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Energy efficient lighting system retrofit for retail environments

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Abstract

Lighting retrofit in retail environments is essential and is often necessitated in order to improve the retail atmosphere, increase energy efficiency and provide visual comfort conditions. This study introduces the lighting design criteria for retail environments in terms of visual comfort conditions and lighting energy efficiency and investigates a retail lighting retrofit application on the example of a department store. Several lighting system design alternatives including diverse lighting technologies are assessed in terms of visual comfort conditions and lighting energy efficiency. Obtained results emphasize that without compromising visual comfort conditions in retail environments, it is possible to obtain significant lighting energy consumption on an annual basis. This study clearly underlines the importance of a proper lighting retrofit project in terms of providing visual comfort conditions and lighting energy efficiency.

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Keywords
Retail lighting, Lighting system retrofit, Retail environments, Visual comfort, Energy efficient lighting.

1. Introduction

Retail environments are of the building typologies where the relationship between human factors and lighting conditions are linked closely. The role of lighting in retail environments is to attract the eye, to illuminate the merchandise, to excite the shopper and to reinforce the shopper's sense of value and price point (Karlen & Benya, 2004). Quantitative and qualitative perspectives in retail lighting design help to attract the customers and their experience in the built environment. In the literature there are many interdisciplinary studies investigating the effect of lighting on visual comfort conditions, space perception, visual stimulus, spatial cognition, user behaviour for the retail environments as well as energy efficiency.

In a study by Custers, lighting attributes and interior qualities are related to perceived atmosphere and lighting is found to play a significant role in creating an ambiance in retail environments (Custers, P.J.M. et al. 2010). Similarly, Schielke states that different lighting concepts can also help to shape different image in terms of corporate identity for retail environments and lighting can also be used for brand communication in order to define the image of a company more clearly (Schielke, 2010). Lighting design and color scheme are other contributing factors to the brand image (Kutlu, Manav & Kılanç, 2013). Different retail environment characteristics can be obtained by the help of diverse lighting strategies and lighting has a direct influence on the perception of atmosphere (Quartier, 2011; Quartier, Vanrie & Van Cleempoel, 2014). Flexible retail lighting system design is essential since retail environments are open to changes concerning the rapid improvement of lighting technology and variations in brand communication.

An appropriate lighting design in retail buildings should provide visual comfort conditions and reduce lighting energy requirements, environmental impact and lighting costs. A proper retail lighting design concept also helps to create a suitable corporate identity and communication. The European Standard 'EN 12464-1 Light and Lighting -Lighting of Work Places -Part 1: Indoor Work Places' defines lighting requirements that should be followed in order to obtain proper lighting solutions and gives guidance on visual comfort conditions for different space types. This standard specifies requirements for lighting solutions in retail spaces and their associated areas in terms of quantity and quality of illumination as well as giving recommendations for better lighting practice (EN 12464-1, 2011). According to the Society of Light and Lighting Handbook, lighting has four major roles in retail premises that are to attract attention, to send a message to shoppers about the atmosphere of the shop, to guide shoppers around the shop and to display the merchandise to advantage (Society of Light and Lighting, 2009). The IESNA Lighting Handbook states that lighting for retail spaces should help to create an atmosphere emphasizing the space character, make a desirable place in which to shop, permit accurate examination of the features and qualities of the merchandise and minimize glare and harsh brightness differences (IESNA, 2011).

Sustainability is increasingly important in retail lighting design due to the dwindling energy resources, rising energy costs and the negative impact of energy consumption on nature. In Europe, The Energy Performance of Buildings Directive (EPBD) 2002/91/EC requires all EU countries to enhance their building regulations in order to monitor and reduce energy consumption. Additionally, recent EPBD Recast 2010/31/EU Directive is aimed at building professionals to design or renovate buildings to a nearly zero energy use state (European Commission, Directive 2010/31/EU, 2010). Energy performance assessment of buildings in Europe is performed using several methodologies in the frame of the developed standards. Retail sector consumes a significant amount of lighting energy due to long opening hours and reducing lighting energy consumption and CO_2 emissions in retail buildings is essential. Energy is often wasted due to a lack of appropriate control strategies and improper choice of lamps and luminaires (Ticleanu, Littlefair

Table 1. *Illuminance criteria for retail environments.*

EN 12464 Standard	**E_m (lx)**					
Sales area	300					
Till area	500					
Wrapper table	500					
SLL Lighting Handbook	**E_m range (lx)**					
budget shops (without accent or display lighting)	500 to 1000 lx.					
shop with an exclusive profile (widespread use of accent and display lighting)	100 to 200 lx.					
shops with value for money and quality profiles (with accent lighting)	250 to 500 lx					
IESNA Lighting Handbook	**Horizontal Illuminance E_h**			**Vertical Illuminance E_v**		
Retail by Classification:	Visual age of observers			Visual age of observers		
	<25	25-65	>65	<25	25-65	>65
Department store (general retail)	200	400	800	75	150	300

& Howlett G., 2013). Achieving these benefits usually requires integration of daylight and artificial light sources during the building design process. The role of daylighting is crucial when reducing the lighting energy requirements in retail buildings therefore the choice of proper daylight strategies becomes necessary in the design phase of retail buildings. There is also evidence that daylight has the potential to increase sales when used in retail buildings (Heschong Mahone Group, 2003). Daylight linked lighting control strategies are also known to be quite effective in decreasing lighting energy use in retail spaces. As well as saving energy, lighting control is important in retail lighting because it provides flexibility, helps to create different working patterns of lighting, and can give dynamic or special lighting effects (Littlefair, 2014).

Lighting retrofit in retail environments is often performed in order to improve the ambiance and corporate identity. A comprehensive lighting retrofit can help to improve the visual comfort conditions as well as providing significant energy savings, controlling the cooling and lighting loads (EERE, 2011). The lighting retrofit schemes are performed by either protecting current lighting system's main features such as the placement and number of the lamps and luminaires or lighting tracks but replacing them with a more efficient technology. Lighting system's re-design can also be applied as a lighting retrofit.

The aim of this study is to provide energy efficient lighting retrofit solutions and to explore the lighting energy saving potential in retail environments while providing visual comfort conditions on the example of a selected department store. Based on a quantitative analysis of a department store lighting retrofit application, different lighting retrofit scenarios are evaluated and obtained results are compared in terms of visual comfort conditions and lighting energy efficiency.

2. Retail lighting design criteria in terms of visual comfort and energy efficiency

In this part of the study, general principles affecting the lighting system design in retail environments is introduced in terms of visual comfort conditions and lighting energy efficiency. Quantitative and qualitative aspects of retail lighting principles and recommendations addressed in international standards are presented in this chapter.

2.1. Visual comfort criteria in retail lighting design

Criteria for visual comfort conditions can be investigated in the aspects of illuminance levels, uniformity, luminance distribution and glare caused by light sources, colour property of the space and light sources.

Illuminance levels: Maintained illuminance level for retail environments differ according to the type of the retail environment. Therefore, lighting design of each retail environment should be performed considering the specific retail environment's requirements and the shop profile. EN 12464 Standard gives recommendations on required illuminance for sales areas, till areas and wrapper tables. In 'SLL Lighting Handbook', illuminance recommendations for retail environments are given depending on the shop profile and in 'The IESNA Lighting Handbook: Reference & Application', space by space classification is performed. Illuminance criteria for department store sale areas given in these publications are presented in Table 1 (EN 12464-1, 2011; IESNA, 2011; Society of Light and Lighting, 2009).

Uniformity: Uniformity is defined as the ratio of the minimum to average illuminance. Uniformity is required in order to supply the visual comfort conditions in spaces and control the occurrence of high contrasts on the interior surfaces. The uniformity criteria given in Table 2 should be fulfilled for the retail environments in order to obtain visually pleasing environments.

Luminance distribution and glare caused by light sources: The luminance distribution in the visual field controls the adaptation level of the eyes, which affects task visibility. Therefore, a well-balanced adaptation luminance is required in order to increase visual acuity, contrast sensitivity and efficiency of the ocular functions (EN 12464-1, 2011). For retail environments, luminance distribution is very effective on the strength of accent lighting where different sorts of luminance ratios can result in diverse strength of accenting. Table 3 gives the luminance ratio and the strength of accent lighting for retail environments (Society of Light and Lighting, 2009).

The luminance distribution in the visual field affects visual comfort conditions. In the lighting design of retail environments, control of glare is a necessity in order to perform the required visual comfort conditions. Glare is the sensation produced by a sufficiently greater luminance within the visual field causing annoyance, discomfort or loss in visual performance and visibility (IESNA, 2011). The assessment of discomfort glare caused directly from the artificial lighting system can be performed using the CIE Unified Glare Rating (UGR) method for the typical field of view directions in the retail space. Maximum UGR limits given for sales areas is 22 and this value is 19 for till and wrapper areas (EN 12464-1, 2011).

Table 2. *Uniformity criteria for retail environments.*

EN 12464 Standard	U_O
Sales area	0,4
Till area	0,6
Wrapper table	0,6
SLL Lighting Handbook	U_O
General recommendation (Regardless of the shop profile)	at least 0.7
IESNA Lighting Handbook (for several shop types)	U_O
Department store (general retail)	0,33-0,66

Colour property of the space and light sources: In the lighting design phase for retail environments, the following aspects should be considered in terms of colour:

- Surface material's colour specifications in retail environments,
- Colour Temperature and Correlated Colour Temparature (CCT),
- Colour Rendering index (Ra).

Colour considerations are determined by the special properties of the displayed merchandise as well as branding characteristics in retail environments. Colour parameter is a factor that affects the lighting performance especially in the finishing material selection phase. Light reflectance

Table 3. *The influence of luminance ratio on the strength of accent lighting (Society of Light and Lighting, 2009).*

Luminance ratio (accent/ background)	**Strength of accenting**
1	None
2	Noticeable
5	Low theatrical
15	Theatrical
30	Dramatic
> 50	Very dramatic

value of the surface materials should be selected studiously depending on the displayed merchandise, branding characteristics. The ranges of useful reflectances for the major interior surfaces are 70% - 90% for ceiling, 50% - 80% for wall, 20% - 40% for floor (EN 12464-1, 2011).

Colour temperature selection of lamp sources depend on classification of retailer, quality of merchandise, client preference and designer preference (IESNA, 2011). It is common that the colour appearance of the light sources used in retail environments change from cool to warm as the shop profile moves from low budget to exclusive (Ticleanu, Littlefair & Howlett G., 2013). The correlated colour temperature (CCT) of a light source determines whether it looks 'warm' or 'cool'. As for colour appearance, a light source with a correlated colour temperature (CCT) ≤ 3000 K will appear warm and if it has a CCT ≥ 5300 K it will appear cool, if the CCT is in between 3300 and 5300, it is considered 'intermediate' (Society of Light and Lighting, 2009, EN 12464-1, 2011). To provide an objective indication of the colour rendering properties of a light source the general colour rendering index Ra is used, having a maximum value of 100. The minimum value of colour rendering index given in lighting standards and international lighting recommendations for retail environments is '80' but this value can be higher when colour judgment is crucial (EN 12464-1, 2011; IESNA, 2011; Society of Light and Lighting, 2009).

2.2. Energy efficiency criteria in retail lighting

Lighting design phase should represent a major route to reducing lighting energy consumption and CO2 emissions in buildings. It is known that retail sector consumes significant portion of the energy used in the buildings so it is important to minimise the lighting energy requirements in retail environments. Lighting retrofits in retail buildings often concentrate on minimisation of lighting energy consumption. In the design of lighting retrofit applications for retail environments, selection of appropriate lamps, luminaires and lighting control strategies is essential.

In Europe, lighting energy requirements of buildings are performed with the methodology described in EN 15193 Energy performance of buildings - Energy requirements for lighting European Standard. In cases where the detailed artificial lighting system specifications are not present, the recommendations given for lighting power density (LPD) in ANSI/ASHRAE/IESNA and EN 15193 standards guide the lighting designer to propose energy efficient lighting retrofit projects (EN 15193, 2007; ANSI/ASHRAE/IESNA, 2013).

Lighting Power Density (LPD) criteria for retail environments: Lighting Power Density (LPD) represent the installed power per area (W/m^2) and this value defines benchmark criteria for retail environments in terms of lighting energy efficiency. Limiting LPD value given in ANSI/ASHRAE/IESNA Standard is 13,56 W/m^2 for retail environments (ANSI/ASHRAE/IESNA, 2013). EN 15193 Standard recommendations for installed power per area depend on the fulfillment of requirements in the evaluated retail spaces. According to this standard, basic fulfillment of requirements represents the conditions where maintained illuminance on horizontal visual tasks, appropriate control of discomfort glare (UGR) and avoidance of flicker and stroboscopic effects are supplied according to EN 12464 Standard. For basic fulfillment of requirements, recommended LPD criteria is given as 15 W/m^2 for retail environments in EN 15193 (EN 15193, 2007).

Lighting energy performance for retail environments: EN 15193 Energy Performance of Buildings - Energy Requirements for Lighting Standard specifies a calculation methodology for evaluation of the amount of energy used for indoor lighting inside the building and provides a Lighting Energy Numeric Indicator (LENI) for certification purposes (EN 15193, 2007). In order to calculate lighting energy requirement in buildings, energy requirement used for illumination (kWh) and luminaire parasitic energy requirement must be summed.

Energy requirement used for illumination ($W_{L,t}$) is calculated depending on the methodology specified in EN 15193 Standard based on P_n-total installed lighting power (W), F_c - Constant illuminance factor, tD - Daylight time usage (h), t_N - Non-daylight time usage (h), F_o -Occupancy dependency factor and F_D - Daylight dependency factor (EN 15193, 2007). Luminaire parasitic energy consumption ($W_{P,t}$) assumptions given in EN 15193 Standard are 1 kWh/(m^2/year) for presence of emergency lighting and 5 kWh/(m^2/year) for presence of lighting control systems.

To quantify the lighting energy use, the EN 15193 standard specifies a calculation methodology for the Lighting Energy Numeric Indicator (LENI) in buildings, which can be used for existing buildings and for the lighting retrofit applications. LENI values can be calculated by total annual lighting energy requirement (W_t) per total area (m^2). LENI benchmark values given for the retail buildings are 78.1 kWh/(m^2/year) for conditions without constant illuminance lighting control system and 70.6 kWh/(m^2/year) for presence of constant illuminance lighting control system (EN 15193, 2007).

3. Retail lighting retrofit application for a department store case study

This section focuses on development of different lighting retrofit applications for a department store example and assessment of obtained visual comfort conditions and lighting energy performance for each evaluated scenario. In this part of the study, evaluated department store is described; baseline artificial lighting system alternatives are introduced and proposed lighting retrofit schemes are evaluated in terms of visual comfort conditions and lighting energy efficiency.

3.1. Description of the investigated department store, lighting patterns and evaluated lighting system alternatives

In this chapter, description of the investigated department store is performed and baseline artificial lighting system alternatives are presented.

Figure 1. Plan, sections and model of the investigated department store.

3.1.1 Description of the investigated department store

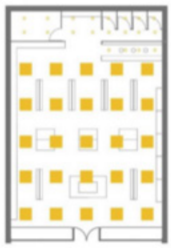
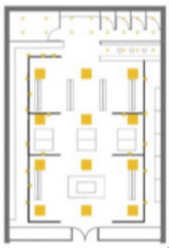
Selected space type is a hypothetical department store clothes shop having a shop type of 'shops with value for money and quality profiles'. The space has a grid plan with dimensions of 10 m x 15 m and a height of 3.5 m. Light reflectance of the selected space are 70% for ceiling, 50%, for walls and 20% - for floor. The space has a total area of 150 m^2 containing sales area, till area, four fitting rooms and a storage room. This space is assumed to be situated in a shopping mall in Istanbul without direct access to daylighting. Figure 1 shows the plan layout (Figure 1.a) and two sections (Figure 1. b, c) and a model (Figure 1. d) of the investigated space.

3.1.2. Description of lighting system patterns

Different artificial lighting system patterns are considered in this study depending on the use of "general lighting", "general and accent lighting" and "accent lighting". In this regard, five different layouts are generated depending on the use of most frequently observed lighting system installations in clothes shop retail environments with value for money and quality profiles. These installations consist of:

- use of square - recessed luminaires only,
- use of circular recessed downlight luminaires only,
- use of square - recessed luminaires and spotlights,
- use of recessed downlight luminaires and spotlights,

Table 4. *Baseline artificial lighting system design alternatives.*

General lighting		General and accent lighting		Accent lighting
A	B	C	D	E
Use of square - recessed luminaires only	Use of circular recessed downlight luminaires only	Use of square - recessed luminaires and spotlights	Use of recessed downlight luminaires and spotlights	Use of spotlights only
				
				

- use of spotlights only.

Table 4 gives information on the evaluated artificial lighting systems patterns, their representative images and lighting plans. While generating the artificial lighting system patterns, changes for the sales area only is considered and the lighting system of the fitting rooms, storage and till area supplied by 20 recessed downlight luminaires equipped with compact fluorescent lamps (TC-T, 18 W) is kept constant.

3.1.3. Description of the evaluated lighting system alternatives

In this part of the study, the artificial lighting retrofit scenarios for the evaluated baseline artificial lighting system alternatives are introduced. Diverse artificial lighting system retrofit applications are proposed for baseline scenarios A1, B1, C1, D1 and E1 so that they are upgraded with a more energy efficient artificial lighting system having lower installed power compared to the baseline scenarios. Table 5 represents the information for baseline artificial lighting system designs and artificial lighting retrofit alternatives. In Table 6, information on the lamps and luminaires used in baseline lighting designs and proposed artificial lighting retrofit alternatives are given where each luminaire is given a name (L1, L2, L3, L4, L5, L6, L7).

Scenario A1 (use of square - recessed luminaires only) represent the conditions where a total of 25 suspended ceiling mounted square - recessed luminaires with diffuser equipped with fluorescent lamps (T16, 2x24W) are used in the sales area. In this respect, the lighting retrofit scenario for A1 is generated so that the square - recessed luminaires equipped with florescent lamps (having 49W luminaire power each) are replaced with a more energy efficient LED system (with a luminaire power of 19,6 W each) and this scenario is given the name A2.

In *Scenario B1* (use of circular recessed downlight luminaires only) the sales area is illumnated with 35 recessed downlight luminaires equipped with 2xPL-C/2P18W compact fluorescent lamps. The upgrade of B1 baseline scenario is performed by replacing the circular recessed downlight luminaires equipped with compact florescent lamps (having 50,6 W luminaire power each) with LED luminaires having a lower installed power of 30 W.

Scenario C1 (use of square - recessed luminaires and spotlights) considers the use of 12 suspended ceiling mounted square - recessed luminaires with diffuser equipped with fluorescent lamps (T16, 2x24W) together with 25 adjustable halojen spotlights (CDM, 45W). Three different lighting retrofits are proposed as alternatives to Scenario C1:

Table 5. *Baseline artificial lighting system designs and artificial lighting retrofit alternatives.*

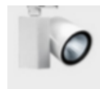
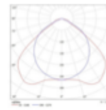
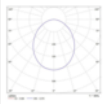
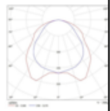
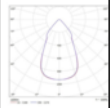
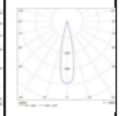
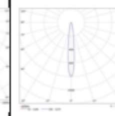
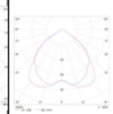
Scenario codes		Scenario names	Type and number of luminaires
A	A1	use of 25 square - recessed luminaires equipped with flurescent lamps	25 L1+ 20 L7
	A2	use of 25 square - recessed luminaires equipped with LEDs	25 L2+ 20 L7
B	B1	use of 35 circular recessed downlight luminaires equipped with compact flurescent lamps	35 L3 + 20 L7
	B2	use of 35 circular recessed downlight luminaires equipped with LEDs	35 L4 + 20 L7
C	C1	use of 12 square - recessed luminaires equipped with flurescent lamps and 25 halogen spotlights	12 L1+ 25 L5 + 20 L7
	C2	use of 12 square - recessed luminaires equipped with LED lamps and 25 halogen spotlights	12 L2 +25 L5 + 20 L7
	C3	use of 12 square - recessed luminaires equipped with flurescent lamps and 25 LED spotlights	12 L1 + 25 L6 +20 L7
	C4	use of 12 square - recessed luminaires equipped with LEDs and 25 LED spotlights	12 L2 +25 L6 +20 L7
D	D1	use of 25 recessed downlight luminaires equipped with compact fluorescent lamps and 18 halogen spotlights	25 L3 + 18 L5 +20 L7
	D2	use of 25 recessed downlight luminaires equipped with LEDs and 18 halogen spotlights	25 L4 + 18 L5 +20 L7
	D3	use of 25 recessed downlight luminaires equipped with compact fluorescent lamps and 18 LED spotlights	25 L3 + 18 L6 +20 L7
	D4	use of 25 recessed downlight luminaires equipped with LEDs and 18 LED spotlights	25 L4 + 18 L6 +20 L7
E	E1	use of 61 adjustable halojen spotlights	61 L5 + 20 L7
	E2	use of 50 adjustable LED spotlights	50 L6+20 L7

- In lighting retrofit scenario -C2, use of 12 square - recessed luminaires equipped with LED lamps (with a luminaire power of 19,6 W each) and 25 halogen spotlights (having a luminaire power of 45 W) is proposed
- In lighting retrofit scenario C3, 12 square - recessed luminaires equipped with florescent lamps (used in Scenario C1) and 25 LED spotlights (having a luminaire power of 12 W each) are used together.
- In lighting retrofit scenario C4, all the downlights and spotlights in the sales area is replaced with an energy efficient LED system (using 12 LED-based downlight luminaires having a lower installed power of 30 W each and 25 LED spotlights having a luminaire power of 12 W each.

In *Scenario D1* (use of recessed downlight luminaires and spotlights), 25 recessed downlight luminaires equipped with 2xPL-C/2P18W compact fluorescent lamps are used together with 18 adjustable halojen spotlights (CDM, 45W). Three different lighting retrofits are proposed as alternatives to this scenario:

- Lighting retrofit scenario -D2 considers the use of 25 recessed downlight luminaires equipped with LEDs (having an installed power of 30 W each) together with 18 halogen spotlights (having a luminaire power of 45 W).
- In lighting retrofit scenario-D3, use of 25 recessed downlight luminaires equipped with compact fluorescent lamps (50,6 W luminaire power each) together with 18 LED spotlights (having a luminaire power of 12 W each).
- Lighting retrofit scenario-D4 considers the replacement of all luminaires with a more energy efficient artificial lighting system and in this scenario, use of 25 recessed downlight luminaires equipped with LEDs (having an installed power of 30 W each) and 18 LED spotlights (with a luminaire power of 12 W each) are used together.

Table 6. *Information on the lamps and luminaires used in baseline lighting designs and proposed artificial lighting retrofit alternatives.*

	L1	L2	L3	L4	L5	L6	L7
Lamp type	Fluorescent lamps (T16, 2x24W)	Low power LED (LP, 19,6 W)	Compact fluorescent (2xPL-C/2P18W)	LED (Oslon, 30W)	Halojen (CDM, 45W)	LED	Compact fluorescent (TC-T, 18 W)
Lamp luminous flux (lm)	3500 lm	2600 lm	2400 lm	1600 lm	840 lm	1500 lm	1200 lm
Luminaire type	Square - recessed luminaires with diffuser	Square - recessed luminaires with diffuser	Recessed downlight luminaires	Recessed downlight luminaires	Adjustable spotlight	Adjustable spotlight	Recessed downlight luminaires
Luminaire luminous flux (lm)	2657 lm	2582 lm	1896 lm	1600 lm	840 lm	1108 lm	1000 lm
Luminaire wattage (W)	49 W	19,6 W	50,6 W	30 W	45 W	12 W	19 W
Luminaire image							
Luminaire luminous intensity distribution							
Ra	≥80	≥80	≥80	≥80	≥80	≥80	≥80
UGR	<22	<22	<22	<22	<22	<22	<22

Scenario E1 represents the conditions where the department store sales area is illuminated with 61 adjustable halojen spotlights (CDM, 45W). The number of selected luminaires for each scenario are determined depending on fulfilling the visual comfort conditions for the selected retail environment. Lighting system retrofit scenario-E2 represents the conditions where 61 halogen spotlights used in scenario E1 are replaced with LED spotlights and the number of luminaires are reduced to 50, providing the visual comfort conditions addressed in EN 12464 Standard.

3.2. Visual comfort performance determination of lighting design walternatives

Visual comfort performance determination of the investigated department store is performed considering the benchmark values specified in EN 12464 Standard and IESNA recommendations. In order to assess the visual comfort conditions, the baseline scenarios and lighting retrofit alternatives are modelled on a computational basis and necessary calculation of each lighting design alternative is obtained in an accredited lighting simulation software- Dialux (CIE Publication, 2006; Dialux, 2009). The assessment of visual comfort conditions are performed on a horizontal workplane (h1) with a height of 80 cm and on 15 vertical workplanes (v1-v15), considering the placement of the exhibited merchandise. The width of the vertical workplane are 1 m, and the length is 10 m for v1, 2.3m for v2, 7,6m for v11 and 2 m for the rest of the vertical workplanes. Figure 2 illustrates the layout of 16 workplanes within the investigated department store in each lighting design scheme.

3.2.1. Assesment of illuminance

Assesment of illuminance is performed on the horizontal workplane (h1) and vertical workplanes (v1-15) in the investigated department store.

Horizontal illuminance calculations are performed on h1 workplane for each scenario and obtained illuminance maps are presented in Figure 3.

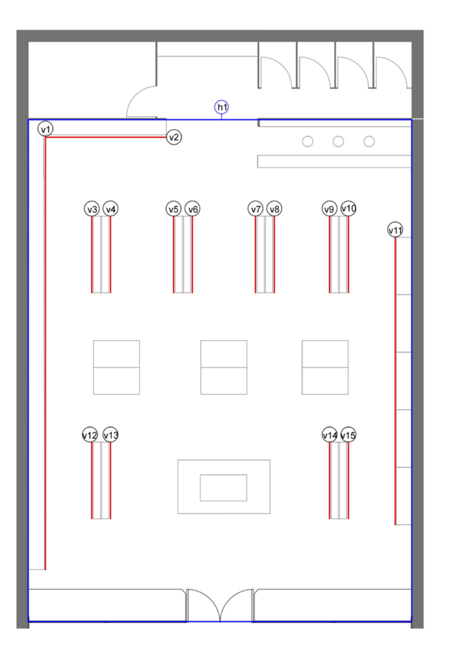


Figure 2. *Illustration of calculation workplanes for the investigated space.*

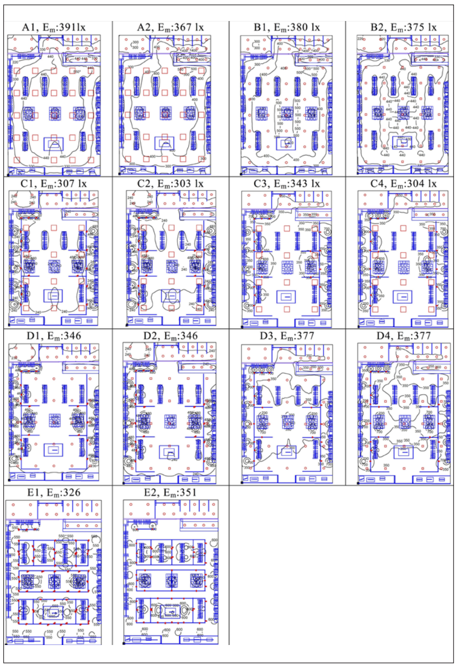


Figure 3. *Illuminance maps for evaluated baseline and lighting retrofit scenarios.*

Figure 4 gives the results of calculated E_m values on the horizontal workplane (h1) in a graphical expression. It is clear from the results that all the baseline lighting system scenarios and lighting retrofit applications fulfil the minimum requirement of 300 lx for horizontal workplanes in retail environments as specified in EN 12464 Standard.

Vertical illuminance calculations (v1-v15) are performed and average illuminance results are obtained as given in Table 7. Results indicate that a minimum average illuminance-100 lx as specified in IESNA recommendations are provided for each baseline scenario and lighting retrofit.

Determination of *minimum illuminance* is essential in order to evaluate the distribution of illuminance within the task workplanes and calculation of uniformity levels. Therefore, minimum illuminance values are calculated on the horizontal workplane (h1) and vertical workplanes (v1-15). In Figure 5, calculated minimum illuminance values on the h1 workplane are given. Table 8 gives the results of obtained minimum vertical illuminance calculation results on the vertical workplanes (v1-v15).

Assessment of illuminance results clearly underline that horizontal and vertical illuminance obtained in the workplanes fulfil the required criteria given for retail environments. Table 9 summarises the evaluated scenarios illuminance calculation results in terms of horizontal and vertical illuminance criteria.

3.2.2. Assesment of uniformity- U_o

Uniformity calculations are performed on the task areas that are set as vertical workplanes in order to assess

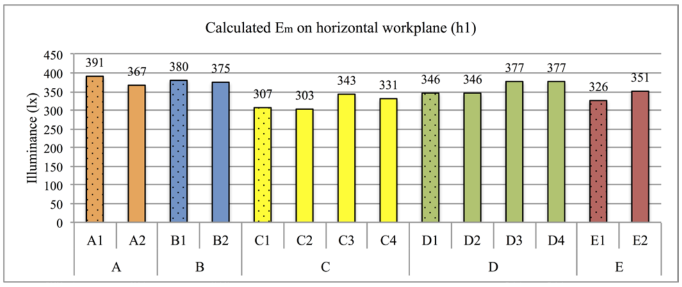


Figure 4. *Results of calculated Em values on the horizontal workplane (h1).*

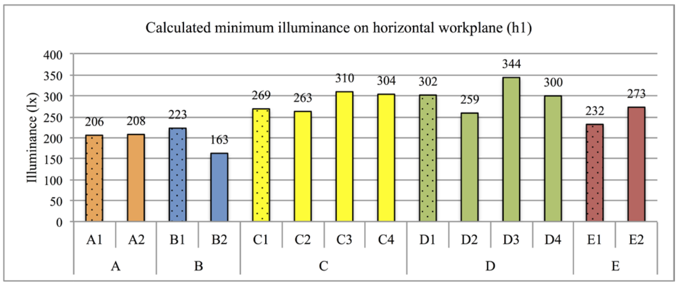


Figure 5. *Results of calculated minimum illuminance values on the horizontal workplane (h1).*

Table 7. *Mean vertical illuminance (Em) calculation results on the vertical workplanes (v1-v15).*

	A		B		C				D				E	
	A1	**A2**	**B1**	**B2**	**C1**	**C2**	**C3**	**C4**	**D1**	**D2**	**D3**	**D4**	**E1**	**E2**
v1	206	208	223	163	269	263	310	304	302	259	344	300	232	273
v2	219	222	218	168	328	333	380	384	375	339	426	389	212	197
v3	149	143	151	152	135	134	144	145	196	195	204	205	135	130
v4	246	238	260	197	133	127	141	134	206	160	212	166	260	372
v5	221	202	216	181	159	139	166	146	190	163	197	170	326	340
v6	240	230	248	195	138	142	139	143	191	152	192	153	330	395
v7	246	234	256	193	148	149	148	149	203	158	204	158	264	351
v8	223	204	214	182	157	138	158	139	173	150	174	150	273	409
v9	245	237	260	196	133	126	136	129	201	156	204	157	181	180
v10	137	136	139	148	***86***	***86***	***97***	***98***	123	128	128	132	116	106
v11	220	225	244	178	293	285	316	308	326	278	347	300	241	289
v12	144	140	146	146	115	115	121	121	172	174	178	180	103	101
v13	245	237	261	191	126	121	132	127	203	154	209	160	207	265
v14	247	238	262	192	127	119	128	121	199	151	201	153	153	152
v15	129	125	130	138	***75***	***75***	***84***	***84***	128	133	138	143	***75***	***75***

Table 8. *Minimum vertical illuminance calculation results on the vertical workplanes (v1-v15).*

	A		B		C				D				E	
	A1	**A2**	**B1**	**B2**	**C1**	**C2**	**C3**	**C4**	**D1**	**D2**	**D3**	**D4**	**E1**	**E2**
v1	151	154	162	114	128	127	173	173	155	117	199	160	92	124
v2	183	189	186	150	168	168	209	213	216	179	252	224	106	117
v3	131	131	133	138	81	82	111	111	140	134	167	159	85	97
v4	233	224	241	179	116	119	120	123	192	138	200	142	109	192
v5	211	190	199	166	149	130	152	136	173	139	178	146	116	161
v6	229	218	237	176	131	133	134	134	182	128	181	131	166	198
v7	230	219	241	172	138	141	141	142	195	138	194	140	125	173
v8	212	193	201	161	147	129	148	131	163	123	164	125	109	192
v9	232	225	249	173	113	116	118	117	192	135	196	135	112	119
v10	121	121	123	129	70	70	78	80	114	109	119	111	63	83
v11	194	198	207	150	136	134	168	158	173	120	185	124	88	82
v12	125	126	129	130	76	75	97	97	132	133	152	155	62	79
v13	228	218	242	174	105	110	110	115	185	127	191	132	94	124
v14	229	219	245	173	111	112	113	115	185	125	186	127	102	107
v15	116	116	117	126	69	68	77	77	116	110	126	119	63	63

the distribution of illuminance within the retail environment. A required uniformity criterion is given as 0,4 for sales areas according to EN 12464-1 Standard. Table 10 gives obtained U_o results on the evaluated workplanes. It is found that recommended U_o results are obtained for all scenarios as 100% for all scenarios except for E1 and E2. In E1 scenario, uniformity is supplied as 86% and for E2, this ratio is 93%.

3.2.3. Assesment of glare caused by light sources- Unified Glare Rating (UGR)

Assessment of glare caused by light sources is performed depending on the UGR values of the luminaires given by the manufacturers. Maximum UGR limits given for sales areas is 22 supplied for each baseline scenario and lighting retrofit proposals.

Table 9. *Evaluated scenarios illuminance calculation results in terms of horizontal and vertical illuminance criteria workplanes (v1-v15).*

Scenario names		Total light output for lamps (lm)	Total light output for luminaires (lm)	E_m-horizontal workplane (lx)	Horizontal illuminance criteria	E_m-15 vertical workplanes (lx)	Vertical illuminance criteria
A	A1	111500	86419	391	✓	208	✓
	A2	89000	84559	367	✓	201	✓
B	B1	108000	86366	380	✓	215	✓
	B2	80000	76002	375	✓	175	✓
C	C1	87000	72884	307	✓	161	✓
	C2	76200	71991	301	✓	157	✓
	C3	103500	79590	343	✓	173	✓
	C4	92700	78697	331	✓	169	✓
D	D1	99120	82526	346	✓	213	✓
	D2	79120	75123	346	✓	183	✓
	D3	111000	87354	377	✓	224	✓
	D4	91000	79951	377	✓	194	✓
E	E1	75240	71246	326	✓	207	✓
	E2	99000	75417	351	✓	242	✓

Table 10. *U_o calculation results obtained for task areas and total Uo percentage results for each scenario.*

	A		B		C				D				E	
	A1	**A2**	**B1**	**B2**	**C1**	**C2**	**C3**	**C4**	**D1**	**D2**	**D3**	**D4**	**E1**	**E2**
v1	0,73	0,65	0,73	0,70	0,48	0,49	0,56	0,57	0,51	0,45	0,58	0,54	0,40	0,46
v2	0,84	0,85	0,85	0,89	0,51	0,51	0,55	0,56	0,57	0,53	0,59	0,58	0,50	0,59
v3	0,88	0,80	0,88	0,91	0,60	0,61	0,77	0,77	0,72	0,69	0,82	0,78	0,63	0,74
v4	0,95	0,88	0,93	0,91	0,87	0,94	0,85	0,92	0,94	0,86	0,94	0,86	0,42	0,52
v5	0,95	0,86	0,92	0,91	0,94	0,94	0,92	0,93	0,90	0,86	0,91	0,86	**0,36**	0,47
v6	0,95	0,90	0,96	0,90	0,95	0,94	0,96	0,94	0,95	0,84	0,94	0,86	0,50	0,50
v7	0,94	0,89	0,94	0,90	0,94	0,95	0,95	0,95	0,96	0,88	0,95	0,89	0,47	0,49
v8	0,95	0,89	0,94	0,88	0,94	0,93	0,94	0,95	0,94	0,82	0,95	0,84	0,40	0,47
v9	0,95	0,95	0,96	0,88	0,85	0,92	0,87	0,91	0,96	0,87	0,96	0,89	0,62	0,66
v10	0,88	0,81	0,88	0,88	0,81	0,82	0,80	0,81	0,93	0,85	0,93	0,84	0,55	0,78
v11	0,89	0,84	0,85	0,85	0,46	0,47	0,53	0,51	0,53	0,43	0,53	0,41	**0,37**	**0,28**
v12	0,87	0,90	0,89	0,89	0,66	0,65	0,81	0,80	0,76	0,76	0,86	0,86	0,61	0,79
v13	0,93	0,92	0,93	0,91	0,84	0,91	0,84	0,91	0,92	0,83	0,91	0,82	0,46	0,47
v14	0,93	0,92	0,93	0,90	0,87	0,94	0,88	0,95	0,93	0,82	0,92	0,83	0,67	0,70
v15	0,90	0,93	0,90	0,91	0,93	0,91	0,91	0,91	0,91	0,83	0,91	0,83	0,83	0,84
total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	86%	93%

3.2.4. Assesment of colour property of the space and light sources

Assesment of colour property of the space is performed depending on the colour specifications of the surface materials and their light reflectance values. Light reflectance of the selected space are 70% for ceiling, 50%, for walls and 20% for floor, which are in the recommended ranges according to EN 12464 Standard. Colour rendering index-Ra of selected light sources are higher than 80 as specified in the EN 12464-1 therefore all the baseline sce-

Table 11. Lighting system's total power-Pn (W), provided LPD value (W/m2) for lighting design alternatives and comparison of results in terms of EN 15193 and ANSI/ASHRAE/IESNA Standard LPD criteria.

Scenario names		Lighting system's total power-P_n (W)	Provided LPD value (W/m²)	EN 15195 Standard LPD Criteria (15 W/m²)	ANSI/ASHRAE/ IESNA Standard LPD Criteria (13,56 W/m²)
A	A1	1605	10,7	✓	✓
	A2	870,00	5,8	✓	✓
B	B1	2151	14,3	✓	✓
	B2	1430	9,5	✓	✓
C	C1	2093	14,0	✓	✗
	C2	1740,2	11,6	✓	✓
	C3	1318	8,8	✓	✓
	C4	965,2	6,4	✓	✓
D	D1	2455	16,4	✗	✗
	D2	1940	12,9	✓	✓
	D3	1897	12,6	✓	✓
	D4	1382	9,2	✓	✓
E	E1	3125	20,8	✗	✗
	E2	1080	7,2	✓	✓

narios and lighting retrofits fulfill the necessary criteria in terms of colour rendering property of lamps.

3.3. Lighting energy performance determination of lighting design alternatives

The lighting energy requirements in retail environments depend on characteristics and number of lamps and luminaires, space dimensions and its occupancy hours. In this regard, evaluated lighting retrofit scenarios are assessed in terms of their annual lighting energy requirements expressed in kWh, LENI values (annual energy consumption for lighting per unit area expressed in kWh/m²/year) along with the lighting power density expressed (LPD) in W/m². Obtained results are used to produce estimates of lighting energy efficiency potential in the retail environment.

3.3.1. LPD Assessment in terms of EN 15193 and ANSI/ASHRAE/ IESNA Standards

LPD assessment of the baseline scenarios and lighting retrofit alternatives are performed and obtained results are compared with the EN 15193 and ANSI/ASHRAE/IESNA Standard LPD criteria. Table 11 represents the lighting system's total power-P_n (W), provided LPD value (W/m²) for lighting design alternatives as well as the comparison of results in terms of EN 15193 and ANSI/ASHRAE/IESNA Standard LPD criteria.

According to obtained results, scenarios A1 and B1 have found to have lower LPD values than the criteria LPD values given in EN 15193 and ANSI/ASHRAE/IESNA Standard. C1 baseline scenario has a LPD value of 14 W/m² which is lower than EN 15193 Standard LPD criteria but higher than ANSI/ASHRAE/IESNA Standard LPD Criteria. Baseline scenario D1 and E1 have higher LPD values than the recommended benchmark LPD criteria with LPD values of 16,4 W/m² and 20,8 W/m² respectively. It is clear from the results that all of the lighting retrofit schemes have lower LPD values than the baseline LPDs given in the standards.

3.3.2. Assessment of annual lighting energy performance according to EN 15193 Standard

In this part of the study, assessment of annual lighting energy performance by EN 15193 Standard is performed for

__Table 12.__ $W_{L,t}$- energy requirement used for illumination, $W_{P,t}$- Luminaire parasitic energy requirement, W_t- total annual lighting energy requirement and LENI values for evaluated scenarios.

	$W_{L,t}$ (kWh)	W_{pt} (kWh)	W_t (kWh)	LENI kWh/(m²/year)	LENI Supplied (Benchmark: 78.1 kWh/(m²/year)
A1	8025	150	8175	55	✓
A2	4350	150	4500	30	✓
B1	10755	150	10905	73	✓
B2	7150	150	7300	49	✓
C1	10465	150	10615	71	✓
C2	8701	150	8851	59	✓
C3	6590	150	6740	45	✓
C4	4826	150	4976	33	✓
D1	12275	150	12425	83	X
D2	9700	150	9850	66	✓
D3	9485	150	9635	64	✓
D4	6910	150	7060	47	✓
E1	15625	150	15775	105	X
E2	5400	150	5550	37	✓

evaluated baseline cases and proposed lighting design scenarios. Depending on the annual lighting energy requirement results, Lighting Energy Numeric Indicator (LENI) is calculated and obtained findings are compared with the benchmark LENI values for retail environments given in EN 15193 Standard.

EN 15193 annual lighting energy requirement calculation method is followed to obtain $W_{L,t}$- energy requirement used for illumination (kWh) and WP,t- Luminaire parasitic energy requirement (kWh) results per each scenario:

P_n-total installed lighting power (W) results given in Table 11 are taken into consideration in the lighting energy calculations. F_c -constant illuminance factor is assumed as "1" as specifies in the EN 15193. Daylight time usage (h)- t_D and non-daylight time usage (h)- t_N is considered as 3000 h and 2000 h respectively (total usage of 5000 h annually) for the retail environment as suggested by the EN 15193 standard. F_o - occupancy dependency factor is "1" as the space is fully occupied through the occupancy hours. Since the evaluated space has no access to daylighting, FD-daylight dependency factor is "1" and daylight penetration is "none".

The space is equipped with an emergency lighting system therefore luminaire parasitic energy requirement (kWh)-W_{pt} is 1 kWh/m² x year constituting a parasitic energy of 150 kWh annually. Total annual lighting energy requirement and evaluated Lighting Energy Numeric Indicator (LENI) results are given in Table 12.

Results show that the highest LENI value is reached for scenario E1 with a 105 kWh/(m²/year). This is followed by scenario D1 having a LENI value of 83 kWh/(m²/year). These two scenarios have LENI values that are higher than the recommended value given in EN 15193 Standard for retail spaces. Rest of the evaluated baseline alternatives and lighting retrofit proposals fulfil the LENI criteria given in EN 15193. Figure 6 represents the obtained LENI values for evaluated cases in a graphical expression.

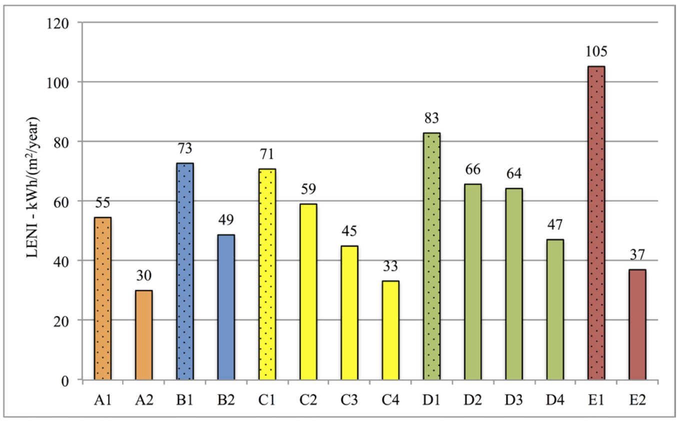


***Figure 6.** Results of Lighting Energy Numeric Indicator (LENI).*

3.4. Discussion of results

In this study, five different baseline lighting design schemes (A1, B1, C2, D1, E1) and nine lighting retrofit alternatives are considered depending on the use of diverse lighting technologies. This application example clearly shows that it is possible to apply lighting retrofit proposals that are fully providing the required visual comfort conditions and lighting energy performance criteria given the standards. Thus, this study shows the importance of an integrated lighting retrofit design process.

When the lighting energy saving possibilities are investigated, it is found that for category A, 45% lighting energy consumption is obtained by the help of lighting retrofit where for category B, this value is 33%. In category C, lighting energy consumption up to 17% is obtained for C2, 37% for C3 and 53% for C4. For category D, a lighting energy consumption reduction up to 21% is obtained for D2, 22% for D3 and 43% for D4. The highest lighting energy consumption is obtained for the case of D category where the halogen spotlights are replaced with a more energy efficient LED spotlights. In this lighting retrofit, a high lighting energy consumption ratio of 65% is supplied. Obtained results show the significant possibility of lighting energy savings by the help of lighting retrofit proposals.

4. Conclusion

This study aims to emphasize the importance of an integrated lighting retrofit project for retail environments in terms of visual comfort conditions and lighting energy efficiency. Introducing the visual comfort criteria for retail lighting requirements, this study gives necessary recommendations related with illuminance, luminance distribution, unified glare rating, uniformity, colour aspects of the space and light sources on the scope of current building standards and regulations.

Diverse lighting patterns consisting of different lighting retrofit applications are taken into consideration in this study on the example of a department store, demonstrating the most frequently observed lighting system layouts in retail environments. Visual comfort assessment is performed on a computational basis by using Dialux lighting simulation program, which is accredited by CIE. Lighting energy performance assessment is performed based on an up-to-date lighting energy calculation methodology described in EN 15193 Standard. Concentrating on the impact of lamp and luminaire selection on lighting energy efficiency, this study shows that it is possible to have energy-efficient lighting solutions enhancing the retail environments. Improving the appearance of the store, energy-efficient upgrade of lighting systems can also reduce lighting energy costs as well as overheating and cooling costs, which can be investigated as a future study.

Results of this research provides a practical retail lighting design retrofit guidance to retailers, architects and lighting designers in order to refurbish existing lighting schemes and develop new lighting design solutions considering the use of different lighting technologies in retail spaces.

The possibility to evaluate visual comfort conditions and lighting energy efficiency in retail spaces during the lighting retrofit phase is necessary in order to obtain an optimal lighting design variant. Therefore, this study shows the importance of using computational simulations in lighting retrofit projects so that diverse lighting retrofit proposals are evaluated practically and effectively.

This study is limited to the retail environments without access to daylighting and as a future work, the study can be expanded to evaluate the impact of daylighting on visual comfort conditions and lighting energy efficiency in retail environments. Integration of lighting control strategies in retail lighting retrofits also have direct effects on lighting energy savings therefore the lighting retrofit schemes can also be generated by depending on the integration of daylight- linked lighting control strategies as a future study.

As a conclusion, this study is aimed to show the potential for energy savings in retail environments on the example of a department store lighting retrofit. With the correct implementation of diverse lighting schemes during the lighting retrofit phase, lighting designer can help to design a sustainable and energy efficient retail building fully providing the required visual comfort conditions.

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