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STUDIES OF APPLICATION OF LED-BASED LIGHTING DEVICES IN A CAR ASSEMBLY SHOP

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ABSTRACT

The article describes the problem of replacement of active fluorescent lamp lighting installations of an assembly line of a car assembly plant with LED LDs including a comparison of the gained lighting and economic indicators. Therefore, several LED-based LDs by different manufacturers were selected. Based on LI computer modelling using *DIALux Evo*, an optimal option in terms of light engineering and economy was found. Lighting characteristics of the active LI and areas of the assembly line with the application of LED-based LDs were determined experimentally. The results of the study allow assessing relevant changing of visual performance of shop workers and to compare the pay-off periods of LED and fluorescent lamps-based lighting devices.

Keywords: industrial lighting, LED, lighting installation, lighting, assembly line, lighting quality

1. INTRODUCTION

Due to increasing application of LED-based lighting devices (LD), recently the number of publications related to LED-based LDs lighting of, in particular, industrial premises has been increasing (see, for instance, [1, 2]). In the meantime, it should be noted that:

- The main aspect of shop lighting design is consideration of not only quantitative but also qualitative characteristics of lighting installations (LI) such as visual discomfort indicators and flicker index;
- The transfer to LEDs requires correct solutions related to optics, *IP*, and luminous efficacy of a LED-based LD.

It is also known that:

- In many industries, there are assembly shops where intermediate or final assembly of products is performed; the working process in them is associated with both small parts (assembly of domestic appliances, soldering of electronic components, etc.) and large parts (assembly of car body elements, installation of large units of industrial machines/installations, etc.) operation, which, in return, require different approaches to design of lighting in such premises;
- The artificial lighting conditions in an industrial facility are extremely important since they largely affect the workers' health and quality of manufactured products [3]; differentiation of items against a particular background, light perception, and visual comfort of workers depend on characteristics of LI;
- Light is a natural condition of a human life and activities, which plays an important role in health preservation and high working capacity. Human visual performance is the main source of information about the world.

This study comprises LED-based LDs application capabilities analysis for the lighting of car assembly lines with consideration of enhancement importance of visual performance conditions and increase of labour productivity.

The studied object was an active car assembly line (located in the Russian Federation), and the subject of the study was local lighting along it.

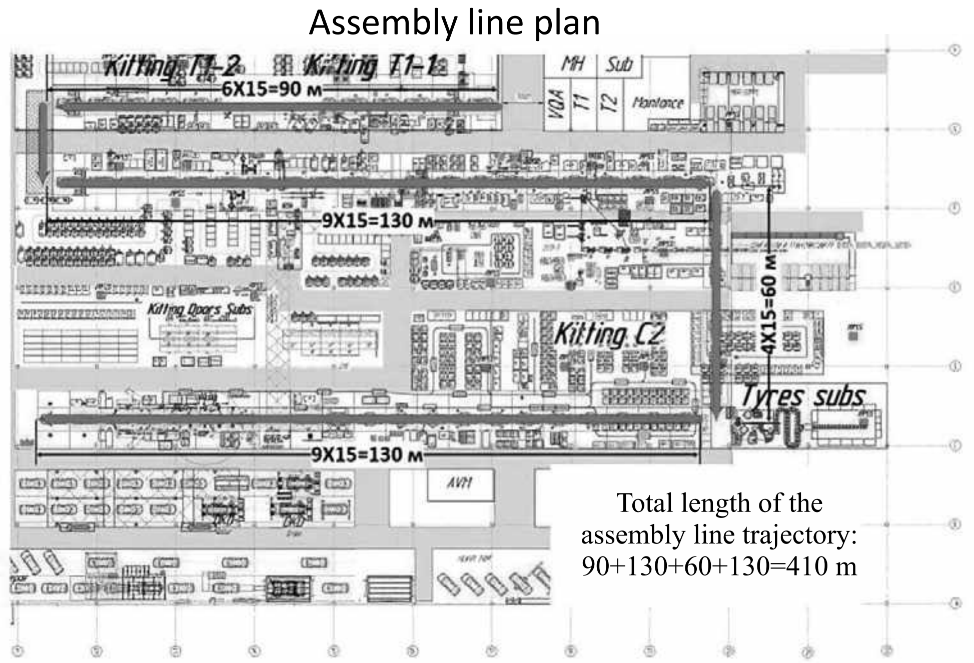


Fig. 1 Assembly line plan

Development of the optimal lighting (for this line) with the application of LED-based LDs instead of the active ones was considered the practical relevance of the study.

In addition, several variants of LI fitting for car production were studied; for the avoidance of mistakes, the distinctions of workplaces, the reflectance of the floor, the walls, and the ceiling, etc. were taken into account in the course of development of the computer model (see below).

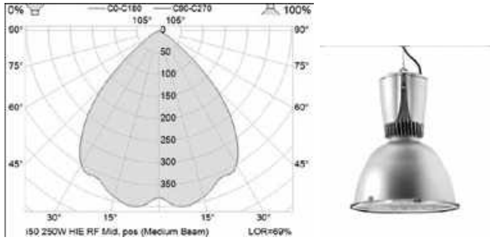
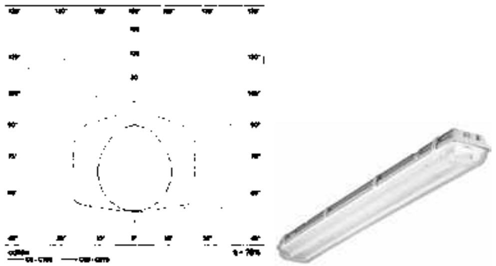
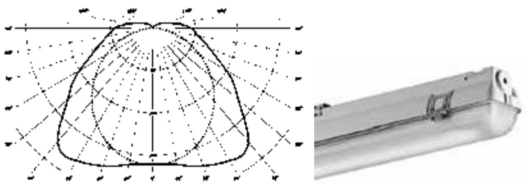
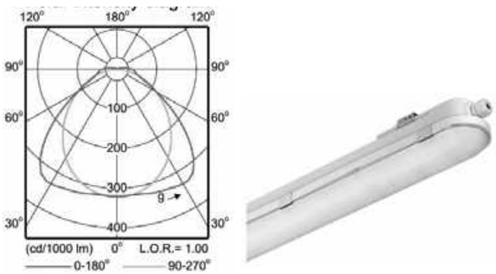
2. LI COMPUTER MODELLING AND ECONOMIC CALCULATION

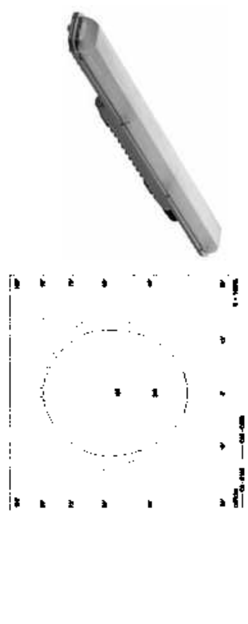
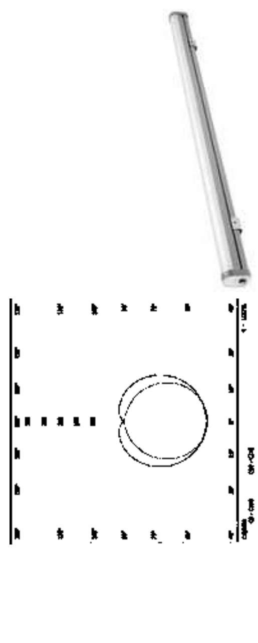
The study object is located on the first floor of the building. The height of the ceiling with the ambient illumination LDs (luminaires) installed on it is 10 m, the height between the floor and the girder is 8 m. The height of the local illumination LI is 3.5 m. The total area of the illuminated premises is 39,600 m^2 and the total length of the line is 420 m. The plan of the illuminated assembly shop and its photos are presented in Figs. 1 and 2. There are no windows in the premises, and it is used for permanent human presence. The finishing of the premises complies with its designation and the values of reflectance of the ceiling, the walls, and the floor are approximately the same: 0.49. At both sides of the line, at the height of 3.5 m, the LIs for local illumination are installed. The active variant uses *Lighting Technology ARS254*-type fluorescent lamps (FL) (Fig. 2).

For lighting engineering calculations, *DIALux Evo* software was used since it is one of the most popular lighting design tools, among its advantages are: free license; good quality of images after model calculation (similar to the images after ray tracing); completely new calculation algorithm, which takes the correlated colour temperature T_{cc} of LD into account [4].

Fig. 2. Active LI of the assembly line

Table 1. Characteristics of LDs (Luminaires)

Type of LD	Luminous intensity distribution curve	Efficiency (%)	*P*, W	IP	Dimensions, mm	Note
Glamox i50		69	250	20	Diameter 222 Height 319 Weight 9 kg	Ambient illumination
Lighting Technologies ARS254		70	54	65	Width 100 Length 1280 Height 110 Weight 2.3 kg	Existing illumination of the line (Fl luminaires)
Osram Compact Monsun LED		92.5	38.8	65	Width 84 Length 1577 Height 102 Weight 2.7 kg	Variant No. 1
Philips Coreline Waterproof		97	29	65	Width 87 Length 1530 Height 96 Weight 1.8 kg	Variant No. 2

Type of LD	Luminous intensity distribution curve	Efficiency (%)	*P*, W	IP	Dimensions, mm	Note
Lighting Technologies SLICK. PRS LED		95	31	65	Width 96 Length 953 Height 86 Weight 2.6 kg	Variant No. 3
Philips GreenUp Waterproof		95	36	65	Width 90 Length 1400 Height 110 Weight 1.5 kg	Variant No. 4

In the course of LI modelling and illumination engineering analysis, the authors relied on the documents [5, 6].

Depending on the nature of production and location of workplaces, the local illumination may be established using two methods: 1) by means of individual LDs for each workplace; 2) for a group of closely located workplaces such as lines, streams, etc.

It is mandatory to consider ambient illumination for calculation of illuminance; otherwise, some indicators will become irrelevant. That is why the calculation of combined illumination of the assembly shop with existing ambient illumination LDs (LDs with 250W *Glamox i50* MHL) was conducted, and the LDs of local illumination LIs were varied. The ambient illumination was considered for the whole premises and combined illumination was used for the assembly line. There were 4 variants of LI with the following LED-based LDs selected for replacement of the existing LI with FL-based LDs: *Osram Compact Monsun LED*, *Philips Coreline Waterproof*, *Lighting Technologies SLICK. PRS LED*, and *Philips GreenUp Waterproof* (Table 1).

These variants were selected with consideration of economic efficiency, environmental conditions, and the customer's feedback.

In the course of modelling, the following parameters were estimated for all LI variants (the existing variant, the variant No. 1 (*Osram* LD), the variant No. 2 (*Philips* LD), the variant No. 3 (*Lighting Technologies* LD), and the variant No. 4 (*Philips* LD)):

- Horizontal and vertical illuminance (minimal, average, maximum) at the heights of 0.0 m and 1.8 m above the floor level;
- Unified glare rating *UGR* in the whole shop and at each point of the assembly line at the heights of 1.2 m and 1.7 m above the floor level;
- Illuminance uniformity U_o (in accordance with GOST [6]).

The results of these estimations are listed in Table 2, and the results of calculation of annual depreciation costs of the selected variants of LI/LD are listed in Table 3.

For the selection of the most efficient LI variant for the assembly line, the comparative analysis of annual expenditures for maintenance of all 5 variants of LI was performed. These expenditures are composed of the sum of annual depreciation costs of LI and annual cost of power consumed by the LI [7].

Table 2. Results

Parameters	Name of LD				
	Lighting Technologies **Existing variant**	***Osram Compact Monsun LED*** **Variant No. 1**	***Philips GreenUp Waterproof*** **Variant No. 2**	***Lighting Technologies SLICK.PRS LED*** **Variant No. 3**	***Philips GreenUp Waterproof*** **Variant No. 4**
E_m, lx (H-0.0)	503	504	508	508	503
E_m, lx (V-0.0)	352	343	347	336	310
E_m, lx (H-1.8)	510	519	514	510	508
E_m, lx (V-1.8)	355	366	335	341	336
U_o, on a horizontal plane (0.0 m)	0.93	0.93	0.92	0.90	0.89
U_o, on a vertical plane (0.0 m)	0.89	0.89	0.92	0.86	0.9
U_o, on a horizontal plane (1.8 m)	0.85	0.84	0.83	0.84	0.82
U_o, on a vertical plane (1.8 m)	0.72	0.88	0.62	0.87	0.65
UGR, the whole shop	21.7	22.1	21.7	21.0	22.3
UGR, on the assembly line (1.2 m)	More than 30	24.1	22.8	22.0	23.8
UGR, on the assembly line (1.7 m)	27.1	24.9	23.4	23.0	25.0
Number of LD in LI, pcs.	232	250	371	306	374

3. COMPARATIVE ANALYSIS OF LI WITH DIFFERENT TYPES OF LD

The values of the maintained average illuminance E_m and U_o of the existing variant of LI comply with the standard, and the *UGR* is significantly larger than the standardised one (Table 2). Apparently, ambient illumination is not used for this reason. In addition, Table 2 shows that:

- The values E_m and U_o of the variant with the LD *Osram Compact Monsun LED* (variant No. 1) comply with the standards, and the value of *UGR* complies neither in the shop nor on the line itself; however, these indicators are better than those of the existing variant of LI;
- The values E_m and U_o of the variant with the LD *Philips Coreline Waterproof* (variant No. 2) comply with the standards, and the value of *UGR* complies with the standard only in the shop; *UGR* does not comply with the standard on the assembly line, but its value is close to it at the height of 1.2 m;
- The values E_m and U_o of the variant with the LD *Lighting Technologies SLICK.PRS LED* (variant No. 3) comply with the standards, and the value of *UGR* complies with the standard just insignificantly exceeding it at the height of 1.7 m;
- The values E_m and U_o of the variant with the LD *Philips GreenUp Waterproof* (variant No. 4) comply with the standards, and the value of *UGR* does not. In the meantime, these values are better than those of the existing LI variant but worse than those of the other selected ones.

Table 2 and the above-mentioned analysis show that the optimal solution in terms of overall acquired characteristics is LI with *SLICK.PRS LED* LD by *Lighting Technologies* (variant No. 3).

Calculation of annual energy costs was also performed (Table 4). The duration of LI operation was accounted for in accordance with the number of working hours per year with 40-hours working week and one-shift operation. The summary economical calculation showed (Table 5) that existing illumination is the most expensive variant and the most efficient one may be provided using LI with *SLICK.PRS LED* LD by *Lighting Technologies* (variant No. 3).

Table 3. Calculation of Annual Depreciation Cost of the Artificial Lighting System

Illumination variant	Useful life, hours	Lifetime, years	Initial cost of LI, ₽	Annual depreciation costs, ₽
Lighting Technologies Existing variant	24,000	8	1,149,560	143,695
Osram Compact Monsun LED Variant No. 1	50,000	10	1,500,000	150,000
Philips Coreline Waterproof Variant No. 2	50,000	10	1,595,300	159,530
Lighting Technologies SLICK.PRS LED Variant No. 3	50,000	10	887,400	88,740
Philips GreenUp Waterproof Variant No. 4	40,000	10	1,047,200	104,720

Table 4. The Cost of Consumed Energy per Year

Illumination variant	Power consumption of one LD, W	Number of LDs, pcs.	Operation time of LI per year, hours	Electricity cost, ₽/kWh	The cost of consumed electricity per year, ₽
Lighting Technologies Existing variant	108	232	1973	5	247177
Osram Compact Monsun LED Variant No. 1	36	250	1973	5	88785
Philips Coreline Waterproof Variant No. 2	29	371	1973	5	106138
Lighting Technologies SLICK.PRS LED Variant No. 3	31	306	1973	5	93579
Philips GreenUp Waterproof Variant No. 4	36	374	1973	5	132822

4. MEASUREMENT OF LIGHTING ENGINEERING CHARACTERISTICS OF LI

The values of horizontal and vertical illuminance on workplaces created by the existing variant of LI were measured at the heights of 0.0 and 1.0 m from the floor level, and the values of LD luminance were measured at the distance of 10 m from the working area. By way of experiment, LDs of the four selected variants were installed in some areas of the line. *UGR* was calculated for all variants (Table 6). Wherein:

- In the course of experiment, the LDs were descended down to the height of 2.5 m;
- In the model of the local illumination, there is spacing between LDs of the LI, but actually they are located close to each other (due to application of excessive LDs), therefore, the "measured" (calculated on the basis of the measured data) value of *UGR* is less than the modelled one;
- Ambient illumination was not switched on in the course of measurements and luminance meter, spectrometer/illuminance meter, distance meter, and a photo camera were used.

The distance (10 m) between the studied LD and the luminance meter was measured by means of the distance meter. The luminance of the studied LD was measured by luminance meter. The required photos were made. Horizontal and vertical illumi-

Table 5. Total Annual Maintenance Cost of Lighting Installations

Illumination variant	Annual depreciation costs, ₽	The cost of consumed electricity per year, ₽	Annual maintenance cost of LI, ₽
Lighting Technologies Existing variant	143,695	247,177	390,872
Osram Compact Monsun LED Variant No. 1	150,000	88,785	238,785
Philips GreenUp Waterproof Variant No. 2	159,530	106,138	265,668
Lighting Technologies SLICK.PRS LED Variant No. 3	88,740	93,579	182,319
Philips GreenUp Waterproof Variant No. 4	104,720	132,822	237,542

Table 6. Measurement Results

LD	*Lighting Technologies* Existing variant	Philips GreenUp Waterproof	Philips GreenUp Waterproof	*Lighting Technologies SLICK.PRS*
E (H-0.0), lx	698	778	799	686
E(V-0.0), lx	267	341	311	392
E(H-1.0), lx	1140	1050	933	1300
E (V-1.0), lx	429	473	344	558
L, overall luminance of the luminous part of the i-th luminaire in the direction of observer's eyes, cd/m^2	772	1189	769	616
UGR	26.2	25.3	24.7	23.5

nance values were measured at the heights of 0.0 and 1.0 m above the floor level on the line itself. All instruments for measurement of lighting indicators had undergone calibration, and the acquired results are presented in Table 6.

As compared to the initial technical specification, the differences of suspension height and the number of LDs of the local illumination LI were discovered. Therefore, the LDs of the local illumination LI model were located at a height of 2.5 m and close to each other (after measurement).

The analysis of illumination in the new model of LI showed, in particular, that switching off the general lighting increases visual discomfort.

5. DISCUSSION AND RESULTS

This article describes the efficiency study of LED-based LDs application in the car assembly shop and determines the optimal replacement variant of the existing LI.

Using *DIALux Evo*, the model of LI was formed, the lighting analysis was performed, and qualitative and quantitative lighting indicators were considered. The aspects of operation on the assembly line were taken into account during modelling of LI: operation with separate units and their subsequent adjustment, movement of the working surface. Based on the models created by ourselves for selection of the optimal solution, several variants of illumination of the assembly line were analysed. The following indicators were taken into account during the analysis: average illuminance, U_o, and UGR. The economical calculation was performed additionally with comparative analysis of annual maintenance expenditures of each LI variant. The comparative analysis of the lighting and economical parameters showed that the UGR level (more than 30), operational, and maintenance costs of the existing variant are the worst.

The optimal solution within the scope of this study is LI with *SLICK.PRS LED* luminaires by

Table 7. "Measured" and Modelled Values of *UGR*

LD	***Lighting Technologies* Existing variant**	***Philips GreenUp Waterproof***	***Philips Coreline Waterproof***	***Lighting Technologies SLICK.PRS LED***
UGR, "measured"	26.2	25.3	24.7	23.5
UGR, calculated using the *3D* model	27.3	25.1	23.8	23.1
Relative error,%	4.0	0.8	3.6	1.7

Lighting Technologies. The values of average illuminance and U_0 are within the acceptable ranges, and the *UGR* level is close to the standard value: at the height of 1.2 m above the floor it is equal to 22 (in compliance with GOST [6]), and at the height of 1.7 m above the floor, it is equal to 23 (insignificantly exceeding the standard value). Therefore, by compliance with the standard [6], this variant of LI provides the required level of workers' visual performance.

Comparison of the results of *UGR* calculation with the results of *3D*-modelling in *DIALux Evo* showed a relative error of (0.8–4) %. This confirms that the computer model is relevant to the object (Table 7).

Analysing all the presented conclusions, we can conclude that the values of *UGR* of the most of the reviewed cases (among the presented variants of LI) are higher than the standard ones, and it should be taken into account during further improving of LI for the assembly line.

REFERENCES

1. Prokofiev A. Reiting promyshlennykh svetodiodnykh svetilnikov [Rating of the Industrial LED Luminaries] // Sovremennaia svetotekhnika, 2012, Vol. 1, pp. 3–13.
2. Titkov S. Svetodiodnye svetilniki dlia tsekhov i ulits [LED Luminaires for Shops and Streets] // Sovremennaia svetotekhnika, 2014, Vol. 1, pp. 32–36.
3. Aizenberg Yu.B. Spravochnaia kniga po svetotekhnike [Reference book on lighting engineering. 3rd revised edition // Znak Publ., Moscow, 2006, 972 p.
4. Tatyana V. Meshkova and Vladimir P. Budak "DIALux 4.10 and DIALux EVO – Main Differences"// Light & Engineering Journal, 2013, Vol.21, #3, pp.58–63.
5. SP 52.13330.2016 Daylighting and artificial lighting.
6. GOST R55710–2013 Lighting of indoor work places. Norms and methods of measuring.
7. Rekomendacii po tekhniko-ekonomicheskoj ocenke osvesheniya proizvodstvennyh zdanij [Recommendations for technical and economical assessment of illumination of production facilities. NIISF of Gosstroy of the USSR] // Stroyizdat Publ., Moscow, 1983, pp. 10–14.

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Fig. 2. Active LI of the assembly line