

Study of Visibility Indices of Traditional Japanese Horizontal Blind “Sudare” Based on the Illuminance Different Level Using Physical and Digital Image Experiment

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Abstract

Sudare is a traditional Japanese blind made from bamboo. It has been used in Japanese houses for a long time, especially in summer. Its original function was to prevent direct solar radiation from entering a room, and to introduce outside air into a room at the same time. As an element of building, Sudare has the other function of creating space for different activities that need different levels of privacy. The characteristic form of Sudare makes it possible to see objects outside the house. During daytime, it is possible to see clearly the outside environment from inside but still maintain privacy from outside to inside. The privacy level is determined by the visibility level between each space, or from outside to inside, which are separated by partitions. At the same time, Sudare as a shading device can reduce thermal energy consumption.

This study aims to evaluate the effect of the diameter, spacer, scale, and whiteness of Sudare on the level of visibility by comparing people's responses by means of a questionnaire using physical and digital images experiment with different conditions of illuminance level.

The results of the questionnaire using physical and digital image experiments indicate that both the experiments showed the same trend. The illuminance ratio is the main factor that affects the visibility value. A higher ratio of illuminance difference between the observer's room and the object room will increase the value of visibility. The physical characteristics of Sudare (diameter, spacer, and scale) also influence the visibility value. Small scale Sudare have a better visibility value in a low illuminance ratio whereas large scale Sudare have better visibility value in high illuminance. High visibility value can be achieved when the illuminance ratio is more than 4.30.

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Introduction

The façade of a building functions as a thermal medium that will introduce thermal into the room by radiation and conduction from its window and by conduction from its wall (Vijayalaxmi, 2010, pp. 75-80); (Paryudi, Fenz, & Tjoa, 2013, pp. 49-54). The other function of a façade is to connect with the environment. Each function can be measured by thermal performance and visual performance. A larger opening will increase the visual performance but, on the other hand, it will decrease the thermal performance.

In Japan, Sudare have been used as external shading and internal partitions. Many traditional Japanese houses use Sudare as external shading to maintain thermal comfort inside the house in the summer; they protect the houses from direct solar radiation but still introduce outside air into the room (Figure 1, no. 1). This passive design strategy is effective for detached houses in suburban areas where the environment is still good and natural. As in some Islamic-architecture buildings, which use a traditional porous wall, it can create a uniform distribution of illuminance in the interior, resulting in a more direct relationship with the external environment and visual comfort (Ruggiero, Florensa & Dimundo, 2009, pp. 1886-1891). As an internal partition, Sudare can divide a space into two or more different spaces with different functions and levels of privacy. In some conditions, especially on bright days, people inside the room can see activities on the other side of the room or outside the house, although people outside the house cannot see the activities inside (Figure 1, no. 2, (a), (b), (c), (d)) (Yagi, 1982). The difference between outside and inside in this condition is the illuminance level of the room. The inside room has approximately 200 lux without electrical light, while the outside illuminance level can be more than 15,000 lux in clear sky or even more when the sky is overcast.

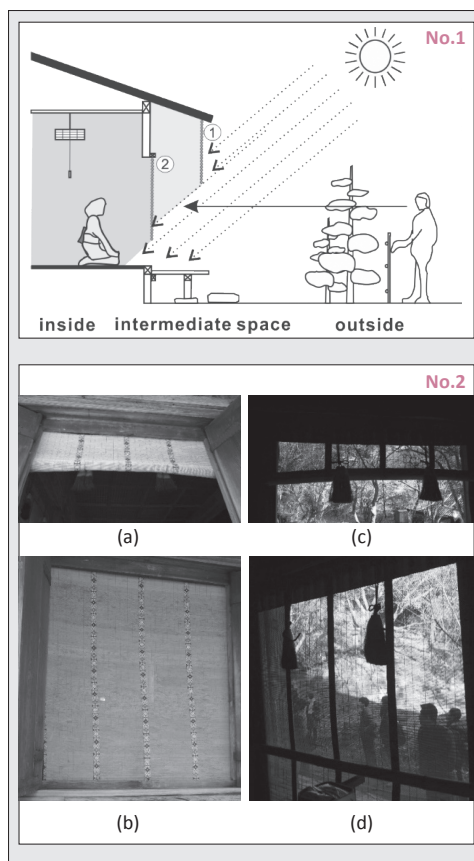


Figure 1. Japanese traditional blind "Sudare" (a) & (c) view from outside to inside (b) & (d) view from inside to outside).

There has been some research on visual comfort indices, but the scope of the index is mostly glare and light amount or light quality (Carlucci, Causone, De Rosa & Pagliano, 2015, pp. 1016-1033); the visibility of the outside view as a visual comfort index has not yet been researched. A modern adaptation of traditional masrabia for solar protection and privacy has been introduced in research using vertical cables, but has not been explored (Chambers, 2014).

In modern houses, most of which use the HVAC system, this strategy can no longer be used because they need to seal air inside the house. Modern houses or buildings used to have big glass openings to get a view of the outside from the inside, which increased the thermal load from the outside introduced to the inside of the building through its façade. This caused an increase in cooling energy use

(Chirarattananon & Taveekun, 2004, pp. 680-689; Radhi, Sharples & Fikiry, 2013, pp. 178-188). The challenge is to find a façade that has good thermal performance but still maintains its visual performance.

In this research, visual performance will be investigated to develop an index of visibility using the Japanese traditional horizontal blinds called Sudare based on visibility value, which is the scalar metric of visibility to recognize the shape, color, and details of an object. This value is the observer judgment for each condition of a room divided by Sudare with a value between 0-6, as will be described later in this paper.

Methodology

This research examines the effect of different illuminance levels on the visibility value of two rooms separated by Sudare, based on observer perception of five different types of traditional Japanese Sudare.

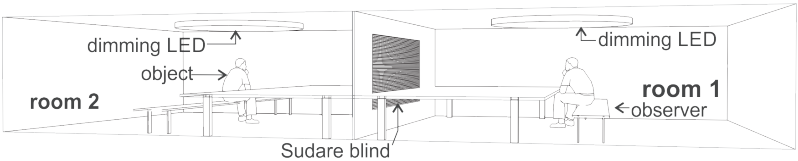


Figure 2. Schematic experiment room.

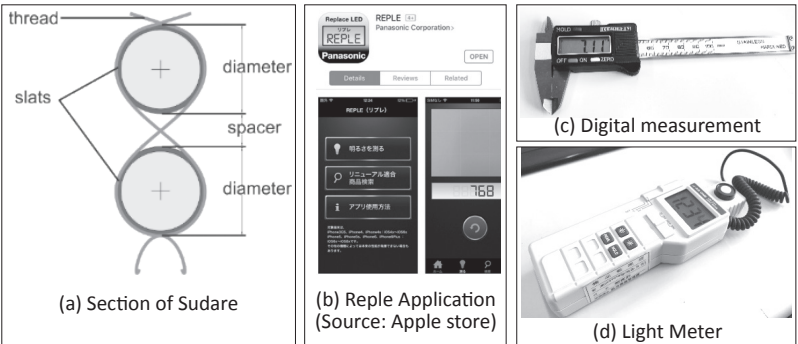


Figure 3. Object and tools of research.

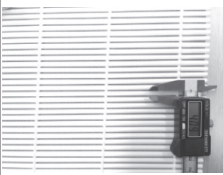


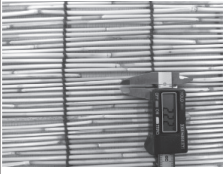



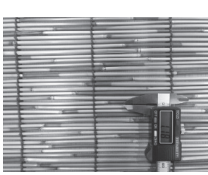


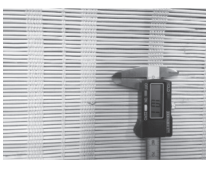

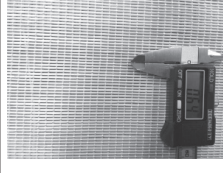
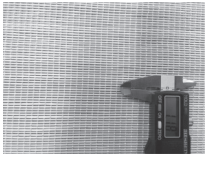

Schematic Methodology

An experiment room was used to set up a controllable illuminance-level condition by using a room that had been isolated from outside light. Basically, one room is divided into two different zone-rooms, on one side of which was the observer, and on the other was the object, or a person as an object, to be seen by the observer. Both sides had LED lamps with a remote to change the illuminance level, measured at the height of the work plane (0.8m above the floor). The distance between observer and Sudare blind was the same as the distance between object and Sudare blind. The LED lamp was placed above the observer and above the object. By using this method, we could make sure that both rooms had the same variable value of illuminance level. To measure the illuminance level, we used an illuminance meters (Figure 3 (d)) that was placed above the table, under the LED lamp. A Sudare blind, which could be changed for each type, was placed in the middle of the room and separated the room into observer room and object room. The schematic detail is shown in Figure 2.

Type of Sudare

In this research, five types of Sudare were used to examine the effects of the physical characteristics of Sudare. The differences between each Sudare were the diameter of slats, the space between slats, and the level of whiteness, as shown in Figure 3 (a). The diameter and spacer of each type of Sudare was measured with digital distance measurement (Figure 3 (c)); whiteness level was measured with the Reple Application from Panasonic (Figure 3 (b)). The whiteness level was the result of the reflectance and absorbance value of the Sudare to the same light source when being measured.

Table 1. Physical characteristics of Sudare.

Type	Diameter \varnothing [mm]		Spacer [mm]		VBR [%]	Whiteness Level [lux]	
A		4.09		1.51	24%		755
B		2.42		1.31	33%		363
C		2.42		1.31	33%		196
D		2.47		1.01	27%		467
E		1.18		0.64	34%		419

In Table 1, we describe the physical characteristics of each Sudare. Only type A Sudare is made from plastic straw slats, whereas the other types are made from bamboo slats. Type B and type C Sudare have similar characteristics, being made of small bamboo with some small difference in diameter, but were of different colors. Type D and E Sudare were made from solid bamboo. The comparison between the Sudare's solid part and spacer part can be calculated to determine the void percentage ratio of the Sudare, which was called Void to Blind Ratio (VBR).

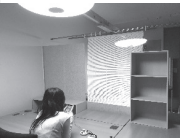


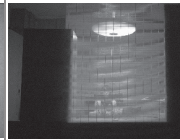










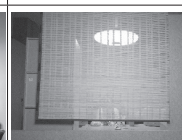



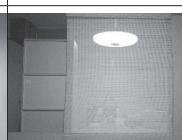

Questionnaire

Data were collected using questionnaires completed by 121 students and teachers of the Kitakyushu University as observers for each different type of Sudare. There are two parts in this questionnaire. Part I was to examine the condition in which observers started to see objects in room 2 when room 1 was at the maximum illuminance level, around 900 lux; part II was to examine the level of visibility with changing illuminance levels in room 1, from a maximum illuminance level of between

Table 2. Illuminance value of 11 conditions.

Type	Level 10 [lux]	Level 09 [lux]	Level 08 [lux]	Level 07 [lux]	Level 06 [lux]	Level 05 [lux]	Level 04 [lux]	Level 03 [lux]	Level 02 [lux]	Level 01 [lux]	Level 00 [lux]
A	876	780	696	605	514	429	344	273	204	108	31
B	854	761	677	589	501	416	335	265	198	104	29
C	838	750	668	581	493	409	330	259	191	97	24
D	860	764	679	592	502	416	334	263	192	98	25
E	859	762	679	591	502	416	334	264	194	98	24

Table 3. Experiment room condition.

Type	Room 2	Room 1	Level 10 (Room 2)	Level 00 (Room 2)
A				
B				
C				
D				
E				

838-876 lux to a minimum level of between 20-31 lux, while room 2 was at the maximum level of illuminance, around 900 lux. Eleven levels of illuminance, from maximum to minimum, are shown in Table 2, and samples of the condition of each experiment can be seen in Table 3.

In this experiment, observers had to judge each condition with a value of between 0-6. The meaning of each value can be seen in Table 4.

Table 4. Meaning of judgment value.

Value	Meaning
0	Cannot see object
1	Recognize silhouette (a dark shape seen against a light surface) of the object
2	Recognize silhouette and color of the object
3	Recognize the object and color but these are not really clear
4	Recognize and start to see the object and color but cannot pick out detail
5	Can see the object and color and pick out some detail
6	Can see the object clearly (identify the detail and color)

The next steps were to re-run the experiment using digital images of each level for the five types of Sudare from the previous experiment, using computer display interaction. Data were collected from 211 respondents. The scale in the questionnaire had been changed from 7 levels to 11 levels to give a larger flexibility scale than in the previous experiment (Figure 4). The scale figure guideline was placed beside each image to give the respondent the same feeling of comparison when deciding the level of visibility. This step was taken to validate and improve the accuracy of the previous experiment. Using this method, the respondent could be anyone who had a computer connected to the Internet.

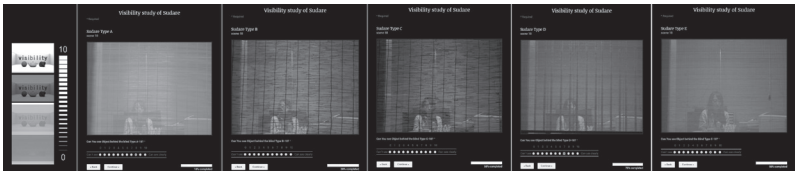


Figure 4. Digital images experiment.

Data and Analysis

Data from the experiments have been compiled and the average level of illuminance at which respondents started to see objects can be seen in Table 5. Although the source of LED light was at the same level, the value of illuminance in the working table area was different because of the difference in the absorbance and reflectance material of the Sudare. The illuminance ratio between the observer room and the object room is calculated by dividing the illuminance value of the object room (I_2) by the illuminance value of the observer room (I_1). The smaller the illuminance value of the object room, the smaller the illuminance ratio.

The aim of this first part is to know the minimum condition of room 2 (object room) in which the observer starts to recognize the object. In this result, type C Sudare has the lowest illuminance ratio (0.18), which means it has the lowest illuminance level needed for the observer to start to see the object in the object room. Type C Sudare has the lowest whiteness (196 lux) of all the types.

In the second part of the questionnaire, the illuminance ratios increased, starting from 1, whereas the illuminance level between the observer room and the object room is the same. The distribution visibility value can be seen in Table 6.

Sudare type	Room 1 (I_1) [Observer]	Room 2 (I_2) [Object]	I_2/I_1
type A	849.24	204.16	0.24
type B	834.89	237.65	0.28
type C	824.93	152.55	0.18
type D	844.54	233.48	0.27
type E	840.95	181.19	0.21

Table 5. Average value of illuminance ratio (I_2/I_1) for each Sudare.

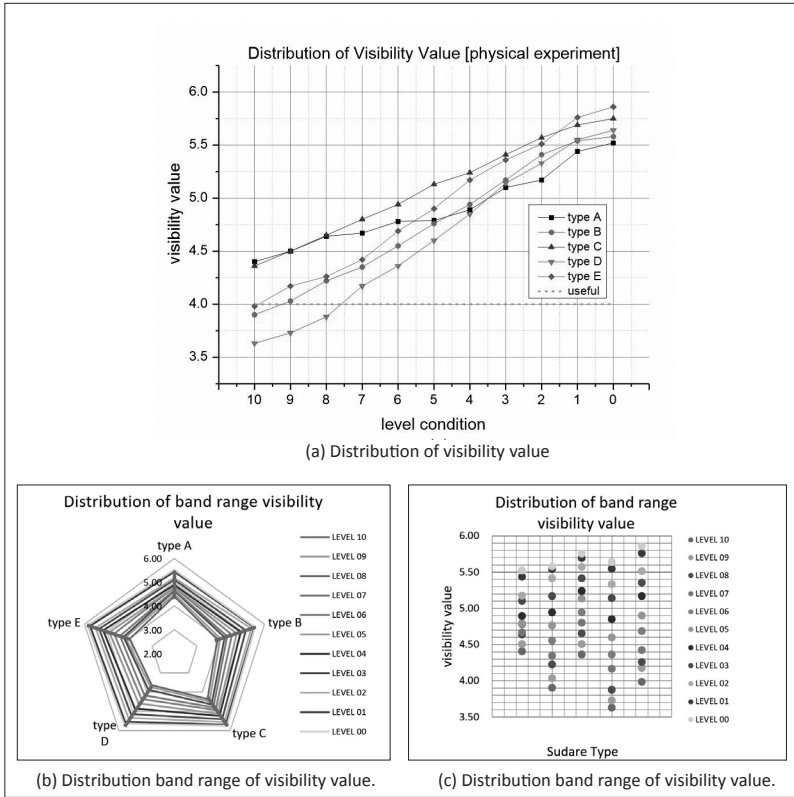


Figure 5. Average distribution value for each type of Sudare in every level condition.

Type	Level	10	09	08	07	06	05	04	03	02	01	00
type A	visibility	4.40	4.50	4.64	4.67	4.78	4.79	4.89	5.10	5.17	5.44	5.52
	I_2/I_1	1.00	1.12	1.26	1.45	1.70	2.04	2.55	3.21	4.30	8.15	87.58
type B	visibility	3.90	4.03	4.22	4.35	4.55	4.76	4.94	5.17	5.41	5.54	5.58
	I_2/I_1	1.00	1.12	1.26	1.45	1.71	2.05	2.55	3.23	4.32	8.19	85.44
type C	visibility	4.37	4.51	4.66	4.81	4.95	5.14	5.26	5.43	5.58	5.70	5.76
	I_2/I_1	1.00	1.12	1.25	1.44	1.70	2.05	2.54	3.24	4.39	8.60	83.78
type D	visibility	3.63	3.73	3.88	4.16	4.36	4.60	4.85	5.14	5.33	5.54	5.63
	I_2/I_1	1.00	1.13	1.27	1.45	1.71	2.07	2.58	3.28	4.47	8.77	86.04
type E	visibility	3.98	4.17	4.26	4.42	4.69	4.90	5.17	5.36	5.51	5.76	5.86
	I_2/I_1	1.00	1.13	1.26	1.45	1.71	2.06	2.57	3.25	4.43	8.78	85.92

Table 6. Illuminance ratio in each level condition.

From the visibility value of all configurations in physical experiment step, it seems that observers give quite a high value of visibility. However, comparing each other type of Sudare, it has variations that can be analyzed the effect of different condition of environment.

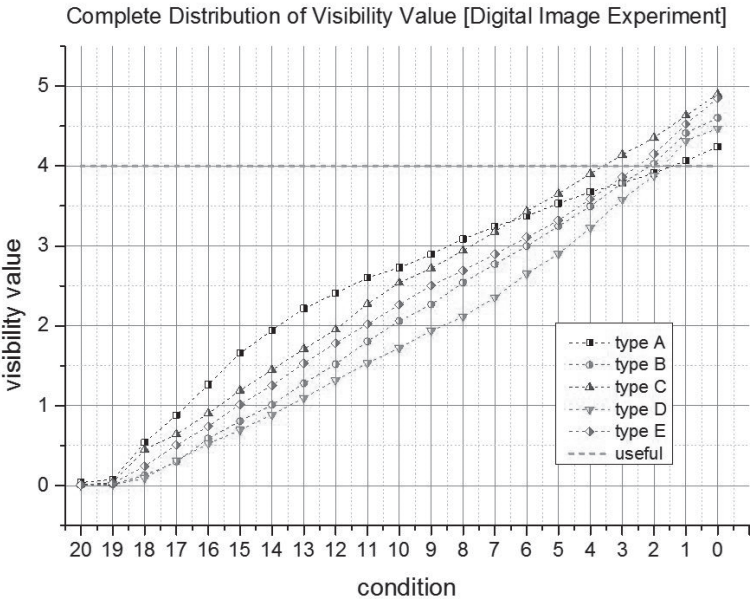


Figure 6. Visibility value distribution of digital images experiment.

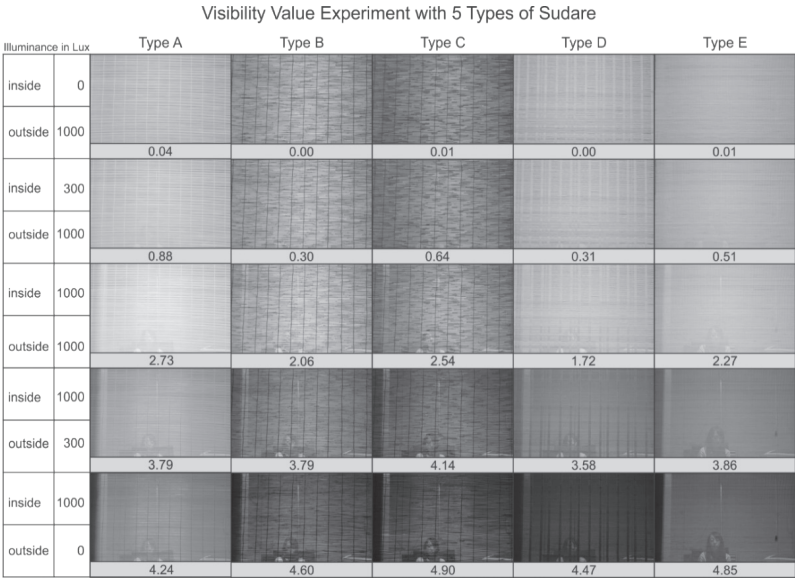


Figure 7. Visibility value distribution of digital image experiment.

Based on the average distribution of visibility value for each Sudare type at every step of illuminance level, all showed a value increase because of the decrease in illuminance level in room 1 (observer room), as seen in Figure 5 (a) and Table 6. Comparing the Sudare types based on diameter and spacer, a wider diameter and spacer did not always have a higher visibility value, and type A Sudare (bigger diameter and wider spacer), with 24% VBR, had a higher value from level 10 to level 6, but after level 5, type E Sudare (smaller diameter and narrower spacer), with 34% VBR, had a higher value than type A Sudare. This means that in the lower illuminance ratio, Sudare with a large scale and a smaller VBR have a better visibility value, whereas in a high illuminance ratio, Sudare with a small scale and a bigger VBR have a better visibility value. This also happens if we compare type A Sudare with type D and type B Sudare, which have nearly the same whiteness level. In Figure 5 (b) and Figure 5 (c), we can see that a smaller scale will result in a wider band range of visibility value from level 10 to level 0 condition. This result is also an indication that the scale of Sudare has to be analyzed in more detail in later research.

Comparing type B and type C Sudare, these types have similar characteristics of diameter and spacer, with different whiteness levels: Sudare with lower whiteness levels (type C Sudare with a whiteness level of 196 lux) have a higher value of visibility at every level than higher whiteness level (type B of Sudare with whiteness level 363 lux).

The next step was re-run the experiment using images from the previous experiment for 211 respondents. In this experiment, the respondents not only gave responses to two steps of the experiment, which were when they started to see the object and another 10 different conditions, but they had to give responses to 21 different conditions, as shown in Figure 6. With this method, the distribution figure shows the gradual changes from the minimum visibility level (cannot see anything) to the maximum level, based on their perception.

The standard environment condition that can be used to analyze the possibilities of Sudare to be used on façade design can be seen in Figure 7. The results of the visibility value when the inside illuminance levels were below 1000 lux were below 3, which means it has a low visibility value from outside and high privacy from inside. The value is still under 3 when the illuminance level was the same as the outside. When the outside illuminance was 300 lux and the inside 1000 lux, the visibility value was near 4, which means high visibility. This also means when the observer was inside the room with 300 lux illuminance and the object was outside with 1000 lux illuminance or, more likely, in daytime where the outside value of illuminance level is always more than 5,000 lux, and usually 10,000 lux or more, the visibility value will also high. A high visibility value of between 4 and 6 can be achieved when the illuminance ratio is more than 4.30.

A comparison of the visibility value distribution of the physical experiment with the normalized value of the digital image shows the same trend in Figure 8. The maximum and minimum visibility values of the digital images experiment are lower than physical experiment. This condition is more realistic because of the number of steps in 21 different conditions. In condition level 10, the illuminance value between inside and outside was the same. This is the minimum condition that will happen when using Sudare as an external blind, and when the inside illuminance is higher than that outside, the effect of the visibility will be the opposite (in night-time).

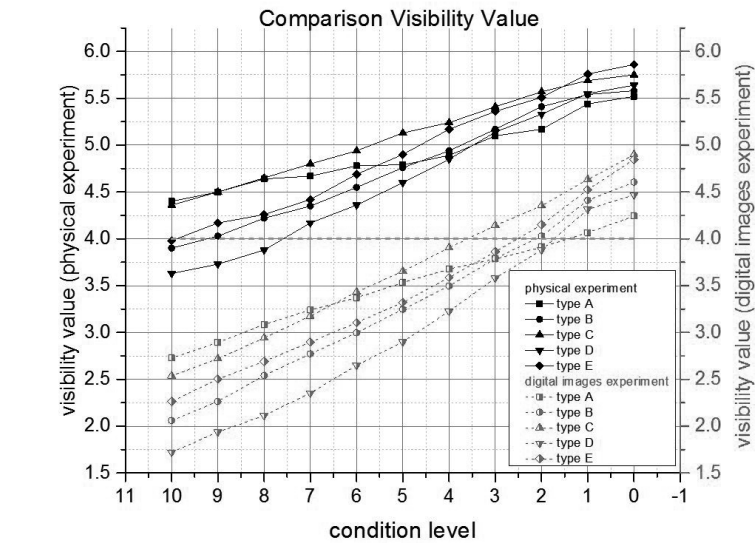


Figure 8. Visibility value distribution.

A visibility value of between 0 and 2 is considered low, which means only the object's silhouette is seen, but the object is not recognized. However, the level of privacy is considered high. A visibility of between 2 and 4 is considered medium, which means that not only an object's silhouette is seen, but the object and its color are recognized although they are not clear. This means that the level of privacy is also medium. Meanwhile, a visibility value between 4 and 6 is considered high and useful for occupants to see outside, but, for privacy, it is considered to be low because people can see what happens on the other side.

In this research, the configuration of Sudare was fixed, which means the diameter or spacer between slats could not be changed. For this reason, the results could not identify the optimum configuration of a Sudare to be used as a building façade.

Conclusion

Based on the analysis of the questionnaire data comparing physical and digital experiments, the ratio of illuminance is the main factor that affects the value of visibility. The combination of whiteness factor, scale, and the ratio between the Sudare's diameter and spacer have a correlation with the distribution band of the visibility value. In a low illuminance ratio, a bigger scale has better visibility value but in high illuminance, a small scale has a better visibility value. A high visibility value can be achieved when the illuminance ratio is more than 4.30. A wider band range will effect more flexibility of controlling the way to see and can be achieved with the small ratio of Sudare.

The comparison of the visibility value distribution of the physical experiment and the normalized value of the digital image shows the same trend. The maximum and minimum visibility values of the digital images experiment are lower than those of the physical experiment. This condition is more realistic because of the number of steps in 21 different conditions.

In real conditions, the visibility value of Sudare will improve when using outdoor illuminance as an object room because the illuminance level is always more than 1000 lux, while the standard interior illuminance will be 300 lux.

Future Work

The next research to undertake is to investigate more deeply the optimal configuration of Sudare and the minimum ratio of illuminance at which observers can see through a Sudare blind, using more precise and uniform material within the same ratio but different scales. This research has a high potential to be implemented in façade design with a parametric approach: changing the spacer of the Sudare according to the environment illuminance value.

Simulating thermal energy consumption with the different types of Sudare is also possible, to compare the effect of each type on the effectiveness of the energy reduction of the building (Hariyadi, Fukuda & Ma, 2017). By controlling the environmental energy input on the building envelope, energy saving can be achieved (Tagliabue, Buzzetti & Arosio, 2012, pp. 693-703; Hariyadi, Suryabrata, Fitriana & Fukuda, 2015, pp. 7-12).

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