THE OPTICAL DESIGN OF LED BASED ENERGY EFFICIENT INDUSTRIAL LUMINAIRE

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ABSTRACT

In this study, EN 12464-1 – "Light and lighting - Lighting of work places - Part 1: Indoor work places", which is also accepted in Turkey, has been considered and calculations have been done accordingly. In this scope, in order to yield energy efficient solutions, LED based luminaires have been designed by "SPEOS - optical design software" according to the equivalent of the based conventional luminaires. Luminaire calculations have been done in an environment, which represents industrial production hall, has 16 m width, 40 m length for the base area and changing heights of 6, 8, 10 and 12 m where the illuminances are 200, 300 and 500 lx. For this environment, it has been taken that working plane is 1 m, maintenance factor is 0.8 and it was considered that all luminaires are surface mounted for all calculations. While LED based luminaire's designs are made, the thermal and electrical efficiencies were accepted in a considerable range and thus, luminaire has been designed and analyzed only optically. These calculations are compared with the results for IP65 class high-bay luminaires, which have 150W and 250W metal halide lamps, 2x58W and 4x58W fluorescent lamps, and energy efficient luminaires are determined.

Keywords: Optical Design, Industrial Lighting, Luminaire, LED

1. INTRODUCTION

Energy demand of human kind is increasing day by day with developing technology. Energy efficient systems must be preferred in order to leave a viable environment to the future generations by regarding limited sources of the earth and sustainability concept. In this manner, when the lighting systems, which have important amount within electrical energy consumption, are considered, the usage of energy efficient luminaires is quite crucial. In Turkey, the approximately half of the electrical energy are consumed by industry [1]. Hence, the usage of energy efficient luminaires in industry provide energy saving and make a major contribution to gross national product. In addition to this, it is essential that the energy efficient luminaires must have long life, low maintenance and operating costs and provide the necessary specifications in terms of visual, safety and lighting criteria for industrial lighting. Optical design is one of the most important and critical processes in luminaire design. This is because; the bare lamp might not provide the desired light distribution all the time. Therefore, efficient optical design must be made to direct the light and to use it more efficiently. Admittedly, the increase in the efficacies of LED (light emitting diode) light sources lead an increase of usage of LEDs in general lighting applications. However, since LEDs are different from the conventional light sources, the design process must be investigated separately. Hence, making use of optical design software consciously shall provide substantial convenience when making designs [2]. Lighting solutions are provided at the industrial facilities with the concerns of visual comfort, visual performance and security criteria. These solutions must be carried out according to the lighting of the work environments standard EN 12464-1 [3]. In this study, this standard has been considered and the calculations have been done accordingly. Also, it has been aimed in this study that how much energy efficient the use

of well-design LED based luminaires optically in industrial facilities instead of the conventional luminaires based on 150W and 250W metal halogen lamps, 2x58W and 4x58W fluorescent lamps. Since the ceiling heights can be changed for every industrial facility, it is obvious that one luminous flux and light distribution curve for luminaire can not be enough. Therefore, while LED based luminaires are designed, the equivalent luminous fluxes are selected 12000 lm and 20000 lm as a design criteria because of the based conventional luminaires' luminous flux. Besides, it has been elaborated that based conventional luminaires are one of the most efficient inside their group and goaled energy saving potential for the best luminaires.

2. THE OPTICAL DESIGN OF LED BASED LUMINAIRES FOR INDUSTRIAL FACILITIES

In the optical design of LED based luminaires, lenses or reflectors can be used to control light effectually. Since they have advantages and disadvantages to each other, it should be selected properly for the design accordingly. In this study, lenses are used to control LEDs' light. There are a lot of software for luminaire's optical design such as SPEOS, OPTIS, ASAP, APEX, Lucidshape, Lightools, etc. Within these softwares, while some of them have CAD property to build luminaire, the others use different 3D software as main software. For instance, SPEOS uses ProEngineer for 3D design and it is just a plug-in for ProEngineer allows us to define part properties, sources, detectors and make simulations. SPEOS was chosen as optical design software in this study. Thus, all luminaire's parts are made in ProEngineer and they were simulated with SPEOS. LED's type and quantity should be defined for the targeted LED based luminaire design. Since LED's luminous flux and power can change with LED's junction temperature and driver's efficiency, thermal and driver efficiencies of luminaires are selected reasonably and optical design are made according to that. Within normal conditions, thermal efficiency must be maximized after optical design and optical design must be repeated after that. On the other hand, driver efficiency is only effective in luminaire efficacy and power. For this reason, efficient drivers should be selected for lower power or higher efficacy.

2.1. Reference Conventional Luminaires

While reference high-bay luminaires are selecting, efficient luminaires are selected and energy saving potential are calculated between the good conventional luminaires and LED based luminaires that are designed. As a metal halide luminaire, Philips Performalux series are used for 150W and 250W luminaires. Their powers are 165W and 275W with ballast losses [4]. Moreover, narrow, medium and wide beams are used for these series for the calculations. One example is shown in Figure 1. For the 2x58W and 4x58W fluorescent lamp luminaires, EAE Revo Arena series luminaires are selected and they are indicated in Figure 2, respectively [5].

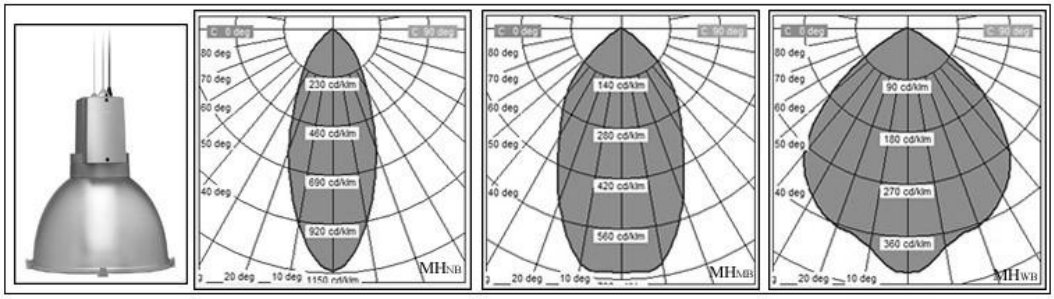

Figure 1 – Philips Performalux Metal Halide 150W Luminaire and Polar Curves for Narrow Beam, Medium Beam and Wide Beam

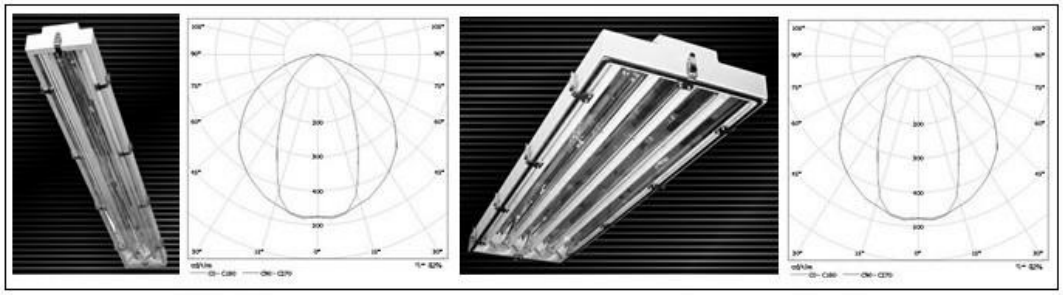

Figure 2 - EAE Revo Arena 2x58W and 4x58W fluorescent lamp luminaires.

2.2. Design Aims and Criteria

In this scope of study, LED based luminaires are designed equivalent to luminaires that are generally used in industry such as luminaires which have 150W and 250W metal halide lamp, 2x58W and 4x48W fluorescent lamp. Design aims and criteria are shown in Table 1 for reference luminaires and designed luminaires.

Table 1 – Design aims and Criteria for LED based luminaires

	2x58W T8 F. Luminaire	4x58W T8 F. Luminaire	150W M.H. Luminaire	250W M.H. Luminaire	A LED Luminaire	B LED Luminaire
Area of Use	Industry High-Bay	Industry High-Bay	Industry High-Bay	Industry High-Bay	Industry High-Bay	Industry High-Bay
Total Lamp Luminous Flux [lm]	10400	20800	13500	22500	>12000	>20000
Luminaire Efficiency (LOR)	82.10%	82.50%	80%	80%	>%82.5	>%82.5
Total Luminaire Luminous Flux [lm]	8538	17160	10800	18000	12000	20000
Luminaire Power [W]	110	220	165	275	<165	<275
Luminaire Efficacy [lm/W]	77.6	78	65.5	65.5	>78	>78
Color Temperature [°K]	4000	4000	2800	2800	4500	4500
Color Rendering Index (Ra)	85	85	85	82	80	80
IP Class	IP65	IP65	IP65	IP65	IP65	IP65

According to the Table 1, 150W and 250W metal halide lamps have 13500 lm and 22500 lm respectively [4] and 2x58W and 4x58W fluorescent lamps have 10400 lm and 20800 lm respectively [5]. However, since those are the lamp's luminous flux, we need luminaire luminous flux. While selected metal halide lamp luminaires as a reference have %80 light-output-ratios (LOR), selected fluorescent lamp luminaires as a reference have %82 light-output-ratios. In this regard, target luminaire flux are selected 12000 lm and 20000 lm for LED based luminaire so that they are called "A" luminaire for 12000 lm and "B" luminaire for 20000 lm. Also, narrow, medium and wide beam lenses are used to achieve energy efficient solutions and provide necessary lighting criteria for different heights. Besides, LEDs' junction temperatures are selected as 90°C and driver's efficiency is selected as %90.

2.3. Components used in the design

In LED based luminaire design, LEDs, lenses, MCPCB, glass and housing are used as a part of luminaire. Cree XM-L T5 series LEDs are chosen and forwarded with 0.7A current. Table 2 shows the details about it [6]. Lenses are selected from LEDIL and they

are given in Table 3 with detailed information [7]. In addition to this, MCPCB are used with %90 reflection and BK7 glass component are used in the design.

Table 2 – CREE XM-L T5 Series LED (0.7A Forward Current and differences for junction temperature)

Junction Temperature	Luminous Flux of LED [lm]	Forward Voltage of LED [V]	Power of LED [W]	Efficacy of LED [lm/W]
25°C	260	2,9	2,03	128,1
90°C	222,8	2,7	1,89	117,9

Table 3 – LEDIL Lenses used in LED based luminaire design

			
Company	LEDIL	LEDIL	LEDIL
Name	Tina3 W (NB)	Tina3 WW (MB)	Tina3 WWW (WB)
Diameter [mm]	16,1	16,1	16,1
Height [mm]	7,3	7,1	6,9
Optical Property	PMMA	PMMA	PMMA
Beam Angle	37°	56°	71°
Efficiency	%92	%89	%88

In addition to lenses' efficiency, it is thought that there will be %5 lost inside the luminaire because of internal reflection and absorption of materials so that %5 lost is added as a loss of luminaire LOR in the design criteria. Moreover, inside the housing part is evaluated that it has %96 reflective. Consequently, all are shown in Table 4. Also, polar curves and luminaires are shown in Figure 3.

Table 4 - Optic, Thermal and Electrical Properties of Designed Luminaires

	A_{NB}	A_{MB}	A_{WB}	B_{NB}	B_{MB}	B_{WB}
LEDs	CREE XM-L T5	CREE XM-L T5	CREE XM-L T5	CREE XM-L T5	CREE XM-L T5	CREE XM-L T5
Quantity of LEDs	64	66	66	105	108	110
Color Temperature of LEDs [°K]	4500	4500	4500	4500	4500	4500
Color Rendering Index of LEDs [Ra]	80	80	80	80	80	80
Luminous Flux of LEDs at 25°C Tj for 0.7A Forward Current [lm]	260	260	260	260	260	260
Juntion Temperature Used at Design [°C]	90	90	90	90	90	90
Luminous Flux of LEDs at 90°C Tj for 0.7A Forward Current [lm]	222.8	222.8	222.8	222.8	222.8	222.8
Efficiency of Lens	%92	%89	%88	%92	%89	%88
Luminous Flux Output from Lens for 90°C Tj [lm]	205,0	198.3	196.1	205.0	198.3	196.1
Luminaire Light Output Ratio (LORL) (After simulations)	%100	%100	%98.47	%100	%100	%98.52
Total Luminaire Luminous Flux [lm]	13118	13087	12742	21522	21416	21248
Driver Efficiency	%90	%90	%90	%90	%90	%90
Individual LED Power for 90°C Tj [W]	1.89	1.89	1.89	1.89	1.89	1.89
All LEDs's Power Used in Design [W]	121.0	124.7	124.7	198.5	204.1	207.9
Total Luminaire Power [W]	134.4	138.6	138.6	220.5	226.8	231.0
Luminaire Efficacy [lm/W]	97.6	94.4	91.9	97.6	94.4	92.0
Material Properties Used in Design						
Reflection of MCPCB	%90	%90	%90	%90	%90	%90
Reflection of inner part of Housing	%96	%96	%96	%96	%96	%96
Glass	BK7	BK7	BK7	BK7	BK7	BK7
Rays Used in Simulation						
	10.000.000	10.000.000	10.000.000	10.000.000	10.000.000	10.000.000

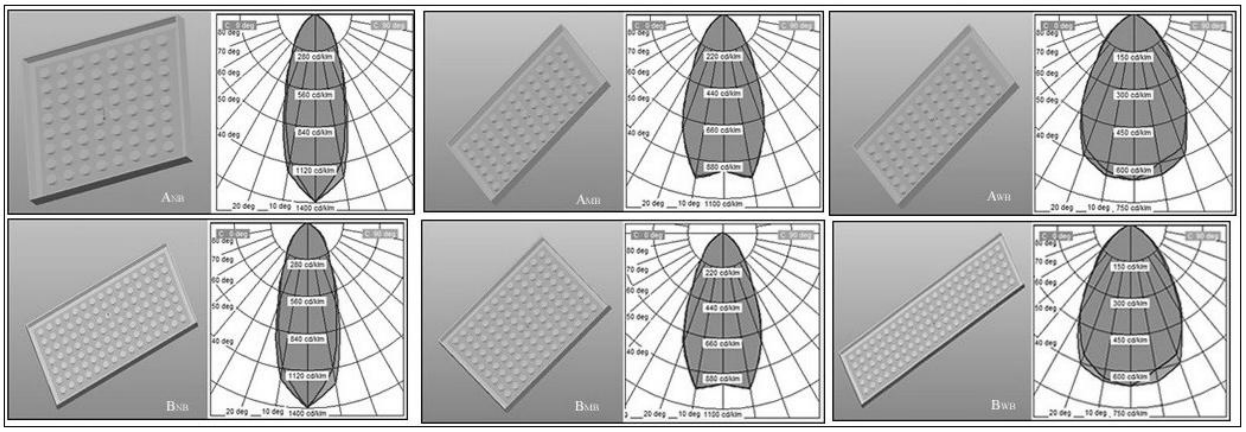

Figure 3 – Designed Luminaires and Their Polar Curves

3. LIGHTING CALCULATIONS FOR METAL HALIDE (MH), FLUORESCENT AND DESIGNED LED BASED LUMINAIRES

In order to yield energy efficient solutions, LED based luminaires have been designed. Luminaire calculations have been done in an environment, which represents industrial production hall, has 16 m width, 40 m length for base area and changing heights of 6, 8, 10 and 12 m where the illuminances are 200, 300 and 500 lx. For this environment, it has been taken that working plane is 1 m, maintenance factor is 0.8 and it was considered that all luminaires are surface mounted for all calculations. These calculations are compared with results for IP65 class high-bay luminaires, which have 150W and 250W metal halide lamps, 2x58W and 4x58W fluorescent lamps, and energy efficient luminaires are determined using W/m^2/100lx by DiaLux. In the tables, wide beam, medium beam and narrow beam angles are indicated by the notations "$_{WB}$, $_{MB}$ and $_{NB}$" respectively. As a result of calculations, all luminaires are compared and energy potentials of using designed LED based luminaires are shown Table 7 instead of using selected conventional luminaires.

Table 5 - Comparison of Luminaires after Calculations

	Proper Metal Halide Luminaires			Proper Fluorescent Lamp Luminaires			Proper LED Based Luminaires		
	200 lx	300 lx	500 lx	200 lx	300 lx	500 lx	200 lx	300 lx	500 lx
6m	150_{WB}	150_{WB}	250_{WB}	2x58W	2x58W	4x58W	A_{WB}	A_{WB}	B_{WB}
8m	150_{WB}	150_{WB}	250_{WB}	4x58W	4x58W	4x58W	A_{WB}	A_{WB}	A_{MB}
10m	150_{MB}	150_{MB}	250_{MB}	4x58W	4x58W	4x58W	A_{MB}	B_{MB}	B_{MB}
12m	250_{MB}	250_{MB}	250_{NB}	4x58W	4x58W	4x58W	B_{MB}	B_{MB}	B_{NB}

Table 6 - W/m2/100lx for the best fit luminaires after Calculations

	W/m^2/100lx for LED Based Luminaires			W/m^2/100lx for Metal Halide Lamp Luminaires			W/m^2/100lx for Fluorescent Lamp Luminaires		
	200 lx	300 lx	500 lx	200 lx	300 lx	500 lx	200 lx	300 lx	500 lx
6m	1,46	1,47	1,47	1,99	2,01	2,01	1,71	1,72	1,66
8m	1,59	1,6	1,47	2,17	2,19	2,19	1,75	1,79	1,81
10m	1,54	1,54	1,57	2,21	2,22	2,23	1,93	1,95	1,97
12m	1,65	1,66	1,62	2,35	2,38	2,29	2,1	2,11	2,13

Table 7 - Energy saving potential using LED Based Luminaires instead of Metal Halide Luminaires and Fluorescent Lamp Luminaires

	Energy saving potential using LED Based Luminaires instead of Selected Metal Halide Luminaires			Energy saving potential using LED Based Luminaires instead of Selected Fluorescent Lamp Luminaires		
	200 lx	300 lx	500 lx	200 lx	300 lx	500 lx
6m	%26,6	%26,9	%26,9	%14,60	%14,50	%11,40
8m	%26,7	%26,9	%32,9	%9,10	%10,60	%18,80
10m	%30,3	%30,6	%29,6	%20,20	%21,00	%20,30
12m	%29,8	%30,3	%29,3	%21,40	%21,30	%23,90

4. CONCLUSION

According to the obtained data, the use of well-designed LED based luminaires instead of reference conventional high-bay luminaires, provide energy saving and represent energy efficient lighting installations in the same industrial production hall for 200 and 300 lx illuminance; with the use of wide beam in 6 and 8 m height, with the use of medium beam in 10 and 12 m height; for 500 lx illuminance; with the use of wide beam in 6 m height, with the use of medium beam in 8 and 10 m height, with the use of narrow beam in 12 m height. Therefore, more efficient lighting systems can be obtained by luminaires that have narrow beam when the ceiling heights are increased. In addition to this, while it is suggested using of luminaires that have a lower luminous flux (e.g. 12000 lm) in low ceiling heights (e.g. 6 and 8 m), it is suggested using of luminaires that have a higher luminous flux (e.g. 20000 lm) in high ceiling heights (e.g. 10, 12 m and above) because of low luminaire quantities and initial investment cost of installation of lighting fixture.

Selecting the length of luminaires' suspension fittings of various heights to provide the same results of the calculations will be possible for higher ceiling heights. Also, the ceiling, wall and floor reflection coefficients in the place that will be illuminated affect uniformity and glare. Hence, the use of light-colors for ceiling, wall and floor and keeping them clean in an industrial environment will be extremely useful.

Consequently, the well-designed luminaires with LEDs result between %26.6 and %32.9 energy saving than those of the conventional luminaires employed with 150W and 250W metal halide lamps, and result between %9.1 and %23.9 energy saving than those of the conventional luminaires employed with 2x58W and 4x58W fluorescent lamps. Thus, according to the obtained simulation results, although the using of LED based luminaires in industry is quite efficient, the initial investment cost of installation and payback time should be considered for energy efficiency and saving potential.

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