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Glare Reduction of the Artificial Lighting System Using the Digital Software Solution

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***Abstract* – Artificial lighting systems are an integral part of production halls. These systems are typically used to supplement daylight, although in some cases they are the sole source of lighting in the workplace. Every artificial lighting system is accompanied by an unfavourable phenomenon: glare. This phenomenon is one of the main factors affecting the quantitative parameters of internal lighting systems. Glare needs to be reduced in each production area to ensure visual well-being, which is linked to the visual performance of employees and consequently affects the efficiency and productivity of production. Obtaining information about glare in a real system is a difficult and lengthy process. However, digital software tools can be used in a simulated environment to predict and reduce glare. This article addresses the issue of reducing glare in artificial lighting systems using a digital software solution. The introduction discusses the theoretical aspects of glare caused by artificial lighting systems. This is followed by a practical example using the simulation method with the Dialux Evo tool to reduce glare in the workplace. The conclusion of the article provides an analysis of the results achieved and offers recommendations for practical implementation.**

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1. Introduction

Glare, as one of the main quantitative parameters of lighting systems, creates visual discomfort in the workplace, affecting the quality of work, and its safety. The need to eliminate visual discomfort is associated with ensuring well-being in the workplace, which impacts the overall efficiency and productivity of production [1], [2]. In the design of lighting systems in production, there are principles, through which appropriate lighting system can be created [3], [4]. Neglecting these principles subsequently leads to the creation of a lighting system that affects the performance of workers with an overall impact on the business outcomes [5]. The issue of glare is addressed by numerous researchers and companies developing lighting fixtures with the goal of continuously reducing this parameter. Based on the investigation of the issue of glare, its degree of effect, nature, and distribution of dazzling brightness, as well as the tracing of lighting, glare is categorized in the following groups [6].

Glare can be categorized according to the degree of effect as follows [7]:

- Distracting glare, which disturbs visual comfort without apparently worsening or limiting vision. It arises because the dazzling source captures attention at the expense of the location on which the vision should focus. Attention is scattered.
- Disabling glare, a higher degree of glare, makes recognition difficult, and vision becomes strained. It creates a feeling of uncertainty and fatigue.
- Blinding glare, which makes vision impossible sometimes even after the cause of the glare has ceased. In many cases (especially in transport), such a state is very dangerous.

Glare can be categorized according to the nature and distribution of dazzling brightness as follows [8]:

- Absolute (by critical brightness) - occurs when the brightness in the visual field is so great that the eye is unable to adapt to it. At night, when the sensitivity of the eye is significantly increased due to prolonged adaptation, even lower brightness levels can have the same effect.
- Relative (by contrast) - occurs if areas with very different brightness levels are simultaneously present in the visual field. These can be surfaces that are differently lit, or lighting fixtures (or unshielded light sources) contrasting with a dark background (environment). Visual comfort is already compromised under some conditions when the brightness ratio is 1:10 and glare begins if the brightness ratio in the visual field exceeds about 1:100.
- Transitional - occurs with a sudden change in brightness of the visual field because the eye adapts to the change with a delay. This happens when transitioning from a dark environment to a bright one or when lighting is turned on. Visual comfort is disturbed if the change in brightness in the visual field exceeds a ratio of 1:10, and glare occurs when the brightness change ratio is 1:100. Transitional glare fades independently due to the eye's adaptation. It is problematic where the brightness of the visual field changes significantly.
- Veiling glare - occurs if a brighter environment (cloudy or with a relatively fine structure), such as a curtain, dirty glass, rain, or fog, is between the eye and the observed object. The greater brightness of the veil forces the eye to adapt to a higher level than is appropriate for the background brightness, thereby reducing the recognizability of shapes and contrast.

Based on the tracing of glare, categorization is as follows [9]:

- Direct - caused by excessive brightness or light contrast from the source in the visual field. To prevent glare with artificial lighting, direct light from the source mustn't come to the eye at an angle less than 30° above the horizontal plane or above the usual direction of view. Therefore, fixtures are hung sufficiently high or suitably adjusted fixtures are used. It is also necessary to prevent glare from task lighting and possible glare from windows in combined lighting systems.
- By reflection - arises from reflections off ceilings, walls, from tabletops, or other surfaces in the visual field. High brightness can occur especially if the surfaces are smooth or mirror-like glossy. Brightness caused by light reflection often tires more than direct brightness, especially if it is directly in view and the eye cannot avoid it. Corrections can be achieved by appropriate placement and direction of lighting fixtures.

Glare, as a primary parameter of the lighting system, can be quantified through objective evaluation systems that were introduced over the last century. The quantification options are presented in the following section of the article.

2. Material and Methods

In the 90´s, the Unified Glare Rating (UGR) method was introduced for the assessment of glare in indoor workspaces. This method replaced the glare assessment method in the United Kingdom and the Söllner boundary luminance curves method in Germany [10]. The evaluation of glare according to the UGR method is based on a relationship that is founded on the effect of glare from light sources in terms of their average luminance, position, and distribution towards the assessed area. The method also takes into account the sensitivity of the eye with respect to the luminance of the background. The mathematical expression is as follows [11]:

$$UGR = 8 \cdot log_{10}\left[\frac{0{,}25}{L_b} \cdot \sum \frac{L_S^2 \cdot \Omega}{P^2}\right] \qquad (1)$$

With following characteristics of parameters:

- L_b - background luminance in cd/m², calculated from Eind/π with Eind as vertical indirect illumination at the observer's eye.
- L - average luminance in cd/m² of the light emitting surface of each luminaire in the direction of the observer's eye.
- ω - solid angle in steradiant (sr) of the light emitting surface of each luminaire relative to the observer's eye.
- p - postion index by Guth for each luminaire, depending on their spatial deviation from the main line of sight.

The glare parameter identified by the UGR method is represented by a dimensionless numerical expression, where a higher UGR value indicates a greater degree of exposure to glare from the indoor lighting system. The position of the observer's eyes is considered in relation to the center of the light-emitting part of the fixture, not its edge, as is the case with some other systems used for glare evaluation (Fig. 1) [12].

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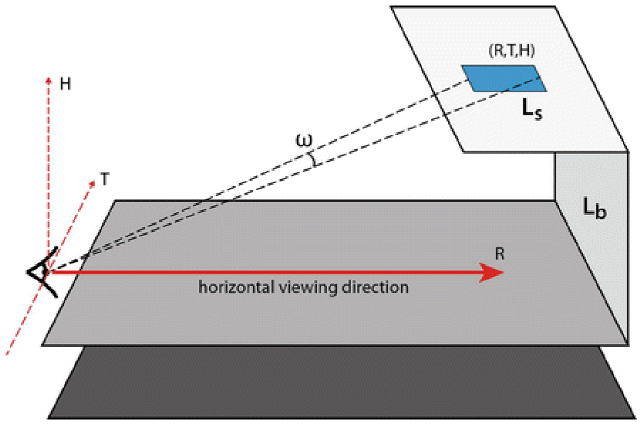

Figure 1. Graphical interpretation of glare [12]

Currently, there are several tools on the market for digitization and realization of simulations, for fulfilling the concept of Industry 4.0 in every area, including lighting design [13], [14]. The mentioned relationship is utilized for glare identification also within the Dialux Evo program, which is used to reduce glare in a model study described in the following section of the article. The software automatically generates the UGR value for light sources with direct emission of light (Fig. 2).

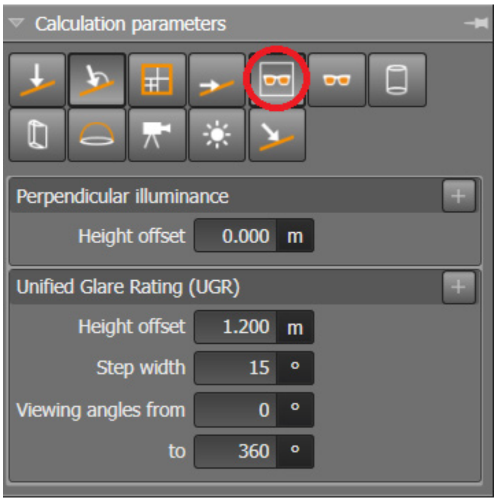

Figure 2. Basic settings panel for determining glare

3. Glare Reduction via Digital Software Solution

In the Dialux Evo program, used for designing all kinds of lighting, a model of an assembly room was created (Fig. 3) where glare from the artificial lighting system was subsequently analyzed. The assembly room is located on the ground floor of a manufacturing hall and was designed as an interior room of the building, a former warehouse without the possibility of introducing a daylight lighting system.

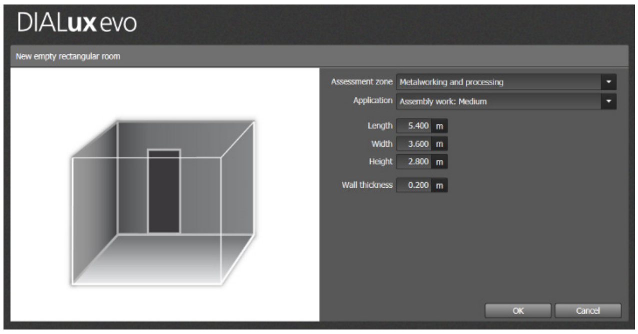

Figure 3. Defining the room characteristic for model solution

The assembly room contains three assembly workstations for standard assembly tasks performed in the mechanical engineering industry, two cabinets, and a hanging rack for storing necessary tools (Fig. 4). The layout of objects in the assembly room is illustrated in the following figure.

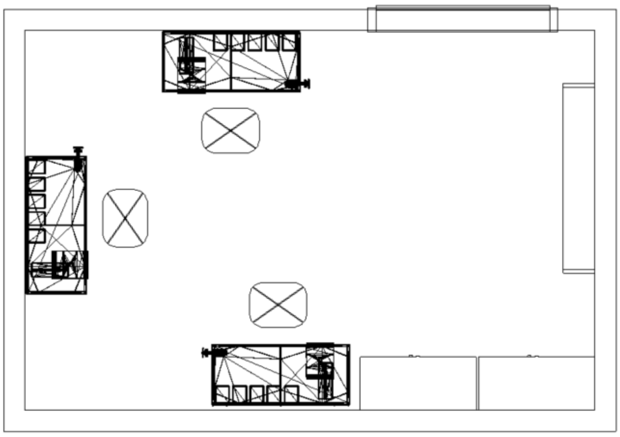

Figure 4. Layout of assembly room

Within this room, models of the lighting system were designed. The basic specification of alternative lighting systems is given in the following table. The difference between alternatives lies in defining different mounting heights of the fixtures due to the study of the impact of the fixture's placement above the level of the visual task and the resulting glare. To ensure the correctness of the solution, the same room condition with the same lighting system and the same luminance curve is modeled, however, identified at different mounting heights. The reference mounting height of the selected fixture is 2300 mm, which was considered as an input data and marked as Alternative 1. Subsequently, two alternatives were created, through which the mounting height was adjusted by 50 mm in both vertical directions.

Table 1. Specification of alternatives

	Alternative No. 1	Alternative No. 2	Alternative No. 3
Lighting number	2	2	2
Lamp power	75 W	75 W	75 W
Total flux	14 000 lm	14 000 lm	14 000 lm
CCT	4 000 K	4 000 K	4 000 K
CRI	80	80	80
Mounting hight	2 300 mm	2 250 mm	2 350 mm

Simulation methods were implemented in the model solutions using the Dialux Evo software tool.

The results obtained from the simulations were recorded in a table and, in the first step, compared with normative requirements.

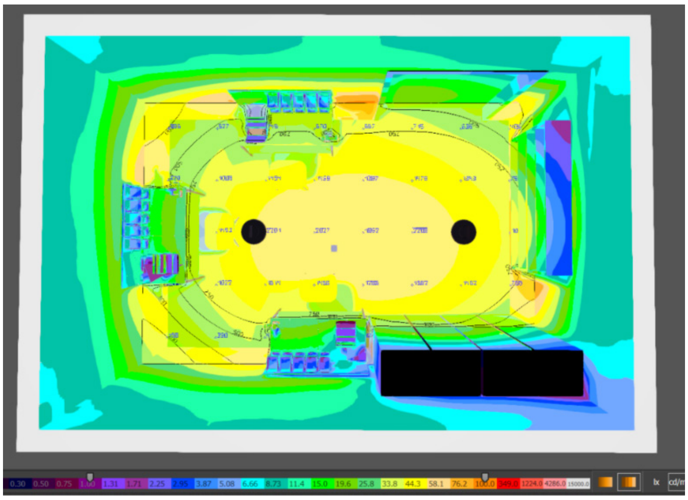

Figure 5. Graphical interpretation of glare – the first alternative

Within each alternative, the lighting intensity was monitored as the main parameter for ensuring visual well-being in the workplace, along with the UGR parameter for glare. In the first alternative, with a mounting height of 2,300 mm, all values of lighting intensity were satisfactory at all three monitored locations (Fig. 5). However, glare, graphically interpreted in the previous image, showed above-limit values at the first workplace. The UGR grid layout in the first alternative (Fig. 6) recorded the strongest brightness (glare) at 270°, with a value of almost 27.

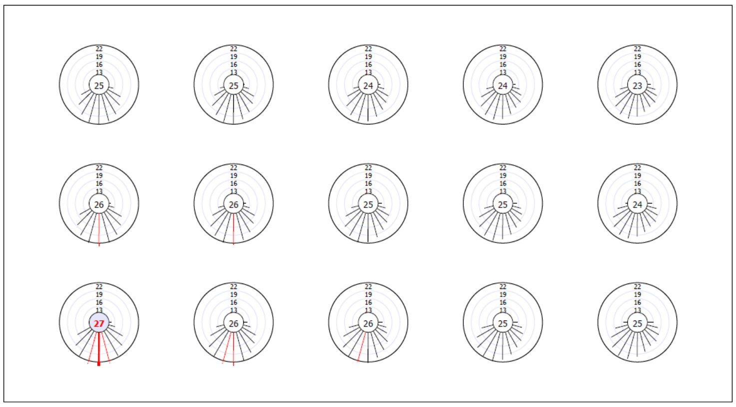

Figure 6. UGR Grid – the first alternative

As part of the second alternative, where an assembly height of 2,250 mm was defined, at each of the monitored assembly workplaces in the place of the visual task, the values of the lighting intensity and the UGR glare values were within the prescribed normative requirements.

The distribution of brightness at workplaces can also be observed through the graphic output (Fig. 7) where no excessive brightness was recorded in this interpretation.

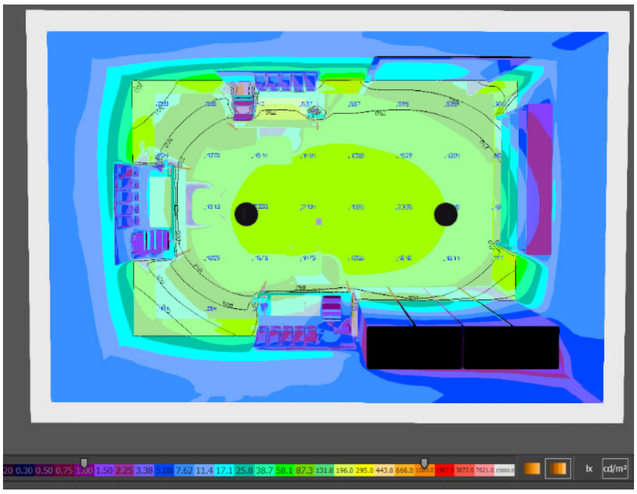

Figure 7. Graphical interpretation of glare – the second alternative

The third alternative, where the mounting height of the lamps was dimensioned to a value of 2,350 mm, presented satisfactory requirements for the lighting intensity at each of the monitored workplaces. However, based on the calculation and distribution of brightness (Fig. 8), above-limit UGR values were identified.

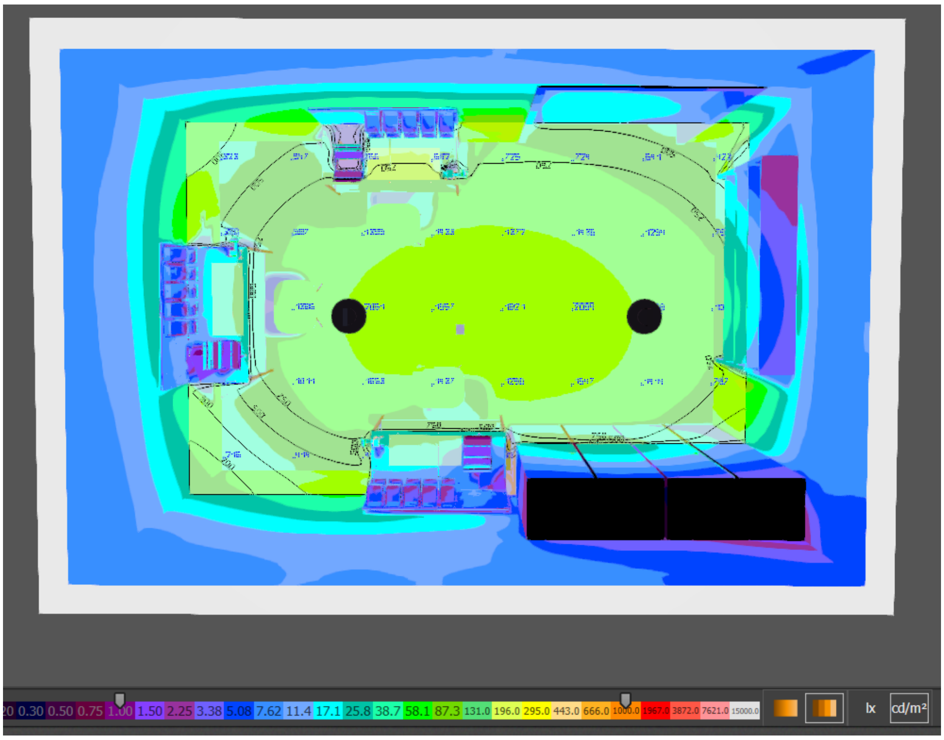

Figure 8. Graphical interpretation of glare – the third alternative

As in the case of the first alternative, the UGR values were recorded and limited to 270°. At this point (Fig. 9), a value of UGR exceedingly almost 4 above the permitted limit, i.e. 29, was identified.

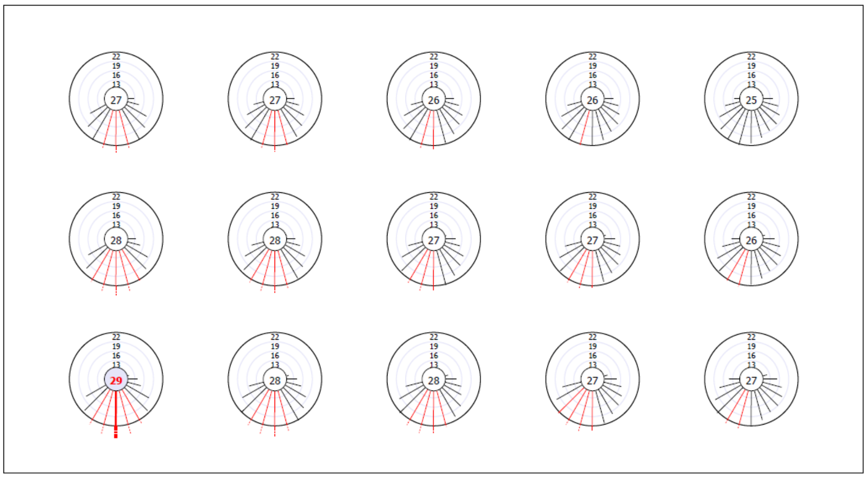

Figure 9. UGR Grid – the third alternative

The following table summarizes all the results obtained during the implementation of the simulation for all alternatives for better clarity.

Table 2. Comparison of obtained results with normative requirements

		E		
		Simulation	STN 12 464-1	Result
Alternative No. 1	Workplace 1	732	500	Acceptable
	Workplace 2	630		Acceptable
	Workplace 3	560		Acceptable
Alternative No. 2	Workplace 1	722	500	Acceptable
	Workplace 2	618		Acceptable
	Workplace 3	528		Acceptable
Alternative No. 3	Workplace 1	740	500	Acceptable
	Workplace 2	636		Acceptable
	Workplace 2	587		Acceptable
		UGR		
		Simulation	STN 12 464-1	Result
Alternative No. 1	Workplace 1	26.9	< 25	Not acceptable
	Workplace 2	19.7		Acceptable
	Workplace 3	15.3		Acceptable
Alternative No. 2	Workplace 1	23.4	< 25	Acceptable
	Workplace 2	<10		Acceptable
	Workplace 3	<10		Acceptable
Alternative No. 3	Workplace 1	28.7	< 25	Not Acceptable
	Workplace 2	23.3		Acceptable
	Workplace 2	18.4		Acceptable

Based on the above-mentioned table, it can be concluded that when assessing the intensity of lighting against normative requirements, all values were satisfactory. For a clearer illustration of the assessment of glare in the various alternatives, a graphical interpretation of the results has also been created (Fig. 10).

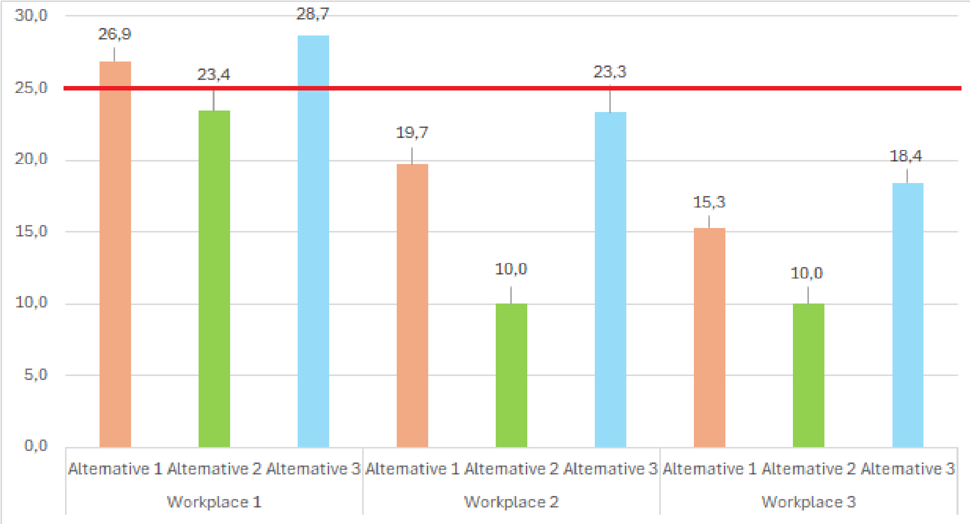

Figure 10. UGR values obtained from simulation

From the results of the simulations, it is clear that only alternative No. 2, in which the mounting height of the fixture was 2250 mm, conforms to the normative requirements. The glare values in this alternative significantly decreased.

4. Conclusion

In the design of lighting systems in manufacturing spaces, it is essential to pay attention to all quantitative attributes, including the phenomenon of glare, which negatively affects not only the employees and their well-being and safety but also the overall efficiency and productivity of production. The discussed article was dedicated to the issue of glare reduction in the artificial lighting system using a digital software solution. In three alternatives involving changes in the mounting height of the fixtures proposed for the assembly room, UGR levels were identified that adversely affect workers. From the conducted simulations, it was concluded that, for the given type of fixture with direct orientation, the final glare value is influenced not only by the surface finish of objects, the distribution of light flux, but also by the mounting height of the fixture. Changing the mounting height of the fixture by 50 mm resulted in a significant reduction in the UGR parameter, down to values below 10. Based on the research presented, future studies could verify the observed dependency for other types of lighting systems, incorporating multiple quantitative lighting parameters.

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