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A Study on Performance Evaluation of Mixed Light Shelf Type According to the Angle of Light Shelf

Woori Chae[1.1], Heangwoo Lee[2.1] and Yongseong Kim[2.2]

[1]The Graduate School of Techno Design Kookmin University, Jeongneung-dong, Seongbuk-gu, Seoul, 136-702, Korea
[2] The Graduate School of Techno Design Kookmin University, Jeongneung-dong, Seongbuk-gu, Seoul, 136-702, Korea
woori1983@nate.com[1.1],moonup2001@nate.com[2.1], yongkim@kookmin.ac.kr[2.2]

Abstract

A light-shelf, one of natural lighting methods, has advantages in constructability and economic feasibility in comparison with other passive natural lighting system. A movable light-shelf enables a user in a room to adjust the angle according to his or her preference to control the amount of indoor light. In addition, a light-self serves as a shield to the intense light on window sides when the solar light is strong to relieve glare. The purpose of this study was to investigate the effect of angle adjustment of a mixed type light-shelf on indoor natural lighting and determine efficient light-shelf lighting performance values by using an actual size test-bed. This study was conducted in the following procedures: 1) Previous studies were investigated to analyze the definition of a light-shelf and identify experimental factors for a light-shelf; 2) On the basis of previous studies, the light-shelf experimental factors were set up with reference to the illumination values under clear sky at the meridian transit altitude in each season to perform an experiment; and 3) The performance of the light-shelf was evaluated to examine the effectiveness. The performance evaluation was performed for each season according to the solar altitude of the mixed light-shelf. The indoor distribution of illumination was analyzed on the basis of the day light introduction depending on the angle of the mixed type light-shelf to verify the correlation with variables and the efficacy.

Keywords: *Light Shelf, Daylighting Performance, illumination*

1. Introduction

1.1. Background and Purpose

As the issues of climate change and global warming come to the fore, energy consumption inside buildings is continuously increased. Therefore, more concerns and efforts are required to reduce energy consumption by building energy load. As technologies for environment-friendly alternative energy sources has developed, natural lighting technology using day light has started to develop in view of energy saving. A light-shelf, one of natural lighting methods, introduces day light by reflecting the light to the ceiling in the inside, enabling to reduce energy consumption for lighting during the day time. A light-shelf has high usability due to the excellent constructability and economic feasibility in comparison with other active natural lighting technologies. At present, studies on a light-shelf are limited to simulations and miniaturized models, and the correlations with the angles of a mixed type light-shelf have not been investigated sufficiently. Therefore, the purpose of this study was to investigate the effect of angle adjustment of a mixed type light-shelf on indoor natural lighting and evaluate the

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efficiency of a mixed type light-shelf lighting performance by using an actual size test-bed.

1.2. Methods

This study was conducted to evaluate the performance of a mixed type light-shelf depending on the angle in an actual size test-bed at summer solstice, winter solstice, vernal equinox, and autumnal equinox by using an artificial solar light of which external illumination may be employed as a set-up variable for each season. The lighting performance of a mixed type light-shelf was evaluated by analyzing the illumination value of the day light introduced to the inside and calculating the average illumination and the uniformity. The study was conducted in the following procedures.

1) Review of Light-Shelf

Previous studies were reviewed to identify the experimental factors and variables of a light-shelf.

2) Light-Shelf Experimental Setup Variables

On the basis of previous studies, the illumination values at the meridian transit altitude in each season under clear sky were applied. The light-shelf experimental factors were set up to perform the experiment.

3) Evaluation of Light-Shelf Performance

Performance evaluation was performed to verify the effectiveness of a light-shelf. The performance evaluation was performed for each season according to the solar altitude of a mixed type light-shelf. The distribution of indoor illumination by the introduced day light was analyzed depending on the angle of the mixed type light-shelf to verify the correlation with variables and the efficacy.

2. Review on Light-Shelf

2.1 Concept of Light-Shelf

A light-shelf is a light-controlling apparatus which may save lighting energy during day time and increase viewing environment quality by introducing the day light by reflecting it on an indoor ceiling. A light-shelf has advantages in constructability and economic feasibility in comparison with other active natural lighting systems. Light-shelves are classified as three types: internal type, external type, and mixed type.

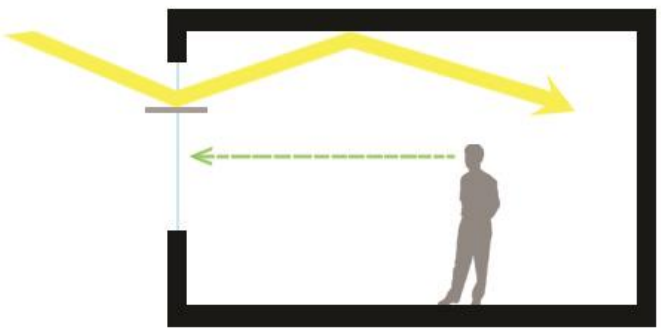

Figure 1. Light-Shelf

2.2 Light Shelf Angle Control

Although an angle-controllable light-shelf is generally more expensive than a fixed type light-shelf, an angle-controllable light-shelf is more flexible in use. When the angle of a light-shelf is tilted downward, the light-shelf shields the windows and thus reduces the amount of light reflected on the ceiling. When the angle of a light-shelf is tilted upwards, penetration of the reflected solar light is increased but the light shielding effect of the windows are reduced. A light-shelf fixed externally may shield more direct solar light introduced through the opening for viewing under the shelf and thus decrease more indoor air conditioning load. A light-shelf fixed internally does not make the top surface of the light shelf be shaded and thus increases the radiant heat of the light introduced through a fan light. Various sensor technologies corresponding to the required conditions are used in collecting spatial information. The information collected by using the technologies are analyzed by an algorithm based on smart lighting control system control logic to derive the optimal values. The finally derived values are put out as the physical performance of light control for effective lighting energy consumption and optimal light environment.

2.3 Characteristics of Light Shelf

A light-shelf is generally installed horizontally or nearly horizontally to the inside or outside of a vertical window. A light-shelf should be planned as an integrated factor when a building facade is designed. During a building facade design, not only a light-shelf but also the window system and the ceilings are important factors, and the architectural circumstances of a building to which a light-shelf is to be installed should be taken into account. A light-shelf must be considered in an early stage of construction design because a light-shelf affects the architectural and structural designs of a building and a high ceiling is required to have excellent lighting performance. Although both an internal type and an external type light-shelf may be used under clear sky, an external type light-shelf is more functional in the aspect of shading. A surface finishing having a high reflective ratio is necessary to efficiently reflect the natural light introduced to the inside. On the other hand, when under overcast sky, or in a region where a light-shelf is installed on the windows northwards, an internal type light-shelf or an inclined external type light-shelf is advantageous.

2.4 Environmental Factors of Light Shelf

Since light is reflected on a light-shelf to a ceiling and the light reflected on the ceiling is introduced to the inside, the properties of the ceiling affecting the light-introducing procedures are the surface finishing and the tilt angle. A finishing which has a highly reflective surface may reflect more light to the inside. To avoid glare by finishing reflection, a white diffusive material or matte paint is generally used as the finishing. A ceiling which is inclined from the windows heading to the center of a building to the top further increases the light-introducing depth from a light-shelf to the inside. The environmental factors to the performance of a light-shelf include glass materials, which affect the light permittivity of windows, the tilt angle of the ceiling, and the reflective indices of the ceiling finishing, wall finishing, and bottom surface finishing.

3. Overview on Test-bed Environment for Mixed Type Light-Shelf Performance Evaluation

3.1 Overview of Test-bed

3.1.1. Test-bed

This study was conducted to evaluate the performance of a mixed type light-shelf depending on the angle and the size in an actual size test-bed at summer solstice, winter solstice, vernal equinox, and autumnal equinox by using an artificial solar light of which external illumination may be employed as a set-up variable for each season. The lighting performance of a mixed type light-shelf was evaluated by analyzing the illumination values of the day light introduced to the inside, using six internal illumination sensors, and calculating the average illumination and the uniformity. The test-bed was 4.9 m wide, 6.6 m deep, and 2.5 m high to the ceiling. The size of the opening was 2.2 m wide and 1.8 m high. The glass material of the opening was 12T double glazing.

Table 1. Test-Bed [12]

Summary of the Test-bed Model	
Room Size and Material	4.9m(W) x 6.6m(D) x 2.5m(H), Wall : reflectance 46%, Ceiling : reflectance 86%
Window Size and Material	2.2m(W) x 1.8m(H), Pair Glass 12mm(3mm+6mm+3mm)

Figure 2. Test-bed and Artificial Sunlight

3.1.2. Illumination Sensors

To analyze the introduction of day light to the inside depending on the variables of a light-shelf, illumination sensors were arranged in an interval of 1600 mm vertically and 1650 mm horizontally with reference to the windows. The height of the illumination sensors was 450 mm from the bottom with reference to the working plane of a user on the basis of previous studies.

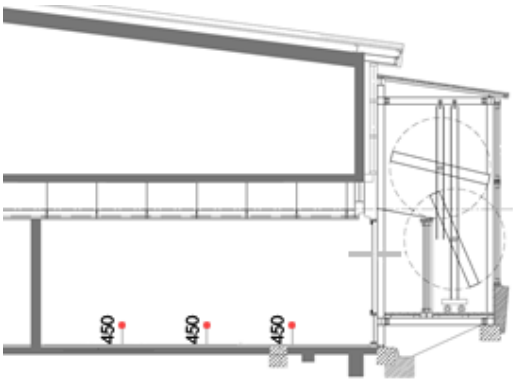

Figure 3. Test-bed and Artificial Sunlight Sectional

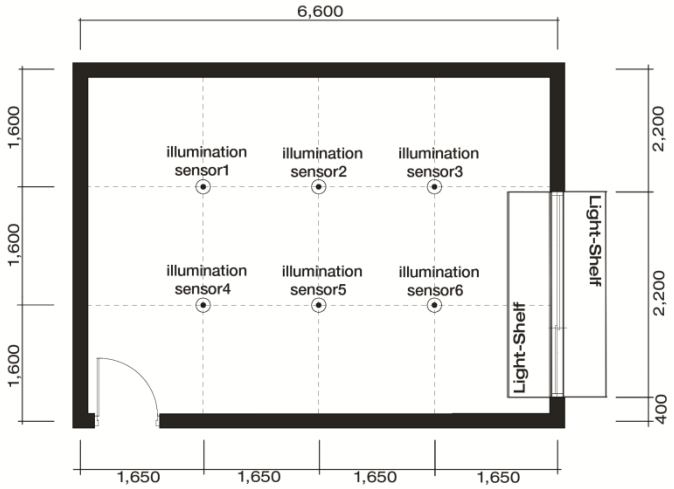

Figure 4. Test-bed and Artificial Sunlight Plan

3.2 Setup of External Environment and Light-Shelf Variables

The external environment variables for the experiment were the meridian altitude in each season, which were 76.5° at the summer solstice, 53° at the vernal equinox and autumnal equinox, and 29.5° at the winter solstice. The direction of the building windows was due south. The illumination values for each season were set up as 80,000 lux at the summer solstice, 60,000 lux at the vernal equinox and autumnal equinox, and 30,000 lux at the winter solstice on the basis of previous studies. The height of the light-shelf was set up as 1800 mm which was higher than the eye level to avoid glare to a person inside the building. The width of an external type light-shelf was set up to be 200 mm. The width of a mixed type light-shelf was 200 mm for both the inside and the outside. The surface of the light-shelves was finished by using a reflective film having a surface reflection ratio of 85%. In addition, to investigate correlation of the light-shelf tilt angle with the indoor illumination variation and with the light-shelf performance, the tilt angle of the external type light-shelf was varied from −30° to +30°, by 10° each time, during the experiment. For the mixed type light-shelf, the tilt angle of the outside part was varied from −30° to +30°, by 10° each time, and that of the inside part was varied from −30° to +30°, by 10° each time. The external environment variables and the light-shelf variables were set up as follows.

Table 2. Setup of the Experimental Environment [12]

<table>
<tr><th colspan="2">Light Shelf System</th><th colspan="3">Exterior Environment</th></tr>
<tr><td>Width of Light Shelf System (mm)</td><td>200/200</td><td colspan="2">Culmination Altitude</td><td>Exterior Luminance</td></tr>
<tr><td>Angle</td><td>-30°, -20°, +10°, 0°, +10°, +20°, +30°</td><td>Summer Solstice</td><td>76.5°</td><td>80,000 lx</td></tr>
<tr><td>Height of Light Shelf System (mm)</td><td>1800</td><td>Spring and Autumnal Equinoxes</td><td>53°</td><td>60,000 lx</td></tr>
<tr><td rowspan="2">Reflexibility of Light Shelf System</td><td rowspan="2">specular reflection film (reflexibility 85%)</td><td>Winter Solstice</td><td>29.5°</td><td>30,000 lx</td></tr>
<tr><td>Direction</td><td colspan="2">Full South</td></tr>
</table>

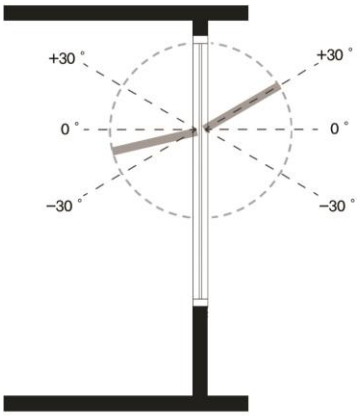

Figure 5. Light-Shelf Angle

4. Result and Discussion of Light Shelf Performance Evaluation

To investigate the effectiveness of the lighting performance of a mixed type light-shelf in each season, the illumination values of the day light introduced to the inside were analyzed by using six internal illumination sensors, and the average illumination and the uniformity were calculated. The uniformity was calculated by as Emin/Eave on the basis of previous studies.

4.1. Performance Evaluation of External Type Light-Shelf

The performance of the mixed type light-shelf was analyzed by comparing the performance with that of an external type light-shelf. The results of the experiment performed with the external light-shelf are as follows.

Table 3. Result of Performance Evaluation According to the External Type Light Shelf

season	height	size (mm)	angle	Sensors(lx)						Average illumination (lx)	Uniform ratio of illuminance
				1	2	3	4	5	6		
summer	1800	200	-30	52	348	700	28	552	2400	680	0.0412
			-20	52	344	1080	20	544	2328	728	0.0275
			-10	64	364	1164	32	584	2488	783	0.0409
			0	80	408	1288	60	640	2692	861	0.0697
			+10	124	460	1392	84	744	3064	978	0.0859
			+20	168	488	1320	160	828	3012	996	0.1606
			+30	212	420	1192	164	672	2752	902	0.1818
spring & autumn	1800	200	-30	378	711	1506	345	1239	7749	1988	0.1735
			-20	384	720	1596	345	1266	7923	2039	0.1692
			-10	405	771	1773	363	1314	8466	2182	0.1664
			0	435	834	1908	399	1434	8796	2301	0.1734
			+10	474	876	1914	444	1560	5808	1846	0.2405
			+20	510	873	1800	558	1494	8580	2303	0.2215

			+30	531	816	1878	591	1821	9051	2448	0.2169
winter	1800	200	-30	792	1253	1279	1022	7704	7865	3319	0.2386
			-20	818	1298	1560	1025	7764	11784	4042	0.2025
			-10	866	1356	1709	1082	7872	13032	4320	0.2006
			0	917	1423	1706	1157	8033	13070	4384	0.2091
			+10	953	1406	1553	1238	7958	12660	4295	0.2218
			+20	919	1373	1531	1181	7838	14424	4544	0.2023
			+30	905	1286	1764	1147	7368	21096	5594	0.1617

At the summer solstice, the external type light-shelf was directly affected by the artificial solar light. With reference to the No. 4 illumination sensor located at the innermost part, the illumination was the highest as 164 lx at the upward tilt angle of +30° and the uniformity was also the highest as 0.1818 at the same angle of +30°. At the vernal equinox, with reference to the No. 4 illumination sensor, the illumination was the highest as 519 lx at the upward tilt angle of +30°, while the uniformity was the highest as 0.2405 at the angle of +10°. The uniformity might have been higher because the external type light-shelf played the role of a shade to the high illumination on the window side at the angle of +10° at the vernal equinox. At the winter solstice, with reference to the No. 4 illumination sensor, the illumination was the highest as 1238 lx at the upward tilt angle of +10°, while the uniformity was the highest as 1.2386 at the downward angle of -30°. The efficiency was high at the light-shelf tilt angle of +10° due to the low solar altitude at the winter solstice. The illumination measured at the No. 6 illumination sensor was low at the downward tilt angle, indicating that the uniformity was the highest at the tilt angle of -30° probably because of the shading effect of the light-shelf.

4.2. Mixed Type Light-Shelf Performance Evaluation

An experiment was performed with the mixed type light-shelf to evaluate the performance by adjusting the internal and external tilt angles for each season.

4.2.1. Evaluation of Mixed Type Light-Shelf Performance at Summer Solstice

At the summer solstice, the mixed type light-shelf was directly affected by the artificial solar light. With reference to the No. 4 illumination sensor located at the innermost part, the illumination of the mixed type light-shelf was the highest as 220 lx at the internal/external angles of -30°/+20°, -30°/+30°, -20°/+30°, and -10°/+30°. The uniformity was the highest as 0.2376 at the angle of -30°/+30°, at which the lighting performance was also the highest. The efficiency of the mixed type light-shelf at the summer solstice was high at the downward internal angles of -30°, -20°, and -10°, and at the upward external angles of +20° and +30°. When compared with that of the external type light-shelf with reference to the No. 4 illumination sensor, the illumination value of the mixed type light-shelf was higher by 56 lx, and the uniformity of the mixed type light-shelf was also higher by 0.0558. This showed that the mixed type light-shelf was more advantageous in the deep introduction of day light and in the aspect of uniformity, which represents the quality of light, than that of an external type light-shelf.

Table 4. Result of Performance Evaluation According to the Mixed Type Light Shelf During Summer

season	height	size (mm)	Angle (In/Out)	Sensors(lx)						Average illumination (lx)	Uniform ratio of illuminance
				1	2	3	4	5	6		
summer	1800	200/200	-30/-30	100	384	1084	64	560	2388	763	0.0838
			-30/-20	92	352	1092	52	552	2368	751	0.0692
			-30/-10	112	384	1192	68	588	2512	809	0.0840
			-30/0	144	424	1344	108	660	2808	915	0.1181
			-30/+10	168	468	1444	132	768	3212	1032	0.1279
			-30/+20	220	508	1328	220	840	3008	1021	0.2155
			-30/+30	220	448	1232	220	684	2752	926	0.2376
			-20/-30	84	388	1128	68	1032	2472	862	0.0789
			-20/-20	80	388	1140	68	628	2468	795	0.0855
			-20/-10	92	428	1224	84	692	2620	857	0.0981
			-20/0	128	452	1384	88	732	2904	948	0.0928
			-20/+10	160	488	1488	124	840	3300	1067	0.1163
			-20/+20	204	528	1364	208	908	3108	1053	0.1937
			-20/+30	223	464	1252	220	752	2868	963	0.2284
			-10/-30	68	388	1112	44	620	2532	794	0.0554
			-10/-20	164	392	1164	72	800	2732	887	0.0811
			-10/-10	180	392	1240	40	648	2704	867	0.0461
			-10/0	112	440	1372	60	792	3148	987	0.0608
			-10/+10	100	492	1460	105	872	3352	1064	0.0940
			-10/+20	175	528	1360	180	912	3168	1054	0.1661
			-10/+30	240	480	1288	220	888	3100	1036	0.2124
			0/-30	44	352	1124	20	568	2492	767	0.0261
			0/-20	32	352	1124	24	568	2512	769	0.0312
			0/-10	48	372	1204	32	604	2664	821	0.0390
			0/0	72	420	1352	52	668	2932	916	0.0568
			0/+10	120	464	1460	84	780	3364	1045	0.0804
			0/+20	168	504	1368	168	868	3168	1041	0.1614
			0/+30	148	444	1272	160	720	2956	950	0.1558
			+10/-30	28	340	1028	12	552	2280	707	0.0170
			+10/-20	24	344	1040	12	544	2312	713	0.0168
			+10/-10	28	360	1128	20	572	2440	758	0.0264
			+10/0	52	400	1264	40	644	2724	854	0.0468
			+10/+10	92	452	1380	72	752	3148	983	0.0733
			+10/+20	144	500	1280	152	840	2948	977	0.1473
			+10/+30	124	424	1212	112	664	2800	889	0.1259
			+20/-30	20	328	1028	12	548	2092	671	0.0179
			+20/-20	28	332	1028	8	532	2104	672	0.0119
			+20/-10	52	364	1120	12	584	2248	730	0.0164
			+20/0	80	400	1268	44	644	2528	827	0.0532
			+20/+10	112	444	1364	112	760	2968	960	0.1167
			+20/+20	128	464	1312	140	824	2828	949	0.1348
			+20/+30	92	412	1264	68	664	2720	870	0.0782
			+30/-30	20	320	952	20	544	1852	618	0.0324
			+30/-20	12	332	980	20	528	1880	625	0.0192
			+30/-10	32	364	1052	12	568	2032	677	0.0177
			+30/0	60	408	1200	48	640	2284	773	0.0621
			+30/+10	92	460	1300	68	760	2720	900	0.0756
			+30/+20	108	460	1232	112	800	2584	883	0.1224
			+30/+30	60	408	1184	52	648	2480	805	0.0646

4.2.2. Evaluation of Mixed Type Light-Shelf Performance at Vernal Equinox

At the vernal equinox, with reference to the No. 4 illumination sensor, the illumination of the mixed type light-shelf was the highest as 885 lx at the internal/external angle of -30 °/+30°, followed by 819 lx and 810 lx at the internal/external angles of 30°/+20 and -20° /+30, respectively. The uniformity was the highest as 0.2376 at the angle of -30°/+20, at which the lighting performance was also high. The efficiency of the mixed type light-shelf at the vernal equinox was high at the downward internal angles of -30° and -20°, and at the upward external angles of +20° and +30°. When compared with that of the external type light-shelf with reference to the No. 4 illumination sensor, the illumination value of the mixed type light-shelf was higher by 294 lx, and the uniformity of the mixed type light-shelf was also higher by 0.0298. This showed that the mixed type light-shelf was more advantageous in the deep introduction of day light and in the aspect of uniformity, which represents the quality of light, than that of an external type light-shelf at the vernal equinox, too.

Table 5. Result of Performance Evaluation According to the Mixed Type Light Shelf During Spring and Autumn

season	height	size (mm)	Angle (In/Out)	Sensors(lx)						Average illumination (lx)	Uniform ratio of illuminance
				1	2	3	4	5	6		
spring & autumn	1800	200/200	-30/-30	498	693	1464	603	1221	8046	2088	0.2386
			-30/-20	516	705	1569	630	1260	8280	2160	0.2389
			-30/-10	543	741	1755	639	1308	8784	2295	0.2366
			-30/0	561	774	1869	666	1398	9066	2389	0.2348
			-30/+10	600	834	1866	720	1509	9099	2438	0.2461
			-30/+20	651	813	1773	819	1464	8928	2408	0.2703
			-30/+30	660	783	1881	885	1536	9390	2523	0.2616
			-20/-30	498	783	1581	525	1491	8376	2209	0.2254
			-20/-20	495	798	1695	531	1518	8595	2272	0.2179
			-20/-10	525	831	1875	549	1566	9120	2411	0.2178
			-20/0	570	879	1998	588	1671	9420	2521	0.2261
			-20/+10	600	930	1998	636	1779	9423	2561	0.2343
			-20/+20	633	924	1884	729	1725	9204	2517	0.2515
			-20/+30	633	879	1995	810	1773	9675	2628	0.2409
			-10/-30	423	741	1689	399	1443	8736	2239	0.1782
			-10/-20	429	756	1815	408	1455	8958	2304	0.1771
			-10/-10	450	789	1986	426	1503	9414	2428	0.1755
			-10/0	486	831	2115	456	1611	9738	2540	0.1796
			-10/+10	516	885	2118	516	1725	9615	2563	0.2014
			-10/+20	573	891	2019	609	1671	9564	2555	0.2243
			-10/+30	555	834	2124	639	1548	10086	2631	0.2109
			0/-30	381	690	1734	351	1275	8790	2204	0.1593
			0/-20	390	696	1860	351	1296	9021	2269	0.1547
			0/-10	414	726	2001	375	1329	9378	2371	0.1582
			0/0	444	774	2118	399	1437	9678	2475	0.1612
			0/+10	489	828	2118	459	1551	9720	2528	0.1816
			0/+20	549	828	2031	561	1491	9516	2496	0.2200
			0/+30	489	786	2184	486	1455	10203	2601	0.1869
			+10/-30	339	618	1599	303	1104	8349	2052	0.1477
			+10/-20	360	633	1704	315	1128	8571	2119	0.1487
			+10/-10	384	678	1890	336	1185	9111	2264	0.1484
			+10/0	420	708	2004	363	1284	9408	2365	0.1535
			+10/+10	459	765	2025	423	1404	9435	2419	0.1749
			+10/+20	495	786	1959	513	1386	9339	2413	0.2051
			+10/+30	426	729	2094	408	1416	9909	2497	0.1634

			+20/-30	336	606	1554	300	1095	8013	1984	0.1512
			+20/-20	348	621	1656	300	1104	8220	2042	0.1470
			+20/-10	369	660	1821	315	1158	8676	2167	0.1454
			+20/0	396	696	1935	351	1263	8979	2270	0.1546
			+20/+10	438	750	1965	384	1371	9039	2325	0.1652
			+20/+20	450	729	1944	444	1404	9099	2345	0.1893
			+20/+30	405	690	2061	360	1224	9549	2382	0.1512
			+30/-30	306	561	1296	270	1023	6858	1719	0.1571
			+30/-20	321	570	1401	279	1050	7104	1788	0.1561
			+30/-10	351	303	1656	300	1089	7608	1885	0.1592
			+30/0	369	651	1701	333	1194	7884	2022	0.1647
			+30/+10	399	693	1710	360	1296	7941	2067	0.1742
			+30/+20	390	663	1698	354	1215	7959	2047	0.1730
			+30/+30	366	636	1785	333	1134	8391	2108	0.1580

4.2.3. Evaluation of Mixed Type Light-Shelf Performance at Winter Solstice

At the winter solstice, with reference to the No. 4 illumination sensor located at the innermost part, the illumination of the mixed type light-shelf was the highest as 1334 lx at the internal/external angle of -20°/+10°, followed by 1332 lx at -20°/+20°. The uniformity was the highest as 0.2793 at the angle of -10°/-30°. The efficiency of the mixed type light-shelf at the vernal equinox was high at the downward internal angle of -20°, and at the upward external angles of +10°, +20°. When compared with that of the external type light-shelf with reference to the No. 4 illumination sensor, the illumination value of the mixed type light-shelf was higher by 96 lx, and the uniformity of the mixed type light-shelf was also higher by 0.0409. This showed that the mixed type light-shelf was more advantageous in the deep introduction of day light and in the aspect of uniformity, which represents the quality of light, than that of an external type light-shelf at the winter solstice, too.

Table 6. Result of Performance Evaluation According to the Mixed Type Light Shelf During Winter

`season	height	size (mm)	Angle (In/Out)	Sensors(lx)						Average illumination (lx)	Uniform ratio of illuminance
				1	2	3	4	5	6		
winter	1800	200/200	-30/-30	823	1102	1217	1109	7584	6691	3088	0.2666
			-30/-20	876	1157	1514	1152	7649	10399	3791	0.2311
			-30/-10	895	1205	1639	1212	7814	11580	4058	0.2206
			-30/0	953	1262	1603	1250	7896	11486	4075	0.2338
			-30/+10	977	1250	1457	1313	7814	11206	4003	0.2440
			-30/+20	950	1214	1478	1310	7745	12936	4272	0.2225
			-30/+30	938	1145	1694	1224	7241	18528	5128	0.1830
			-20/-30	821	1123	1202	1133	7627	6629	3089	0.2657
			-20/-20	869	1166	1490	1159	7663	10248	3766	0.2307
			-20/-10	907	1224	1620	1229	7790	11570	4057	0.2236
			-20/0	948	1284	1596	1277	7910	11501	4086	0.2320
			-20/+10	979	1255	1433	1334	7867	11186	4009	0.2442
			-20/+20	977	1226	1445	1322	7745	12929	4274	0.2286
			-20/+30	934	1164	1675	1229	7231	18480	5119	0.1824
			-10/-30	845	1094	1248	1169	7061	6720	3023	0.2795
			-10/-20	866	1123	1550	1190	7123	10308	3694	0.2346
			-10/-10	902	1181	1661	1226	7236	11609	3969	0.2274
			-10/0	955	1243	1632	1310	7385	11558	4014	0.2380
			-10/+10	974	1219	1478	1238	7238	8798	3491	0.2790
			-10/+20	950	1190	1488	1313	7193	12857	4165	0.2282
			-10/+30	938	936	1718	1262	7157	18480	5082	0.1842

			0/-30	775	1039	1351	1070	6708	6890	2972	0.2608
			0/-20	809	1085	1634	1092	6718	10505	3640	0.2222
			0/-10	842	1133	1764	883	6830	11731	3864	0.2180
			0/0	902	1190	1745	1193	6967	11714	3952	0.2283
			0/+10	929	943	1598	1253	6888	11393	3834	0.2423
			0/+20	905	914	1620	1190	6818	13063	4085	0.2215
			0/+30	878	1118	1807	1152	6756	18574	5048	0.1740
			+10/-30	734	1013	1385	1025	6617	6941	2952	0.2487
			+10/-20	763	1061	1680	1058	6672	10562	3633	0.2101
			+10/-10	804	1116	1802	1082	6797	11904	3918	0.2052
			+10/0	859	1169	1766	1154	6890	11808	3941	0.2180
			+10/+10	878	1159	1668	1212	6823	11561	3884	0.2262
			+10/+20	857	893	1661	1152	6768	13284	4102	0.2089
			+10/+30	845	1118	1865	1135	6720	18845	5088	0.1660
			+20/-30	698	967	1325	1001	6530	6636	2860	0.2442
			+20/-20	734	1008	1608	1027	6605	10238	3537	0.2076
			+20/-10	773	1070	1754	1073	6698	11587	3826	0.2020
			+20/0	830	1116	1733	1135	6821	11549	3864	0.2149
			+20/+10	818	1106	1637	1142	6746	11366	3803	0.2152
			+20/+20	809	1087	1613	1118	6662	12950	4040	0.2002
			+20/+30	806	1075	1812	1118	6665	18475	4992	0.1615
			+30/-30	655	965	1193	960	6504	5731	2668	0.2456
			+30/-20	686	1015	1490	986	6569	9413	3360	0.2043
			+30/-10	734	1068	1622	1027	6679	10685	3636	0.2020
			+30/0	768	1102	1603	1073	6749	10627	3654	0.2102
			+30/+10	761	1092	1526	1061	6655	10440	3589	0.2120
			+30/+20	756	1070	1495	1063	6638	12089	3852	0.1963
			+30/+30	758	1063	1706	1061	6617	17597	4800	0.1580

5. Conclusions

The lighting performance of a mixed type light-shelf was evaluated by investigating the effect of the light-shelf tilt angle on the indoor space. To evaluate the performance of a mixed type light-shelf, the experiment was performed with an external type light-shelf under the same conditions and the results were compared and analyzed. The performance evaluation results are as follows.

First, at the summer solstice, the mixed type light-shelf was directly affected by the artificial solar light. With reference to the No. 4 illumination sensor located at the innermost part, the illumination of the mixed type light-shelf was the highest as 220 lx at the internal/external angles of -30°/+20°, -30°/+30°, -20°/+30°, and -10°/+30°. The uniformity was the highest as 0.2376 at the angle of -30°/+30°, at which the lighting performance was also the highest. The efficiency of the mixed type light-shelf at the summer solstice was high at the downward internal angles of -30°, -20°, and -10°, and at the upward external angles of +20° and +30°. When compared with that of the external type light-shelf with reference to the No. 4 illumination sensor, the illumination value of the mixed type light-shelf was higher by 56 lx, and the uniformity of the mixed type light-shelf was also higher by 0.0558.

Second, at the vernal equinox, with reference to the No. 4 illumination sensor, the illumination of the mixed type light-shelf was the highest as 885 lx at the internal/external angle of -30°/+30°, followed by 819 lx and 810 lx at the internal/external angles of -30°/+20 and -20°/+30, respectively. The uniformity was the highest as 0.2376 at the angle of -30°/+20, at which the lighting performance was also high. The efficiency of the mixed type light-shelf at the vernal equinox was high at the downward internal angles of -30° and -20°, and at the upward external angles of +20°

and +30°. When compared with that of the external type light-shelf with reference to the No. 4 illumination sensor, the illumination value of the mixed type light-shelf was higher by 294 lx, and the uniformity of the mixed type light-shelf was also higher by 0.0298.

Third, at the winter solstice, with reference to the No. 4 illumination sensor located at the innermost part, the illumination of the mixed type light-shelf was the highest as 1334 lx at the internal/external angle of -20°/+10°, followed by 1332 lx at -20°/+20°. The uniformity was the highest as 0.2793 at the angle of -10°/-30°. The efficiency of the mixed type light-shelf at the vernal equinox was high at the downward internal angle of -20°, and at the upward external angles of +10°, +20°. When compared with that of the external type light-shelf with reference to the No. 4 illumination sensor, the illumination value of the mixed type light-shelf was higher by 96 lx, and the uniformity of the mixed type light-shelf was also higher by 0.0409.

At all the summer solstice, vernal equinox, and winter solstice, the mixed type light-shelf was more advantageous in the deep introduction of day light and in the aspect of uniformity, which represents the quality of light, than that of an external type light-shelf. This shows that the mixed type light-shelf had better lighting performance than that of the external type light-shelf due to the function of adjusting the internal/external angles. This study was performed only with the light-shelf having a width of 200 mm. Future studies may need to be conducted to evaluate the light performance of a mixed type light-shelf by investigating the effect of the width and title angle on the indoor space.

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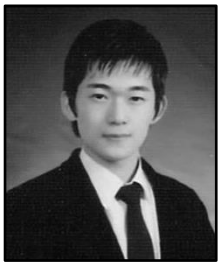
Author



Woori Chae. Master's course, Graduate School of Techno Design Department of Architectural Design, Kookmin University. Researcher, Smart Home Industrialization Support Center by the Ministry of Trade, Industry & Energy

