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A comparative study of fluorescent and LED lighting in industrial facilities

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Abstract. Industrial facilities have always been in search for reducing outgoings and minimizing energy consumption. Rapid developments in lighting technology require more energy efficient solutions not only for industries but also for many sectors and for households. Addition of solid-state technology has brought LED lamps into play and with LED lamp usage, efficacy level has reached its current values. Lighting systems which uses fluorescent and LED lamps have become the prior choice for many industrial facilities. This paper presents a comparative study about fluorescent and LED based indoor lighting systems for a warehouse building in an industrial facility in terms of lighting distribution values, colour rendering, power consumption, energy efficiency and visual comfort. Both scenarios have been modelled and simulated by using Relux and photometric data for the luminaires have been gathered by conducting tests and measurements in an accredited laboratory.

1. Introduction

There have been rapid and significant changes in lighting technologies since the invention of incandescent lamps. These changes and inventions mostly aimed to provide more efficient and higher quality lighting systems for different areas and usage [1]. Fluorescent lamps consume approximately %65 less energy when compared to incandescent lamps in the same luminous flux level. Energy efficiency has not been the only advantage of fluorescent lamps, along with this huge benefit, fluorescent lamps has also a considerably larger lifetime than regular incandescent lamps [2]. Fluorescent lamps also dissipate less heat, which is beneficial for the systems that are sensitive to heat. Fluorescent lamps contain vaporized mercury which is ionised with applied voltage across the tube. Ionisation of the mercury vapour requires a higher voltage than the mains voltage; therefore, a starter and a ballast are necessary to provide the required voltage for initial ionisation. After ionisation occurs and fluorescent lamb starts operating, the lamp shows negative resistance effect. The conductivity of the lamb increases with the current flows through it. In order to solve this issue, ballast must be used in order to limit the current by adding inductive resistance into the circuit [3].

Fluorescent lamps require ballasts to operate which causes additional power loss and also increases the initial cost [3]. Ballasts can be magnetic, electronic and hybrid. Magnetic ballasts contain magnetic core wrapped copper windings to regulate the current and voltage based on the principle of magnetic induction [4]. Magnetic ballasts work with line frequency which causes a higher flicker index. On the other hand, since they don’t contain semi-conductors, harmonic emission is not an issue for magnetic ballasts when comparing to electronic ballasts. Electronic ballasts work in a different way. Advanced technology in electronics allowed to use semi-conductors in ballasts. Thus, magnetic core and windings were replaced with electronic components. With the addition of semi-conductors, frequency control became possible for electronic ballasts [5]. A comparison of magnetic and electronic ballasts can be found in Table 1.

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Table 1. Comparison between magnetic and electronic ballasts

Advantages of Magnetic Ballasts	Advantages of Electronic Ballasts
Considerably lesser harmonic emission	High energy efficiency
Able to operate in tough conditions	High power factor
Failures/malfunctions occur less since magnetic ballasts do not have delicate components	Extend lifetime of the lamp %20-25
Lesser manufacturing costs	Compatible with dimmable systems
EMC is not an issue since the operating frequency is low (mains frequency)	Compatible with automation applications

LED lamps have been developed and became popular rapidly with the evolution of technology. When LED lamps appeared in the market, they were inefficient; however, developments in LED technology have taken the LED lamps to top of the energy efficient lighting solutions [6]. In order to use LED lamps with mains voltage and current or the DC voltage and current as needed, LED drivers are required. LED drivers are basically AC/DC or DC/DC converters. Drivers contain semi-conductors which cause massive harmonic emissions; therefore, LED drivers are being used with PFC [7].

2. Illuminating industrial facilities

Lighting quality is one of the most essential elements in a work place. Complex and large industrial facilities have different lighting requirements for different parts of the facility [8]. Lighting requirements of a facility also changes with personal tasks. These requirements have been set by certain standards. EN 12464-1 standard sets the minimum lighting needs in a work place.

In industrial facilities, increasing energy efficiency has always been the top priority to maximize profit and to help preserving natural resources [9]. With the scientific breakthroughs, advancing technology and new inventions, many ways of increasing energy efficiency have been discovered and developed. Automation technology, using new methods and materials for isolation, energy efficient motors and energy efficient lamps are the most effective ways to decrease energy consumption [9], [10].

Among all methods which aim to increase energy efficiency, switching into a more efficient lighting system is mostly the cheapest and the most effortless method. Depending on the luminaire type, quantity and price, initial costs can be different. Installation costs, maintenance costs and labor costs during installation must be considered as initial cost [10].

Lighting requirements for buildings used as warehouses depend on the usage of the building and personal tasks. A warehouse which contain forklift works, needs a clear vision for safety and performance reasons. Moreover, warehouses with packaging and loading jobs need a higher lux value. As can be seen in table 2, lighting standards for a warehouse can change depending on the task and the usage of the building according to EN 12464-1.

The photometric tests and measurements of the luminaires have been conducted in an accredited laboratory and the necessary luminaire data have been acquired. Both scenarios have been built based on a warehouse in İstanbul by considering require lighting standards and visual comfort. Figure 1. shows the luminaires which have been used in the study. In order to perform simulation, the warehouse have been modelled in Relux software.

3. Case study

The case study has been conducted in a warehouse of a factory in Istanbul. The dimensions of the warehouse are 20 m for length, 10 m for width and 8 m for height respectively. The height of the work plane is 0.75 m and the distance between floor and the luminaire is 7.5 m.

The reflection coefficient rates of the walls are ρ wall=0.5, floor ρ floor=0.2, and the ρ ceiling=0.7.

As seen on the Table 2, the required lux level which can provide minimum illumination needs for the warehouse mentioned must be above 300 lx.

The maintenance factor has been assumed as 0.8.

Figure 1. 53. AKYT 254 (fluorescent) and 53.AKYTL 220 (LED) luminaires

Table 2. EN 12464-1 lighting standards for a warehouse

Interiors Activities	Em[lx]	Ra	UGRL
Store room aisles and passages	100	60	25
Warehouses with uniform or bulky items	300	60	25
Warehouses with various items and search requirements	300	60	25
Warehouses with reading requirements	300	60	25

In this study, the economical and efficient ways have been researched in two different scenarios by using two different lighting solutions in order to provide minimum light requirements for visual comfort and visual task according to ISO 8995-1:2002(E)/CIE S 008/E:2001 standard. In scenario 1, the storage room has been designed by using 12 pieces of Alkan 53.AKYT 254 luminaire with TL 5 fluorescent lamp. The photometric data of the luminaire which has been used in scenario 1 according to test results have been shown in Figure 1. In scenario 2, the warehouse has been designed by using 12 pieces of Alkan 53.AKYTL 220 LED luminaire. The photometric data that have been acquired from test results of the luminaire which has been used in scenario 2 have been shown in Figure 6. The facility where experiment has been conducted operates 7 days and 24 hours.

The lighting scheme for the study has been designed by using Relux simulation software and the simulation results are presented for each scenario.

3.1 Scenario 1

An Alkan product 53.AKYT 254, which contains 2X54W fluorescent lamps, is used for the illumination of the warehouse in the facility. The luminous flux of used luminaire is 7120 lumen (lm) and the power is 113,5 W. The luminous flux of each lamp in luminaire is 4450 lumen. The efficiency of the luminaire can be calculated as;

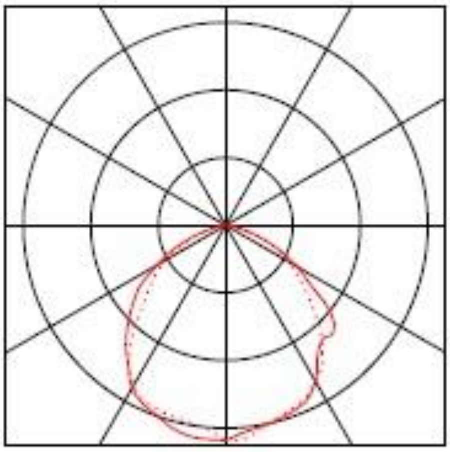
$$\frac{7120\ \text{lm}}{4450\ \text{lm x } 2} = \%80$$

Totally 12 luminaires were used for the study. The total luminous flux is the sum of all the flux emitted by 12 luminaires and equals 85440 lm, also the total used power equals to;

$$Pt = n.P = 12x113{,}5W = 1362W$$

According to result of Relux program, the average illuminance measured at work plane Eav=232 lux, the minimum illuminance measured at work plane Emin=156 lux and the maximum illuminance measured at work plane Emax=277 lux.

Figure 2 presents photometric data for scenario 1. The positioning of the luminaires can be seen in Figure 3. The lighting distribution values in Lux are illustrated in Figure 4. Figure 5 is 3-D colour rendering and presents the effect of lighting on different areas in the room. Figure 6 presents false colour rendering scheme.



Luminaire efficiency	80%	**Luminaire ID**	53.AKYT 254
Luminaire efficacy	69.13 lm/W	**Luminous flux of the lamps**	4450 lm
CIE Flux Codes	53 85 98 100 80	**Power of the lamps**	54 W
UGR 4H 8H	22.3 / 21.2	**Whole circuit power**	113,5 W
Luminous flux of the luminaire	7120 lm	**Quantity of the lamps**	2

Figure 2. Polar diagram and photometric data of the luminaire 53.AKYT 254

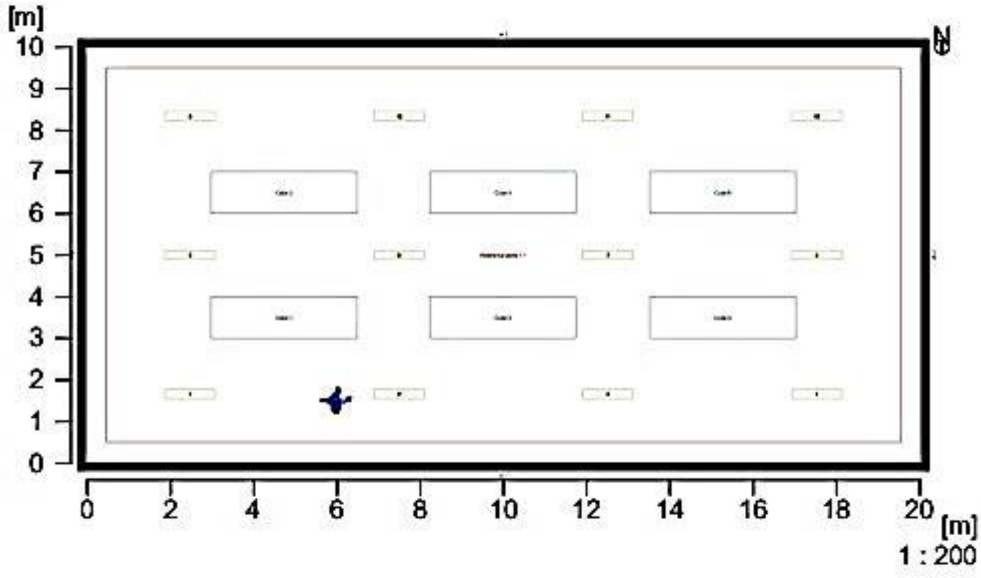


Figure 3. Layout plan for Scenario 1

3.2 Scenario 2

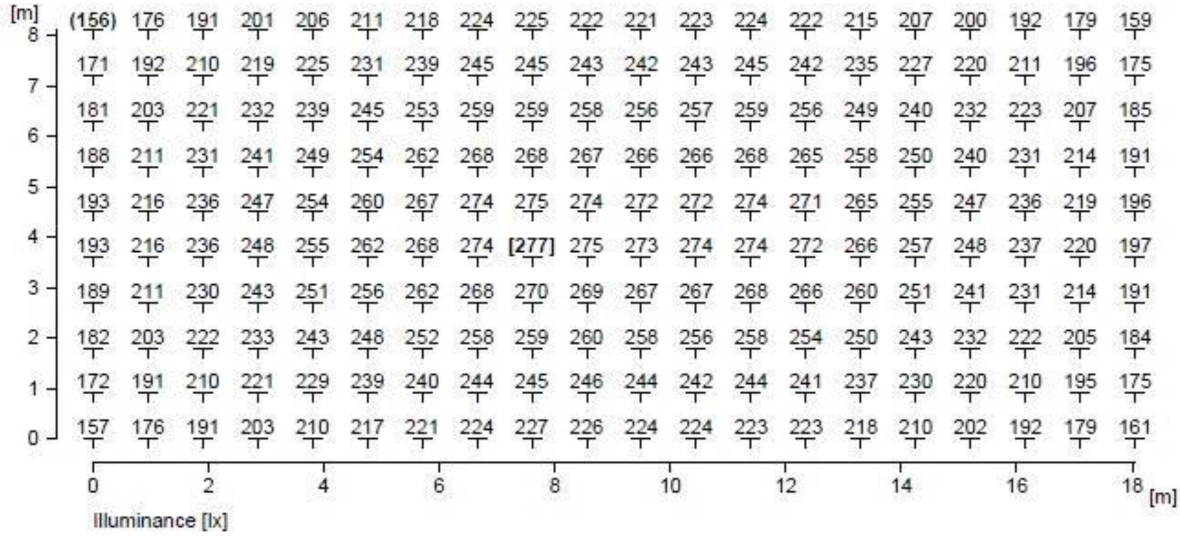
Alkan product 53.AKYTL 220 LED Panel is used for the illumination of the warehouse for the concerned facility.

The luminous flux of each LED luminaire is 11450 lm and the power is 112W. The luminous flux of the LED lamps in each luminaire is 14800 lm. The efficiency of the luminaire can be calculated as;

$$\frac{11450\ \text{lm}}{14800\ \text{lm}} = \%77$$

Totally 12 luminaires were used for the study. The total luminous flux is the sum of all the flux emitted by 12 luminaires and equals 137400 lumen. Also the total used power equals;

$$Pt = n.P = 12x112\ W = 1344\ W$$



Evaluation area 1	Reference plane 1.1	
	Horizontal	
Em	232 lx	
Emin	156 lx	
Emin/Eav (Uo)	0.67	
Emin/Emax (Ud)	0.56	
UGR (1.6H 3.2H)	<=21.3	
Position	0.75 m	
Major surfaces	Em	Uo
m 1.5 (Ceiling)	55 lx	0.83
m 1.1 (Wall)	143 lx	0.36
m 1.2 (Wall)	131 lx	0.41
m 1.3 (Wall)	140 lx	0.36
m 1.4 (Wall)	127 lx	0.40

Figure 4. Light distribution values for Scenario 1

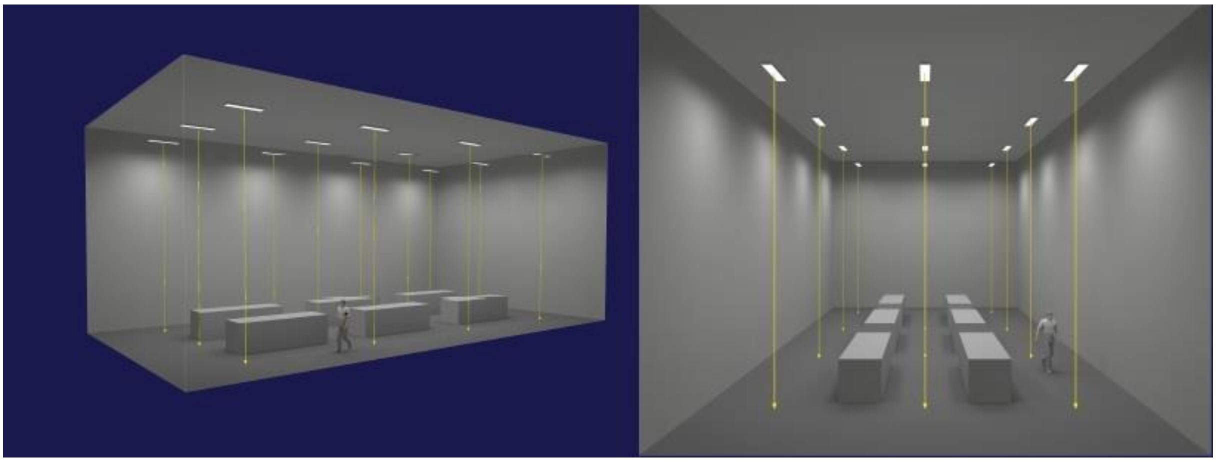


Figure 5. Colour rendering for Scenario 1

According to result of Relux program, the average illuminance measured at work plane Eav=422 lux, the minimum illuminance measured at work plane Emin=270 lux and the maximum illuminance measured at work plane Emax=520 lux.

Figure 7 presents photometric data for scenario 2. The positioning of the luminaires can be seen in Figure 8. The lighting distribution values in Lux are illustrated in Figure 9. Figure 10 is 3-D colour rendering and presents the effect of lighting on different area in the room. Figure 11 presents false colour rendering scheme.

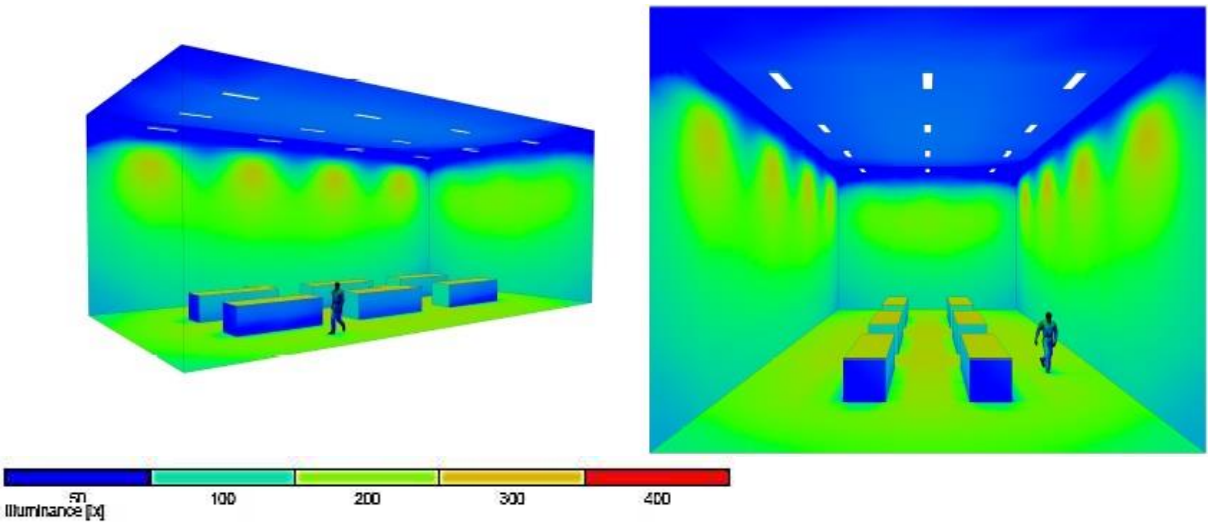
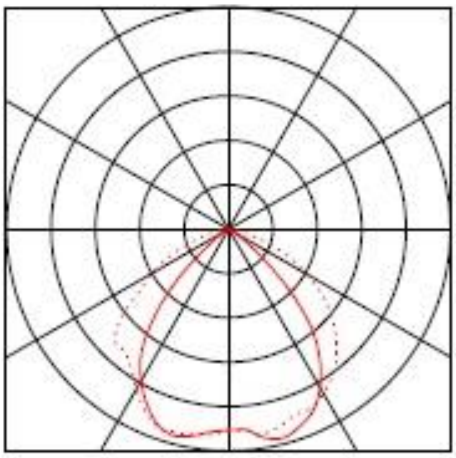


Figure 6. False colour rendering



Luminaire efficiency	77%	**Luminaire ID**	53.AKYTL 220
Luminaire efficacy	102.23 lm/W	**Luminous flux of the lamps**	14800 lm
CIE Flux Codes	53 85 98 100 80	**Power of the lamps**	100 W
UGR 4H 8H	17.8 / 24.1	**Whole circuit power**	112 W
Luminous flux of the luminaire	11450 lm	**Quantity of the lamps**	240

Figure 7. Polar diagram and photometric data of the luminaire 53.AKYTL 220

4. Results and discussion

In this study, the lighting system of a workplace has been designed and analysed with 2 different approaches. The aim of both methods was to determine the energy efficient ways in lighting solutions. Fluorescent lamps are still being preferred in a lot of facilities because of the advantages such as efficiency and accessibility in open market. However, with the development in power electronics and technology, LED lamps are becoming more useful and efficient each day.

In designing process of the warehouse, fluorescent and LED luminaires have been placed on the same spots in order to collect consistent data and to make comparison more conclusive.

Illumination values for both scenarios have been shown in Table 2. It can be seen that LED lamps has higher efficacy than fluorescent lamps which shows that, when used in the same wattage, LED lamps have higher luminous flux than fluorescent lamps.

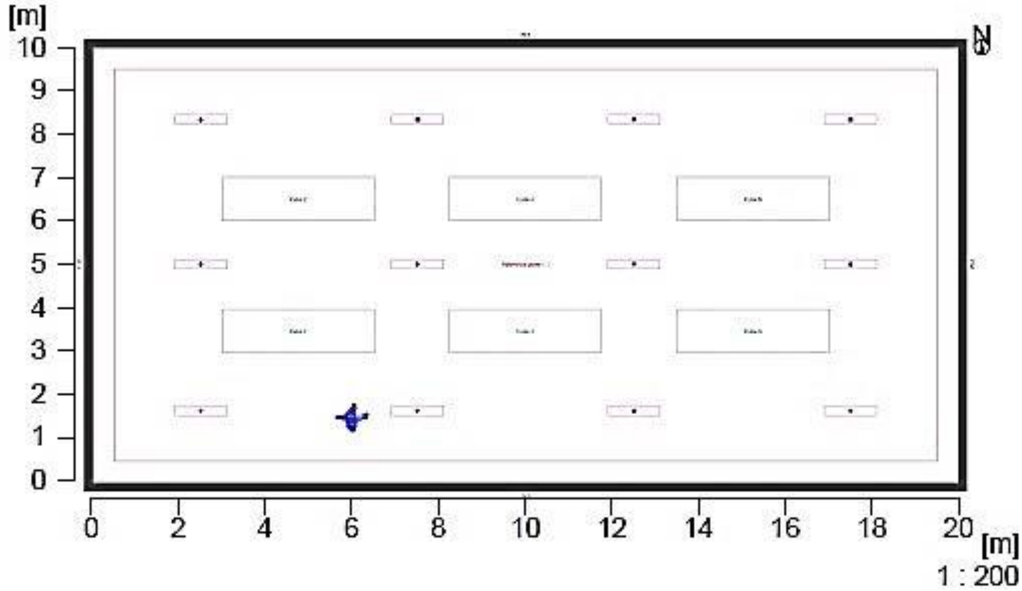


Figure 8. Layout plan

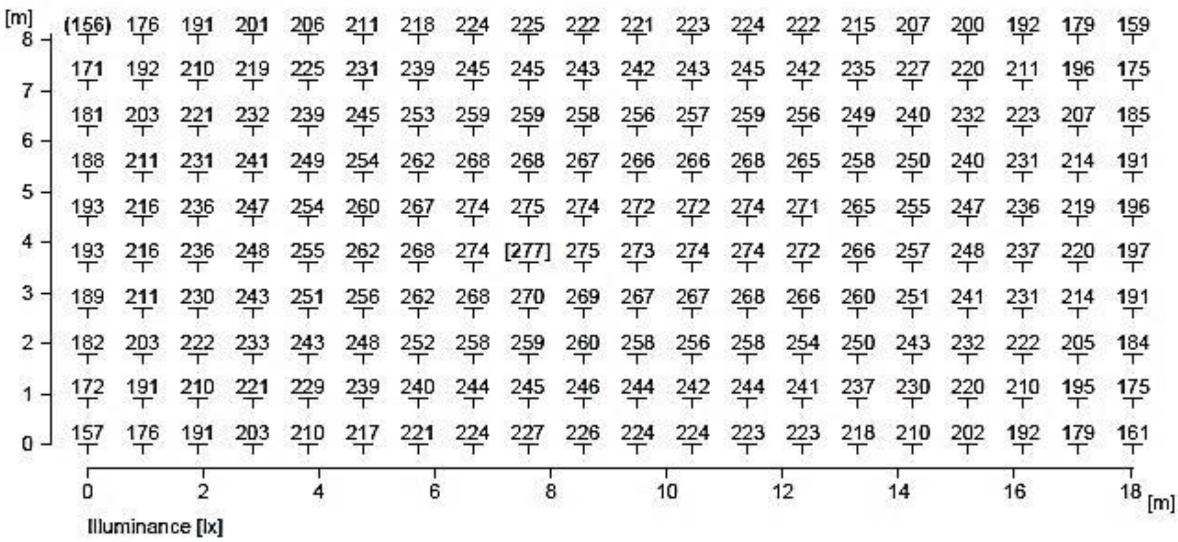


Figure 9. Lighting distribution for LED

Power consumption and emitted luminous flux can be seen together in Table 3. Luminous efficacy value can be reached by using luminous flux and power consumption data of a luminaire. In scenario 1, luminous flux has been calculated as;

$$7120\ \mathrm{lm}/113{,}5\ \mathrm{W}\ =\ 69{,}13\ \mathrm{lm/W}$$

As for scenario 2, luminous flux of the luminaire used is;

$$11450\mathrm{lm}/112\ \mathrm{W}\ =\ 102{,}23\ \mathrm{lm/W}$$

By referring to this data, it can be said that LED lamps can emit more luminous flux than fluorescent lamps in the same power consumption level because of the difference between their luminous efficacy values. When the same number of luminaires has been used, it has been seen that the system using fluorescent lamps cannot provide the required luminous flux for a healthy working environment according to international standards.

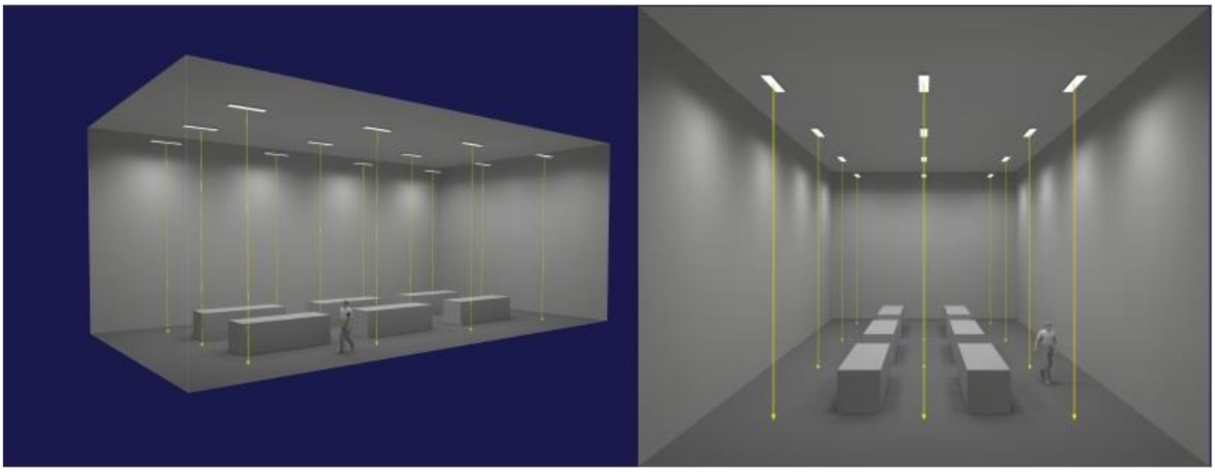


Figure 10. 3D Colour Render

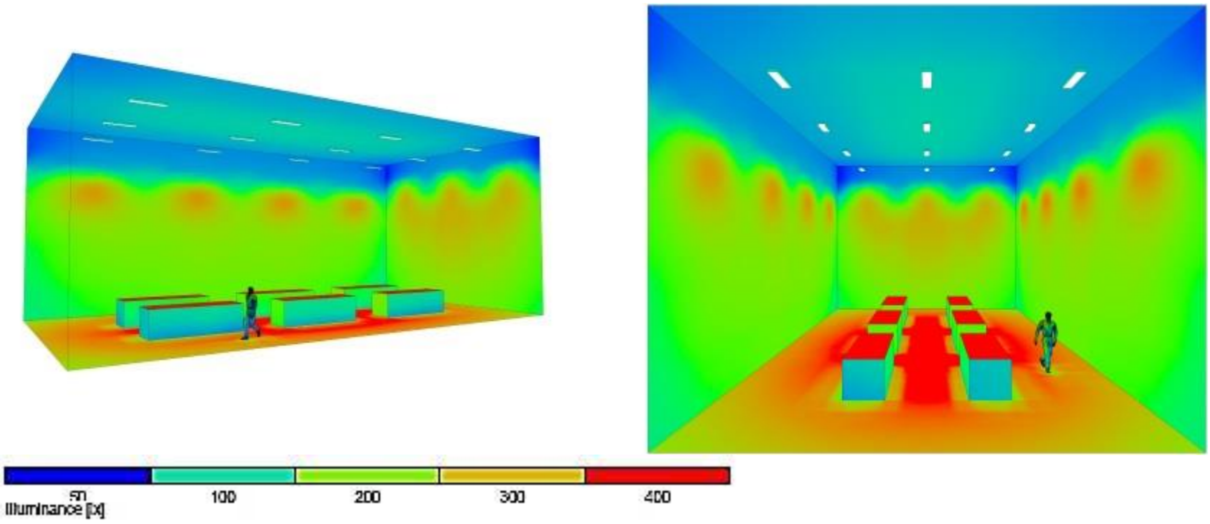


Figure 11. False Colour Render

Table 3. Illumination values for two scenarios

Type	Luminous Flux of Lamps	Luminous Flux of Luminaires	Luminous Efficacy	Total Luminous Flux (For 12 Luminaires)
Fluorescent	9900 lm	7120 lm	69,13 lm/W	85440 lm
LED	14800 lm	11450 lm	102,23 lm/W	137400 lm

Table 4. Power consumption and illumination values for two scenarios

Type	Power Consumed	Total Power Consumed	Luminaire Efficacy	Total Luminous Flux (For 12 Luminaires)
Fluorescent	113,5 W	1362 W	69,13 lm/W	85440 lm
LED	112 W	1344 W	102,23 lm/W	137400 lm

In order to reach the minimum lux level which can provide a healthy work place in scenario 1, more luminaires must be used and this design will have undesired consequences. Using more luminaires increases power consumption of the facility. In order to use more luminaires, more space will be required in warehouses, and placing luminaires can be problem since the room might be used at full capacity with products or wares that have been placed in the warehouse.

5. Acknowledgements

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6. References

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