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A pilot study regarding to analysing the performance of the lighting system

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Abstract

Through the studies that obtain information about the user experience on lighting system performance, user satisfaction can be obtained. These studies are significant in order to analyse the system as a later stage and make recommendations. Following a post-occupancy evaluation (POE) study having focused on the user experience on the lighting system, the lighting system of the case study building has been analysed within this paper. In this analysis, the daylighting system and artificial lighting system have been examined. The design parameters for each system have been determined and different scenarios have been created. Under the impact of different scenarios, the performances of the daylighting and artificial lighting systems were analysed through the validated lighting simulation software DIALUX. It has been observed that the scenarios created for both the daylighting system and the artificial lighting system have had different impacts on the related systems. Through this kind of analysis studies, the most suitable lighting system design solution can be obtained for the evaluated space.

Keywords
Artificial lighting system, Lighting system performance, Daylighting system, Post-occupancy evaluation (POE), Visual comfort.

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1. Introduction

Studies that obtain information on user experience regarding to the lighting system's performance are significant as user satisfaction can be provided accordingly. Related to this, obtaining the information on user experience through these studies is noteworthy when analysing the performance of the lighting system.

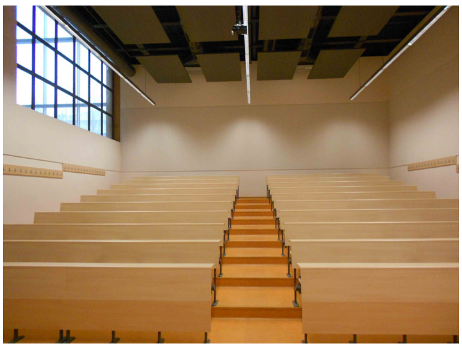
The related scholar literature underlines that user satisfaction on daylighting system, artificial lighting system and lighting control systems can be acquired through the post-occupancy evaluation (POE) studies. By means of a POE study, drawbacks of the above-mentioned systems can be determined and appropriate design solutions can be produced (Hygge and Löfberg, 1999).

This paper aimed at analysing the performance of the lighting system in the case study building following a formerly conducted POE study that focused on obtaining the user experience on the lighting system. Daylighting system and artificial lighting system were analysed. The methodology consisted of determining the design parameters for each system and developing different scenarios evaluating the determined parameters. Using the lighting simulation software DIALUX, the illuminance levels on the determined work planes were calculated and compared considering the project information and the generated scenarios. It was observed that the parameters resulted in distinct impacts on the performance of daylighting and artificial lighting systems.

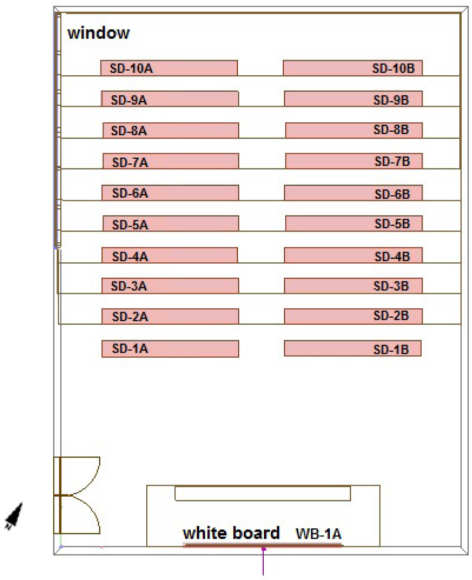
2. The pilot study

Istanbul Technical University (ITU) Lecture Hall A Building in the Ayazaga Campus (Maslak, Istanbul) has been evaluated as the case study building. As the first phase, a POE study was conducted in the lecture halls and seminar rooms of this case study building in March 2015 in order to obtain the evaluation of the students on the existing daylighting and artificial lighting systems. When the students were asked their general impression related to the visual environment in the lecture halls in the former POE study, more than half of them evaluated the lecture halls as bright. Some of their general evaluations indicated that little light entered from the window and illumination of the board could be increased (Kaçel and Yener, 2015).

Based on the user evaluations obtained from the POE study at the first phase, the performances of the lighting systems in the lecture halls were analysed as the second phase within this paper (Figure 1a). The width of the lecture hall studied in this paper was 10.28m, the depth was 13.72m and the height was 7.03m. The illuminance levels on the work planes in the lecture hall were calculated for the evaluation the lighting system performance considering the selected parameters. As the work planes, horizontal plane was



(a)



(b)

Figure 1. *The picture of the studied lecture hall (photo by the author) (a) and the representation of the work planes used in the simulation study on the plan generated by DIALUX (diagram by the author) (b).*

assigned on the student desk surface and vertical plane was assigned on the white board surface on the wall opposite the desk rows (Figure 1b).

The illuminance levels were calculated through the daylight simulation and artificial light simulation using the validated lighting simulation software DIALUX (DIALUX, 2016). The daylight simulation was carried out for the Equinox date March 23rd at noon time. The International Commission on Illumination (Commission Internationale de l´Eclairage - CIE) intermediate sky model was used in the daylight simulation.

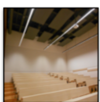
3. Design parameters of the lighting system and the pilot study

The design parameters, which have impact on providing the visual comfort conditions in the built environment, are defined as "*sky luminance distribution and illuminance; position of the sun, its impact on the luminance and illuminance; ground reflectance; dimension, location and reflectance of external obstructions (natural-artificial); window orientation; dimension, form and location of windows; light transmittance of windows; room dimensions; light reflectance of internal surfaces; qualitative and quantitative attributes of artificial light sources; qualitative and quantitative attributes of luminaires; location of artificial light sources or luminaires; equipment and control system of artificial lighting system*" (Küçükdoğu, 1982, p. 58-59).

3.1. The design parameters within the frame of the pilot study

Among the design parameters indicated in the scholar literature, three design parameters related to the daylighting system and three design parameters related to the artificial lighting were selected. The impact of the selected design parameters on the performance of the daylighting system and artificial lighting system in the studied lecture hall were evaluated. As the design parameters related to the daylighting system; dimension of window, light transmittance of window glazing and reflectance of internal surfaces were investigated. As the design parameters related to the artificial lighting system; type and specifications of lamp, type of luminaire and reflectance of internal surfaces were under consideration (Table 1).

Table 1. *The design parameters for the daylighting system and artificial lighting system analysed in this pilot study.*

The design parameters related to the daylighting system	The design parameters related to the artificial lighting system
• Dimension of the window	• Type and specifications of the lamp
• Light transmittance of the window glazing	• Type of the luminaire
• Reflectance of the internal surfaces	• Reflectance of the internal surfaces

In the studied lecture hall in this pilot study, there was one side window looking towards the glazed gallery space between the two lecture halls. The dimension of the window was indicated 6.00m (width) and 4.00m (height) as the information on the project drawings. The light transmittance of the glazing was considered as 71% with the guidance of the manufacturer catalogue information for the type of glazing used in the building. The information for the artificial lighting system was indicated as linear 58W fluorescent luminaire on the project drawings. With the guidance of manufacturer catalogue information, direct linear 58W fluorescent luminaire providing 5240lm luminous flux was evaluated in the artificial light simulation. The reflectance of internal surfaces were considered as 20% for the ceiling (ceiling material: metal sheet painted in dark colour), 73% for the walls (wall material: paint in light colour) and 46% for the floor (floor material: vinyl covering in medium colour) as a result of the materials determined during observing the lecture hall.

In this pilot study considering a lecture hall two evaluation matrices were generated, one of which focused on the daylighting system and the other one focused on the artificial lighting system, in order to investigate the impact of selected design parameters of the systems' performances. Each matrix contained four different scenarios by changing the design parameters. In the related given tables (Table 2 and Table

3), the grey-coloured boxes indicated the project information and the diagonally-hatched boxes indicated the changed design parameters:

- The evaluation matrix for the daylighting (DL) system (Table 2)
  - Scenario *DL-1*: The dimension of the window 8.00m (width) x 3.00m (height)
  - Scenario *DL-2*: The light transmittance of the glazing 79%
  - Scenario *DL-3*: The reflectance of the ceiling 80%
  - Scenario *DL-4*: The simultaneously change of the above-mentioned three design parameters
- The evaluation matrix for the artificial lighting (AL) system (Table 3)
  - Scenario *AL-1*: The type and power of lamp 40W light-emitting diode (LED) luminaire providing 4200lm luminous flux
  - Scenario *AL-2*: The type of luminaire as direct and indirect
  - Scenario *AL-3*: The reflectance of the ceiling 80%
  - Scenario *AL-4*: The simultaneously change of the above-mentioned three design parameters

As explaining the scenarios in detail, the scenario *DL-1* provided a longer window towards the middle of the lecture hall but kept the same window area as given on the project information. The scenario *DL-2* provided a higher light transmittance value chosen from the same manufacturer's catalogue information. The scenario *DL-3* applied the average of the recommended reflectances for the ceiling as between 70% and 90% in the EN 12464-1 (EN 12464-1, 2011). The scenario *DL-4* evaluated the impact of all three parameters within the evaluation matrix of the daylighting as a result of changing the parameters simultaneously. The scenario *AL-1* underlined a luminaire with less lighting power consumption when compared with the project information. The scenario *AL-2* considered the impact of artificial light reflecting from the ceiling surface. The scenario *AL-3* applies the same target as explained in the scenario *DL-3*. The scenario *AL-4* evaluated the impact of all three parameters within the evaluation matrix of the artificial lighting as a result of changing the parameters simultaneously.

4. Evaluation of the daylighting system

In the evaluation of the daylighting system performance; minimum (E_{min}), average (E_{ave}) and maximum (E_{max}) illuminance levels on the work planes in the lecture hall were analysed (Table 4). The work planes were considered as being on the student desks and the white board on the wall.

Table 2. *The evaluation matrix for the design parameters of the daylighting system analysed in this study.*

Daylighting	Dimension of window (meters)				Light transmittance of glazing (%)		Reflectance of internal surfaces (%)			
	Width		Height				Ceiling		Wall	Floor
	6m	8m	3m	4m	71%	79%	20%	80%	73%	46%
Project										
DL-1										
DL-2										
DL-3										
DL-4										

Table 3. *The evaluation matrix for the design parameters of the artificial lighting analysed system in this study.*

Artificial lighting	Type of lamp and power		Type of luminaire		Reflectance of internal surfaces (%)			
	58W Fluorescent	40W LED	Direct	Direct + Indirect	Ceiling		Wall	Floor
					20%	80%	73%	46%
Project								
AL-1								
AL-2								
AL-3								
AL-4								

4.1. Work plane on the student desks

In the evaluation of the project information named as the *Project*, the average illuminance levels on the student desks on the window wall side (indicated with the work planes *A*) were higher than the average illuminance levels on the student desks opposite the window wall (indicated with the work planes *B*). This proved the contribution of the side window on the illuminance levels. The average illuminance levels on the student desks on the window wall side from the middle of the lecture hall towards the upper levels (from the work plane *SD-5A*) provided the maintained illuminance level 500 lux given by the EN 12464-1 in order to provide the visual comfort conditions in adult education and lecture halls. This given illuminance level could not be provided on the student desks opposite the window wall.

In the scenario *DL-1* evaluating the change in the dimension of the window, the width of the window was enlarged towards the middle of the lecture hall. The illuminance levels on the student desks both on the window wall side and opposite the window wall increased. The average illuminance levels on the student desks on the window wall side provided 500 lux starting from the work plane *SD-4A*. The scenario *DL-2* was about the light transmittance of the window glazing and more effective for increasing the illuminance levels provided in the *Project* than the scenario *DL-1*, starting from the middle of the lecture hall towards the upper levels (from the work plane *SD-5A* for the student desks on the window wall side and the work plane *SD-6B* for the student desks opposite the window wall). In the scenario *DL-3*, which focused on the reflectance of the ceiling, a similar pattern was observed with the scenario *DL-1* in terms of the increase in the illuminance levels. It has been seen that the scenario *DL-4* changing the dimension of the window, the light transmittance of the glazing and the reflectance of the ceiling simultaneously has the largest impact on the illuminance levels. The average illuminance levels on the student desks on the window wall side was calculated as 577 lux (E_{ave}) on the work plane *SD-2A* and increased towards the upper levels of the lecture hall. The maintained illuminance level 500 lux given in the EN 12464-1 was not provided on the student desks opposite the window wall. The maximum illuminance level on the work plane *SD-6B* was calculated as 542 lux (E_{max}) and increased towards

Table 4. *The illuminance level on the student desks and the white board in terms of the daylighting system.*

Work planes	Daylighting (DL) – Illuminance Levels (lux)														
	Project			DL-1			DL-2			DL-3			DL-4		
	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}
On the student desks (SD)															
SD-1A	104	147	172	197	282	331	129	182	213	160	203	228	327	433	493
SD-1B	106	127	146	138	180	223	132	157	181	159	180	199	251	303	356
SD-2A	142	212	242	279	394	460	176	263	300	202	272	302	435	577	659
SD-2B	102	142	175	137	195	239	127	176	218	159	199	232	257	329	384
SD-3A	258	304	342	369	494	601	319	376	423	324	370	408	554	709	841
SD-3B	123	159	199	160	220	288	152	197	247	184	221	261	292	367	451
SD-4A	343	468	563	452	620	752	424	579	697	412	537	632	659	867	1030
SD-4B	127	180	227	160	237	311	159	224	282	191	244	291	289	384	476
SD-5A	391	612	827	507	745	918	483	757	1024	464	685	900	733	1028	1243
SD-5B	136	192	245	163	243	327	168	238	304	206	262	316	296	396	499
SD-6A	448	732	987	566	885	1099	555	907	1224	525	809	1064	809	1204	1470
SD-6B	138	205	279	158	250	361	172	255	348	208	275	350	291	405	542
SD-7A	529	885	1312	619	993	1291	656	1096	1627	607	962	1390	877	1343	1713
SD-7B	138	208	306	160	253	380	171	258	380	209	279	377	298	412	570
SD-8A	578	1015	1543	644	1086	1452	715	1259	1917	654	1092	1621	906	1455	1912
SD-8B	137	213	313	154	247	367	171	265	390	205	280	381	284	400	548
SD-9A	612	1121	1760	675	1166	1585	760	1391	2184	687	1196	1835	941	1553	2073
SD-9B	135	205	308	149	236	362	169	255	383	198	267	370	274	382	538
SD-10A	624	1211	2048	705	1234	1712	769	1504	2549	698	1286	2123	978	1635	2231
SD-10B	137	201	296	154	230	351	170	249	367	199	263	358	276	372	525
On the white board (WB)															
WB-1A	78	95	115	92	113	133	96	117	143	104	124	150	151	183	217

the upper levels of the lecture hall.

When all the student desks were evaluated, the average illuminance level was calculated as 427 lux (E_{ave}) in the *Project*. In the scenarios providing the maintained illuminance 500 lux given in the EN 12464-1, the average illuminance level was calculated as 510 lux (E_{ave}) in the scenario *DL-1*, 529 lux (E_{ave}) in the scenario *DL-2* and 728 lux (E_{ave}) in the scenario *DL-4*.

4.2. Work plane on the white board

The illuminance levels on the white board were evaluated (*WB-1A*). Starting from the scenario *DL-1*, each scenario increased the illuminance levels on the white board gradually. Having the largest impact, the average illuminance level was calculated as 183 lux (E_{ave}) in the scenario *DL-4*. The maintained illuminance 500 lux given in the EN 12464-1 for the boards could not be obtained on the white board surface.

5. Evaluation of the artificial lighting system

In the evaluation of the artificial lighting system performance; minimum (E_{min}), average (E_{ave}) and maximum (E_{max}) illuminance levels on the student desks and the white board on the wall were analysed as in the daylighting system evaluation (Table 5).

5.1. Work plane on the student desks

In the evaluation of the project information named as the *Project*, it has been seen that most of the average illuminance levels on the student desks provided the maintenance illuminance 500 lux indicated in the EN 12464-1.

In the scenario *AL-1* that evaluated the type of lamp and power as 40W LED, all the average illuminance levels on the student desks increased when compared with the *Project* and provided the maintained illuminance 500 lux given in the EN 12464-1. The average illuminance level on the work plane *SD-1A* in the *Project* as 631 lux (E_{ave}) was calculated as 788 lux (E_{ave}) in the scenario *AL-1*. The scenario *AL-2* considered the impact of the direct and indirect luminaire on the artificial lighting performance. Due to the light reflected towards the dark-coloured ceiling with the reflectance 20%, the illuminance levels on the student desks decreased when compared with the *Project*. The number of student desks providing the maintained illuminance 500 lux largely decreased. The scenario *AL-3*, which increased the reflectance of the ceiling as 80%, had less impact than the scenario *AL-1*. However, the

Table 5: *The illuminance level on the student desks and the white board in terms of the artificial lighting system.*

Work planes	Artificial Lighting (AL) – Illuminance Levels (lux)														
	Project			AL-1			AL-2			AL-3			AL-4		
	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}	E_{min}	E_{ave}	E_{max}
On the student desks (SD)															
SD-1A	594	631	668	673	788	854	407	465	497	699	735	773	591	639	668
SD-1B	604	643	680	683	796	859	415	472	500	710	749	785	594	640	667
SD-2A	619	652	690	682	803	866	419	478	513	725	758	796	607	658	687
SD-2B	631	667	705	692	812	873	428	487	519	737	774	811	611	661	688
SD-3A	632	663	701	686	809	869	426	486	523	739	770	808	616	670	699
SD-3B	649	681	719	702	823	878	437	497	530	758	791	829	625	677	704
SD-4A	641	666	703	681	809	870	429	488	525	745	770	807	609	666	696
SD-4B	660	687	725	703	826	880	442	500	535	767	794	832	631	683	706
SD-5A	642	659	696	675	803	862	427	484	518	746	763	800	599	657	686
SD-5B	662	684	722	698	822	876	442	500	534	773	792	828	629	682	706
SD-6A	617	641	677	658	786	846	419	472	505	716	740	776	581	638	667
SD-6B	651	671	710	682	812	873	439	494	527	755	775	814	618	675	702
SD-7A	583	616	655	643	766	828	410	458	486	678	711	750	560	615	642
SD-7B	617	647	686	664	793	857	432	482	513	719	748	788	596	652	679
SD-8A	534	576	618	618	733	796	392	432	457	626	668	710	538	588	615
SD-8B	568	607	649	642	761	824	415	458	485	668	706	748	576	628	655
SD-9A	469	514	563	567	671	733	360	394	415	552	596	646	491	536	562
SD-9B	502	544	588	593	699	758	385	420	442	596	638	682	527	573	599
SD-10A	401	445	497	490	579	636	318	346	364	480	524	576	431	470	496
SD-10B	429	473	521	517	605	659	342	372	391	522	565	611	471	508	532
On the white board (WB)															
WB-1A	199	285	392	226	328	416	175	219	263	243	347	450	203	292	370

scenario *AL-3* increased the illuminance levels on the student desks when compared with the *Project*. All the student desks provided the maintained illuminance 500 lux given in the EN 12464-1. In the scenario *AL-4* evaluating the type of lamp and power, the type of the luminaire and the reflectance of the ceiling simultaneously, the illuminance levels increased when compared with the *Project*. Nevertheless, the scenario *AL-4* was less effective than the scenarios *AL-1* and *AL-3*. Except of one number of student desk, the maintained illuminance 500 lux given in the EN 12464-1 was obtained.

When all the student desks were evaluated, the average illuminance level was calculated as 618 lux (E_{ave}) in the *Project*. In the scenarios providing the maintained illuminance 500 lux given in the EN 12464-1, the average illuminance was calculated as 765 lux (E_{ave}) in the scenario *AL-1*, 718 lux (E_{ave}) in the scenario *AL-3* and 626 lux (E_{ave}) in the scenario *AL-4*.

5.2. Work plane on the white board

The illuminance levels on the white board (*WB-1A*) were evaluated. The scenarios *AL-1*, *AL-3* and *AL-4* increased the illuminance levels. As the most effective scenario, the average illuminance level was calculated as 347 lux (E_{ave}) in the scenario *AL-3*. The maintained illuminance 500 lux given in the EN 12464-1 could not be obtained on the white board surface.

6. Conclusion

The performances of the daylighting system and artificial lighting system were evaluated by considering different design parameters in the lecture halls of ITU Lecture Hall A Building as the case study building. In terms of the daylighting system in the project, the side window provided higher illuminance levels on the student desks on the window wall side than on the desks opposite the window wall. The highest increase in the illuminance levels on the student desks as the work plane was provided by the simultaneous change of the three design parameters as the dimension of the window, the light transmittance of the glazing and the reflectance of the ceiling. However, the maintained illuminance 500 lux given for the lecture halls in the EN 12464-1 could not be provided by the average illuminance levels on the student desks opposite the window wall. The average illuminance level on all the student desks opposite the window wall was calculated as 375 lux (E_{ave}) and the average illuminance level on all the student desks on the window wall side was calculated as 1080 lux (E_{ave}).

The impact of the scenarios generated for the artificial lighting system was evaluated. The scenario changing the type and power of lamp as 40W LED was the most effective configuration on the increase in the illuminance levels on the student desks. The average illuminance level on all the student desks on the window wall side was calculated as 755 lux (E_{ave}) and the average illuminance level on all the student desks opposite the window wall was calculated as 775 lux (E_{ave}). Having an uniformity ratio 0.64 in the studied lecture hall, the uniformity ratio 0.60 given for the lecture halls in the EN 12464-1 was provided. In addition, comparing the performance of the 58W fluorescent luminaire and 40W LED luminaire showed the higher illuminance levels obtained with less lighting power consumption. This underlines the significance of energy efficient lighting approach.

None of the scenarios regarding to the daylighting system and artificial lighting system provided the maintained illuminance 500 lux given for the white boards in the EN 12464-1. As the highest values, the average illuminance level 183 lux (E_{ave}) was calculated in the daylighting system analysis when the all three design parameters were changed and the average illuminance level 347 lux (E_{ave}) was calculated in the artificial lighting system when the reflectance of the ceiling was increased. As the maintained illuminance 500 lux were not provided with any of the scenarios, it has been evaluated that a lighting system for the white board was needed as supplementary to the lighting of the lecture hall.

The scenarios, which were generated through the design parameters related to the daylighting system and artificial lighting system in the literature, were analyzed in the studied lecture hall as the pilot study. The analysis aimed at evaluating the performance of the daylighting and artificial lighting systems under the changing scenarios. Being considered in the scenarios, the impact of the design parameters on the performance of the lighting systems were analysed. The analysis results were evaluated through comparing them to the illuminance levels given for providing the visual comfort conditions. The scenarios created for both the daylighting system and the artificial lighting system have had different impacts on the performances of the systems. Through this kind of analysis studies, the most suitable lighting system design solution can be obtained for the evaluated space.

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