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Experimental Analysis of Indoor Illuminance and Daylight Distribution Compared to the Generation Performance of Silicon based PV Window System

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Abstract

In this study, indoor illuminance and daylight distribution compared to the generation performance of PV window system are experimented and analyzed in accordance with the types of silicon (crystalline, amorphous). According to the analysis of generation quantity during the measurement period, when solar radiation is 138.1kW, daily maximum generation quantity is 27.4kW (19.8% of efficiency) for crystalline PV window system, and 5.8kW (4.1% of efficiency) for amorphous PV window system. In addition, according to analysis of indoor illuminance and daylight distribution, the illuminance of 500lx is secured from all measuring points, and in the case of daylight factor, more than 1.5% of minimum standard (BS 8206-2) is indicated. Therefore, it is analyzed that the lighting performance required by residential environment is satisfied by crystalline as well as amorphous PV window system. However, in the case of illuminance uniformity, crystalline PV window system are analyzed to be 10.5% lower for the measuring height of 400mm and 48.6% lower for the measuring height of 850mm compared to the amorphous PV door and window system.

Keywords: *Amorphous Module, Crystalline Module, PV Window System, Generation Performance, Indoor Illuminance, Daylight Factor*

1. Introduction

Recently, the Korean government set the target of supplying 1 million units of "green homes" by 2020, and in the case of photovoltaic power generation system, the target is to supply electricity with the capacity of 3kW to each household. However, in the case of apartments that are typical residential building in Korea, it is difficult to secure the recommended installation capacity only with the typical PV system installed on the roof due to the high density of household-to-floor area ratio within the building site. As a solution to this problem, the photovoltaic(PV) window system that have the visibility, transmissibility, and lighting characteristic intrinsic functions of glass by mixing with the glass on doors and windows of apartments are developed for application [1]. However, existing studies on PV module mainly concentrate on understanding the cell characteristic and generation performance of module itself. Therefore, there is a lack of research on their functions(lighting characteristic, transmissibility, *etc.*,) as the architectural window required by the apartment environment.

Hence, in this study quantitatively compares and evaluates indoor illuminance and daylight distribution(daylight factor, uniformity of illuminance) in comparison to

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generation performance of PV window system, in accordance with the types of silicon(crystalline, amorphous), using mock-up tests in order to apply the PV window system to apartments, the most typical residential building type in Korea.

2. Methodology

The method of the study, which is performed for the comparison and evaluation of indoor illuminance and daylight distribution against the generation performance of PV window system in accordance with the types of silicon (crystalline, amorphous), can be summarized as follows:

First, each of the PV window system with identical shape is designed, and mock-up test piece is fabricated by applying the single plate module for which the crystalline PV cell and amorphous PV cell are laminated.

Second, the solar radiation and generation quantity for each time zone are collected and analyzed for each PV module by utilizing the fabricated mock-up test piece. In addition, for the analysis of indoor illuminance and daylight distribution(daylight factor, uniformity of illuminance), the indoor illuminance and daylight distribution compared to the generation performance of PV window system are compared and evaluated in accordance with the PV module by collecting and analyzing the indoor/outdoor illuminance data under the condition of clear sky.

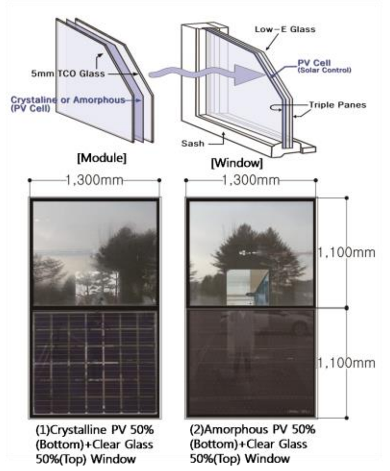
3. Constitution of PV Window and Mock-up

3.1. Constitution of Window

The selected size of PV window system is 1,300×1,100mm, in consideration of the maximum area of PV module, which can be manufactured under the condition of not exceeding the size of the window of the living room and balcony in apartments. In the case of the crystalline module applied to this study, the monocrystalline 5inch PV cell(42 units) is applied, which, in general, is commercialized more widely than the polycrystalline PV cell [2]. In addition, the PV modules (crystalline, amorphous) are applied to the 50% of lower section as the PV application ratio for window by utilizing the preceding study [3] from which the optimal ratio(minimum illuminance securing standard) of amorphous PV module for apartments is selected through the simulation analysis and mock-up verification.

The constitution and characteristic of window are shown in Table 1.

Table 1. Constitution and Characteristic of Window



Division	(1)	(2)
Output Power(W)	94	162
Max Power Voltage(V)	111	24.81
Max Power Current(A)	0.9	20.75
Open Circuit Voltage(V)	143	8.41
Short Circuit Current(A)	1.05	7.84
Module Efficiency(%,STC)	7	14
Transmission Factor(%)	20	20
U-value($W/m^2 \cdot K$)	1.4	1.4

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3.2. Constitution of Mock-up

The location of mock-up experiment is decided to the place which is not affected by the influence of shading among the building site of university located in Yeoju, Gyeonggi-do, Korea(East longitude 127.63°, north altitude 37.27°), and the window are installed so that they face due south.

The horizontal interval of indoor illuminance measuring points is decided as 0.5m, in grid shape(15 points/total 60 points), in consideration of the size of the room, and the height of illuminance measuring surface is decided as 400mm(for living room) and 850mm(for bedroom) respectively. In addition, the reflectivity of indoor finishing materials is set up as 80% for ceiling, 80% for wall, and 10% for floor respectively.

The constitution of mock-up and the specification of measuring device for analyzing the daylight distribution against the generation performance of PV window system are shown in the following Figure 1 and Table 2.

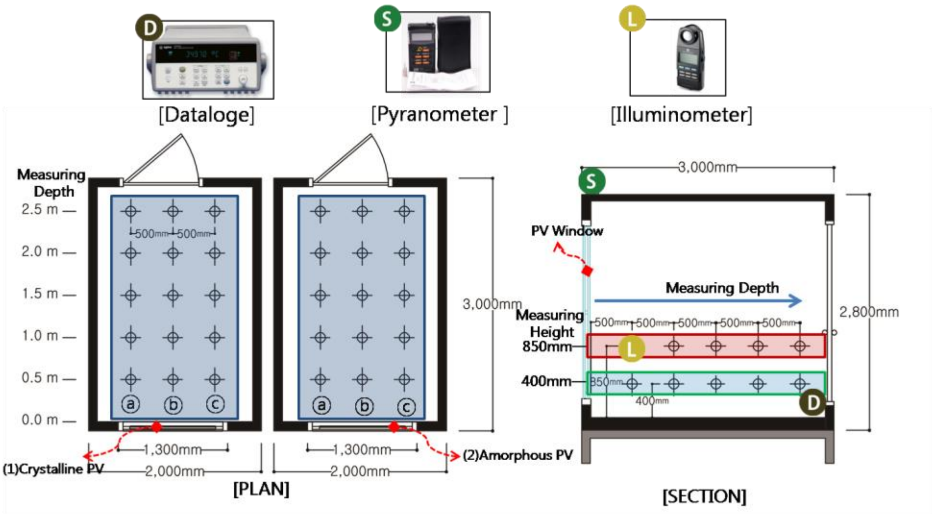

Figure 1. Constitution of Mock-up

Table 2. Specification of Measuring Device

Measuring device	Specification	
Illuminometer (T-10A)	Measuring Range	0.01~299,900 lx
	Functional Compensation	Measured Value×0.500~2.000
	Spectral Response	Below 6%
Dataloge	Max Voltage	300V±(0.002%~0.002%)
	Max Current	1A±(0.004%~0.01%)
	Scanning Speed	60ch/s
Pyranometer	Measuring Range	2,000W/㎡
	Spectral Response	400~1000nm

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In the case of the generation quantity in relation to this study, the data for winter season(2016. 12. 20 ~ 2016. 02. 20) were collected, and in the case of indoor illuminance, the data under the condition of clear sky were collected for the measuring period of generation quantity.

4. Result of Analysis

4.1. Solar Radiation and Generation Quantity

The measurement result of solar radiation and generation quantity are shown in Figure 2.

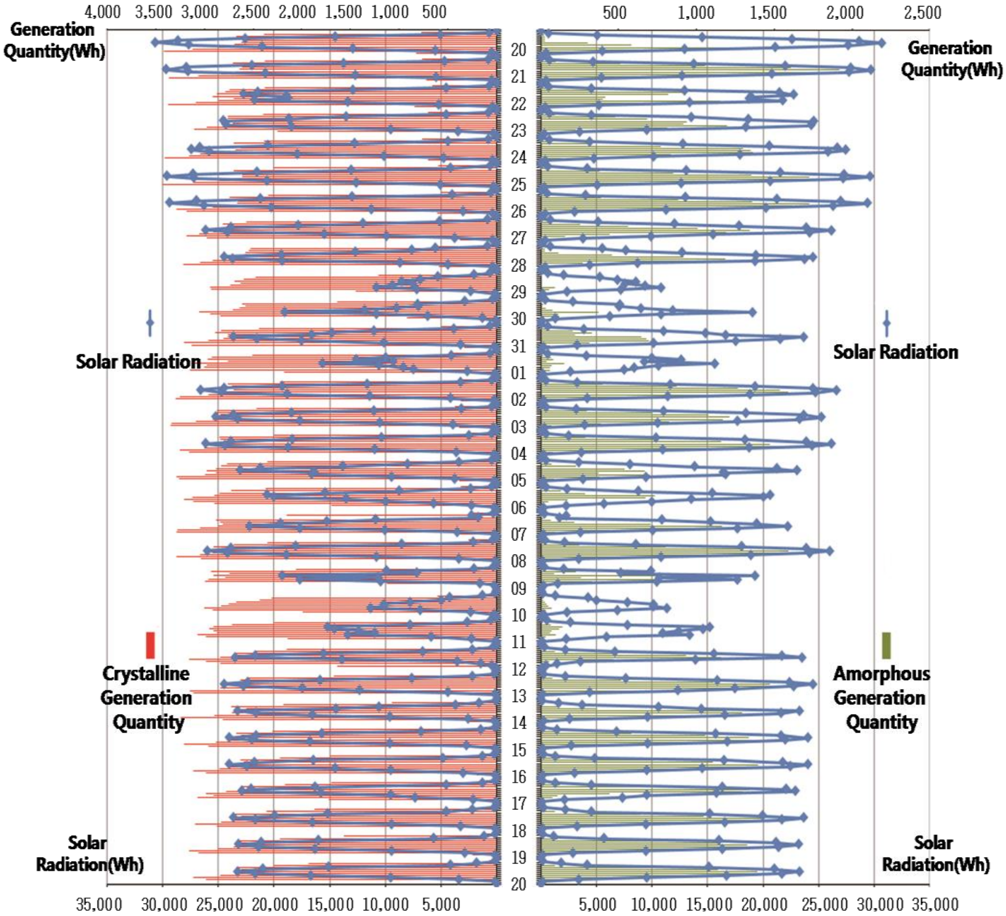

Figure 2. Measurement Result of Solar Radiation and Generation Quantity

According to the analysis of solar radiation and generation quantity, total solar radiation during the measuring period appears to be 4,242.5kW, and in the case of generation quantity, the crystalline PV window system(870.0kW) is analyzed to be 460% higher than the amorphous PV window system(155.2kW) due to the influence of module efficiency and output. And, in the case of maximum generation quantity, when solar radiation is 138.1kW, the crystalline PV window system(27.4kW) are analyzed to be 372% higher than the amorphous PV window system(5.8kW).

At this moment, generation efficiency in relation to solar radiation is analyzed to be 19.8% for crystalline PV window system and 4.1% for amorphous PV window system, respectively [4].

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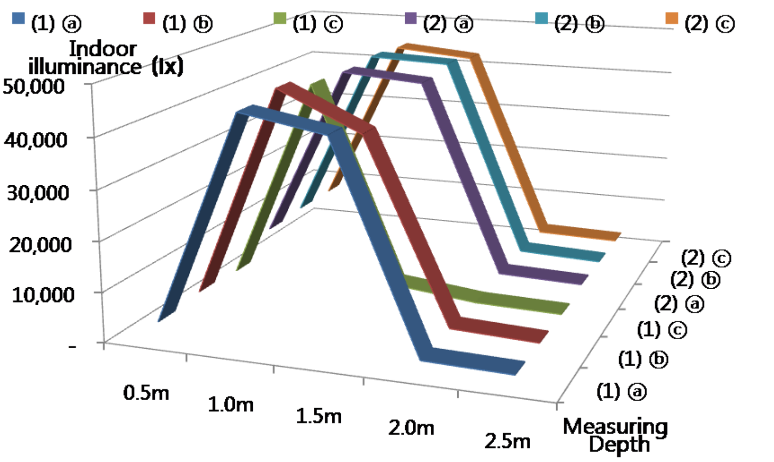
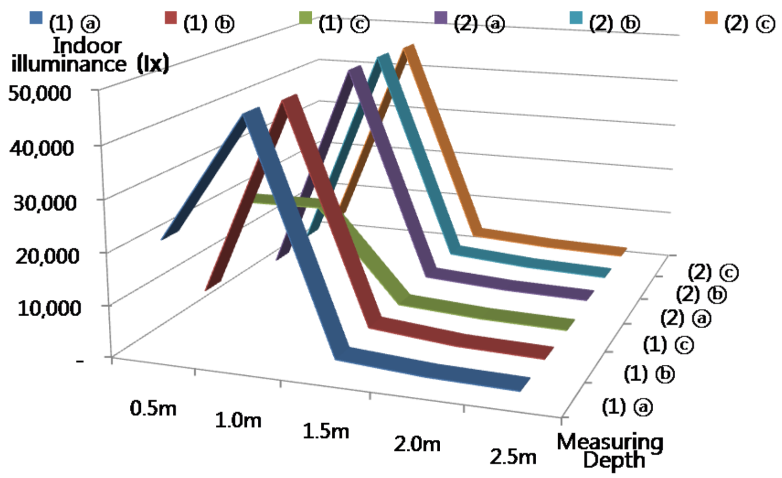
4.2. Indoor Illuminance and Daylight Distribution

The height of illuminance measuring surface is measured at 400mm(living room) and 850mm(bedroom), respectively, which are the working surface standard (KS A 3011: Illuminance standard) [5] for apartments, and the measurement result of total 60 measuring points in accordance with the measuring depth(from the inside surface of glass to the indoor measuring point) is shown in the following Figure 3.



[Measuring Heigh : 400mm]



[Measuring Heigh : 850mm]

Figure 3. Result of Indoor Illuminance Measurement

For the evaluation of indoor illuminance by daylight, the UDI standard illuminance range [6, 7], which is the evaluation method of daylighting design, was applied.

The result of indoor illuminance measurement appears to be more than 500lx for all measuring points of crystalline and amorphous PV window system, and it is analyzed that more than UDI-a(500~2,500lx) of illuminance, under which sufficient indoor illuminance is maintained with daylight without occupants feeling any unpleasantness, is secured.

However, it appears that the indoor illuminance is reduced considerably at the measuring depth of 1.5m(measuring height 400mm) and 1.0m(measuring height

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850mm), respectively, due to the influence of solar altitude angle, and in the case of the crystalline PV window system, the indoor illuminance in relation to the identical measuring depth and measuring point is analyzed to be 24,000~41,000lx lower for some of the measuring points, due to the influence of the shadow of crystalline PV cell.

With the basis of the result of indoor illuminance measurement(Figure 3), the daylight distribution for each PV window system is shown in Table 3.

Table 3. Daylight Distribution

Measuring Height	400mm						850mm					
Measuring Depth	(1) Crystalline PV			(2) Amorphous PV			(1) Crystalline PV			(2) Amorphous PV		
	ⓐ	ⓑ	ⓒ	ⓐ	ⓑ	ⓒ	ⓐ	ⓑ	ⓒ	ⓐ	ⓑ	ⓒ
0.5 m	4.35	5.15	4.26	10.00	10.47	10.29	27.67	9.04	26.42	4.84	5.92	5.65
1.0 m	57.36	58.99	56.10	55.60	56.35	55.60	58.49	57.74	26.70	57.99	58.11	57.48
1.5 m	53.58	49.31	5.31	53.96	55.47	53.71	3.99	4.53	3.67	4.68	5.04	4.49
2.0 m	3.07	3.37	2.92	4.09	4.14	3.74	2.57	2.60	2.40	3.41	3.48	3.34
2.5 m	2.53	2.46	2.39	3.46	3.31	3.26	2.31	2.04	1.98	3.00	2.28	2.28

Regarding the evaluation standard for the appropriate range of daylight factor, British Standard (BS 8206-2) [8] was applied (more than minimum 1.5% for living room).

According to the analysis of daylight factor, it is analyzed to be more than the minimum standard of 1.5% for all measuring points in the case of the crystalline and amorphous PV window system.

However, the indoor illuminance and daylight factor in relation to the identical measuring depth and measuring point appears to be lower for some measuring points of crystalline PV window system (Figure 3, Table 3), due to the shadow of crystalline PV cell, and in the case of the uniformity of illuminance, it is analyzed that the crystalline PV window system has 10.5% lower value at the measuring height of 400mm and 48.6% lower value at the measuring height of 850mm than the amorphous PV window system.

5. Conclusion

The result of performing the mock-up test for the experimental analysis of generation performance of the PV window system in accordance with the type of silicon (crystalline, amorphous), indoor illuminance and daylight distribution is as follows:

(1) During the measurement period, when solar radiation is 138.1kW (06 day), daily maximum generation quantity of crystalline PV window system (27.4kW) appears to be 372% higher than that of amorphous PV window system (5.8kW), and at this moment, generation efficiency in relation to solar radiation is analyzed to be 19.8% for crystalline PV window system, and 4.1% for amorphous PV window system, respectively.

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(2) According to the measurement of indoor illuminance, it is more than 500lx for all measuring points, therefore, the illuminance of more than the standard of UDI-a(500~2,500lx) is secured, and in the case of daylight distribution(daylight factor), it appears to be more than 1.5% of minimum standard(BS 8206-2), so both of the crystalline and amorphous PV window system are analyzed to be satisfying the lighting characteristic required by residential environment. However, in the case of some measuring points of crystalline PV window system(Figure 3, Table 3), the indoor illuminance and daylight factor in relation to the identical measuring depth and measuring point appear to be lower due to the influence of the shadow of crystalline PV cell, and in the case of the uniformity of illuminance, the crystalline PV window system has 10.5% lower value at the measuring height of 400mm and 48.6% lower value at the measuring height of 850mm, respectively, than the amorphous PV window system.

This study is the result of quantitative comparison and evaluation for the generation quantity of PV window system in accordance with the types of silicon (crystalline, amorphous), indoor illuminance and daylight distribution in order to apply the PV window system to the apartments, the most typical building type in Korea. In the future, it is considered that additional study in which comprehensive indoor environment such as heat and perspective together with the evaluation of economic feasibility is combined and verified shall be performed with the target of actual application to the apartments.

Acknowledgments

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References

[1] J. S. Do, J. H. An and D. S. Choi, "Evaluation of Possibility of Designing a-Si Thin Film PV Module for Apartment Window Systems by Taking into Consideration of the Residential Environment and PV Module Generation Performance", Journal of Construction and Environment Research Institute, vol. 9, no. 2, **(2014)**, pp. 184-191.

[2] J. S. Do, J. H. An, K. H. Cho, D. S. Choi and M. K. Cho, "Analysis on the Efficiency of a-Si PV Window System In Apartments Using Mock-Up Test", Proceeding of the 38th Symposium on Human-Environment System, Nagasaki, Japan, **(2014)** December 6-7.

[3] D. S. Choi, J. H. An, J. S. Do, M. E. Lee and H. C. Jeon "Optimized Design of a Photovoltaic Module that Can be Integrated and Applied as Window System in Korea", Journal of Applied Engineering Research, vol. 9, no. 24, **(2014)**, pp. 24837-24845.

[4] D. S. Choi, J. H. An and J. S. Do, "Comparison/Evaluation of Day-lighting Performances depending on the modules of Silicone-based PT Windows System", Proceeding of the International Workshop on Architecture and Civil Engineering, **(2016)** April 19-21.

[5] Korean Industrial Standards, KS A 3011, **(2010)**.

[6] J. H. Sin, T. H. Jung, T. H. Kim, K. H. Kang, H. K. An and D. Y. Han, "Analysis of Power Variation and design Optimization of a-Si PV Modules Considering Shading Effect", Journal of Korean Solar Energy Society, vol. 30, no. 6, **(2010)**, pp. 102-107.

[7] J. H. Yoon and B. S. Kim, "Performance Evaluation of Building Integrated Photovoltaic(BIPV) module by Self-shading Effect of building Forms", Journal of Architectural Institute of Korea, vol. 21, no. 7, **(2005)**, pp. 149-156.

[8] British Standard, Lighting for buildings, BS 8206-2, **(2008)**.

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