

Evaluation of Daylight and Electrical lighting Performance in an Office Space

Dr. Kang-Soo Kim¹, Jeong-Sub Lee², Hoe-Young Jung³, Sung-Haeng Cho⁴

¹Dept. of Arch. , Korea University, Seoul, Korea, kskim@korea.ac.kr

²Dept. of Arch. , Korea University, Seoul, Korea, deadplace@korea.ac.kr

³Dept. of Arch. , Korea University, Seoul, Korea, mrjim@korea.ac.kr

⁴Samoo Architects & Engineers, Seoul, Korea, Chosh23@samoo.co.kr

ABSTRACT:

In this research, lighting performance was compared with actual measured data in a case study of an office area. Various design alternatives were then analyzed in a model of the case study in order to determine the optimum conditions for saving lighting energy and improving illuminance uniformity. Requirements from LEED 2.1 & 2.2 and CASBEE were used as indexes for the evaluation. Results showed that in Case 4 (WWR: 60%, TR: 44%, OH: 150cm), direct sunlight can be controlled near the window area, satisfying the LEED 2.2 requirement. In addition, in Case 2 (WWR: 34%, TR: 82%), where 2 light fixtures near the window were switched off, optimum lighting levels and illuminance uniformity were obtained at noon on the equinox.

Keywords: daylight, electrical lighting, illuminance, illuminance uniformity

1. Introduction

In this research, the case study of an office area was used to compare lighting performance with actual measured data. A model space was then used to analyze various design alternatives in order to determine the optimum conditions for saving lighting energy and improving illuminance uniformity.

LEED 2.1[1] & 2.2[2] and the CASBEE[3] requirements were used as indexes for the evaluation.

LEED 2.1 specifies that a minimum daylight factor of 2% should be obtained in 75% of the occupied space. In CASBEE, 5 levels of daylight factor standards are required from 1.0% to 2.5%.

LEED 2.2 specifies that a minimum daylight illumination level of 25 foot candles (fc) should be achieved in a

minimum of 75% of all regularly occupied areas. It also specifies that modeling should demonstrate 25 horizontal fc under clear sky conditions, at noon on the equinox, and at 30 inches above the floor.

In this research, the computer programs of Radiance [4] and Autodesk VIZ [5] were used, which are able to calculate indoor illuminance with visual images.

2. Model Space Conditions and Validation of Simulations

2.1 Outline of a model space

-Room Size: 35.6 X 20.7 X 2.7 m

-Reflectances:

ceiling 70%, wall 50%, floor 20%

-Lighting conditions: FL32W/2 recessed direct lighting

-Lighting density: 15W/m²

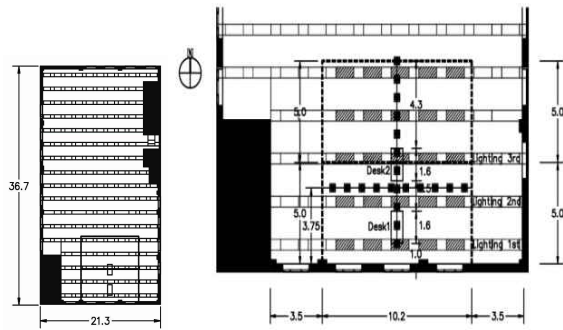


Figure 1: Dimensions and measurement points of a model space

The open plan model space has an area of 672 m² and has 1.8 x 1.8 m windows on all four sides. Measurements were taken at 0.7m above the floor (Fig. 1).

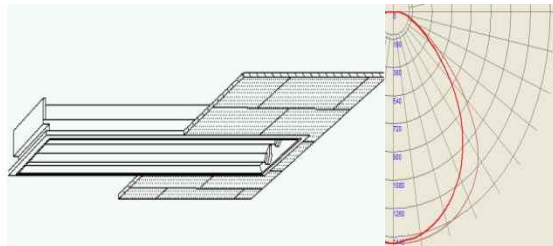


Figure 2: Lighting equipment (left) and intensity distribution curve (right)

Table 1: Lighting equipment

Item	Size	Watt	Size		Base	Characteristics	
			Diameter of tube	Length		Lamp (A)	Total lumen (lm)
High frequency Flowrescent fixture	32	32	25.5±1.5	1.198±1.5	G13	0.255±0.03	3,100

The lighting equipment type (Fig.2, Table1) used in this study is that of FL32W/2, which has a high reflectance cover. 158 lighting fixtures are installed in the working space.

As shown in Figure 1, lighting fixtures are equally spaced with a density of 15W/m². The photometric curve used in the simulation is the ies5393.ies file in the Autodesk VIZ program.

2.2 Comparison between the actual measurements and the simulation data under daylight conditions

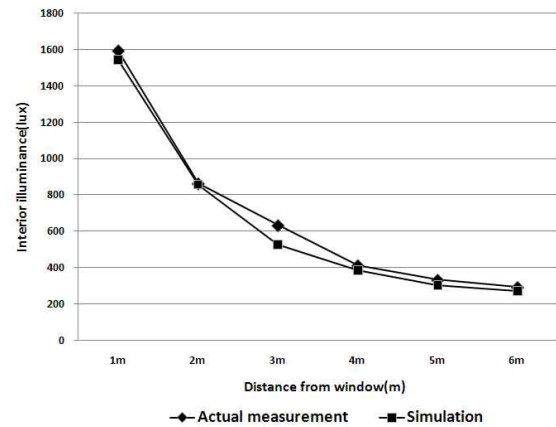


Figure3: Comparison between the actual measurements and the simulations

In order to validate Radiance simulations, measurements were conducted in the north zone of the building under an overcast sky condition (exterior illuminance: 28,380 lux). Figure 3 shows the actual and the simulated data, the results of which are similar.



Figure4: Comparison of direct sun penetrations

Figure 4 shows a comparison of the direct sun penetration image between the actual photo and the Radiance simulation image at 4 pm, where similar results were obtained (sunlight length difference is 4 %).

2.3 Comparison between the actual measurements and the simulation data under electrical lighting conditions

Autodesk VIZ program was used to measure the electrical lighting conditions, and the actual measurements were conducted at 10 pm.

The average difference between the actual measurements and the simulations was 4.7% (Fig. 5). The simulation results and measured results were therefore similar.

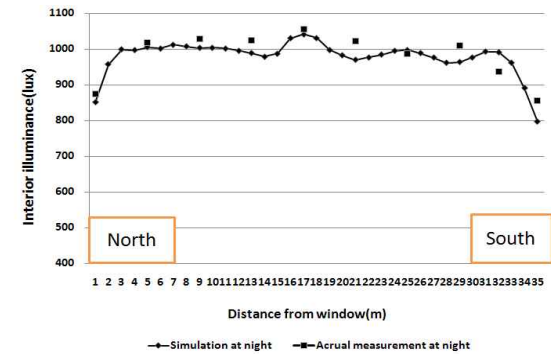


Figure 5: Comparison of measured and simulated data at night (north and south axis)

3. Evaluation of Electrical Lighting

The actual lighting load in the building model was 15 W/m² (Fig. 6). In order to save lighting energy, the lighting load was modified from 15 W/m² to 12 W/m² (Fig. 7). Table 2 shows the simulation results.

Table 2: Simulation Results

Lighting Density	Average Illuminance (Lux)	Maximum Illuminance (Lux)	Minimum Illuminance (Lux)	Uniformity Min./Avg. (%)
15W/m ²	892	1041	607	68
12W/m ²	502	664	283	56

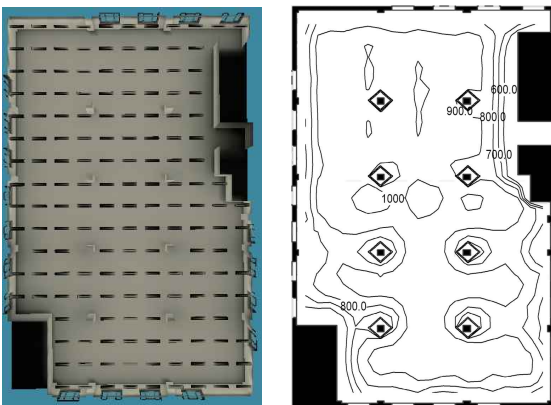


Figure 6: Lighting layout and illuminance contour under light density condition of 15W/m²

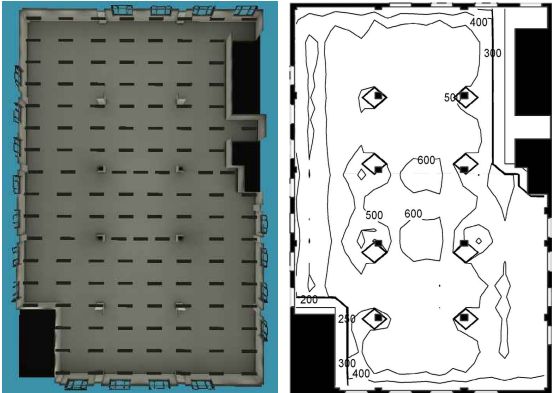


Figure 7: Lighting layout and illuminance contour under light density condition of 12 W/m²

The actual average illuminance at night was recorded at 890 Lux, which is 78% higher than the standard level of 500 lux [6].

The illuminance uniformity ratio in the existing condition is 68%, which is a 12% lower level than the recommended ratio of 80% [7].

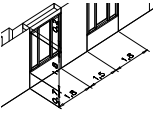
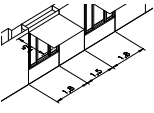
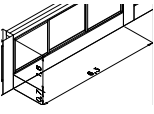
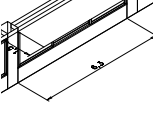
In the second simulation, lighting density was reduced to 12W/m² (Table2, Figure7). Simulation results show 502 Lux, which satisfies the recommended illuminance level. In this case, the illuminance uniformity ratio is 56%.

4. Evaluation of Daylight in the South Zone of a Model Space

For the evaluation of daylight in the south zone of the model, the base space faces south (Fig. 1), and the simulation variables are the window to wall ratios (WWR) based on the ceiling height, visible transmittance (TR), and horizontal overhang (OH), as shown in Table 3.

The evaluation indexes included the daylight factor, the clear sky illuminance in accordance with the LEED 2.2 requirement, and the workplane illuminance uniformity (Lux_{min}/Lux_{avg}). In order to compare the simulations with the LEED 2.2 requirement, they were based on noon of the equinox.

Table 3: Simulation conditions

Case	Image	WWR	TR	OH
Case 1		34% (base model)	82% (clear AFG)	
Case 2		34% (base model)	82% (clear AFG)	150cm
Case 3		60% (whole window)	44% (blue-green AFG),	
Case 4		60% (whole window)	44% (blue-green AFG),	150cm

4.1 Daylight factor (DF,%) in the overcast sky

In this part of the research, a 3.75m line (75% of the 5m perimeter zone) was used to apply the standard requirement.

Table 4 shows the daylight factor based on the LEED 2.1 requirement.

Table4: Daylight factor based on LEED2.1 requirement

Case	Exterior Illuminance (lux)	Average Illuminance(lux) (3.75m)	Daylight Factor (%)	Note (OH)
Case 1		147	1.00	Base model
Case 2	14,691 (Overcast sky)	128	0.87	150cm
Case 3		193	1.32	
Case 4		148	1.08	150cm

The daylight factor in Case 1 (base condition) is 1.00 %, which is 50 percent of the LEED 2.1 requirement, recorded at a line 3.75m (75% of occupied areas) away from the 5m line (end of daylight perimeter zone). In Case 2, the average daylight factor was recorded at 0.87 %, which represents 44 percent of the standard level (2%).

When the window ratio is increased up to 60 % (all glass above the sill) and the window transmittance is decreased to 44 % (Case 3), the daylight factor becomes 1.32 %, which is 66 % of the standard value (2%). For Case 4, where a horizontal overhang was installed, a daylight factor of 1.08 % was recorded.

Table 5 shows daylight factor based on the CASBEE requirement.

Table5: Daylight factor based on CASBEE requirement

Case	Exterior Illuminance (lux)	Average Illuminance(lux) (5m total)	DF (%)	Note (OH)
Case 1		288	1.96	base model
Case 2	14,691 (Overcast sky)	202	1.38	150cm
Case 3		358	2.43	
Case 4		220	1.50	150cm

When the simulated daylight factor is applied to the CASBEE requirement for Japan (where all daylight factors used are within a perimeter zone (5m)), 1.96% was recorded for Case 1 (base condition). This result scores within the 3rd level of the 5 levels (where 5 represents the best) specified in CASBEE, while 1.38% in Case 2 scores within the 2nd level of the CASBEE requirement.

Case 3 scores within level 4, with the recorded daylight factor of 2.43%. Also, in Case 4, which has a horizontal overhang, when the daylight factor falls to 1.50%, it drops to the 3rd level of the CASBEE requirement.

In the LEED 2.1 & CASBEE requirements, a high score level can be obtained when a large window or high transmittance glazing is used, due to the increase of the daylight factor. However, when an overhang is installed to control direct sunlight, it can be more difficult to obtain a high score within the LEED 2.1 & CASBEE requirements.

4.2 Illuminance evaluation in the clear sky

Table 6 shows the daylight illuminance considering the LEED 2.2 requirement.

Table6: Daylight illuminance considering LEED2.2 requirement

Case	Average Illuminance (lux)	Maximum Illuminance (lux)	Minimum Illuminance (lux)	Illuminance difference (lux)	LEED2.2 Requirement lux (25fc=269lux)	Note (OH)
Case 1	584	1382	195	1187	382 (142%)	
Case 2	352	800	139	661	243 (90%)	150cm
Case 3	720	1418	245	1173	484 (180%)	
Case 4	407	736	169	567	293 (109%)	150cm

The clear sky illuminance in Case 1 is 382 lux, which is 142% of the LEED 2.2 requirement level (25 fc (269 lux)) at the 3/4 line of the 5m perimeter zone. In Case 2, the daylight illuminance drops to 90% of the LEED requirement.

In Case 3, a significant amount of daylight (180% of required level) penetrates into the inside space, while in Case 4, the optimum level (109% of required level) is admitted.

By examining Figure 8, it can be seen that in Cases 1 and 3, excessive light is admitted and in Cases 2 and 4, the window-side light levels are controlled down to 700 lux.

In Case 1, where 50% of the full LEED 2.1 score is obtained, the full LEED 2.2 score in the clear sky condition is also obtained. In Cases 1 & 3, while the full LEED 2.2 requirement is obtained, overhangs are still required to control direct sunlight. In Case 4 (full window with an overhang), direct sunlight is controlled near the window area and the LEED 2.2 requirement is satisfied.

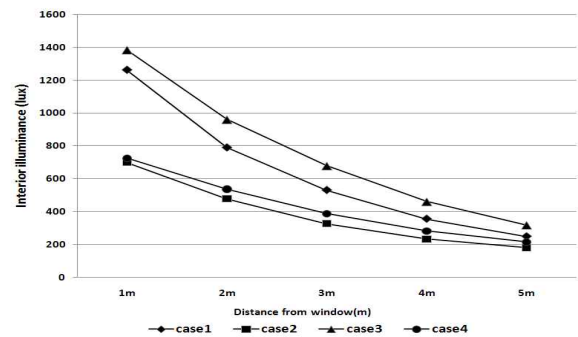


Figure 8: Comparison of Interior illuminance (noon of spring equinox)

4.3 Illuminance uniformity on the desk

Table 7 shows the illuminance uniformity obtained on the desks.

Table7: Illuminance uniformity on the desks

Case	Work plane	Average Illuminance (lux)	Maximum Illuminance (lux)	Minimum Illuminance (lux)	Min /Max (%)	Min /Avg (%)
Case 1	Desk1	774	1075	559	52	72
	Desk2	319	377	258	68	81
Case 2	Desk1	547	703	421	60	77
	Desk2	254	300	215	72	85
Case 3	Desk1	1054	1432	739	52	70
	Desk2	310	409	226	55	73
Case 4	Desk1	515	671	399	59	77
	Desk2	192	239	149	62	78

The workplane illuminance uniformity (minimum/average) in Case 1 is 72%, representing 90% of the required standard level (80%) [7]. The illuminance uniformity (minimum/average) on Desk 2, located 4m from the window, is 81%, which also satisfies the standard. Desk 1 has a higher level of illuminance with a low uniformity due to its close proximity to the window. The workplane illuminance uniformity in Case 2 was improved by 4-5% due to the control of high illuminance obtained by installing an overhang.

In Case 3, the illuminance uniformity was reduced by 2-8% compared with the base condition (Case 1). This is because in

Case 3, while there is a high illuminance due to the large window, the light levels are reduced significantly within the deep zone. The uniformity is somewhat improved in Case 4 (5-7%) due to the overhang, which controls the high illuminance near the window.

In terms of the illuminance uniformity on the desk, the base condition (Case 1) is superior to the whole window alternative (Case 3). Furthermore, a horizontal overhang can contribute to the control of uniformity. Therefore, Case 2 (where horizontal overhangs are installed on the base case 1), shows a superior uniformity among the alternatives.

In the south window, the daylight factor increases with an increase of the window ratio, and the daylight factor can be decreased by 0.13-0.24% (DF) due to the addition of the overhang (Table 4).

In the clear sky, Cases 1 and 3 showed a somewhat excessive level of illuminance (142-180% of the LEED 2.2 requirement level). However, the daylight level was controlled to the optimum level (90-109% of LEED 2.2) with the addition of overhangs, as shown in Cases 2 (WWR: 40%, TR:80%, OH:150cm) and 4 (WWR:60%, TR:40%, OH:150cm).

The workplane illuminance uniformity near the window was poor compared to the workplane illuminance uniformity inside. When a horizontal overhang is installed, as in Cases 2 and 4, the high illuminance near the window was controlled, while the uniformity was slightly improved (5%-7%).

5. Evaluation of Daylight and Electrical Lighting in the South Zone of a Model Space

Table 8 shows the lighting analysis results obtained for Desks 1 and 2 (Fig. 9-12). For this part of the analysis, all the simulations were performed under conditions of the noon spring equinox.

Table 8: Simulation Results using electrical controls

CASE	Lighting control	Work Plane	South zone, Clear sky, Equinox noon (Exterior illuminance : 63,231 Lux)				
			Max (lux)	Min (lux)	Avg (lux)	Min/Avg(%)	Min/Max(%)
Case1 WWR: 34% TR: 80%	All on	Desk1	1714	1164	1419	82	68
		Desk2	823	640	723	88	78
	1off	Desk1	1374	1045	1181	88	76
		Desk2	811	654	729	90	81
	2off	Desk1	1221	687	902	76	56
		Desk2	640	574	613	94	90
	3off	Desk1	1215	620	876	71	51
		Desk2	326	254	277	92	78
	All on	Desk1	1301	971	1105	88	75
		Desk2	823	669	748	89	81
	1off	Desk1	919	812	837	97	88
		Desk2	742	633	690	92	85
Case2 WWR: 34% TR: 80% +OH	2off	Desk1	780	469	581	81	60
		Desk2	649	552	612	90	85
	3off	Desk1	733	349	499	70	48
		Desk2	222	188	201	94	85
	All on	Desk1	2058	1610	1821	88	78
		Desk2	1271	891	1080	82	70
	1off	Desk1	1721	1486	1587	94	86
		Desk2	1236	885	1064	83	72
	2off	Desk1	1199	693	926	75	58
		Desk2	672	600	644	93	89
	3off	Desk1	1164	586	849	69	50
		Desk2	350	274	299	92	78
Case3 WWR: 60% TR: 44%	All on	Desk1	1150	858	986	87	75
		Desk2	721	629	678	93	87
	1off	Desk1	835	761	779	98	91
		Desk2	709	634	677	94	89
	2off	Desk1	662	387	492	79	58
		Desk2	596	463	545	85	78
	3off	Desk1	659	324	458	71	49
		Desk2	235	188	210	89	80
Case4 WWR: 60% TR: 44% +OH	All on	Desk1	1150	858	986	87	75
		Desk2	721	629	678	93	87
	1off	Desk1	835	761	779	98	91
		Desk2	709	634	677	94	89
	2off	Desk1	662	387	492	79	58
		Desk2	596	463	545	85	78
	3off	Desk1	659	324	458	71	49
		Desk2	235	188	210	89	80

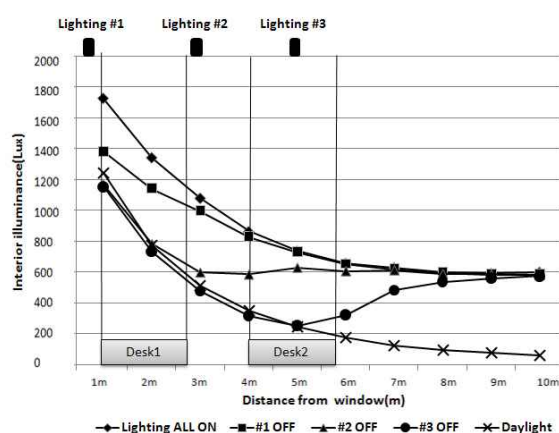


Figure 9: Lighting performance of Case 1

In Case 1 (Fig. 9), when all the electric lights are switched on, the simulated light levels on Desks 1 and 2 are 1,419 & 720 lux, respectively. Even when lighting fixture 1 is switched off, the uniform illuminance condition can be satisfied at Desks 1 and 2, while the illuminance at Desk 1 is still high (1,181 lux).

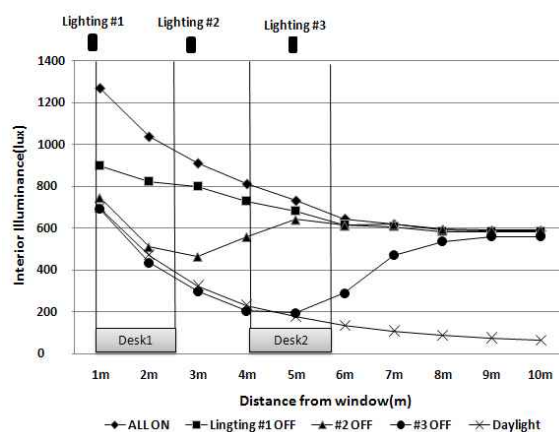


Figure 10: Lighting performance of Case 2

For Case 2 (Fig. 10), a work plane illuminance of 1,105 lux was obtained, with a uniformity of 88% on Desk 1. However, a high level of illuminance was still obtained near the window (all on condition).

Thus, an illuminance level of 581 lux and a uniformity of 81% can be achieved on Desk 1 when the 1st and 2nd lighting fixtures are switched off.

A high uniformity was obtained when the 1st light was switched off, while a work plane illuminance of 830 lux was obtained.

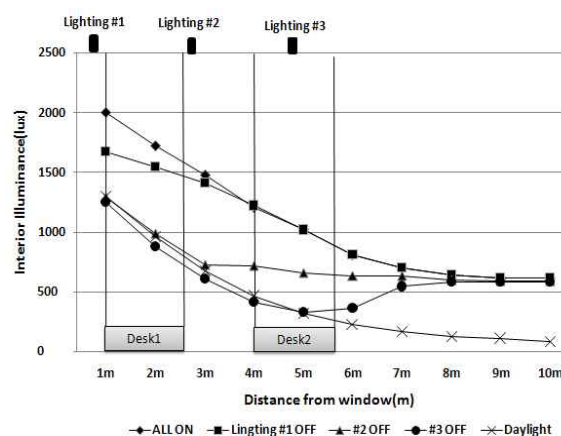


Figure 11: Lighting performance of Case 3

In Case 3 (Fig. 11), the average illuminance on Desk 1 was increased by 400 lux in the daylight condition, when compared to the illuminance of Case 1. When the 1st light was switched off, the average illuminance on Desk 1 was reduced to 1,580 lux, which is still higher than the standard. Because an overhang was not installed in Cases 1 and 3, excessive daylight penetrated onto Desk 1, located at the perimeter of the room.

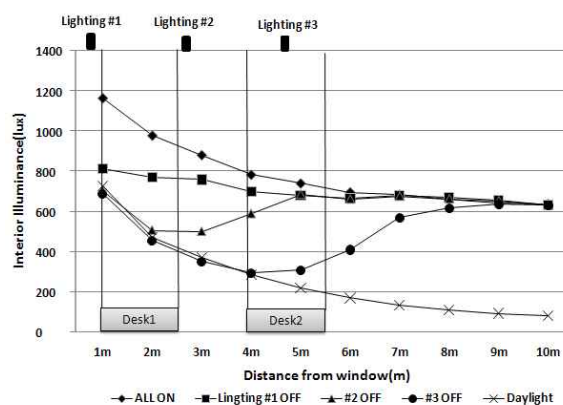


Figure 12: Lighting performance of Case 4

In Case 4 (Fig. 12), due to the effect of the overhang, an average illuminance of 986 Lux was obtained on Desk 1, which was reduced by 46 % compared with Case 3. When both the 1st and 2nd light fixtures are switched off, the illuminance at Desk 1 can be reduced to 492 lux.

For Case 2, when 2 light fixtures are switched off, optimum lighting levels and

uniformity is obtained on Desk 1 at noon of the equinox (see Table 8, Fig.10).

In Cases 1 and 3, where overhangs are not installed, the average illuminance on Desk 1 is over 800 lux although 3 light fixtures are switched off.

In Cases 2 and 4, when the light fixtures are switched on, over 980 lux can be obtained on Desk 1 due to the combination of daylight and electric light.

For Case 3, when lighting fixtures 1 and 2 were switched off, the recommended level of 500 lux and the recommended uniformity on Desks 1 and 2 can be obtained. Also, in Case 4, about 500 lux was recorded when 2 fixtures were switched off.

The average illuminance and the illuminance uniformity achieved on Desk 2 satisfy the minimum required values in most cases (2 light off condition).

This part of the research show an optimum control of electrical lighting should be harmonized with an envelope design.

Two light fixtures can be switched off in all 4 cases at noon of the equinox.

6. CONCLUSIONS

Daylight and electrical lighting of various case studies within a model space were analyzed to determine the optimum case for saving lighting energy and to improve illuminance uniformity. The significant findings are listed below.

The actual measurements show that the average lighting illuminance was 890 Lux. In the alternative simulations, the lighting density was reduced to 12W/m², and the average illuminance of 500 Lux was obtained.

In the LEED 2.1 & CASBEE requirements, large windows or high transmittance glazing score a high level of standard. In Cases 2 and 4, the installation of overhangs can control direct sunlight near the window area, and this can also satisfy the LEED 2.2 requirement. Simulation

results in this study show that LEED 2.2 is a superior tool to LEED 2.1.

In Case 2, when two light fixtures are switched off optimum lighting levels and uniformity can be obtained under the condition of the noon equinox.

This research focused on the lighting performance at noon of the spring equinox. However, similar results might be obtained for the fall equinox, while less sun control problems might occur at the summer solstice due to the higher altitude of the sun.

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