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Comparison of Measured and Predicted Daylight Illuminances in Two Underground Spaces

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Abstract

Daylight simulation methods play an important role for the prediction of daylight illuminances in underground spaces. This daylighting project is designed to compare daylight prediction methods for the application of large underground spaces. In this study, actual measurements were conducted under overcast and clear sky conditions. Also, computer simulations by Radiance, Superlite IEA 2.0 program and scale model testings were conducted to be compared with measured data. Simulation results show the data by Radiance, Superlite IEA 2.0 and the scale model are similar to the measured data in two underground spaces in Seoul. Overall results show that Radiance and superlite IEA 2.0 proved to be useful to predict daylight illuminances even in big underground spaces.

Keywords: daylighting, lightwell, underground space

1. INTRODUCTION

The use of daylighting in the underground space is often done to provide outdoor view and also, to supplement artificial lighting otherwise required. This study involves daylight prediction and measurement of two major underground spaces: Yangchon station and Kimpo Int'l airport station.

In the previous study, Ubbelode tested a two-story architectural office, which is toplighted through a roof-monitor over the central two story space with mezzanine. In her study, Radiance predicts better than other programs in the clear and overcast sky condition.

Also, Aizlewood tested BRE atrium under a CIE overcast sky for the validation of daylighting computer programs.

Two lightwells are included in Yangchon station that is a subway station constructed in 1992 in Seoul. Each lightwell which is covered with four small skylights (5.7x5.7m) measures approximately 11.7 × 11.7m. Total space of the lightwell is about 30% of the underground waiting area including the railroad space. This pyramidal type of the lightwell in Yangchon station allows direct sunlight, and consequently, the levels of natural illumination are very high especially in the clear sky condition (Fig. 1).

In Kimpo airport station in Seoul too, one big lightwell covered with nine small skylights (4.8 × 3.15m), is located in the walkway of the subway station. The width and the length of the lightwell are 14.2m and 9.6m individually, and the depth of the lightwell is 7.4m. As some of glasses are covered with color films, the daylight penetration to the lightwell is somewhat decreased (Fig. 2).

In this study, measured data in the actual stations are compared with Radiance, Superlite IEA 2.0, and scale model data in the overcast and clear sky condition to compare the capacity of simulation tools for the prediction of daylighting in underground spaces.

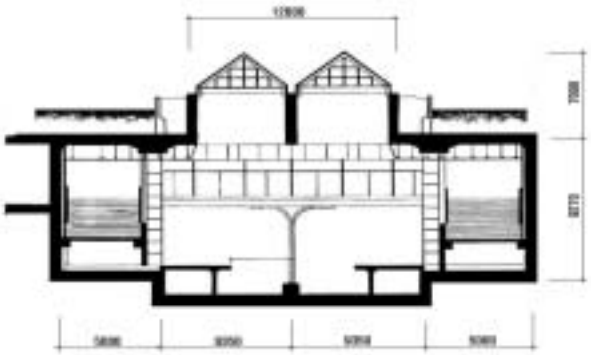


Figure 1. Section through the lightwell: Yangchon subway station

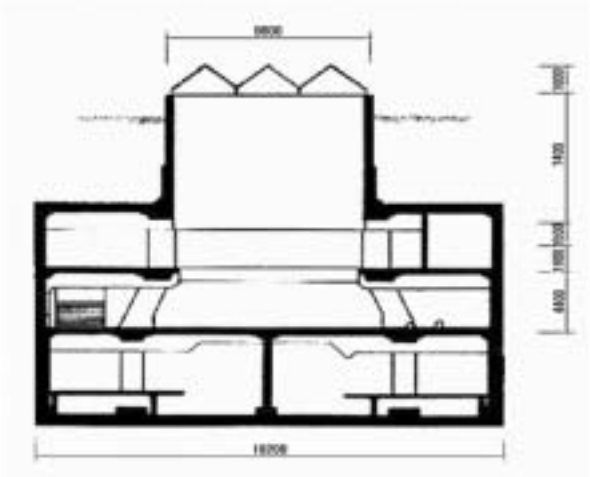


Figure 2. Section through the lightwell: Kimpo Int'l airport station

2. DAYLIGHT PREDICTION AND MEASUREMENT OF BUILDING 1: YANGCHON SUBWAY STATION

1) Overcast Sky Condition

(1) Actual Measurements in the Overcast Sky

The measurements were taken by the illuminance meters (T-1M: Minolta) with remote probes in Yangchon station in June 2000. The important data for this study is not only the absolute light illuminance in the underground space but also the daylight factor (DF).

Exterior illuminances were measured for Building 1. The exterior illumination levels were measured before and after the interior measurements, which were averaged for the outdoor reading. The readings were 6,865 lx in the overcast sky condition.

The effective transmittance was calculated by measuring the natural illumination just below the skylight, and it presents a percentage of the exterior horizontal illuminance. The interior reading was 3,960 lx and the exterior horizontal illuminance was 9,950 lx. Thus, the effective transmittance is 40%. The measured reflectance and transmittance of the primary materials in Building 1(percent) are as follows.

Table 1. Reflectance and Transmittance values of Building 1

Ceiling	40%
Wall(plat-form)	60%
Floor	40%
Wall (Lightwell)	60%
Skylight	40%

There are 5 measurement points in Line 1, and 5 points in Line 2. Horizontal illumiances are measured on the floor of the platform. Fig. 3 shows measurement points in Yangchun station.

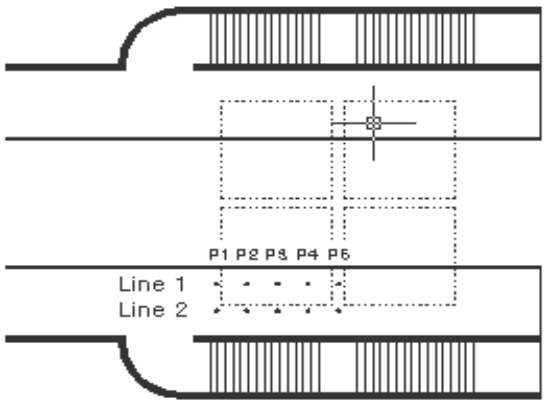


Figure 3. Measurement points of Building 1

(3) Comparison Results in the Overcast Sky

Figure 4. Exterior skylight and scale model of Building 1

Typical illuminances below the skylight area in Building 1 indicated an average level of 302 lx - 521 lx in the overcast sky condition. Therefore, the daylight factors (DF) ranged from 4.4% to 7.5%. Readings in Building 1 indicate an expected tendency that the daylight illuminances are diminished as the distance from the daylight source (skylight) increases, as can be seen in Table 2. The results of this measurement indicate that the lightwell satisfies a minimum light illuminance for typical lobby usages of 100 lx as recommended for circulation areas, up to 3.5m distance from the lightwell in the overcast sky condition.

Table 2. Actual measured data in Building 1 in the overcast sky (lux(DF))

		P1	P2	P3	P4	P5
Actual	L1	322.7 (4.7)	377.6 (5.5)	439.4 (6.4)	473.7 (6.9)	521.7 (7.6)
	L2	302.1 (4.4)	350.1 (5.1)	398.2 (5.8)	432.5 (6.3)	460.0 (6.7)

(2) Simulations in the Overcast Sky

In Radiance simulations, illuminances range from 290 lx (4.2 DF) to 535 lx (7.8 DF). In Superlite IEA 2.0, Illuminances range from 293 lx (4.3 DF) to 551 lx (8.0 DF).

Table 3. Simulation data using a scale model, Superlite and Radiance in Building 1(Overcast sky, lx(DF))

		P1	P2	P3	P4	P5
Scale Model	L1	315.8 (4.6)	363.9 (5.3)	446.3 (6.5)	487.5 (7.1)	514.9 (7.5)
	L2	288.4 (4.2)	336.4 (4.9)	405.1 (5.9)	425.7 (6.2)	446.3 (6.5)
Superlite	L1	330.9 (4.82)	394.1 (5.74)	456.5 (6.65)	510.1 (7.43)	551.9 (8.04)
	L2	293.8 (4.28)	347.4 (5.06)	400.9 (5.84)	447.6 (6.52)	483.3 (7.04)
Radiance	L1	320.6 (4.67)	378.9 (5.52)	426.3 (6.21)	504.6 (7.35)	536.2 (7.81)
	L2	290.4 (4.23)	328.1 (4.78)	389.9 (5.68)	410.5 (5.98)	461.3 (6.72)

Generally, the data from the computer programs and the

scale model are similar to the actual data. The relative difference between Radiance data and the actual data is 3.1%, and the relative difference between Superlite IEA 2.0 data and the actual data is 3.7%. The relative difference between the scale model data and the actual data is 2.6 %. In Fig. 5 and 6, two types of the graph show comparison results.

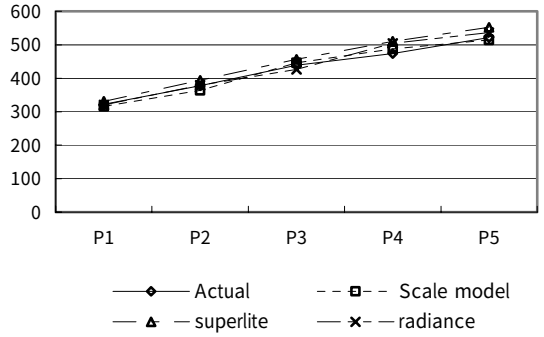


Fig. 5. Comparison results in Line 1 of Building 1in the overcast sky condition (lx)

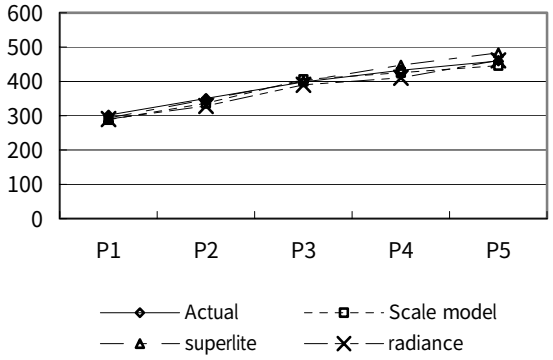


Fig. 6. Comparison results in Line 2 of Building 1 in the overcast sky condition (lx)

Thus, the simulation data by Radiance, Superlite IEA 2.0 and the scale model show similar results to the actual measured data in the shallow lightwell of Yangchon station in the overcast sky condition. However, Radiance data are very similar to the actual measured data

2) Clear Sky Condition

(1) Actual Measurements in the Clear Sky

Unobstructed horizontal exterior illuminances were measured for Building 1. The total exterior illumination level is 51,420 lx (direct sun: 10,841 lx, diffuse light: 41,901 lx).

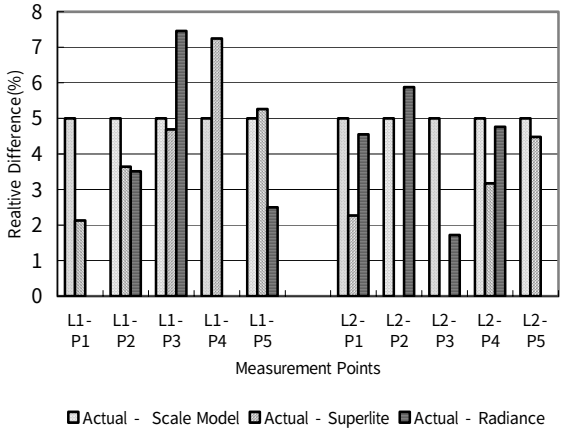


Fig. 7. Relative Differences in Building 1 in the overcast sky condition

Typical illuminances below the skylight area in Building 1 indicated an average level of 1547 lx - 4190 lx in the clear sky condition. Therefore, the daylight factors (DF) ranged from 3.0% to 8.2%.

Table 4. Actual measured data in Building 1 in the clear sky (lux(DF))

		P1	P2	P3	P4	P5
Actual	L1	1,717 (3.34)	2,108 (4.10)	2,972 (5.78)	3,599 (7.00)	4,191 (8.15)
	L2	1,548 (3.01)	2,000 (3.89)	2,324 (4.52)	2,684 (5.22)	3,224 (6.27)

(2) Simulations in the Clear Sky

In Radiance simulations, illuminances range from 1,666 lx (3.2 DF) to 3,922 lx (7.6 DF). In Superlite IEA 2.0 simulations, Illuminances range from 1,695 lx (3.3 DF) to 3,533 lx (6.9 DF).

(3) Comparison Results in the Clear Sky

The data from the computer programs and the scale model are similar to the actual data. The relative difference between Radiance data and the actual data is 4.7%, and the relative difference between Superlite IEA 2.0 data and the actual data is 8.3%. The relative difference between the scale model data and the actual data is 7.8%. In Fig. 8 and 9, two graphs show comparison results.

Table 5. Simulation data using the scale model, Superlite and Radiance in Building 1(Clear sky, lx(DF))

		P1	P2	P3	P4	P5
Scale model	L1	1,769 (3.44)	2,388 (4.64)	3,200 (6.22)	3,585 (6.97)	4,476 (8.70)
	L2	1,674 (3.26)	2,238 (4.35)	2,614 (5.08)	2,956 (5.75)	3,355 (6.52)
Superlite	L1	1,956 (3.80)	2,316 (4.50)	2,777 (5.40)	3,184 (6.19)	3,534 (6.87)
	L2	1,695 (3.30)	1,983 (3.86)	2,304 (4.48)	2,602 (5.06)	2,863 (5.57)
Radiance	L1	1,736 (3.38)	2,088 (4.06)	3,295 (6.41)	3,314 (6.44)	3,922 (7.63)
	L2	1,666 (3.24)	1,925 (3.74)	2,376 (4.62)	2,530 (4.92)	3,219 (6.26)

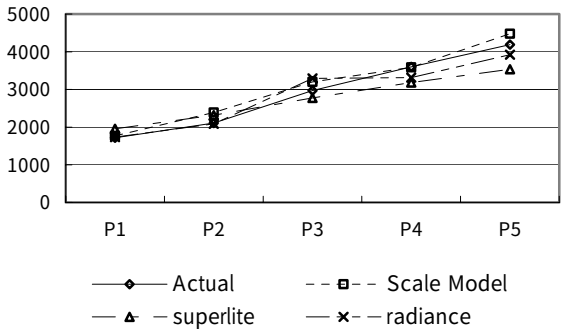


Fig. 8. Comparison results in Line 1 of Building 1 in the clear sky condition (lx)

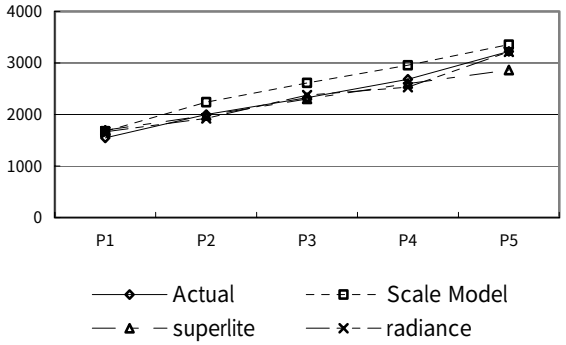


Fig. 9. Comparison results in Line 2 of Building 1 in the clear sky condition (lx)

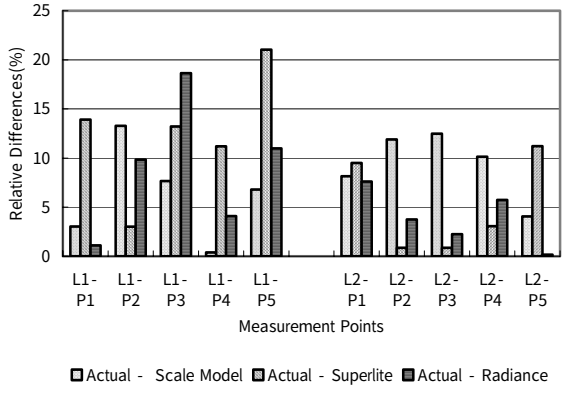


Fig. 10. Relative Differences in Building 1 in the clear sky condition

3. DAYLIGHT PREDICTION AND MEASUREMENT OF BUILDING 2: KIMPO INT'L AIRPORT SUBWAY STATION

1) Overcast Sky Condition

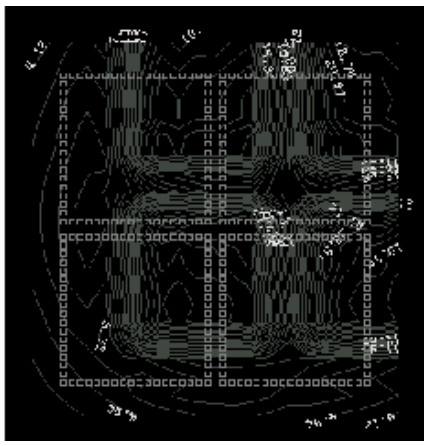


Fig. 11. Superlite IEA 2.0 output in the clear sky condition (Building 1)

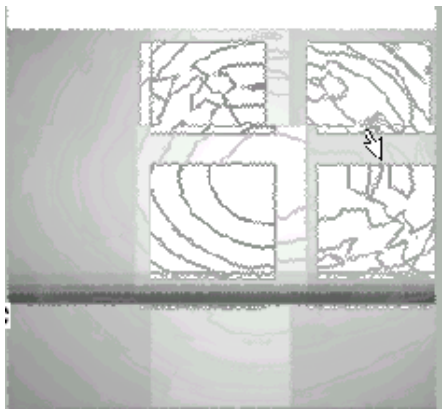


Fig. 12. Radiance output in the clear sky condition (Building 1)

(1) Actual Measurements in the Overcast Sky

Unobstructed exterior illuminances were measured for Kimpo station. The average level was 17,700 lx in the overcast sky condition.

Effective transmittance of the actual skylight system was calculated by glass thickness, glass maintenance, and the opaque area ratio of glass because the lightwell was too deep (9.43m) to measure. The calculated effective transmittance of the skylight is 20%. The surface reflectances and the transmittance (average) are as the follows.

Table 6. Reflectance and Transmittance values of building 2

	Reflectance& transmittance
Ceiling	40%
Wall(platform)	60%
Floor	40%
Wall(lightwell)	60%
Skylight	21%

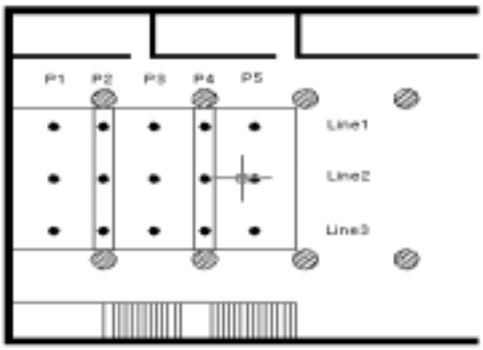


Fig. 13. Measurement points of Building 2

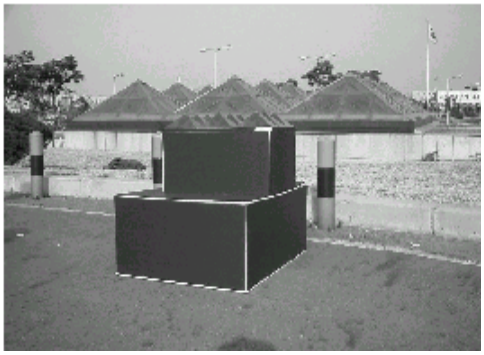


Fig. 14. Exterior skylight and scale model of Building 2

In Building 2, the daylight illuminances were measured on the 1st ground floor (9m below the skylight area). Horizontal illumiances are measured 1.2 meter above the floor of 1st underground floor and there are 5 measurement points in Line 1,2 and 3. Fig 9 shows measurement points in Kimpo station

Typical illuminances indicated an average level of 1,009 lux to 1,381 lx in the overcast sky condition. Therefore, the daylight factor levels ranged from 5.7% to 7.8%. At the center of the lightwell (14.2x9.6m), the daylight illuminance was 1,380 lx (7.8 DF). At the edges of the lightwell, the daylight illuminance ranged from 1,000 to 1,080 lx (5.7 - 6.1 DF).

Table 7. Actual measured data in Building 2 in the overcast sky (lux(DF))

		P1	P2	P3	P4	P5
Actual	L1	1,009 (5.7)	1,044 (5.9)	1,186 (6.7)	1,044 (5.9)	1,009 (5.7)
	L2	1,186 (6.7)	1,239 (7.0)	1,381 (7.8)	1,204 (6.8)	1,115 (6.3)
	L3	1,062 (6.0)	1,097 (6.2)	1,239 (7.0)	1,097 (6.2)	1,080 (6.1)

(2) Simulations in the Overcast Sky

In Radiance simulation, illuminances range from 922 lx (5.2 DF) to 1391 lx (7.9 DF). In Superlite IEA 2.0, Illuminances range from 947 lx (5.4 DF) to 1333 lx (7.5 DF).

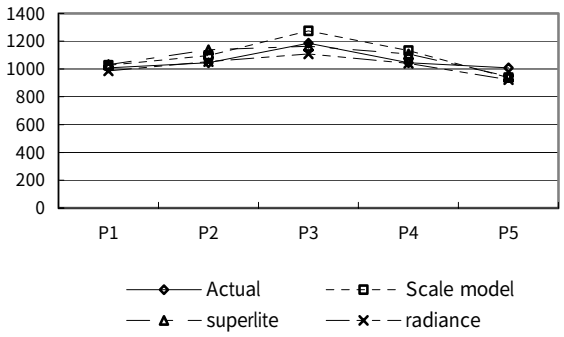
Table 8. Simulation data using the scale model, Superlite and Radiance in Building 2 (Overcast sky, lx(DF))

		P1	P2	P3	P4	P5
Scale model	L1	1,027 (5.8)	1,097 (6.2)	1,274 (7.2)	1,133 (6.4)	938 (5.3)
	L2	1,168 (6.6)	1,204 (6.8)	1,416 (8.0)	1,239 (7.0)	1,080 (6.1)
	L3	1,027 (5.8)	1,062 (6.0)	1,274 (7.2)	1,062 (6.0)	956 (5.4)
Superlite	L1	1,032 (5.83)	1,138 (6.43)	1,165 (6.58)	1,108 (6.26)	947 (5.35)
	L2	1,181 (6.67)	1,304 (7.37)	1,333 (7.53)	1,269 (7.17)	1,085 (6.13)
	L3	1,030 (5.82)	1,138 (6.43)	1,163 (6.57)	1,106 (6.25)	947 (5.35)
Radiance	L1	986 (5.57)	1,053 (5.95)	1,108 (6.26)	1,041 (5.88)	922 (5.21)
	L2	1,232 (6.96)	1,287 (7.27)	1,391 (7.86)	1,253 (7.08)	1,151 (6.5)
	L3	956 (5.40)	1,057 (5.97)	1,158 (6.54)	1,020 (5.76)	938 (5.30)

(3) Comparison Results in the Overcast Sky

Generally, the data from the computer programs and the scale model are similar to the actual data. The relative difference between Radiance data and the actual data is 5.0%, and the relative difference between Superlite IEA 2.0 data and the actual data is 4.6%. The relative difference between the scale model data and the actual data is 4.5%. In Fig.15, 16 and 17, three graphs show comparison results.

Fig. 15. Comparison results in the Line 1 of Building 2 in the overcast sky condition (lx)



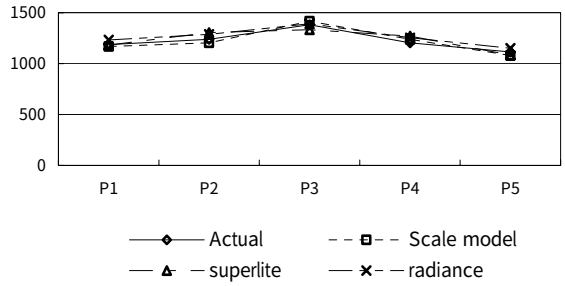


Fig. 16. Comparison results in the Line 2 of Building 2 in the overcast sky condition (lx)

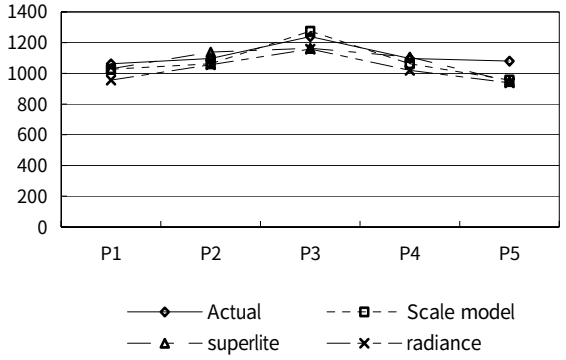


Fig. 17. Comparison results in the Line 3 of Building 2 in the overcast sky condition (lx)

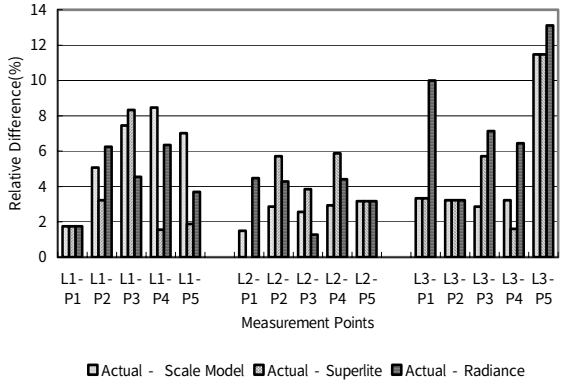


Fig. 18. Relative Differences in Building 2 in the overcast sky condition

2) Clear Sky Condition

(1) Actual Measurements in the Clear Sky

Unobstructed horizontal exterior illuminances were measured for Building 1. The total exterior illumination level is 51,900 lx (direct sun: 29,600 lx, diffuse light: 22,300 lx).

Typical illuminances below the skylight area in Building 2 indicated an average level of 1282 lx - 2240 lx in the clear sky condition. Therefore, the daylight factors (DF) ranged from 2.4% to 4.3%.

Table 9. Actual measured data in Building 2 in the clear sky (lx(DF))

		P1	P2	P3	P4	P5
Actual	L1	1,980 (3.82)	1,810 (3.49)	2,240 (4.32)	1,820 (3.51)	1,940(3.74)
	L2	1,886 (3.63)	1,850 (3.57)	2,173 (4.19)	1,838 (3.54)	1,862(3.59)
	L3	1,432 (2.76)	1,308 (2.52)	1,505 (2.90)	1,282 (2.47)	1,292(2.49)

(2) Simulations in the Clear Sky

In Radiance simulations, illuminances range from 1259 lx (2.4 DF) to 2048 lx (3.6DF). In Superlite IEA 2.0 simulations, Illuminances range from 1000 lx (1.9 DF) to 1781 lx (3.4 DF).

Table 10. Simulation data using the scale model, Superlite and Radiance in Building 2(Clear sky, lx(DF))

		P1	P2	P3	P4	P5
Scale model	L1	2,088 (3.82)	1,810 (3.49)	2,240 (4.32)	1,820 (3.51)	1,940 (3.74)
	L2	1,992 (3.84)	2,004 (3.86)	2,040 (3.93)	1,884 (3.63)	1,994 (3.75)
	L3	1,248 (2.40)	1,272 (2.45)	1,260 (2.43)	1,260 (2.43)	1,200 (2.31)
Superlite	L1	1,652 (3.18)	1,687 (3.25)	1,781 (3.43)	1,654 (3.19)	1,633 (3.15)
	L2	1,613 (3.11)	1,724 (3.32)	1,694 (3.26)	1,692 (3.26)	1,563 (3.01)
	L3	1,054 (2.03)	1,140 (2.20)	1,092 (2.10)	1,117 (2.15)	1,000 (1.93)
Radiance	L1	1,857 (3.58)	1,866 (3.60)	2,048 (3.95)	1,866 (3.60)	1,765 (3.40)
	L2	1,875 (3.61)	2,011 (3.87)	1,965 (3.79)	2,023 (3.90)	1,845 (3.55)
	L3	1,259 (2.43)	1,370 (2.64)	1,322 (2.55)	1,364 (2.63)	1,181 (2.28)

(3) Comparison Results in the Clear Sky

The data from the computer programs and the scale model are similar to the actual data. The relative difference between Radiance data and the actual data is 6.9%, and the relative difference between Superlite IEA 2.0 data and the actual data is 15.9 %. The relative difference between the scale model data and the actual data is 7.1 %. In Fig. 18, 19 and 20, three graphs show comparison results.

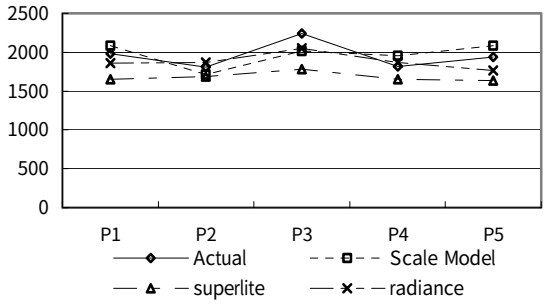


Fig. 19. Comparison results in the Line 1 of Building 2 in the clear sky condition (lx)

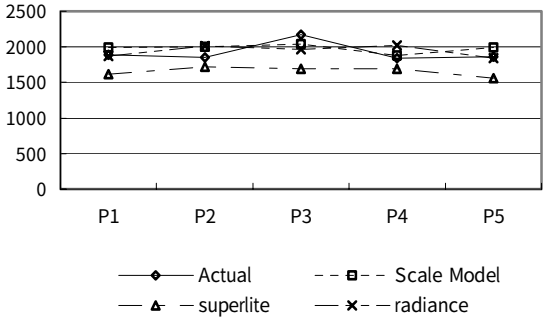


Fig. 20. Comparison results in the Line 2 of Building 2 in the clear sky condition (lx)

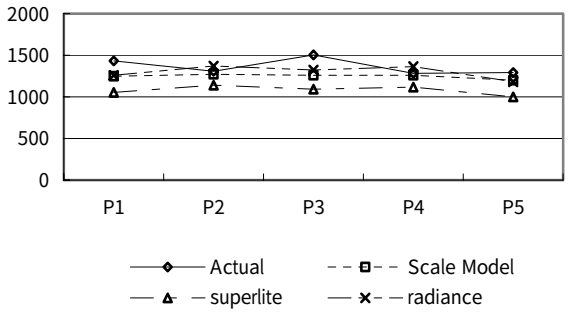


Fig. 21. Comparison results in the Line 3 of Building 2 in the clear sky condition (lx)

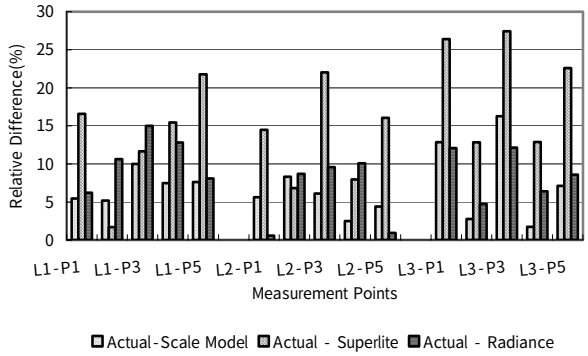


Fig. 22. Relative Differences in the Building 2 in the clear sky condition

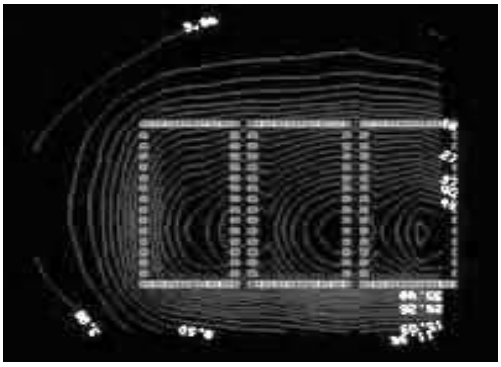


Fig. 23. Superlite IEA 2.0 output in the clear sky condition (Building 2)

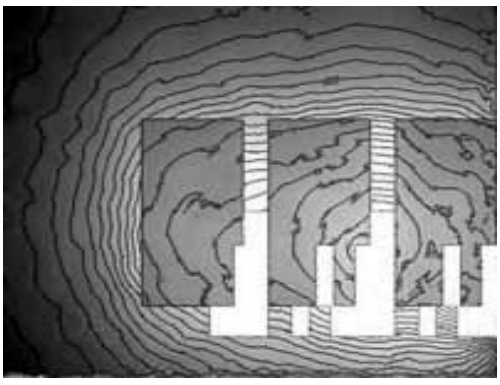


Fig. 24. Radiance output in the clear sky condition (Building 2)

4. Conclusions

This study involves daylight prediction and measurement of two underground spaces. In this paper, actual measurements were conducted in two underground spaces in the overcast and clear sky condition to compare with simulated data using Radiance, Superlite IEA 2.0 and the sclae model.

The results show that the data by Radiance, Superlite IEA 2.0, and the scale model are similar to the actual measured data.

In Yangchon station, relative differences between the actual data and the simulation data using physical model, Superlite IEA2.0 and Radiance are 2.63% ~ 3.71% under Overcast sky and 6.4% ~ 8.8% under clear sky with sun. In Kimpo airport station, relative differences between the actual data and the simulation data are 4.0% ~ 5.3% under Overcast sky and 6.9% ~ 15.8% under clear sky with sun.

As a result, Radiance and Superlite IEA 2.0 proved to be useful to predict daylight illuminances even in large underground spaces.

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