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FOR RESIDENTIAL HOUSES**

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AN INVESTIGATION OF ANNUAL DAYLIGHTING METRICS FOR RESIDENTIAL HOUSES

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Abstract

Simple daylighting metrics is also necessary for the BIM design of residential houses. Prior to the establishment of annual daylighting metrics for residential houses in Japan, we investigated the indoor daylight environment in the houses on three blocks in Passive Town Kurobe. Firstly, several parameters and the settings of physical property values in the simulation were adjusted so that the percentage errors of the simulated average luminance on the interior surfaces in each house were less than 10%. Secondly, the annual daylighting simulation was conducted considering the actual operation of shading devices. Using the simulation results by referring to DA and sDA, we propose verDA (Vertical Daylight Autonomy) and versDA (Vertical Spatial Daylight Autonomy) as new daylighting metrics for residential houses in Japan. These metrics are calculated from the vertical eye illuminance, which is more relevant to brightness perception and human health.

Keywords: Daylighting, Annual daylighting metrics, Residential houses, Radiance,

1 Introduction

1.1 Background and Purpose

While daylighting is still a preferred method for most residents to secure indoor brightness, the role of daylight is now being re-examined from various viewpoints, including energy saving, comfortability and human health, etc. Some metrics for indoor daylight environment has been proposed, and Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), in which annual daylight environment is evaluated by the horizontal illuminance, are currently the most prominent annual daylighting metrics used in LEED -Leadership in Energy & Environmental Design- or WELL Building Standard. However, these metrics are mainly aimed at work spaces in office buildings and could not apply to the daylight environment evaluation in residential houses. Furthermore, there is some discussion as to whether or not these metrics could really cope with comfortability or human health.

Building Information Modeling (BIM) has recently attained widespread attention also in the design of residential architecture. There is a strong demand for the proposal of simple annual daylighting metrics for residential houses, which could secure not only energy saving performance but also comfortability and human health.

The aim of this study is to propose new annual daylighting metrics for residential houses by comparing the predicted annual daylight environment in the actual houses by simulation and the results of the questionnaire survey for the residents.

1.2 Research Flow

Figure 1 shows the flow of this research. In the first step, we will check the accuracy of the simulation results of solar shading device (lace curtain) using Radiance. In the second step, the annual illuminance in actual houses in Passive Town will be calculated and compared with the questionnaire survey results on the satisfaction degree of the daylighting environment for the residents. Finally, we will propose the appropriate range of indoor illuminance and the annual metrics for daylighting environment in residential houses.

Figure 1 – Research Flow

2 Solar Shading Device Simulation: Lace Curtain

Living rooms in the 1st and 2nd blocks of Passive Town have lace curtains on their main windows. It is necessary to accurately reproduce the properties of the material in Radiance simulation prior to the annual calculation of Passive Town houses. Therefore, we examined the accuracy of simulation results when using the lace curtain material. Figure 2 shows the experimental space. It has a southern facing window with double layer glasses and a lace curtain. Solar and sky luminance was measured using automated weather observation system and a CCD camera, and using those data, luminance distribution on the Wall/Floor/Ceiling/Window surface was calculated by Radiance. At exactly the same time as solar and sky luminance was measured, luminance distribution on those surfaces inside the experimental space was also measured using CCD camera system.

Figure 2 – Experimental Space (Left: Interior picture, Right: Vertical section and Size)

The lace curtain had the property that the transmittance is different for each incident angle of light. Therefore, referring to the previous research (Reinhart, C.F., 2006), we used the BRTDfunc material for the simulation. Figure 3 shows the measurement and simulation results

on 10 o'clock in a sunny day. The percentage errors of the simulated average luminance on the interior surfaces were less than 10%.

Figure 3 – Lace Curtain Simulation (Left: Actual Measurement Right: Simulation) and Percentage Errors

3 Annual Calculation and Questionnaire Survey

In this study, we focused on the actual apartment houses called Passive Town Kurobe model. The buildings are located in Kurobe city, Toyama prefecture, Japan. The construction site is divided into three blocks. Each building has at least one southern side opening, which has high insulating performance by using triple pane window. From the difference of the window design, such as the window area, installed shading devices and so on, the indoor daylight environment in the houses on each block varies. The large south openings and the openings on east, west and north can introduce sufficient daylight to the space in the houses on the 1st and the 2nd blocks. Moreover, especially on the 1st block, there are terraces outside the south windows called “Community deck” and the residents can use the movable overhang shading devices in hot seasons. In the houses on the 3rd block, which were in renovated buildings, the area of the south openings with inner Venetian blinds are smaller compared to the houses on other blocks. Each block full views are shown in Figure 4.

Figure 4 – Passive Town Full View (Left: 1st Block Center: 2nd Block Right: 3rd Block)

3.1 Interior Luminance Simulation

In order to bring the annual calculation conditions closer to the actual apartment conditions, as is the case with Chapter 2, illuminance distribution in each apartment was calculated by Radiance using measured data of solar and sky luminance, and compared with the luminance values inside the living room which measured at the same time as solar and sky luminance measurement, then interior and outdoor reflectance values were adjusted so that the percentage errors of the simulation became less than 10%. The target apartments are A1 in the 1st block, B4 in the 2nd block and C1 in the 3rd block. The results of simulation and the percentage errors are shown in Figure 5/6/7. In the verification of the 2nd block apartment, the luminance values in black-painted parts could not be measured because they exceeded the measurable limit. Therefore, the comparative evaluation between simulation and measurement results was performed excluding those black-painted parts.

Figure 5 – 1st Block Simulation (Left: Actual Measurement Right: Simulation) and Percentage Errors

Figure 6 – 2nd Block Simulation (Left: Actual Measurement Right: Simulation) and Percentage Errors

Figure 7 – 3rd Block Simulation (Left: Actual Measurement Right: Simulation) and Percentage Errors

3.2 Annual Calculation

Annual interior illuminance was calculated using Radiance/Honeybee to evaluate interior daylighting environment in the living rooms. Weather data in Uozu (Near Kurobe-city) in EnergyPlus Weather Data (EPW) format was used for the simulation. Some apartments were selected in order to evaluate various characteristics of daylighting environment. We classified the 1st and 2nd blocks into three groups according to the level and the shape of living rooms. Apartments in the 3rd block were classified into four groups according to the shape of living rooms and the operation of the solar shading device (venetian blinds). Apartments for calculating annual illuminance are shown in Table 1.

Table 1 – Apartment for Annual Calculation

1 st Block	2 nd Block	3 rd Block (Flat Type)	3 rd Block (Maisonnette Type)
A1	B1	C3	C2
A2	B2	C4-1	C4-2
A3	B3		

In this study, we calculated vertical eye illuminance because it relates more to not only brightness impression but also health and wellness than horizontal illuminance. Besides, horizontal illuminance is basically useful index for visibility on the desktops, however, the priority order for the visibility would not be high in residential houses unlike offices and schools.

We calculated the vertical illuminance in living and dining rooms. Calculation points were put on a virtual plane at 1200mm in height above the floor, facing the main window, and on the square grid of 500 mm as shown in Figure 8, excluding the space within 500 mm from walls and windows.

Figure 8 – Floor Plan (unit: mm) and Calculation Points

Prior to the annual calculation, we investigated the actual operation of solar shading devices in some apartments in every town block throughout the year. In the apartments in the 1st and 2nd block, the operation of lace curtains and thick curtains was recorded every 10 minutes using illuminance loggers installed around the windows, whereas in the apartments in the 3rd block, the operation of venetian blinds was recorded every 10 minutes using digital video cameras. Based on the investigation data we estimated the monthly average operation of solar shading devices per 1 hour for every apartment type in Table1 and reflect it to the annual daylighting calculation.

3.3 Questionnaire Survey

We conducted a questionnaire survey on daylight satisfaction for all residences in Passive Town. For residences in the 1st and the 2nd block surveys were done twice in summer and winter in 2017, and for the 3rd block in summer and winter in 2018. The relevant question for this annual daylighting investigation is shown in Figure 9. The number of valid responses is shown in Table 2.

Q11. Please tell us about the daylighting environment of the living and dining room.	
11-5.	Are you satisfied with the daylighting environment of the living and dining room during the day?
5:Satisfied	4:Slightly Satisfied 3:Neither Satisfied nor Dissatisfied 2:Slightly Dissatisfied 1:Dissatisfied

Figure 9 – Questionnaire Survey

Table 2 – The Number of Valid Responses

	1 st Block Groups			2 nd Block Groups			3 rd Block Groups			
	A1	A2	A3	B1	B2	B3	C3	C4-1	C2	C4-2
Summer	5	6	11	6	10	7	2	1	1	0
Winter	3	6	7	7	8	10	1	3	1	1

The answer to the question was assumed to be continuous scale from 1:Dissatisfied to 5:Satisfied to calculate the daylight satisfaction score for each group. Average scores of daylight satisfaction throughout the year are shown in Table 3.

Table 3 – Daylighting Satisfaction Score

	1 st Block Groups			2 nd Block Groups			3 rd Block Groups			
	A1	A2	A3	B1	B2	B3	C3	C4-1	C2	C4-2
Satisfaction Score	4.30	3.75	3.74	3.92	4.00	4.75	3.75	3.50	2.50	2.00

4 Annual Daylighting Metrics for Residential Houses

In this section, based on the comparison between the calculated illuminance and the residents' evaluation of daylight environment, annual daylighting metrics for residential houses: verDA (vertical Daylight Autonomy) and versDA (vertical spatial Daylight Autonomy) will be proposed in reference to the current DA and sDA. The definition of each indicator is shown in Table 4.

While verDA and versDA prescribe the lower limit of the indoor daylighting, the upper limit for daylighting can be prescribed by the glare evaluation formula; simplified DGP (sDGP) using vertical eye illuminance, although it would be necessary to investigate the possibility to apply sDGP to residential houses.

Table 4 – Definition of verDA and versDA

	Definition
verDA	Percentage of time above a given vertical eye illuminance threshold
versDA	Percent of an analysis area that meets a minimum daylight vertical eye illuminance level for a specified fraction of the operating hours per year.

4.1 Examining the versDA for Various Thresholds

Annual daylighting metrics; versDA was calculated from the annual vertical eye illuminance. Figure 10-13 shows the area ratio (percent of an analysis area that meets a minimum daylight vertical eye illuminance level) for the various illuminance threshold and a fraction of the operating hours per year.

Figure 10 – A1 Group versDA Calculation Results

Figure 11 – B1 Group versDA Calculation Results

Figure 12 – C3 Group versDA Calculation Results

Figure 13 – C2 Group versDA Calculation Results

For the determination of specific thresholds, we examined the influence of various sun shading devices to the versDA values in reference to the previous report (Heschong, L. 2011). In Passive Town apartments, triple pane glasses, lace curtains and venetian blinds are used for their

opening, therefore, we calculated the verDA on the models with various combination of these solar shading devices. Calculation results are shown in Figure 14. The indoor illuminance values of the apartment in the 3rd block were considerably smaller than those in the 1st and 2nd blocks, and the difference was also observed in the verDA values.

Figure 14 – verDA Calculation Results

4.2 Discussion

The values of verDA are considerably different among the apartments in 1st & 2nd blocks and in 3rd block. Accordingly the satisfaction levels of daylighting also quite differ among the residents in these blocks. Therefore, threshold for verDA could be determined by comparing the annual simulation results and residents' evaluation in future.

5 Conclusion

New annual daylighting metrics for residential houses was proposed based on the examination in the Passive Town Kurobe where various kinds of light environment can be observed. The verDA/versDA has the advantages, by using vertical eye illuminance, that they could relate more to not only brightness impression but also health and wellness, and excessive daylight could be estimated more easily using simplified DGP metrics. In future threshold for versDA could be determined by comparing the annual simulation results and residents' evaluation. It is desirable to continue adding more data for obtaining the reliable metrics.

6 References

- Kawashima, N. 2016. *THE CHARACTERISTICS OF INDEXES AND CRITERIA FOR DAYLIGHTING – The study for the application of evaluation of daylighting and visual comfort for architectural design* -. Journal of Architecture and Planning, Vol.81 Issue 727, 1917-1927.
- Architectural Institute of Japan. 2018. *Standards for Daylighting*. Tokyo: Architectural Institute of Japan.
- Reinhart, C.F. 2006. *Development and validation of a Radiance model for a translucent panel*. Energy and Buildings, 38, 890-904.
- Ward, G. 1998. *Rendering with Radiance The Art and Science of Lighting Visualization Revised Edition*. California: Space and Light.

- IES. 2012. *Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)*. New York: Illuminating Engineering Society of North America.
- Heschong, L. 2012. *DAYLIGHTING METRICS PIER Daylighting Plus Research Program*. California: California Energy Commission