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Influence of the light distribution of luminaires and the room surfaces' reflectance on the illumination levels, uniformity and glare in indoor lighting systems

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Abstract

The increasing use of LED luminaires provides a lot of opportunities for indoor lighting. On one side the use of LED luminaires can lead to significant reduction in the electricity consumption for lighting, on the other side it can be so tuned that it allows human centric lighting. The advantages of LEDs as light sources are indisputable, but they also have some drawbacks, that should be considered. A lot of attention is currently payed to optimization of the light distribution curves of luminaires for indoor lighting. It is very important, but not the only characteristic that should be considered. The real reflective properties of the indoor surfaces also influence to great extend the quality and quantity of indoor lighting.

The current paper aims to make a detailed review of the existing LED luminaires and their efficiency for indoor lighting, based on their light distribution curve and the reflective properties of the surfaces in the room space. Except for the qualitative, also the quantitative properties of the lighting systems are considered in terms of uniformity of the illuminance and glare.

One of the designed solutions is also practically realized and experimentally tested. A comparison between designed and real values of illuminance, uniformity and glare is made.

Index Terms: Light distribution curves, reflectance coefficients, LED luminires' efficiency

1. Introduction

Currently the implementation of LED light sources and luminaires becomes a tendency, because of their reduced energy consumption compared to the conventional sources of light. A lot of attention is payed both to the quality and quantity of the lighting systems, because most people work indoors so the striving is to achieve comfort, productivity and visual environment similar to those achieved by daylighting.

Since energy efficiency and visual comfort are both important and the LEDs as light sources themselves assure the reduction of electricity consumption, more attention should be payed to the quality of the lighting systems [1] and the parameters that directly influence it. For achieving adequate and healthy indoor lighting environment the acquaintance with the influence of the characteristics of the interior on the distribution of light in the premises is critical [2]. Some researchers have proved that in order to be acceptable, the illumination should be considered not only as horizontal illuminance on the task area, but as a combination of horizontal and vertical illuminances, and hence ambient lighting [3]. Also investigations exist, showing that the interference between the light distribution of the luminaires and suitable reflective properties of the different surfaces in the interior are of great importance for achieving the quality of the indoor lighting [4]. According to [5], the optical properties of the interior surfaces are the main factor that influences the quality and quantity of the indoor lighting systems.

Often in the design phase of the lighting systems, the surfaces are not described with their true reflective and optical parameters, which sometimes leads to significant difference in the designed and real illuminance values, glare and uniformity of the indoor illuminance.

Except for the reflective properties of the indoor surfaces, the light distribution of the luminaire itself should also be considered. Most of the LED luminaires have Lambertian light distribution, although some producers have introduced also near to batwing light distribution curves. Both light distributions are acceptable for indoor applications, but the lighting quality evaluated by means of glare and uniformity of the illuminance appear to be different.

Another consideration about the quality of the lighting system is the color rendering. It is interesting to observe the change of the spectral distribution and color rendering index when the correlated color temperature is changed.

According to the requirements of the European Standard EN 12464-1 [6] the recommended values for the useful reflectance of the main indoor surfaces are as following: floor – 0.2 to 0.4; walls 0.5 to 0.8; ceiling: 0.7 to 0.9. Besides these values, however it is important to take in consideration the mirror component of some of the surfaces, not only to consider them diffusively reflective.

2. Experimental setup and analysis

For validation of the results, achieved by the software program used, a real premises have been modelled. First of all the geometry of the laboratory under consideration has been measured as well as the reflectance coefficients and color coordinates of the surfaces of all the objects situated in the room. The total area of the room is 78,5 m^2, with height of 3 m, length of 10,6 m and width of 7,4 m. The coordinates and surfaces of the existing luminaires have been considered and exactly modelled. The lighting installation consists of six LED luminaires, dimmable and with tunable correlated color temperature. Each luminaire is with electric power of 50 W and luminous flux of 6000 lm. The values of the reflectance coefficients of the indoor surfaces estimated by means of their color coordinates, evaluated by ColorStriker Colorimeter. The test room with its floor plan are shown on Figure 1.

Figure 1. Geometry of the test room

The estimation of the optical reflectance behavior of the different interior components was made by a specific experimental setup [7].

The coefficients of reflectance and color coordinates of the room surfaces are given in table 1.

Table 1 Reflectance and color coordinates of the room surfaces

	Reflection faktor	Red	Green	Blue
Ceilings	70	229	228	221
Walls	71	238	230	207
Floors	29	165	152	135
Chairs	18	170	112	53
Student’s desks	35	148	175	157
Teacher‘s desk	9	111	86	64
Desks	28	188	144	102
Window frames	10	0	103	104
Board	68	225	226	219
Sphere	17	115	121	111

In order to make a detailed analysis of the relationship between reflective properties of the room surfaces and the light distribution of the luminaires used, on the illuminance on the working plane and the quality of lighting by means of glare and color rendering a simulation model of the room under consideration has been made in DIALUX EVO Software [8]. The simulation model is shown on Figure 2.

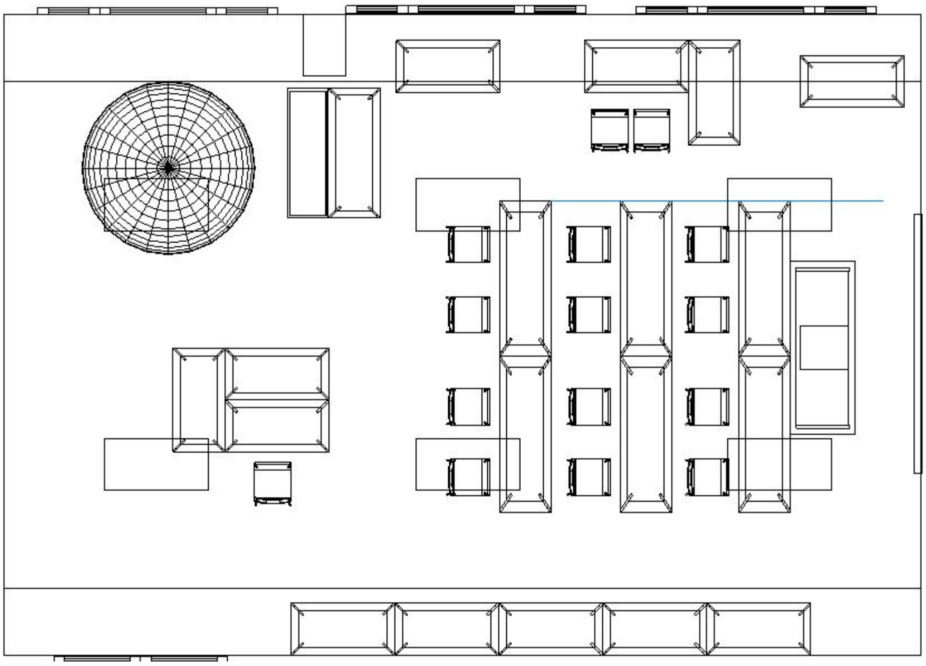

Figure 2. Simulation model of the test room

This software gives the opportunity for simulation, calculation and visualization of the lighting conditions in 3D. The parameters that are varied in the current research are first the light distribution curves of the luminaires (keeping their geometry the same) using the measured values of the reflectance coefficients and color coordinates of the room surfaces. After achieving “best” (in terms of lighting quality – minimum glare, maximum uniformity and norm illuminance) light distribution, it is kept the same and the reflective properties of the room surfaces, as well as their colors are varied until the higher level of illuminance is achieved, keeping the quality of lighting. The reflectance coefficients of the surfaces are varied as following: floor – from 0.1 to 0.7, walls – from 0.3 to 0.9 and ceiling – from 0.5 to 0.9. The reflectance range of the surfaces is according to the requirements of the European Standard [6]. The results are systemized and shown on Figure 3 and Table 2, 3.

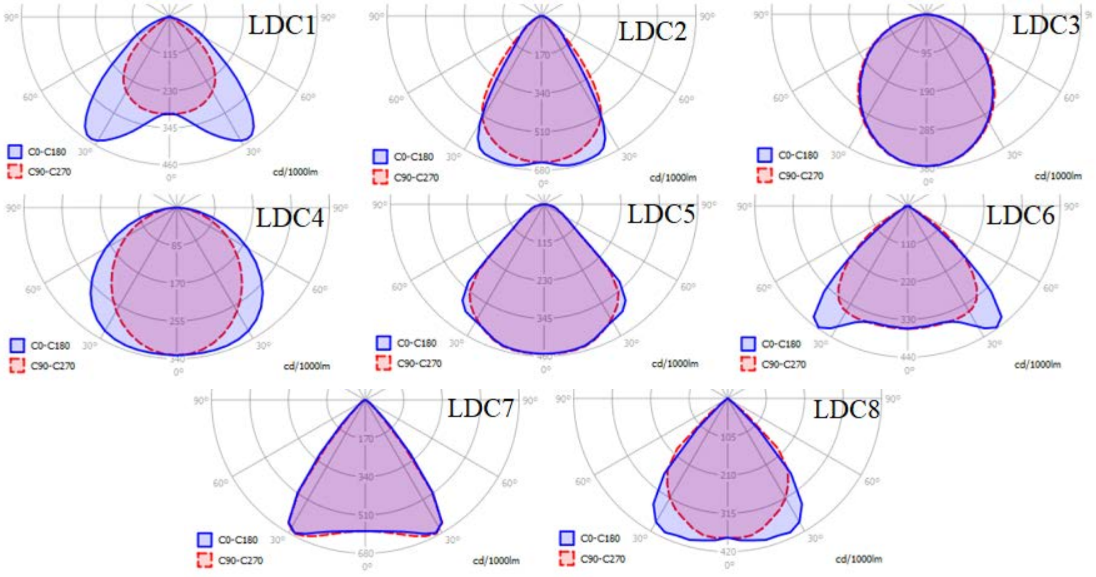

Figure 3 Light Distribution curves considered in the current investigation

It is obvious from Table 2, that the best lighting parameters are realized by means of light distribution curve (LDC) 6.

Table 2 Illuminance, uniformity and UGR, achieved for the chosen light distributions

	Eav, lx	Uo	UGR
LDC 1	385	0,5	16,3
LDC 2	418	0,22	13,6
LDC 3	368	0,41	17
LDC 4	362	0,44	16,4
LDC 5	395	0,37	14,6
LDC 6	399	0,51	16,9
LDC 7	430	0,18	15,4
LDC 8	393	0,31	13,7

Table 3 Illuminance, uniformity and UGR, achieved for the chosen light distributions

Reflectance of the ceiling = 90%					Reflectance of the ceiling = 80%					Reflectance of the ceiling = 70%					Reflectance of the ceiling = 60%					Reflectance of the ceiling = 50%				
Reflectance of the walls, %	Reflectance of the floor, %	Uo	Eav, lx	UGR	Reflectance of the walls, %	Reflectance of the floor, %	Uo	Eav, lx	UGR	Reflectance of the walls, %	Reflectance of the floor, %	Uo	Eav, lx	UGR	Reflectance of the walls, %	Reflectance of the floor, %	Uo	Eav, lx	UGR	Reflectance of the walls, %	Reflectance of the floor, %	Uo	Eav, lx	UGR
90	70	0,54	489	15,6	90	70	0,54	467	15,9	90	70	0,54	449	16,1	90	70	0,53	432	16,4	90	70	0,53	417	16,6
	60	0,54	471	15,9		60	0,53	453	16,1		60	0,53	438	16,3		60	0,52	423	16,5		60	0,52	410	16,7
	50	0,53	456	16,1		50	0,53	440	16,3		50	0,52	427	16,5		50	0,52	415	16,7		50	0,52	403	16,9
	40	0,52	442	16,3		40	0,52	429	16,5		40	0,52	417	16,6		40	0,52	406	16,8		40	0,52	397	17
	30	0,52	429	16,5		30	0,52	418	16,7		30	0,52	408	16,8		30	0,52	399	17		30	0,51	390	17,1
	20	0,52	417	16,7		20	0,51	408	16,8		20	0,51	399	17		20	0,49	392	17,1		20	0,51	385	17,3
	10	0,51	406	16,9		10	0,51	398	17		10	0,49	392	17,1		10	0,49	385	17,3		10	0,49	379	17,4
80	70	0,53	474	15,8	80	70	0,53	455	16,1	80	70	0,52	439	16,3	80	70	0,52	424	16,5	80	70	0,52	411	16,7
	60	0,52	459	16,1		60	0,52	443	16,3		60	0,52	429	16,5		60	0,52	416	16,6		60	0,51	404	16,8
	50	0,52	445	16,3		50	0,52	432	16,4		50	0,51	419	16,6		50	0,51	408	16,8		50	0,51	398	17
	40	0,52	433	16,5		40	0,51	421	16,6		40	0,51	410	16,8		40	0,51	401	16,9		40	0,49	392	17,1
	30	0,51	421	16,6		30	0,51	411	16,8		30	0,51	402	16,9		30	0,49	394	17,1		30	0,49	386	17,2
	20	0,51	410	16,8		20	0,51	402	17		20	0,49	394	17,1		20	0,49	387	17,2		20	0,49	381	17,3
	10	0,51	400	17		10	0,49	393	17,1		10	0,49	387	17,2		10	0,49	381	17,3		10	0,48	376	17,5
70	70	0,52	462	16	70	70	0,52	445	16,2	70	70	0,51	430	16,4	70	70	0,51	417	16,6	70	70	0,51	404	16,8
	60	0,51	449	16,2		60	0,51	434	16,4		60	0,51	421	16,6		60	0,51	409	16,8		60	0,51	398	17
	50	0,51	436	16,4		50	0,51	424	16,6		50	0,5	412	16,8		50	0,5	402	16,9		50	0,49	393	17,1
	40	0,51	425	16,6		40	0,5	414	16,8		40	0,5	404	16,9		40	0,49	395	17		40	0,49	387	17,2
	30	0,5	414	16,8		30	0,5	405	16,9		30	0,49	396	17		30	0,49	389	17,2		30	0,48	382	17,3
	20	0,5	404	17		20	0,48	396	17,1		20	0,48	389	17,2		20	0,48	383	17,3		20	0,48	377	17,4
	10	0,48	394	17,1		10	0,48	388	17,2		10	0,48	383	17,3		10	0,48	377	17,4		10	0,48	373	17,5
60	70	0,51	451	16,2	60	70	0,51	436	16,4	60	70	0,51	423	16,6	60	70	0,51	410	16,8	60	70	0,49	399	17
	60	0,51	439	16,4		60	0,5	426	16,6		60	0,5	414	16,7		60	0,49	403	16,9		60	0,49	393	17,1
	50	0,5	428	16,6		50	0,5	417	16,7		50	0,5	406	16,9		50	0,49	397	17		50	0,48	388	17,2
	40	0,5	417	16,7		40	0,5	407	16,9		40	0,49	399	17		40	0,49	391	17,2		40	0,48	383	17,3
	30	0,5	407	16,9		30	0,49	399	17		30	0,48	392	17,2		30	0,48	385	17,3		30	0,48	378	17,4
	20	0,48	398	17,1		20	0,48	391	17,2		20	0,48	385	17,3		20	0,48	379	17,4		20	0,47	374	17,5
	10	0,48	390	17,2		10	0,48	384	17,3		10	0,47	379	17,4		10	0,47	374	17,5		10	0,47	369	17,6
50	70	0,5	442	16,4	50	70	0,5	428	16,6	50	70	0,5	416	16,7	50	70	0,49	404	16,9	50	70	0,48	394	17,1
	60	0,49	431	16,5		60	0,49	419	16,7		60	0,49	408	16,9		60	0,48	398	17		60	0,48	389	17,2
	50	0,49	421	16,7		50	0,49	410	16,9		50	0,49	400	17		50	0,48	392	17,2		50	0,48	384	17,3
	40	0,49	410	16,9		40	0,49	402	17		40	0,48	393	17,1		40	0,48	386	17,3		40	0,48	379	17,4
	30	0,48	401	17		30	0,48	394	17,2		30	0,48	387	17,3		30	0,48	381	17,4		30	0,47	375	17,5
	20	0,48	393	17,2		20	0,48	387	17,3		20	0,48	381	17,4		20	0,47	376	17,5		20	0,47	371	17,6
	10	0,48	385	17,4		10	0,47	380	17,4		10	0,47	375	17,5		10	0,47	371	17,6		10	0,47	367	17,7
40	70	0,49	433	16,5	40	70	0,49	421	16,7	40	70	0,49	409	16,9	40	70	0,48	399	17	40	70	0,48	389	17,2
	60	0,49	423	16,7		60	0,49	412	16,8		60	0,49	402	17		60	0,48	393	17,2		60	0,48	384	17,3
	50	0,49	413	16,8		50	0,48	404	17		50	0,48	395	17,1		50	0,48	387	17,3		50	0,47	380	17,4
	40	0,48	404	17		40	0,48	396	17,1		40	0,48	389	17,3		40	0,47	382	17,4		40	0,47	376	17,5
	30	0,48	396	17,2		30	0,48	389	17,3		30	0,47	383	17,4		30	0,47	377	17,5		30	0,47	372	17,6
	20	0,47	388	17,3		20	0,47	383	17,4		20	0,47	377	17,5		20	0,47	372	17,6		20	0,46	368	17,7
	10	0,47	381	17,5		10	0,47	376	17,5		10	0,47	372	17,6		10	0,46	368	17,7		10	0,46	364	17,8
30	70	0,49	426	16,7	30	70	0,48	414	16,8	30	70	0,48	403	17	30	70	0,48	394	17,2	30	70	0,48	385	17,3
	60	0,49	416	16,8		60	0,48	406	17		60	0,48	397	17,1		60	0,48	388	17,3		60	0,48	381	17,4
	50	0,48	407	17		50	0,48	399	17,1		50	0,48	391	17,3		50	0,47	383	17,4		50	0,47	376	17,5
	40	0,48	399	17,1		40	0,48	391	17,3		40	0,47	385	17,4		40	0,47	378	17,5		40	0,47	372	17,6
	30	0,48	391	17,3		30	0,47	385	17,4		30	0,47	379	17,5		30	0,47	374	17,6		30	0,46	369	17,7
	20	0,47	384	17,4		20	0,47	379	17,5		20	0,47	374	17,6		20	0,46	369	17,7		20	0,46	365	17,8
	10	0,47	377	17,6		10	0,46	373	17,6		10	0,46	369	17,7		10	0,46	365	17,8		10	0,46	361	17,9

In order to validate the accuracy of the model, the illuminance is measured in the real room and then it is compared to the results, given by the software. The measurement of the illuminance is made in a grid, corresponding to the requirements of EN 12464-1 at the height of the working plane – 0.8m from the floor. The measurement has been carried out with a strictly calibrated for measurement of LED light sources Extech Color LED Light Meter LT 45. A comparison between the measured and simulated illuminance has been made and the results from it are shown on Fig. 4

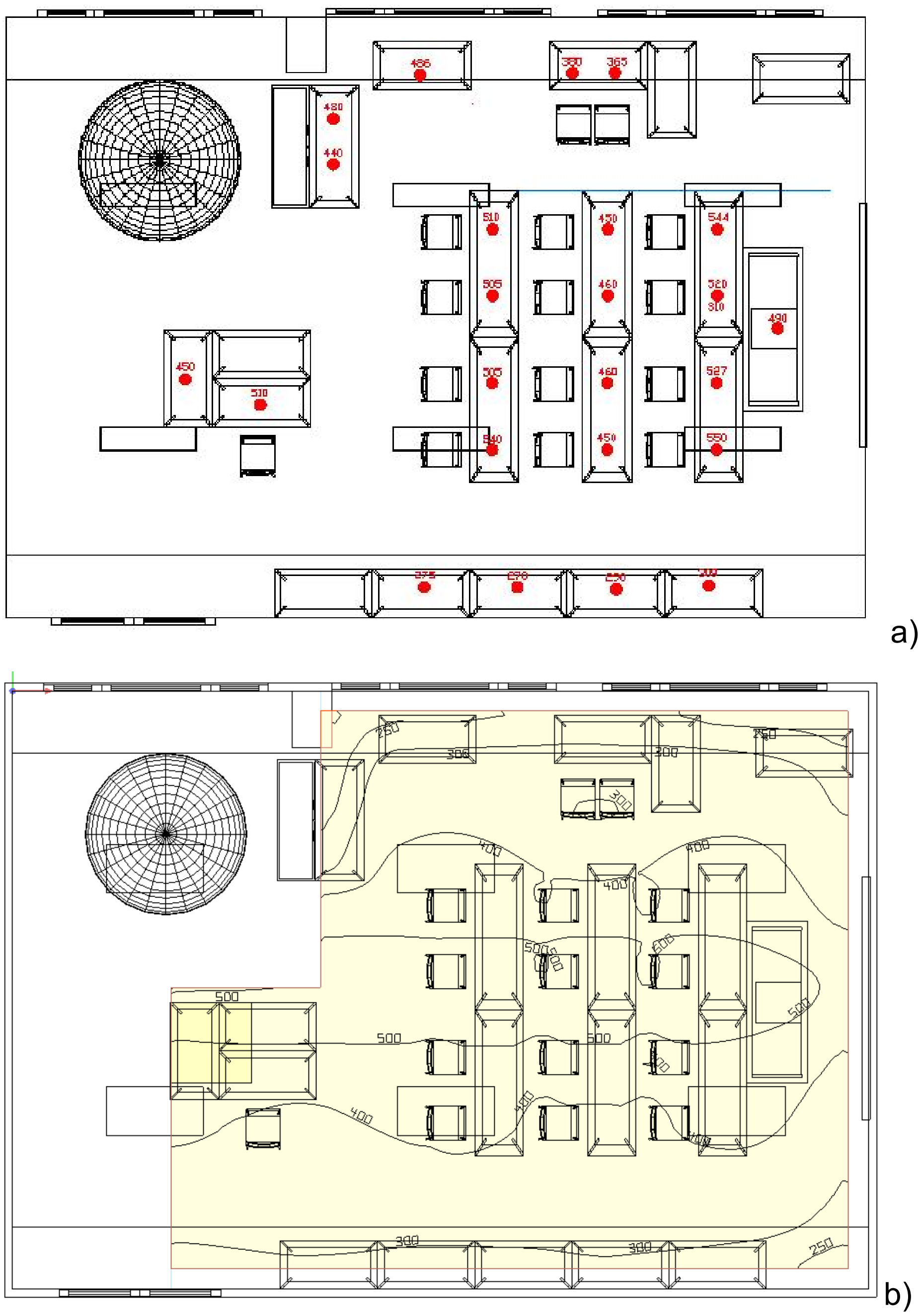

Figure 4 a) Measured values of the horizontal illuminance on the working places, b) simulated isolux curves in the test room

3. Analysis of the results

From the results obtained, as well as based on previous experience, it is obvious that the “best” light distribution (when it comes to quality of the lighting and its uniformity) is the batwing light distribution – fig. 3. The estimation of the quality of the lighting system is made according to EN 12464 – 1 – the unified glare rating and the uniformity of the illuminance on the working plane are calculated for the different light distributions considered in the current paper. These parameters also change when the reflective coefficients of the room surfaces change – Table 4. The highest the reflection coefficients of all surfaces, the higher the illuminance on the work plane and the uniformity and also the lowest the UGR is. Care should be taken about the texture of the surfaces and their mirror reflection.

4. References

[1] Linhart F, JL.Scartezzini, Evening office lighting–visual comfort vs. energy efficiency vs. performance? Build. Environ. 2011: 46(5):981-989, 2011

[2] Mangkuto RA., M. Rohmah, D. Asri, Design Optimization for window size, orientation, and wall reflectance with regard to various daylight metrics and lighting energy demand: A case study of buildings in the tropics, Appl. Energy. 2016:164:211-219, 2016

[3] Loe DL., Energy efficiency in lighting—considerations and possibilities. Lighting Res. Technol. 2009:41(3):209-218, 2009

[4] Reinhart CF. Effects of interior design on the daylight availability in open plan offices. In: ACEEE Summer Study on Energy Efficiency in Buildings 2002:309-322, 2002

[5] Singh R, R. Rawal, Effect of surface reflectance on lighting efficiency in interiors. In 12th Conference of International Building Performance Simulation Association, Sydney, Australia. 2011:2301-2308, 2011

[6] EN 12464-1:2011, Light and lighting - Lighting of work places - Part 1: Indoor work places, 2011

[7] Petrinska I., Estimation of the Reflectance Properties of Real Materials Used for Buildings' Facades, Proceedings of the Technical University-Sofia, v.66, book 3, pp. 223-229, 2016

[8] www.dialux.de