark-shaped construction; (3) ark-shaped glazing; (4) base; (5) thermal insulation.	 where (1) transparent protective dome; (2) PVC frame; (3) inner, ceiling-mounted part; (4) rigid tunnel made of fibreglass yarn or aluminium with reflective coating
Sealing assemblies	 where (1) domes mounted into closed PVC frame; (2) safety frame mounted with integrated sealing; (3) thermal insulation; (4) roofing membrane; (5) thermal insulation; (6) EPDM seal; (7) formed steel base sheet; (8) corrugated steel deck sheet; (9) roof construction.	 where (1) ark-shaped glazing; (2) thermal insulation; (3) roofing membrane; (4) thermal insulation; (5) sealant; (6) formed steel base sheet; (7) corrugated steel deck sheet; (8) roof construction.	 where (1) transparent protective dome mounted on the upper part of roof construction; (2) roofing membrane; (3) thermal insulation; (4) EPDM seal; (5) light reflective tube; (6) formed steel base sheet; (7) corrugated steel deck sheet; (8) roof construction; (9) light tube bottom part mounted in the ceiling construction; (10) vapor barrier; (11) ceilings construction.

Table 2. *Cont.*

Option/ Alternative	Skylight Dome (A_1)	Longitudinal Skylight (A_2)	Tubular Skylight (A_3)
Glazing material type	The rooflight is glazed with a dome of 3 × 2 mm thickness formed of three layers: transparent/transparent/ transparent	Two polycarbonate sheets PC16/7 + PC10/4, matte/matte	Acrylic or polycarbonate dome
Glazing material shape	round shape	ark-shaped	dome
Light transmission, %	71%	28%	54%
U value	1.4 W/m^{2}K	1.3 W/m^{2}K	2.6 W/m^{2}K

The building was modelled with DIAlux evo 10.1 software using the design drawings, setting the geographical location, climate conditions and the time zone (Figure 2).

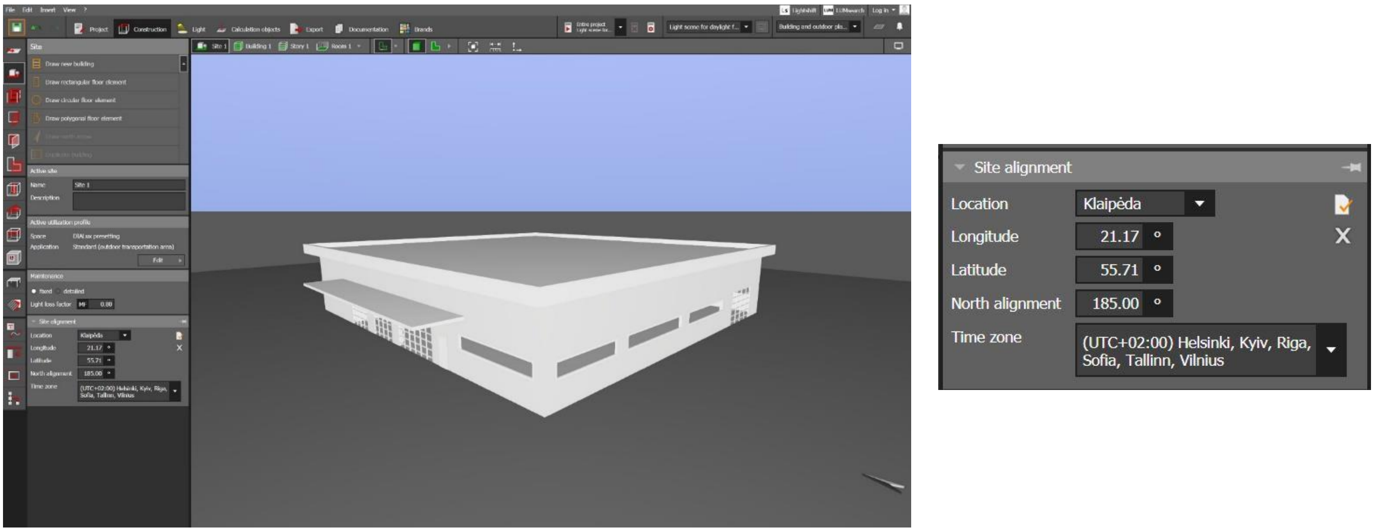


Figure 2. View of the building model developed by the DIAlux evo software and site alignment according to the exact location of the building.

From Figure 2, it can be seen that the building was placed facing north, and this means that the building facades in the system were rotated according to the real alignments of the building project. It is known that north-oriented buildings typically receive the most direct sunlight throughout the day, especially in winter when the sun is at its lowest. Because the roof was flat, all skylight alternatives had an equal chance to receive the same amount of daylight.

It is necessary to know the total area of daylight penetrating through the roof structure in order to compare different skylight alternatives. In the building used for our study, the total area of daylight that could enter through the roof structure was 23.52 m^2 (the area marked in red in Figure 3). The daylight area of this size requires 12 skylight domes sized 1400 × 1400 mm or 2 longitudinal skylights sized 2 × 5880 mm or 12 tubular skylights with diameter of 350 mm. The required number of light tunnels is the same as for skylights (Table 3). Different alternatives of skylights were modelled in the roof area above the centre of the workshop (Figure 3). This specific area requires an increased amount of natural light that enters the building through openings in the roof. The height of the ceiling in the relevant workplace was +5.40.

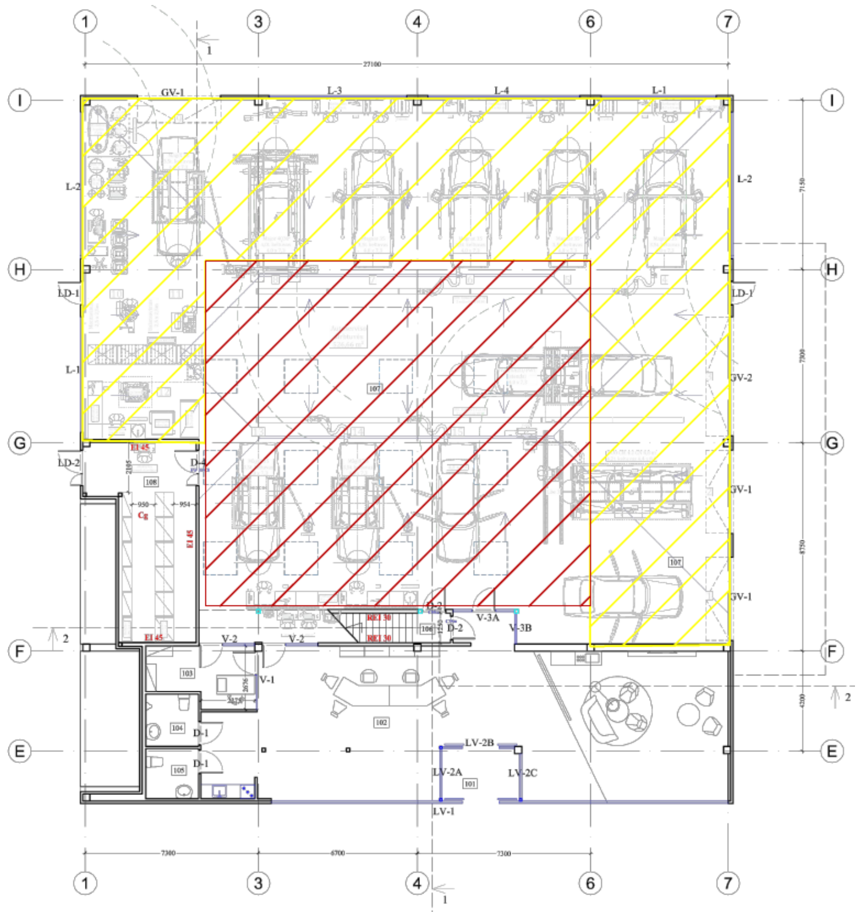


Figure 3. Distribution of natural light in the workshop: the area illuminated through the transparent façade envelope (marked in yellow) and the area illuminated through the skylights (marked in red). Where: the numbers indicate the coordination axes along the side of the building, while the letters indicate the coordination axes across the side of the building. The extension lines marked with a sign, which is an arrow with a shelf indicate elevation marks of levels (heights) of the building.

Table 3. Parameters used for the calculation of natural lighting.

Option/Alternative	Skylight Dome (A_1)	Longitudinal Skylight (A_2)	Tubular Skylight (A_3)
Type of skylight	SOLIDM 3 Skin with dimensions of 140 × 140 cm	KINGSPAN ESSMANN PC16/7 + PC10/4 with dimensions of 200 × 588 cm	VELUX TCF-0K14
Amount, pcs./light area, m^2	12 pcs./23.52 m^2	2 pcs./23.52 m^2	12 pcs./$-$$m^2$
City, Country	Klaipėda, Lithuania		
Time zone	UTC + 02:00 Vilnius		
Location of building	longitude: 21.17°; latitude 55.71°; north alignment 185.00°		
The date and time selected for the calculation of natural lighting	20 March 2020 (spring equinox) 22 September 2020 (autumn equinox)	from 6:00 a.m. until 22:00 p.m., every hour	
Sky conditions (sunny/moderate/overcast)	Average cloud cover		

Parameters used for the calculation of natural lighting are given in Table 3.

Lithuania is located in a cool temperate zone with moderately warm summers and moderately cold winters. In spring, mostly cloudy weather prevails. In autumn, weather is increasingly cloudy with light rain or drizzle. Therefore, the sky conditions at the spring and autumn equinox during the calculation of the illuminance were equated to average cloud cover.

It should be noted that the chosen lighting design software is not a rational option to calculate the illuminance created by skylight tubes. In this case, specialised lighting design programs are used. Despite the differences between skylight alternatives, the illuminance was calculated referring only to the light transmission by the dome glazing material. The inter-reflected light was not taken into account. In this case, all skylight alternatives had an equal chance of being selected. The results of the illuminance created by different roof daylighting systems are presented in Section 3.1.

2.3. The Selection of Evaluation Criteria System

The evaluation criteria system should be developed first in order to select the rational skylight from the available skylight alternatives (Table 2). Based on the past studies, the evaluation criteria that summarize the potential application of skylights for a specific building were selected. Considering the potential application of skylights in a specific building, the authors of this study developed the quantitative and qualitative evaluation criteria based on the performance of skylights. These criteria can be used to choose the rational skylight from the examined alternatives. The following are proposed:

K_1 is skylight cost (in EUR/m^2). It is a quantitative economic indicator that measures the cost of a product per square meter. The cost is calculated from the commercial offers of product suppliers;

K_2 is the installation costs (in EUR/m^2). It is a quantitative economic indicator that measures the cost of product installation per square meter including all sealing works. The cost is calculated from the commercial offers of an installation company;

K_3 is visual light transmission (percentage). It is a quantitative indicator that measures the ability of a product to transmit natural light into a room. The visual light transmission expressed as a percentage (%) is declared by manufacturers;

K_4 is heat transfer coefficient (U value, W/m^{2}K). It is a quantitative indicator of the heat flux density through the envelope at the difference of 1 °C between the air temperatures on either side of the envelope. The lower is the U value; the better is the performance of the product;

K_5 is the amount of natural light (in lux) in the tested object. It is a quantitative indicator indicating the average amount of natural light (lux) in the tested object calculated by DIAlux evo software;

K_6 is the warranty period (in months). It is a quantitative indicator expressed in months indicating the number of calendar months the product is covered;

K_7 is the fire performance class of glass products (rating from 1 to 7). It is a qualitative indicator of the fire performance of glass used in skylights. (A1—7 points, A2—6 points, B—5 points, C—4 points, D—3 points, E—2 points, F—1 point).

2.4. The Determination of the Priority Ranking and Importance of the Evaluation Criteria According to the Survey

After choosing the main evaluation criteria, a survey was designed and conducted in order to determine the priority ranking and importance of the evaluation criteria, which define the choice of the skylight. The survey items are presented in Table 4.

The respondents of the survey ranked the importance of the evaluation criteria from which the criteria priority order was developed. The respondents of the survey represented skylight manufacturers, designers and installers. They were asked to determine the importance of the evaluation criteria by filling in the form. Each criterion had to be scored from 1 to 10 and minimized or maximized accordingly. The respondents could choose one of the options: 1, 2—unimportant criterion; 3, 4—criterion of low importance; 5, 6—moderately important criterion; 7, 8—important criterion; 9, 10—very important criterion. In this case, the reliance was placed only on the subjective opinion of the respondents participating in the survey. The results of the priority order of the criteria by importance are presented in Section 3.2.

Table 4. Initial information for interviewees presented in the survey.

No.	Evaluation Criteria	Optimisation Direction of Criteria		Evaluation in Points (from 1 to 10)
		Min	Max	
1.	K_1, Skylight cost, (EUR/m^2)	×		
2.	K_2, Installation labour cost, (EUR/m^2)	×		
3.	K_3, Light transmission, %		×	
4.	K_4, Heat transfer coefficient, U value (W/m^2K)	×		
5.	K_5, Amount of natural light in the test object (lx)		×	
6.	K_6, Warranty period granted, months		×	
7.	K_7, Fire performance class of glazing materials		×	

2.5. The Determination of Theoretical and Complex Importance of the Criteria Using the Entropy Method

To avoid only the subjective opinion of the respondents, the theoretical and complex importance of the criteria was also determined using the Entropy Method [47,48]. After the subjective importance (obtained from the survey) of the criteria and the theoretical importance (obtained by the Entropy Method) became known, the selected method made it possible to determine the complex importance of the criteria. In this case, not only is the reliance placed on the objective importance of the evaluation criteria but also on the complex importance of the evaluation criteria.

The determination of theoretical and complex importance of the criteria is made as follows. First of all, the initial Matrix P of alternative solutions with criteria optima (Max or Min) has to be built (Table 5).

Table 5. The initial Matrix *P* of alternative solutions.

Criteria / Options	K_1	K_2	K_3	K_4	K_5	K_6	K_n
A_1	-	-	-	-	-	-	-
A_m	-	-	-	-	-	-	-
Sum	-	-	-	-	-	-	-
Optimisation direction	-	-	-	-	-	-	-

Then the initial Matrix P has to be normalized. The normalized Matrix $\overline{P}$ obtained from Equation (1) is presented in Table 6. The reason for matrix normalisation is that the data in the initial matrix P are expressed in different units of measurement and thus are not possible to compare. The normalisation of the initial Matrix P produces non-dimensional values.

$$\overline{P_{ij}} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}};\ \left(V_{ij},\ kai\ i = \overline{1, m}, j = \overline{1, n}\right) \quad (1)$$

where x_{ij}—i is the line, and j is the column of the Matrix.

Table 6. Normalized Matrix $\overline{P}$.

Criteria / Options	K_1	K_2	K_3	K_4	K_5	K_6	K_n
A_1	-	-	-	-	-	-	-
A_m	-	-	-	-	-	-	-

After the normalized Matrix $\overline{P}$ is calculated, the entropy level E_j for each criterion is determined from Equation (2):

$$E_j = -k\sum_{i=1}^{m}\left(P_{ij}\cdot lnP_{ij}\right), \quad \left(i=\overline{1,m}, j=\overline{1,n}\right),\ k=\frac{1}{lnm} \tag{2}$$

where m is alternative solutions, 3.

An additional matrix was created to make the calculation easier (Table 7).

Table 7. Additional matrix $\left(P_{ij}\cdot lnP_{ij}\right)$.

Criteria / Options	K_1	K_2	K_3	K_4	K_5	K_6	K_n
A_1	-	-	-	-	-	-	-
A_m	-	-	-	-	-	-	-

The level of entropy E_j varies in the interval [0; 1], so we can write $0 \le E_j \le 1$, where $\left(j=\overline{1,n}\right)$. The calculated entropy levels are presented in Table 8.

Table 8. The level of entropy E_j.

Criteria / Entropy	K_1	K_2	K_3	K_4	K_5	K_6	K_n
E_j	-	-	-	-	-	-	-

The level of change of the criteria d_j is determined from Equation (3):

$$d_j = 1 - E_j, \quad \text{where } \left(j=\overline{1,n}\right) \tag{3}$$

The calculated levels of change of the criteria d_j are presented in Table 9.

Table 9. The level of change of the criteria d_j.

Criteria / Entropy	K_1	K_2	K_3	K_4	K_5	K_6	K_n
d_j	-	-	-	-	-	-	-

Since all criteria are equally important, the theoretical importance of the criteria is determined from Equation (4):

$$q_{j(t)} = \frac{d_j}{\sum_{j=1}^{n} d_j};\ \left(j=\overline{1,n}\right) \tag{4}$$

The results are presented in Table 10.

Table 10. The theoretical importance of the criteria.

Criteria / Entropy	K_1	K_2	K_3	K_4	K_5	K_6	K_n
$q_{j(t)}$	-	-	-	-	-	-	-

According to the calculated theoretical importance of the criteria, the following criteria ranking order was obtained: $K_1 > K_2 > K_7 > K_4 > K_3 > K_5 > K_6$.

The subjective importance of the criteria $\overline{q_j}$ is known from the survey results (Table 11).

Table 11. The subjective importance $\overline{q_j}$.

K_1	K_2	K_3	K_4	K_5	K_6	K_m	Total
-	-	-	-	-	-	-	1.00

Since the subjective importance of the criteria $\overline{q_j}$ is known, the complex importance of the criteria from the equation can be determined (Equation (5)):

$$\overline{q_{j0}} = \frac{\overline{q_j} \cdot q_{j(t)}}{\sum_{j=1}^{n}\left(\overline{q_j} \cdot q_{j(t)}\right)};\ \left(j = \overline{1, n}\right) \tag{5}$$

The results are presented in Table 12.

Table 12. The complex importance of criteria.

Criteria / Entropy	K_1	K_2	K_3	K_4	K_5	K_6	K_n
q_{j0}	-	-	-	-	-	-	-

The initial Matrix *P* of alternative solutions with criteria optima (Max or Min) and the determined theoretical and complex importance of the criteria are presented in Section 3.3.

2.6. The Determination of the Most Rational Type of the Skylight Using the Proposed Evaluation Criteria and the TOPSIS Method

Finally, the most rational type of the skylight was determined from the alternatives compared in the research using the same evaluation criteria. The most rational option of the three alternative solutions ($A_1 \div A_3$) analysed according to seven evaluation criteria ($K_1 \div K_7$) was determined using the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) [49]. This method is based on the concept that the selected alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution.

The determination of the most rational type of the skylight is made as follows. First of all, the initial Matrix *M* of alternative solutions with criteria optima (Max or Min) and the best value (x^*j) have to be built (Table 13).

Table 13. The initial Matrix *M* of alternative solutions.

Criteria / Options	K_1	K_2	K_3	K_4	K_5	K_6	K_n
A_1	-	-	-	-	-	-	-
A_m	-	-	-	-	-	-	-
$\sqrt{\sum_{i=1}^{m} x_{ij}^2}$	-	-	-	-	-	-	-
Optimisation direction	-	-	-	-	-	-	-
Importance of complex criteria *Cq*, %	-	-	-	-	-	-	-
Importance of theoretical criteria *Tq*, %	-	-	-	-	-	-	-

Then the initial Matrix *M* has to be normalized. The normalized Matrix *M* calculated from Equation (6) is presented in Table 14. The data in the initial matrix *M* are expressed in different units of measurement and thus cannot be compared. Therefore, the initial Matrix M must be normalised to obtain non-dimensional values.

$$x_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{j} x_{ij}^2}},\ i = 1, m; j = 1, n; \tag{6}$$

where: x_{ij}—i is the line, and j is the column of the Matrix.

Table 14. Normalized Matrix $\overline{M}$.

Options \ Criteria	K$_1$	K$_2$	K$_3$	K$_4$	K$_5$	K$_6$	K$_n$
A$_1$	-	-	-	-	-	-	-
A$_m$	-	-	-	-	-	-	-

After the normalisation of the initial Matrix M, a weighted normalized Matrix M* of alternative solutions is developed (Table 15). To this end, the normalized Matrix M is multiplied by the vector of criteria importance (see q_c and q_t above) according to Equations (7) and (8):

$$M^* = [M] \cdot [q_c]; \tag{7}$$

$$M^* = [M] \cdot [q_t]; \tag{8}$$

where: q_c is the importance of complex criteria; q_t is the importance of theoretical criteria.

Table 15. Weighted normalized Matrix M* of alternative solutions.

Options \ Criteria	K$_1$	K$_2$	K$_3$	K$_4$	K$_5$	K$_6$	K$_n$
When the importance of complex criteria *qc* is used							
A$_1$	-	-	-	-	-	-	-
A$_m$	-	-	-	-	-	-	-
When the importance of theoretical criteria *qt* is used							
A$_1$	-	-	-	-	-	-	-
A$_m$	-	-	-	-	-	-	-

The best-case a^+ (the best value) and the worst-case a^- (the worst value) are found from Equations (9) and (10) respectively:

$$a^+ = \left\{ \left[\left(max_i x_{ij} / j \in J \right), \left(min_j x_{ij} / j \in J. \right) \right] / i = \overline{1, m} \right\} = \left\{ a_1^+; a_2^+; a_3^+ \right\}; \tag{9}$$

$$a^- = \left\{ \left[\left(min_i x_{ij} / j \in J \right), \left(max_j x_{ij} / j \in J. \right) \right] / i = \overline{1, m} \right\} = \left\{ a_1^-; a_2^-; a_3^- \right\}; \tag{10}$$

Distances between the real option a_i and the best case a^+, as well as between the real option a_i and the worst-case a^-, are computed from Equations (11) and (12):

$$L_i^+ = \sum_{j=1}^{n} \left| a_{ij} - a_j^+ \right|,\ i = \overline{1, m}; \tag{11}$$

$$L_i^- = \sum_{j=1}^{n} \left| a_{ij} - a_j^- \right|,\ i = \overline{1, m}; \tag{12}$$

Then criterion K_{bit} showing the relative proximity of the compared alternatives to the ideal alternative is calculated. The calculated value of criterion K_{bit} is used to prioritise the alternatives compared. In this case, the alternative with the highest K_{bit} value is the best. Finally, the performance value Ni of the alternatives compared is calculated from Equation (13) (applying the values of the importance of complex criteria and theoretical criteria):

$$K_{bit} = \frac{L_i^-}{L_i^+ + L_i^-}, \ i = \overline{1, m}; \tag{13}$$

The computation results are presented in Table 16.

Table 16. The most rational option obtained by the TOPSIS method.

Options	L_i^+	L_i^-	K_{bit}	Priority Ranking of Alternatives	The Performance Value of Alternatives (N_i), %
		When the importance of complex criteria *qc* is used			
A_1	-	-	-	-	-
A_m	-	-	-	-	-
		When the importance of theoretical criteria *qt* is used			
A_1	-	-	-	-	-
A_m	-	-	-	-	-

The initial Matrix *P* of alternative solutions and determination of the most rational type of the skylight using proposed evaluation criteria and TOPSIS method are presented in Section 3.4.

3. Results and Discussion

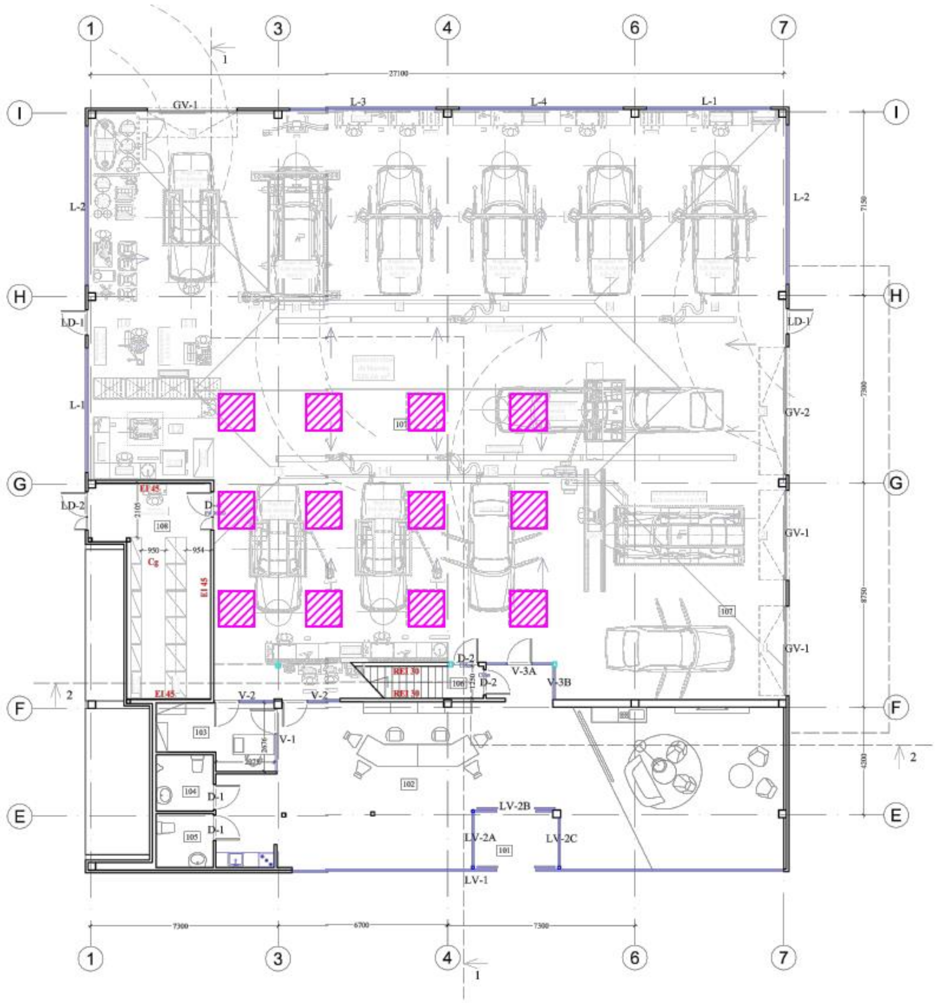
3.1. Comparison of Skylights by Calculating the Amount of Natural Light for the Specific Building

The illuminance created by different roof daylighting systems must be evaluated to ensure adequate daylight levels in the selected building. The natural daylight entering through the selected skylights in the roof structure (skylight domes (A_1), longitudinal skylights (A_2), and tubular skylights (A_3)) was calculated using the DIAlux evo software and data from Table 3. The calculation of illuminance for the chosen skylight alternatives was performed at the spring equinox on 20 March 2020 and at the autumn equinox on 22 September 2020. It is known that skylight performance depends on the sky conditions and solar intensities. In this case, sky conditions with average cloud cover were chosen. The illuminance is given in lux in all cases, whereas the active work surface where the illuminance in lux is indicated is the floor of the service shop, alt. ±0.000 (Figures 4–6, respectively). The process of illuminance calculation by means of DIAlux evo software for the selected building when three skylight alternatives are used as daylight openings is presented in Figures 4–6, respectively. Following the development of the building model by the software, the modelling and calculation of natural light were carried out (Figure 7 and Table 17).

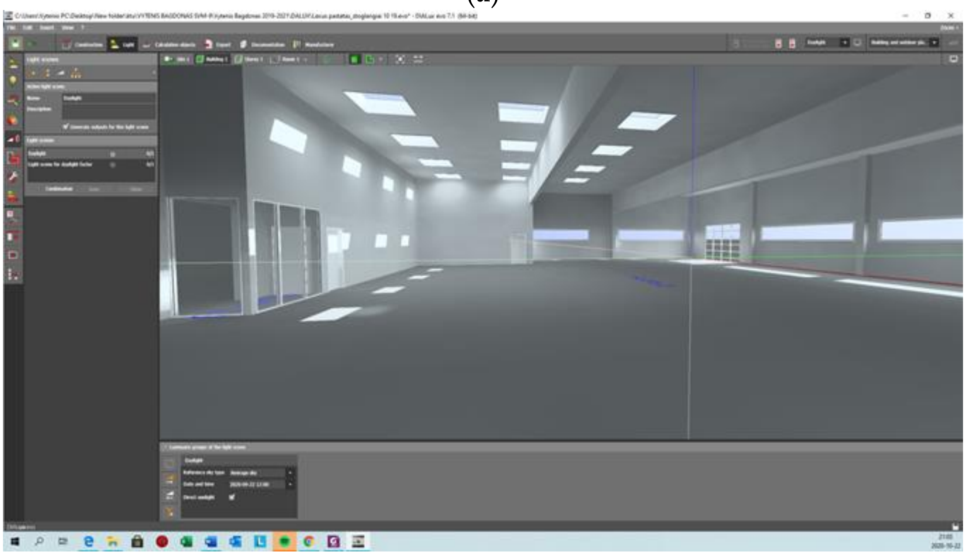
The output of design, calculation and visualisation of natural lighting of the workshop with the selected skylight alternative are presented in Figures 4–6, respectively.

The layout of skylight domes on the floorplan of the studied object is shown in Figure 4a, while the layout of longitudinal skylights appears in Figure 5a and the layout of tubular skylights appears in Figure 6a. The model of the interior of the building with the selected skylight domes is shown in Figure 4b, with the selected longitudinal skylights appearing in Figure 5b and the selected tubular skylights in Figure 6b.

The Luxplot resulting from twelve skylight domes of 1400 × 1400 mm dimensions, at 1:00 p.m. on the 22 September 2020, is presented in Figure 4c. It is clear that such type of skylight creates the largest illuminance values compared to longitudinal skylights and tubular skylights. The Luxplot resulting from two longitudinal skylights of 2000 × 5880 mm dimensions at the same time (Figure 5c) creates average illuminance values compared to skylight domes and tubular skylights. The Luxplot resulting from twelve tubular skylights of diameter 350 mm at the same time (Figure 6c) creates the smallest illuminance values compared to skylight domes and longitudinal skylights. The shape of the skylight has an effect on the amount of natural light entering the building. As previously mentioned, the illuminance was calculated referring to the light transmission of dome glazing material of skylight alternatives.

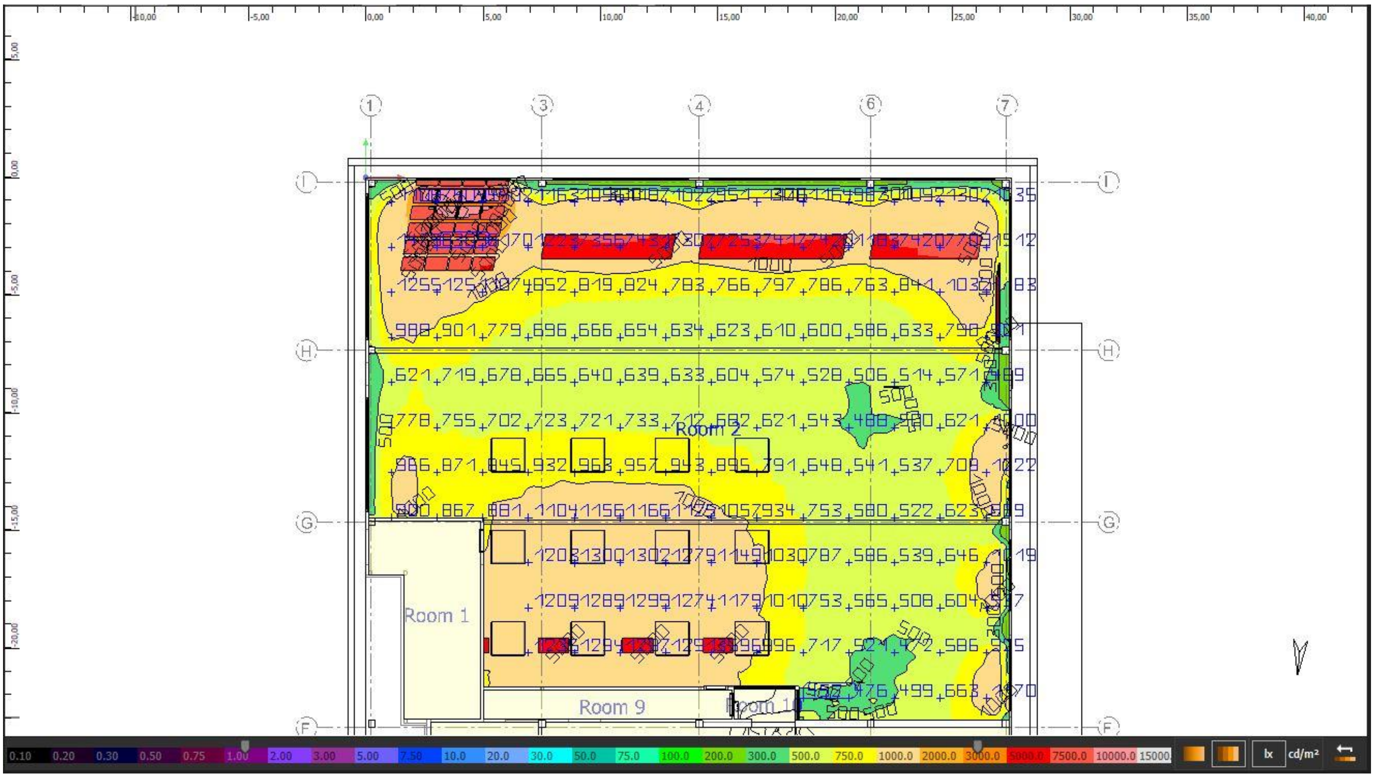


(**a**)



(**b**)

Figure 4. *Cont.*

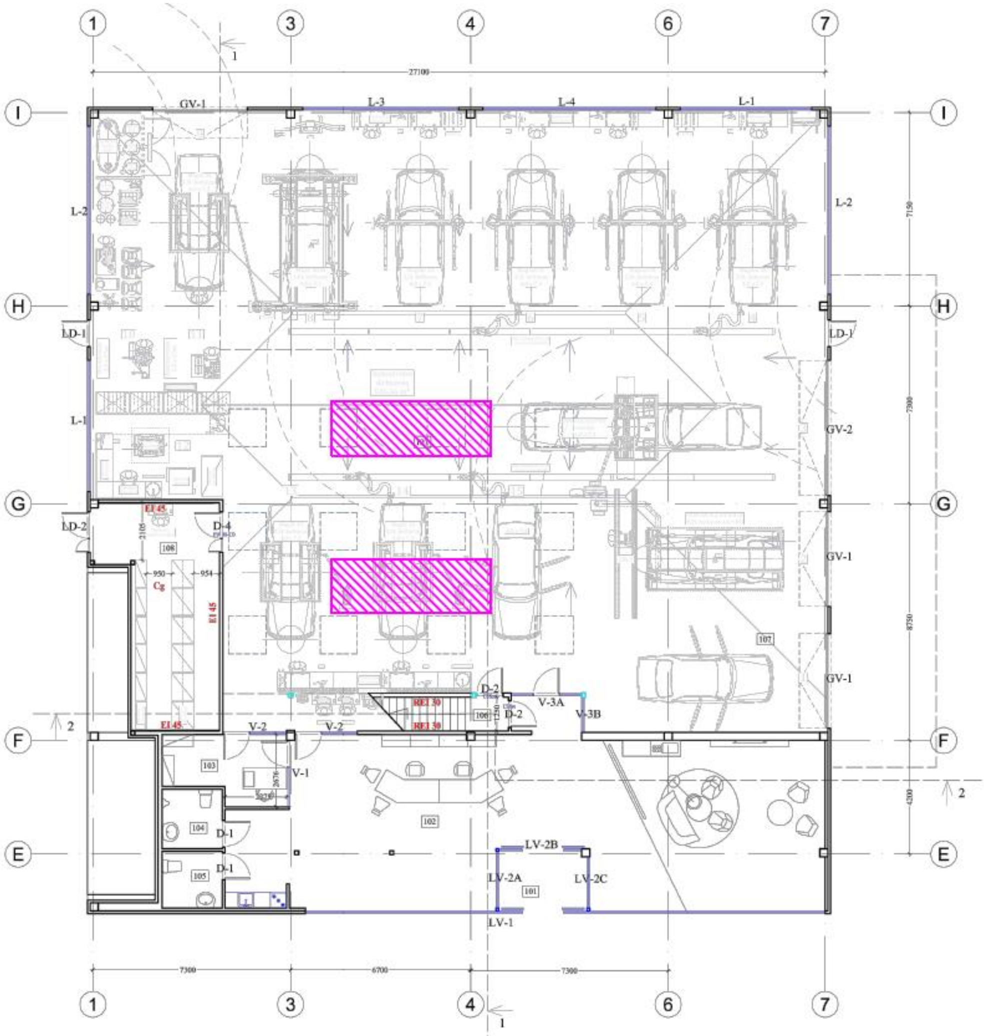


(**c**)

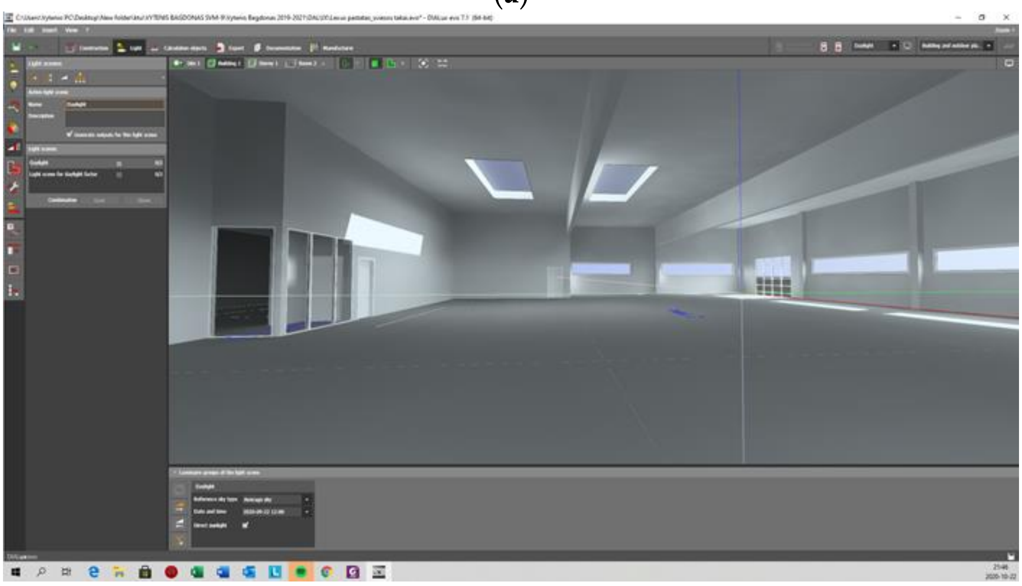
Figure 4. Design, calculation and visualisation of natural light in the service workshop: the layout of skylight domes on the floorplan of the studied object (**a**); the model of the interior of the building with selected skylights (**b**); the Luxplot resulting from twelve skylight domes of 1400 × 1400 mm dimensions at 1:00 p.m. on 22 September 2020 (**c**).

Daylight is strongly favoured by the occupants of buildings as a way to adequately illuminate indoor surfaces and save electric energy. In this research, the daylight entering through different types of skylights installed on a horizontal surface was studied. According to standard EN 17037:2018 'Daylight in buildings', daylight should be a significant source of illumination for all spaces with daylight openings [50]. The standard states that for a space with vertical and/or inclined opening with a given target illuminance, e.g., 300 lx, and appropriate reference plane fraction, i.e., 50%, the target illuminance should be achieved across the reference plane fraction for 2190 h (i.e., half of the daylight hours of the year). For the minimum target illuminance, e.g., 100 lx, the minimum target illuminance should be achieved across the entire (i.e., 50%) reference plane for 2190 h.

The comparison of the average illuminance values of the chosen skylight alternatives at the spring equinox on 20.03.2020 and at the autumn equinox on 22 September 2020 are presented in Figure 7. It shows that at 1:00 p.m. at the spring equinox and autumn equinox the selected skylight domes SOLIDM 3 Skin (A_1) with round-shaped glazing material formed of three layers and with a light transmission of 71% create the largest average illuminance of 1275 lx and 1283 lx, respectively, compared to the longitudinal skylights and tubular skylights. The smallest average illuminance of 935 lx and 933 lx, respectively, was created by tubular skylights VELUX TCR-014 (A_3) with a polycarbonate dome-shaped glazing material and with a light transmission of 54%. The second-best result of average illuminance of 1116 lx and 1115 lx, respectively, was determined using longitudinal skylights KINGSPAN ESSMANN (A_2) with ark-shaped glazing material formed of two polycarbonate sheets and with a light transmission of 28%

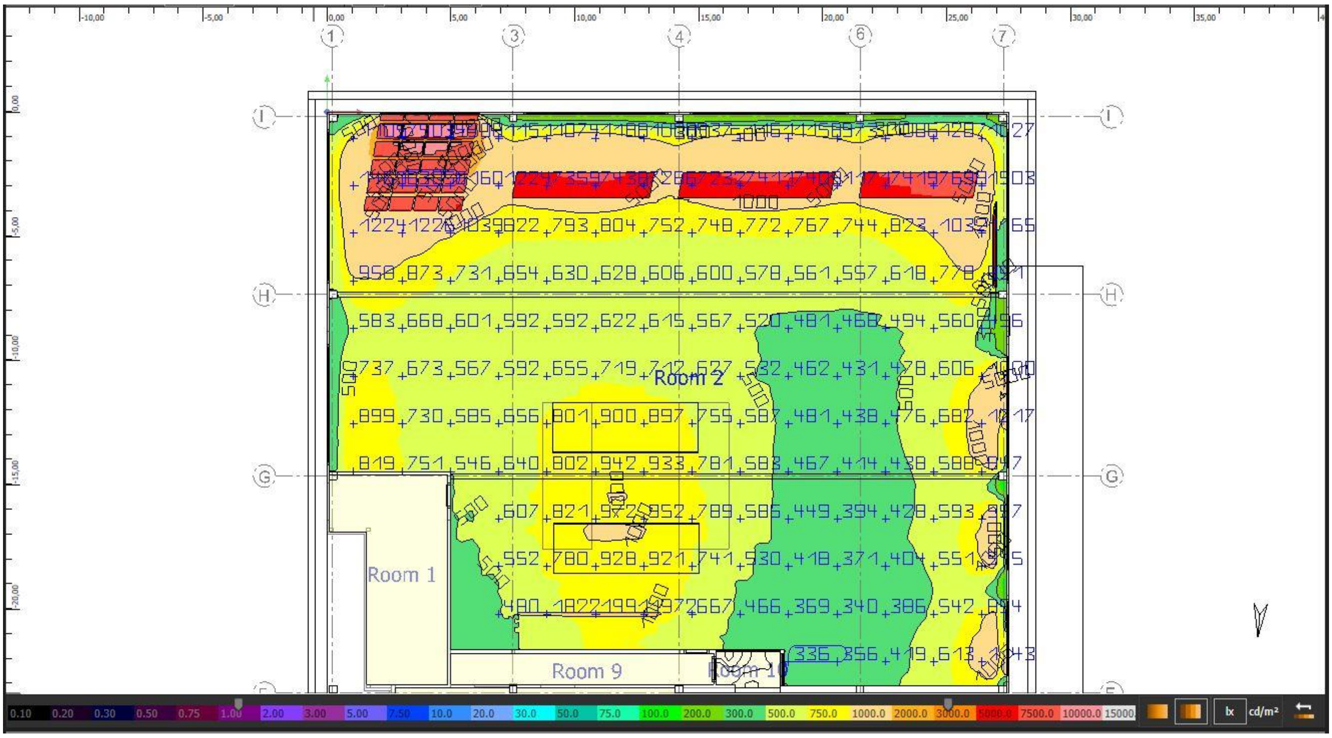


(**a**)



(**b**)

Figure 5. *Cont.*



(**c**)

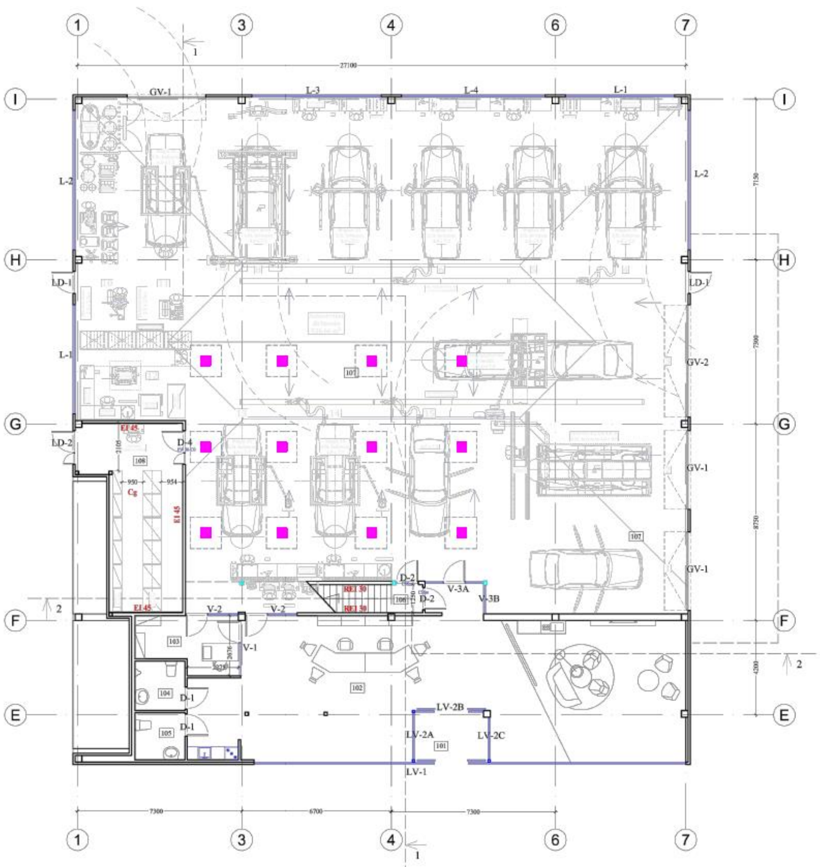
Figure 5. Design, calculation and visualisation of natural light in the service workshop: the layout of longitudinal skylights on the floorplan of the studied object (**a**); the model of the interior of the building with selected skylights (**b**); the Luxplot resulting from two longitudinal skylights of 2000 × 5880 mm dimensions at 1:00 p.m. on 22 September 2020 (**c**).

Table 17. The results of natural light calculation.

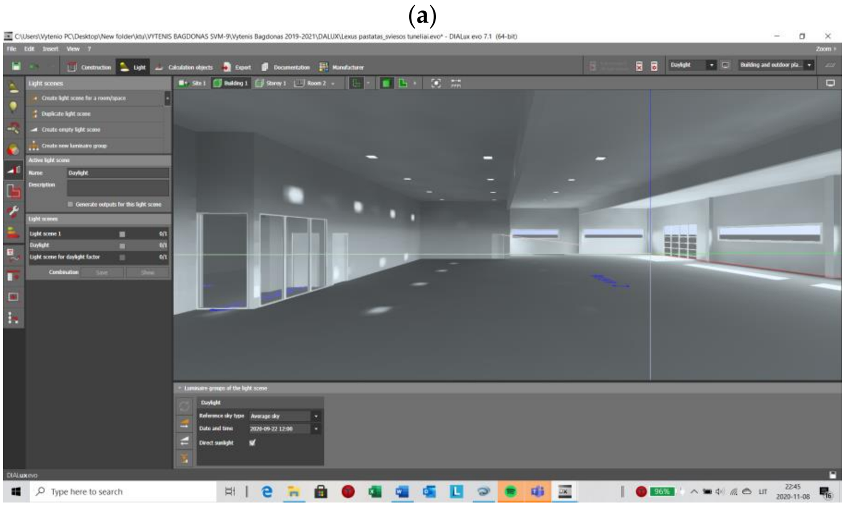
The Date and Time of Natural Light Calculation		The Amount of Natural Light in the Service Workshop, Illuminance (lx)								
		Skylight Domes (A_1)			Longitudinal Skylights (A_2)			Tubular Skylight (A_3)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
20 March 2020	06:00	0	0	0	0	0	0	0	0	0
	07:00	5	110	23	5	111	19	3	110	14
	08:00	32	1083	183	32	1078	163	20	1067	134
	09:00	85	3587	484	74	3562	435	47	3551	364
	10:00	144	6726	822	123	6719	731	77	6644	615
	11:00	188	9448	1094	157	9472	965	111	9366	815
	12:00	211	11,064	1264	173	11,061	1085	132	10,989	911
	13:00	201	11,302	1275	171	11,296	1116	145	11,226	935
	14:00	198	10,118	1174	161	10,139	1035	140	10,034	874
	15:00	161	7752	1022	135	7794	922	117	7707	787
	16:00	107	4746	757	113	4768	693	86	4723	616
	17:00	56	1936	415	53	1939	386	43	1920	347
	18:00	13	257	84	14	257	75	8	254	63
	19:00	0	0	0	0	0	0	0	0	0
	20:00	0	0	0	0	0	0	0	0	0
	21:00	0	0	0	0	0	0	0	0	0
	22:00	0	0	0	0	0	0	0	0	0
22 September 2020	06:00	0	0	0	0	0	0	0	0	0
	07:00	0	0	0	0	0	0	0	0	0
	08:00	11	238	49	10	238	42	6	235	32
	09:00	45	1716	264	45	1706	236	19	1684	196
	10:00	104	4508	588	91	4504	524	55	4457	442
	11:00	160	7702	921	135	7699	815	88	7611	683
	12:00	198	10,185	1164	169	10,195	1019	117	10,082	858
	13:00	208	11,442	1283	177	11,467	1115	138	11,406	933
	14:00	218	11,344	1281	175	11,355	1121	142	11,281	933
	15:00	186	9860	1140	168	9847	1013	136	9756	854
	16:00	159	7247	979	142	7259	891	115	7189	759

Table 17. *Cont.*

The Date and Time of Natural Light Calculation	The Amount of Natural Light in the Service Workshop, Illuminance (lx)								
	Skylight Domes (A_1)			Longitudinal Skylights (A_2)			Tubular Skylight (A_3)		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
17:00	99	4164	698	99	4157	643	79	4143	571
18:00	47	1499	352	47	1501	326	39	1484	293
19:00	9	175	49	9	174	43	7	169	34
20:00	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0

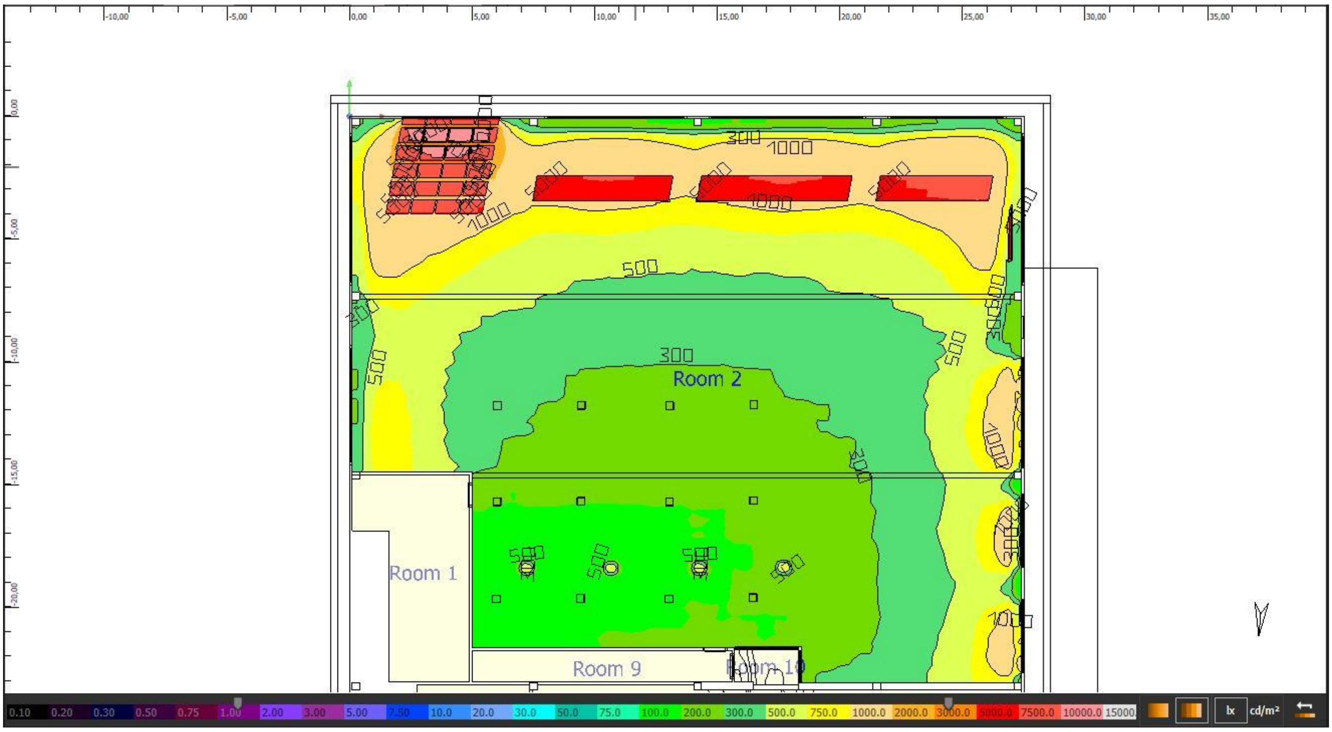


(**a**)



(**b**)

Figure 6. *Cont.*



(**c**)

Figure 6. Design, calculation and visualisation of natural light in the service workshop: the layout of tubular skylights on the floorplan of the studied object (**a**); the model of the interior of the building with selected skylights (**b**); the Luxplot resulting from twelve tubular skylights of diameter 350 mm at 1:00 p.m. on 22 September 2020 (**c**).

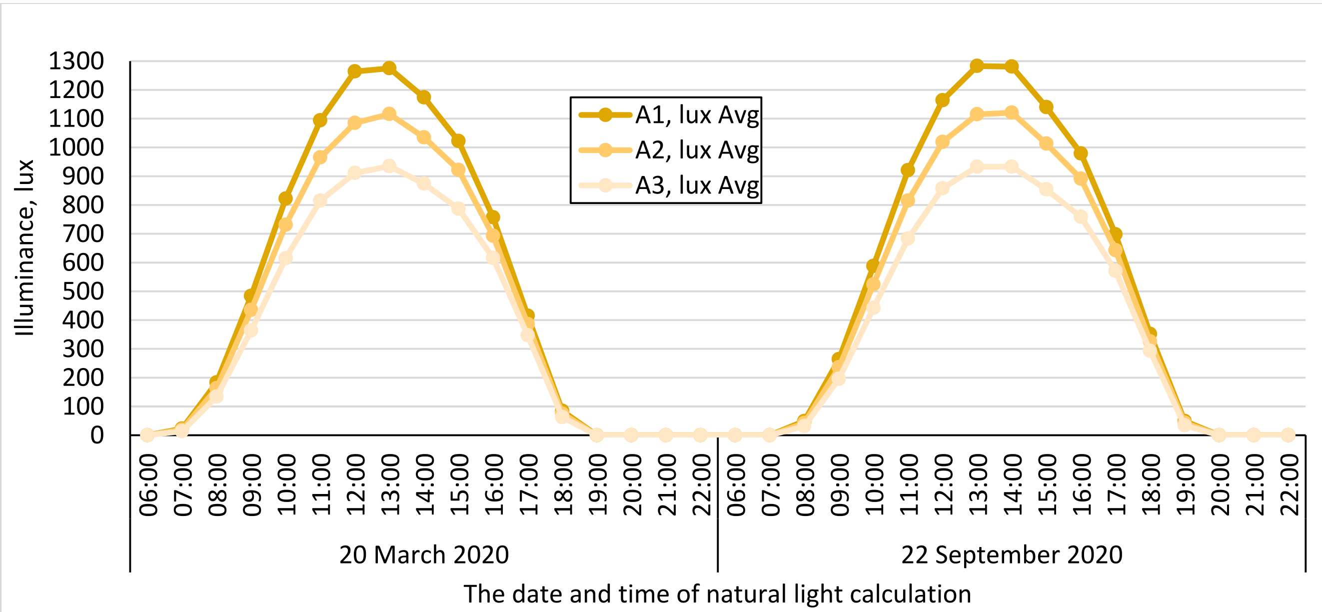


Figure 7. The comparison the average illuminance values.

The results of natural light calculation for skylight alternatives at the spring equinox on 20 March 2020 and at the autumn equinox on 22 September 2020 for the chosen building are presented in Table 17. The table data show the average distribution of illuminance every hour from 6:00 a.m. until 10:00 p.m. It illustrates the variation of illuminance in the service workshop from 7:00 a.m. (start of work) to 5:00 p.m. (end of work) when different skylight alternatives are used. At the spring equinox and the autumn equinox, the skylight domes (A_1) create the largest average illuminance compared to the longitudinal skylights and tubular skylights.

The comparison of illuminance, light transmission and U values of skylight alternatives (Table 3) showed that the skylight dome (A_1) was the best solution for the daylighting system for the selected building roof.

3.2. The Priority Order and Criteria Importance According to the Survey

First of all, the importance of the rating criteria was determined, and the priority order of criteria was obtained through the survey questionnaire (Table 18). As the questions were abstract, the employees having different positions in a company were asked to fill in the questionnaire (Section 2.4). In total, only 16 respondents participated in the survey that was sent out to experts working in skylight business. Seven respondents represented skylight manufacturers; they were specialists whose job was directly related with the products analysed. Nine respondents were architects and project managers. The experts ranked the criteria by importance basing on their experience and the most common cases in their work practice. Project managers usually select and specify the technical characteristics of products in the technical specifications of a building design.

Table 18. Priority order of criteria by importance.

No.	Evaluation Criteria	Optimisation Direction of Criteria		Total Amount of Points by the Survey	Importance of Criteria by the Survey	Priority Order by the Survey
		Min	Max			
1.	K_1, Skylight cost, (EUR/m^2)	×		132	0.1566	2
2.	K_2, Installation cost, (EUR/m^2)	×		108	0.1281	7
3.	K_3, Light transmission, %		×	112	0.1329	6
4.	K_4, Heat transfer coefficient, U value (W/m^{2}K)	×		143	0.1696	1
5.	K_5, Amount of natural light in the test object, (lux)		×	122	0.1447	3
6.	K_6, Warranty period granted, months		×	113	0.1340	4–5
7.	K_7, Fire performance class of glazing materials		×	113	0.1340	4–5
	Total sum:					

The expert evaluation of the criteria showed that the heat transfer coefficient (W/m^{2}K) was the most important criterion (16.96%) followed by the skylight price (EUR/m^2) (15.66%), the second most important criterion. The remaining criteria lined up as follows: the amount of natural light in the tested object (14.47%), the warranty period granted (13.40%), the fire performance class of glazing materials (13.40%) and the light transmission (13.29%). The installation cost criterion was the least important (12.81%). According to the survey, the order of criteria ranking was as follows: $K_4 > K_1 > K_5 > K_{6–7} > K_3 > K_2$. It is also seen that the importance of rating criteria varied in quite a similar range, i.e., in the range from 16.96 to 12.81%. Given to the fact that the survey involved only 16 experts and to avoid the reliance on the subjective opinion of the experts only, the importance of the rating criteria was additionally evaluated using the Entropy Method, where reliance is placed not only on the objective importance of the evaluation criteria but also on the theoretical and complex importance of the evaluation criteria.

3.3. Theoretical and Complex Importance of the Evaluation Criteria According to the Entropy Method

The Entropy Method was applied using the theoretical importance of the evaluation criteria, which was determined referring to the chosen rating criteria and the subjective opinion of the authors of this study, and the complex importance of the evaluation criteria, which was determined basing on the opinion of experts participating in the survey and the theoretical importance. The initial Matrix P of alternative solutions with criteria optima (Max or Min) is presented in Table 19.

Table 19. The initial Matrix *P* of alternative solutions.

Options \ Criteria	K_1	K_2	K_3	K_4	K_5	K_6	K_n
A_1	234.6	35.5	71	1.4	1283	24	1
A_2	361.2	64.3	34	1.3	1115	24	5
A_3	4453.1	955.8	54	2.6	933	24	1
Sum	5048.9	1055.6	159	5.3	3331	72	7
Optimisation direction	Min	Min	Max	Min	Max	Max	Max

According to the methodology described in Section 2.5, the theoretical and complex importance of criteria (Table 20) was calculated. In addition, the priority order of criteria by Entropy Method was obtained.

Table 20. The theoretical and complex importance of criteria.

Entropy \ Criteria	K_1	K_2	K_3	K_4	K_5	K_6	K_n
$q_{j(t)(\text{theoretical})}$	0.3676	0.4054	0.0235	0.0296	0.0047	0.0000	0.1692
Priority order	2	1	3	4	6	7	5
$q_{j0(\text{complex})}$	0.4082	0.3684	0.0221	0.0356	0.0048	0.000	0.1609
Priority order	1	2	4	3	6	7	5

The importance of the evaluation criteria determined in the study by different methods (by the survey and Entropy Method) is presented in Figure 8. This figure illustrates that the importance of criteria obtained by the survey differs from the importance of criteria obtained by the Entropy Method.

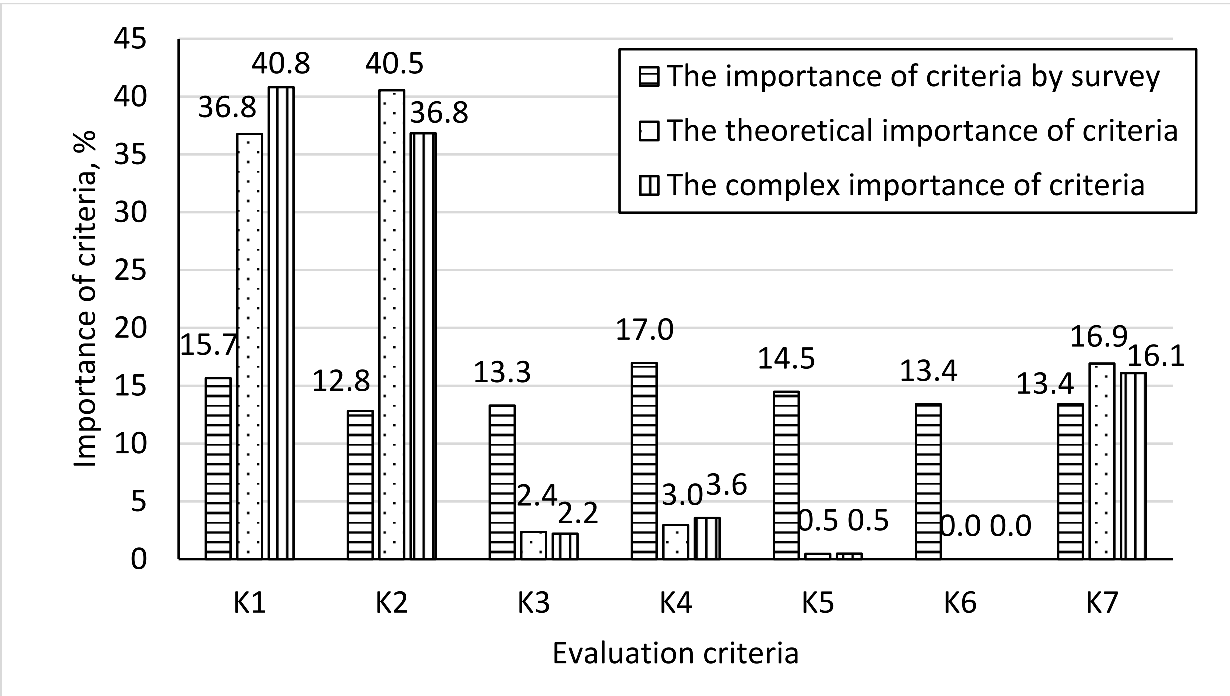


Figure 8. The importance of the evaluation criteria obtained by different methods.

Figure 8 reveals that the importance of the rating criteria obtained in the survey varied in a quite a similar range, i.e., in the range from 16.96 to 12.81%, and the order of the ranking criteria was as follows: $K_4 > K_1 > K_5 > K_{6–7} > K_3 > K_2$. The experts gave the highest importance to criterion K_4, i.e., the heat transfer coefficient (W/m^2K). The values of the theoretical importance of the criteria calculated by the Entropy Method gave the following order of the ranking criteria: $K_2 > K_1 > K_7 > K_4 > K_3 > K_5 > K_6$. In contrast, for the complex importance of the evaluation criteria, the order of the ranking criteria was as follows: $K_1 > K_2 > K_7 > K_4 > K_3 > K_5 > K_6$. It is seen that there are changes only in the order of importance between two criterions, namely K_1—skylight price (EUR/m^2) and K_2—installation cost (EUR/m^2). According to the chosen rating criteria and the subjective opinion of the authors of this study, the criterion K_2—installation cost (EUR/m^2) has the highest theoretical importance. The obtained value was 40.6%. While the complex importance of the evaluation criteria was based on the experts' opinions and the theoretical importance, the criterion K_1—skylight price (EUR/m^2) received the highest importance. The obtained value was 40.9%. In both cases, the criteria K_1—skylight price (EUR/m^2) and K_2—installation cost (EUR/m^2) had the highest importance. It can be concluded that the main criteria for choosing the roof daylighting systems were as follows: K_1—skylight price (EUR/m^2), K_2—installation cost (EUR/m^2) and K_4—heat transfer coefficient (W/m^2K).

3.4. The Rational Option of Comparing Alternatives According to the TOPSIS Method

The rational option of the compared alternatives was found by employing the TOPSIS method. The initial Matrix *M* of alternative solutions with criteria optima (Max or Min) and the best value (*x*j*) are presented in Table 21.

Table 21. The initial Matrix *M* of alternative solutions.

Criteria / Options	K_1	K_2	K_3	K_4	K_5	K_6	K_n
A_1	234.6	35.5	71	1.4	1283	24	1
A_2	361.2	64.3	34	1.3	1115	24	5
A_3	4453.1	955.8	54	2.6	933	24	1
$\sqrt{\sum_{i=1}^{m} x_{ij}^2}$	4473.88	958.62	95.46	3.23	1939.02	41.57	5.20
Optimisation direction	Min	Min	Max	Min	Max	Max	Max
Importance of complex criteria *Cq*, %	40.86	36.87	2.22	3.57	0.38	0.00	16.10
Importance of theoretical criteria *Tq*, %	36.79	40.58	2.35	2.96	0.37	0.00	16.94

According to the methodology described in Section 2.6, the most rational type of skylight chosen as the daylighting system in the studied building was determined. The comparison of the performance values of skylight alternatives is presented in Figure 9. It is obvious that the rational option of the three alternative solutions ($A_1 \div A_3$), analysed according to seven evaluation criteria ($K_1 \div K_7$), was alternative A_1, i.e., the skylight dome (SOLIDM 3 Skin). In both cases when the alternative solutions were compared using the theoretical and complex importance of evaluation criteria, the most rational type of skylight chosen as the daylighting system in the studied building utilizing the TOPSIS method was the same alternative A_1, namely the skylight dome. The obtained performance values were 100% and 99,5%, respectively. According to the calculated performance values, the second place belongs to alternative A_2, the longitudinal skylight (KINGSPAN ESSMANN), and the third place belongs to alternative A_3, the tubular skylight (VELUX TCR-014).

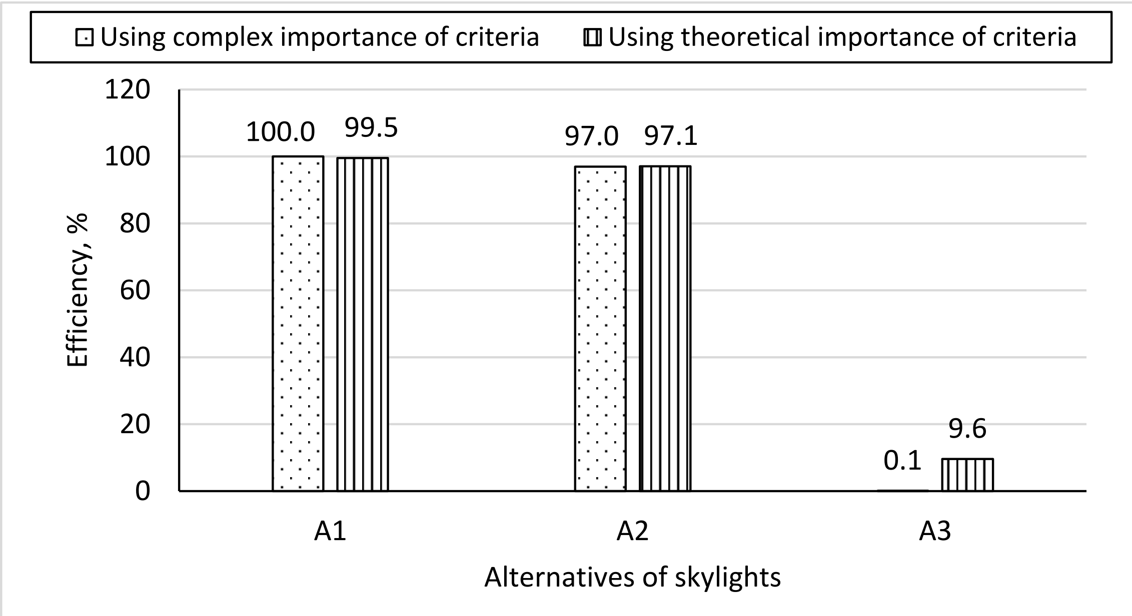


Figure 9. The comparison of performance values of skylights alternatives.

It should be noted that the performance of the second alternative A_2, the longitudinal skylight, was efficient, and, according to the multi-criteria assessment, this alternative is just a slightly worse daylighting system solution for the building tested than alternative A_1.

The view of the as-built non-residential building that was selected for the study is presented in Figure 10. It can be seen that twelve skylight domes of 1400 × 1400 mm dimensions are installed on the flat roof. The dome skylight was the most rational type of skylight chosen as the daylighting system in the studied building using the TOPSIS method.

Figure 10. The view of the as-built auto repair shop. The photo was taken using the Google maps tool on 6 June 2022.

In the future, extra evaluation criteria relating to skylights' thermal bridge and criteria that may support the reduction of the environmental footprint could be included in the proposed evaluation algorithm when comparing the types of skylights.

4. Conclusions

The selection of skylights in a building is solved through the research proposed in the study, which delivers the performance-rating criteria of the skylights compared and reveals the effective solutions of skylights. The survey questionnaire was used to obtain the priority order of evaluation criteria based on the respondents' answers to questions. The theoretical and complex importance of the chosen rating criteria was also determined using the Entropy Method. The rational option from the alternative solutions analysed according to the chosen rating criteria was determined using the TOPSIS method. The following main conclusions were drawn from the results of this study:

1. The results of natural light modelling and calculation for the chosen building show that the selected skylight domes with light transmission of 71% create the largest average illuminance of 1647 lx compared to longitudinal skylights and tubular skylights. The smallest average illuminance of 1240 lx was obtained using the tubular skylights with light transmission of 54%. The second result of average illuminance of 1452 lx was obtained using longitudinal skylights with light transmission of 28%. Comparing not only the values of illuminance but also the values of light transmission and U values of skylight alternatives, the skylight dome was the best solution for the daylighting system for the selected building roof. The illuminance was calculated referring to the light transmission of dome glazing material of skylight alternatives.
2. The expert evaluation of the criteria showed that the heat transfer coefficient (W/m^2K) with the value of 16.96% was the most important criterion and the skylight price (EUR/m^2) with the value of 15.66% was the second criterion by importance. The remaining criteria lined up as follows: the amount of natural light in the tested object (14.47%), the warranty period granted (13.40%), the fire performance class of glazing materials (13.40%), and the light transmission (13.29%). The installation cost (12.81%) received the lowest value. According to the survey, the criteria were ranked in the order of importance as follows: $K_4 > K_1 > K_5 > K_{6–7} > K_3 > K_2$.
3. According to the chosen rating criteria and the subjective opinion of the authors of this study, the installation cost (EUR/m^2) criterion K_2 received the highest theoretical importance value of 40.6%. In contrast, the complex importance of the evaluation criteria was based on the opinion of experts participating in the survey and the theoretical importance; thus, the skylight price (EUR/m^2) criterion K_1 received the highest importance value of 40.9%. In both cases, the criteria K_1 and K_2 had the highest importance determined by Entropy Method.
4. In both cases, when alternative solutions were compared using theoretical and complex importance of the evaluation criteria, the same alternative A_1, i.e., the skylight dome, was the most rational type of skylight chosen as the daylighting system for the studied building by means of the TOPSIS method. In accordance with the performance values, the second place belonged to alternative A_2, the longitudinal skylight, and the third place belonged to alternative A_3, the tubular skylight.

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