Paper

Impressions of Overall Brightness in a Non-Uniformly Illuminated Space

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Received Dec. 17, 1997

ABSTRACT

When an interior space is illuminated non-uniformly, we perceive different levels of brightness. The strongly illuminated areas give a bright impression while the weakly illuminated areas give dark impression. In other words, the whole space is divided into several portions which have different levels of brightness. The purpose of this study is to estimate overall impression of brightness which is divided into such portions which have different brightness.

Two experiments were carried out in this research to assess brightness of whole spaces those were illuminated non-uniformly. In the first experiment, luminance distribution images of an interior space were used as stimuli. In the second experiment, actual interior spaces of non-uniform lighting were used as stimuli. From these results, it could be concluded that the whole space that is illuminated non-uniformly is perceived darker than the space illuminated uniformly. The overall impression of brightness of the space that is illuminated non-uniformly could not explained on the basis of the quantitative average of the luminances. It could be corresponded with the psychological average of all portions' brightness those were divided by the illumination level.

1. Introduction

The luminances in a non-uniformly illuminated space is not uniform. If the reflectance of the interior surfaces is uniform, a strongly illuminated areas show high luminances, and weakly illuminated areas show low luminances. If we assume that individuals observing the inside of the interior space are doing so three-dimensionally, surfaces of high luminance will be seen as being strongly illuminated space, and surfaces of low luminance will be seen as being weakly illuminated space. In other words, the interior space will be seen as consisting of portions of varying levels of brightness (see Fig.1).

Under these conditions it is thought that the impression of overall brightness in a non-uniformly illuminated space is determined by the balance between the various portions of the space.

This research initially investigated spatial luminance variations resulting from non-uniform illumination. As a means of investigating the model described above, first we used an image of varying luminance to experimentally evaluate the impression of brightness. Then, to confirm the result of the first experiment, similar investigations were conducted involving experimental evaluations of brightness in actual interior spaces subject to non-uniform illumination.

In previous researches [4] [5], the experimental results about the brightness in the non-uniform lighting were not corresponded. The experiments in these researches supposed the object room as the specific situation for visual working. So, it would be considered that the impressions of brightness were strongly influenced by the specific area's luminances those were related to the visual work.

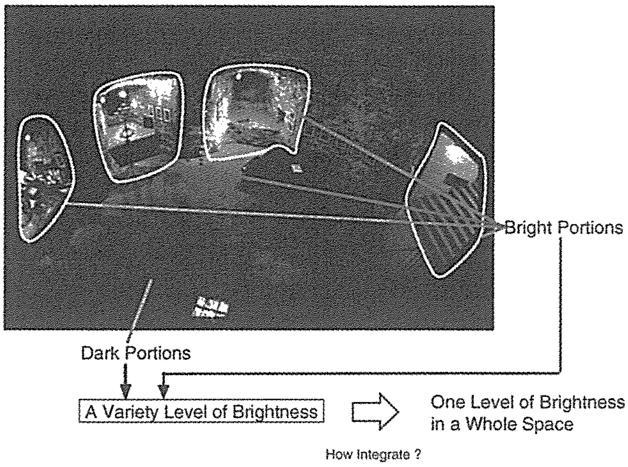


Fig.1 In a non-uniformly illuminated space, the space is devided into several portions which have different levels of brightness

2 Experiment with Luminance Distribution Images

2-1 Experimental Outline

Luminance distribution images (measuring 29.4 cm x 21.5 cm) based on interior models were used as stimuli to assess brightness. Luminance distribution images were obtained from a model room of uniform surface reflectivity and illuminated non-uniformly. Because the room was wrapped by uniform reflectivity, the lightness in this image is dependent upon differences in the amount of light exposed at interior surfaces. The lighting methods of the room were two types, one is centralized lighting by the narrow spotlight and the other is simulated daylighting by the parallel light through the window.

The characteristics of luminance variations in these images are classified into two types.

(1) Spatial luminance variations in small areas of low luminance such as the depressions and shadows on furniture.
(2) Spatial luminance variations resulting from non-uniform illumination of the space.

The low luminance districts caused by (1) do not spread wide area. So, spatial luminance variations in (1) tend to be high frequency. While the low luminance districts caused by (2) spread wide area and spatial luminance variations in (2) tend to be low frequency.

As shown in Fig.2, these two types of luminance variations were extracted separately from the images. Then, we added each extracted luminance variation to, or subtracted from the original image. So, the luminance distribution images were obtained in which the two types of luminance variation were expressed as variables. These luminance distributions could be divided into a number of component sine waves of various frequencies using Fourier transforms. With these frequencies, the spatial interval of luminance variations were expressed [6]; with the amplitude of these sine waves, the intensity of luminance variations can also be expressed. The characteristics of the intensity of luminance variations are shown in Fig.3.

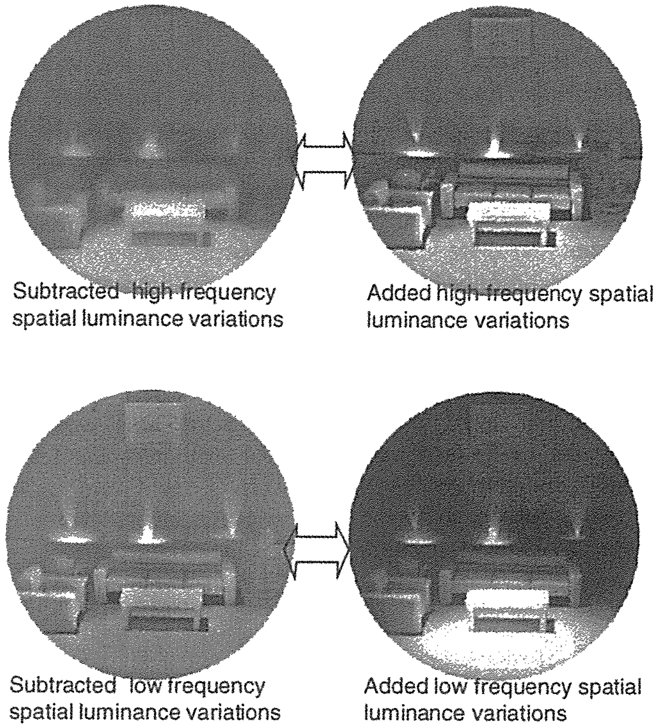


Fig.2 Luminance distribution image in which the two types of spatial luminance variations were expressed as variables
(Lighting type : Centralized lighting)

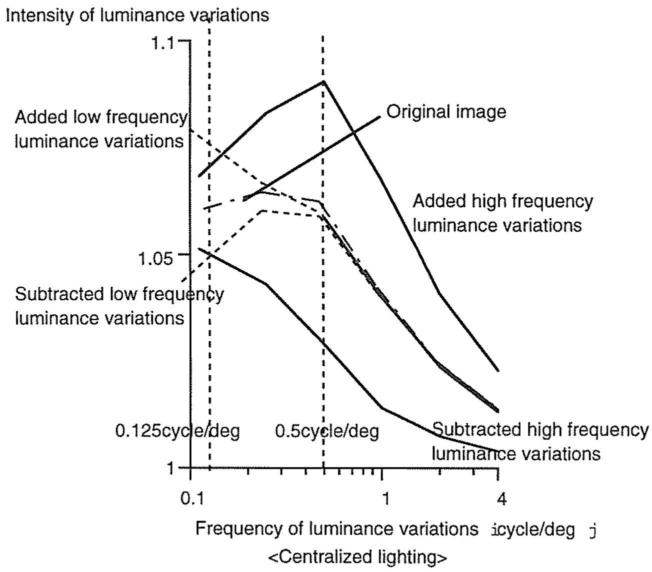


Fig.3 Luminance distributions divided into sine waves of various frequencies

Because the brightness of a room interior can be assessed only after the eye has adjusted to the luminance of that interior, the luminance distribution images used as stimuli did not encompass the entire visual field. For this reason, a semicircular acrylic shield was placed around the luminance distribution images in order to alter the surface luminance and thereby assure agreement between the eye's adjusted luminance and the average luminance of each stimulus. Each of the luminance distribution image was assessed by a group of 20 observers. All observers selfreported normal or correct vision. The ME method was used to assess brightness. Observer saw the standard stimuli at first and it's impression of brightness was specified as 100. Another stimuli was evaluated on comparison with the standard. The order of presentation of the different lighting conditions to each observer was varied to minimize any order effects. Care was taken to ensure that there was a short adaptation time of a minute by the observer to each condition before assessment commenced.

2-2 Experimental Results and Discussion

The individual evaluations for a stimulus were not matched to the same value. But after examining the data in detail, relative evaluations between stimuli were almost stable. So, to understand general tendencies, we used average evaluation values for following explanations.

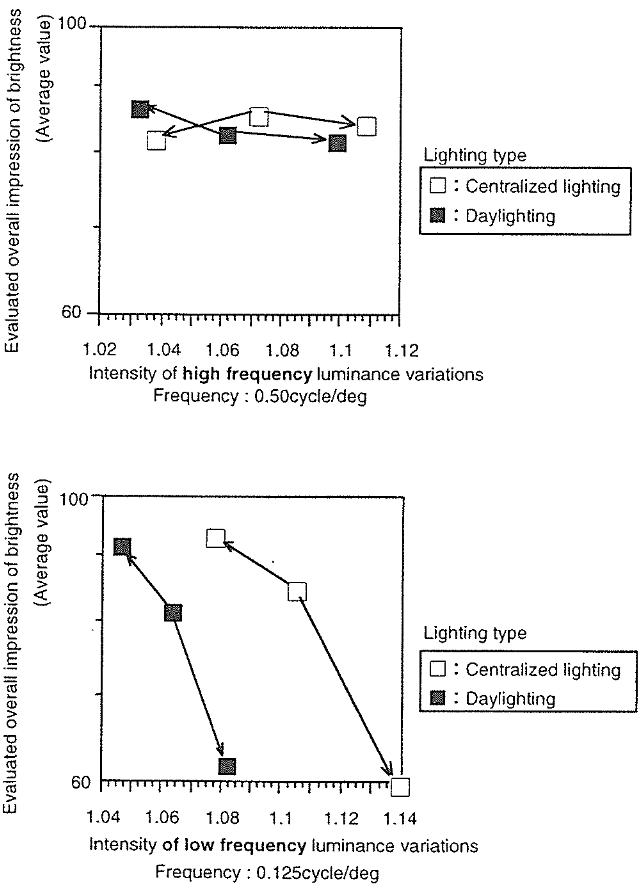


Fig.4 Relationship between frequency luminance variations and impression of brightness

The results of the experiment are shown in Fig.4. Average luminance of these stimuli were the same. The impression of brightness did not change very much with high frequency spatial luminance variations. On the other hand, the impression of brightness was greatly affected by low frequency spatial luminance variations. Stimuli in which low frequency variations were increased were evaluated as being very dark. Table 1 show the test results by each luminance variation. Low frequency spatial luminance variations result from non-uniform illumination of the interior space, and the illumination is evaluated as being dark. This suggests that even if the average luminance of images were equal, uneven brightness caused by uneven illumination was a factor that reduced impression of brightness.

Centralized lighting

	High frequency luminance variations		Low frequency luminance variations	
	subtract	add	subtract	add
t	-1.439	-0.348	-2.468	4.651

Daylighting

	High frequency luminance variations		Low frequency luminance variations	
	subtract	add	subtract	add
t	0.546	-1.502	-4.327	3.316

(shading legend: $p < 0.01$; $p < 0.05$)

Table 1 Result of t-test

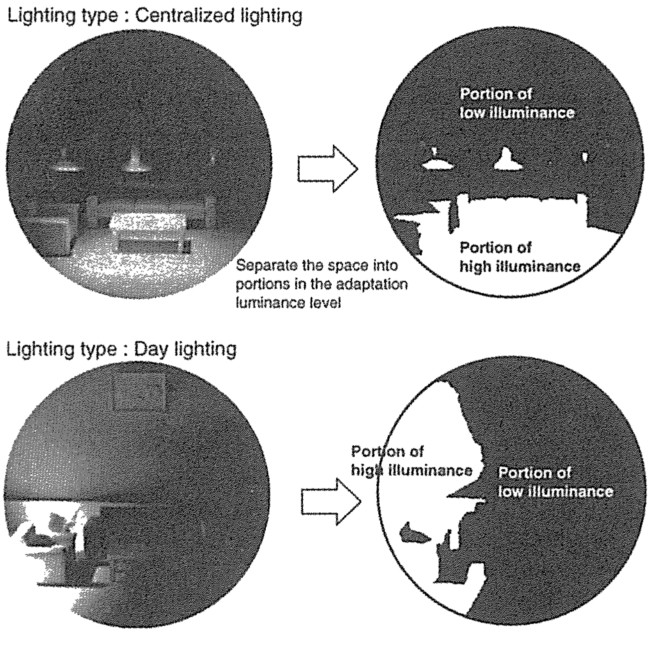


Fig.5 Separate the spaces into portions

The result that uneven illumination effect the total impression of brightness might be connected with the separate impressions of brightness in the uneven illuminated room. If we assume that individuals observing the interior space are doing so three-dimensionally, surfaces of high luminance will be seen as being strongly illuminated space, and surfaces of low luminance will be seen as being weakly illuminated space. So we suggested a hypothesis that the overall impression of brightness in the interior space was determined from the sum of the impressions of brightness for all portions of the space. In order to test this hypothesis, the interior space used as the stimulus was divided into equally illuminated portions of the space. The method used to separate the space into portions is shown in Fig.5. The interior space was divided into two portions in which the luminance was greater than, and those portions in which the luminance was less than, the average luminance of the stimulus image. In this experiment, the average luminance of the stimulus was equal to the adaptation luminance of the eye. Then, to predict the each portion's impression of brightness, the Stevense equation [7] was employed. Each portion's impression of brightness was calculated by the average luminance of the portions and the adaptation luminance of the eye. This impression of brightness is referred to as the 'predicted impression of brightness' and is distinct from the evaluated impression of brightness. The 'predicted impression of brightness' for each portion of the space is then is weighted with each solid angle, and the overall average value calculated. The overall average is calculated on logarithm to take the psychological average of portions. The process of calculating this value is shown in Fig.6. Table 2 shows the each value.

Fig.7 shows the distribution of the 'predicted overall impression of brightness', and the experimentally evaluated impression of brightness. It is apparent that the 'predicted impression of brightness' approximates the evaluated impression of brightness.

That is, the reduction in the impression of brightness resulting from the non-uniform illumination of the space is compensated for by the average perceived brightness of the space. While the average luminance is a quantitative average, the perceived average is a value close to the geometric average. As the latter is always less than the calculated average. So, the non-uniformly illuminated space would be perceived darker.

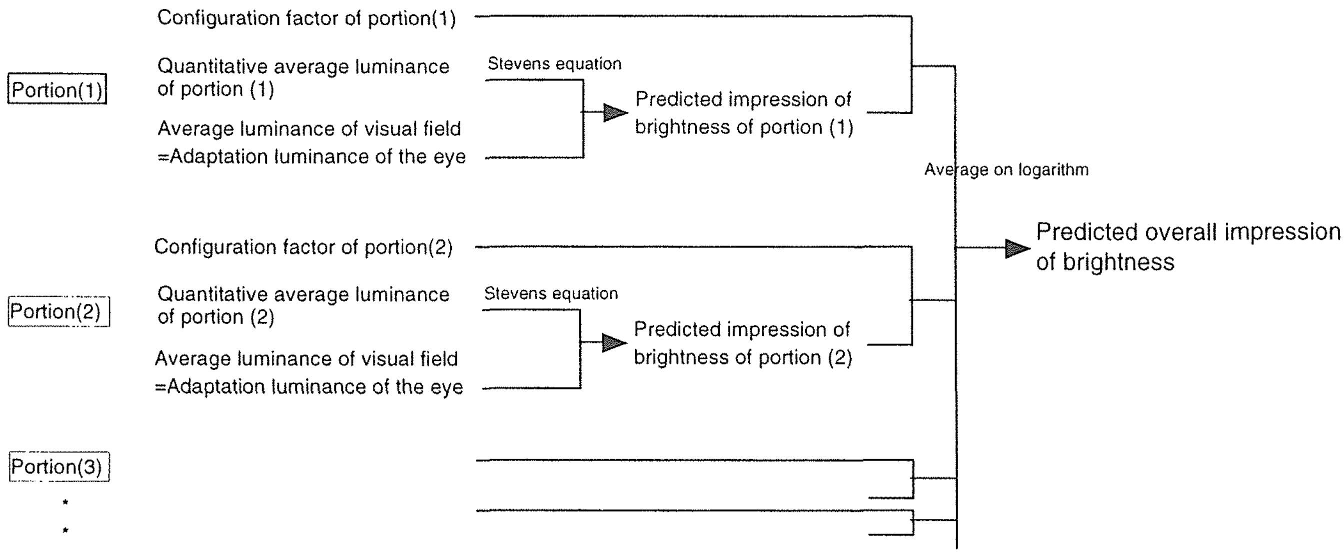


Fig.6 Process of calculating brightness

	Uniformity of the illumination	Evaluated overall impression of brightness	Average luminance of the whole space	Portion of high illuminance			Portion of low illuminance			Predicted overall impression of brightness
				Configuration factor	Average luminance	Predicted Impression of brightness	Configuration factor	Average luminance	Predicted Impression of brightness	
Centralized lighting	Non-uniform	60.27	139.15	0.31	369.80	117.37	0.69	35.53	55.51	70.01
	↕	86.51	137.82	0.31	287.37	107.06	0.69	70.63	71.37	80.93
	Uniform	93.49	138.80	0.31	152.68	100.71	0.69	132.56	95.16	96.85
Day lighting	Non-uniform	63.43	139.00	0.28	378.97	119.75	0.72	45.68	59.48	72.35
	↕	83.19	139.04	0.28	285.13	107.06	0.72	82.23	74.54	82.50
	Uniform	92.24	139.10	0.28	158.04	100.71	0.72	131.74	95.16	96.69

Table 2 Predicted impression of brightness of each portion

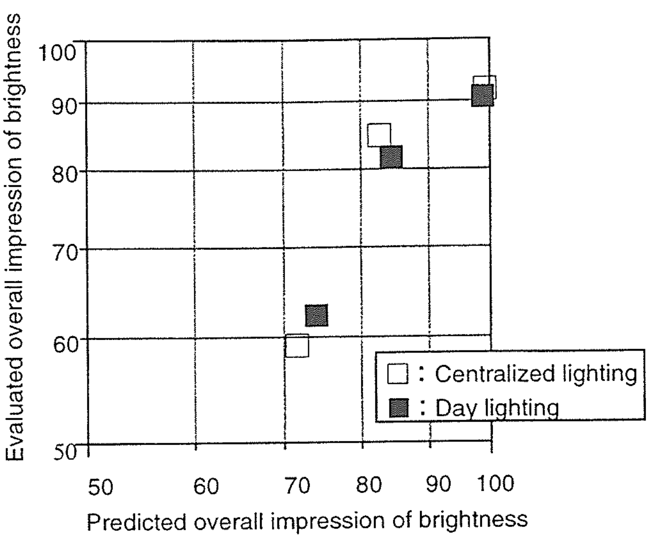


Fig.7 Relationship between predicted impression of brightness and evaluated impression of brightness

3 Experiment with Actual Environments

3-1 Experimental Outline

To confirm above results under actual visual environments, next experiment evaluated the impression of brightness in the real interior spaces. The room consisted of five office working rooms. To ensure that a variety of distances and views of the spaces from the seats were available, 15 positions were selected. Plan views of each space, and locations of each position, are shown in Fig.8. The experiment evaluated the extent of the impression of brightness from each position. Impressions of brightness were evaluated in five stages from 'bright' to 'dark', with 2 or 3 subjects located at each position. In this experiment, a total of 16 subjects participated . Subjects were different group from the prior experiment.

Luminance distribution was measured by photometer using an orthographic projection lens.

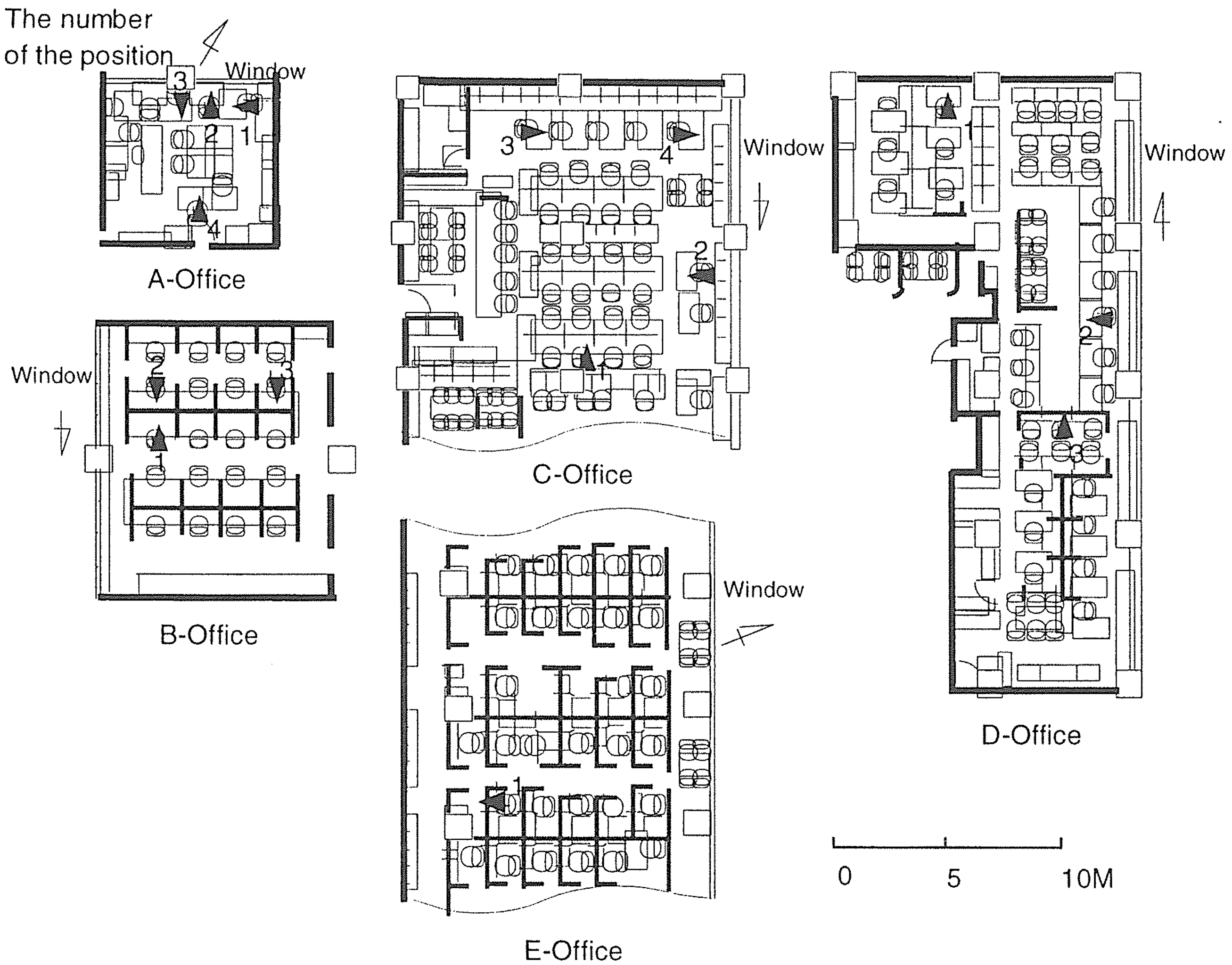
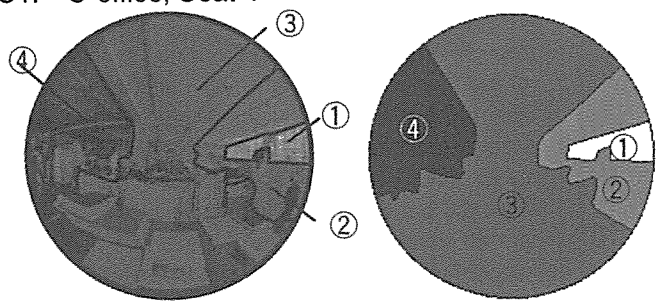


Fig.8 Plan location and orientation of each seat position

3-2 Experimental Results and Discussion

C1: C-office, Seat-1



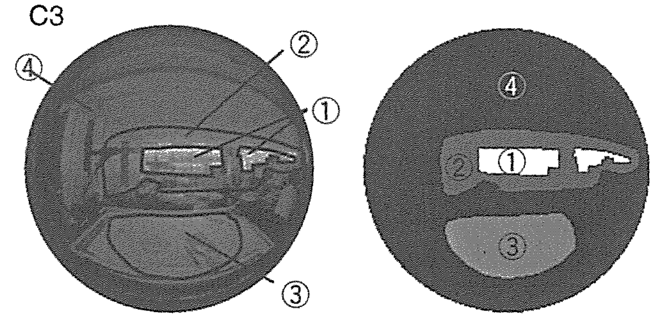
Evaluated overall impression of brightness 2.00

Average luminance 41.16 cd/m²

	Configuration factor	Average luminance	Predicted brightness
Portion ①	0.03	673.2	230.0
Portion ②	0.10	54.2	83.3
Portion ③	0.62	21.2	62.6
Portion ④	0.25	10.8	47.6

Predicted overall impression of brightness 62.6

C3



Evaluated overall impression of brightness 1.33

Average luminance 70.56 cd/m²

	Configuration factor	Average luminance	Predicted brightness
Portion ①	0.04	936.6	198.3
Portion ②	0.09	100.4	81.7
Portion ③	0.17	54.2	65.8
Portion ④	0.71	19.3	43.6

Predicted overall impression of brightness 52.5

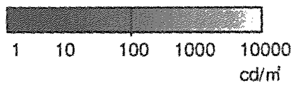


Fig.9 Example luminance distributions and divisions of the field-of-view

It was expected that some individual differences of the rating scale exited. But in this experiment, fixed subjects did not participated in each situation. So, the rating scores were not standardized with subject's mean and variance. In this case as well, overall impression of brightness was calculated from the brightness for each portion of the space. The field of view was split up based on the luminance level for each of the 15 positions for which luminance distribution was measured. It has previously been the case that the boundary of the field of view be drawn by the subject on the basis of 'a change in level of illumination'. However in this experiment, for the sake of convenience, the boundary was drawn on the basis of a difference in brightness of a factor of approximately five with the same reflectivity. Fig.9 shows and example of the luminance distribution from the viewing position, the division of the field of view, and the 'predicted impression of brightness' for each portion. The overall impression was calculated on logarithm to take the psychological average of portions.

Fig.10 shows the relationship between the average luminance in the field of view at each position, and the average evaluated value for the impression of brightness. Fig.11 shows the relationship between the 'predicted overall impression of brightness' found by dividing up the field of view, and the average evaluated value for the impression of brightness. In real environment as well, the overall impression of brightness was corresponded with the psychological average. It was apparent that the relationship of between the evaluated value and the 'predicted overall impression of brightness' was improved.

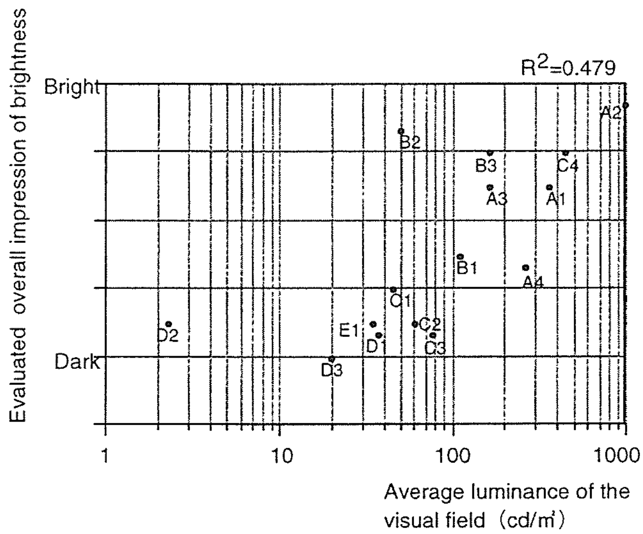


Fig.10 Relationship between the average luminance and evaluated value for the impression of brightness

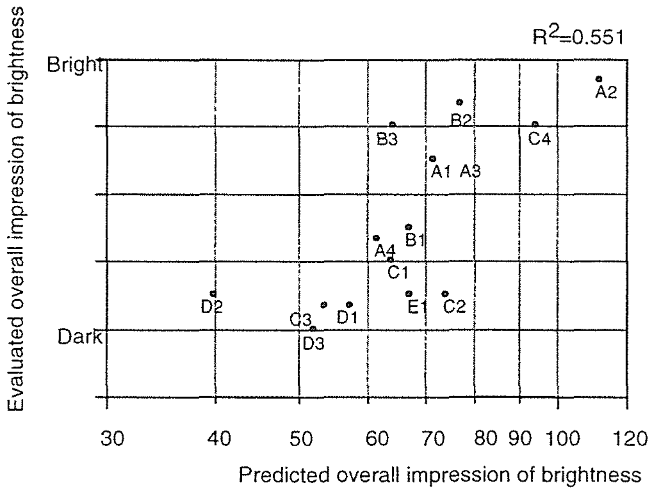


Fig.11 Relationship between the calculated impression of brightness and evaluated value for the impression of brightness

Fig.12 shows two different processes in a non-uniform luminance distribution space for overall impression of brightness. That is, non-uniform illuminated space and non-uniform reflectance space. It appears that the overall impression of brightness of the non-uniformly illuminated interior space is based on separate impressions of brightness for each space, bright portion from strongly illuminated areas and dark portion from weakly illuminated areas. The overall impression of brightness determined from the balance of each impression of brightness. That is, the overall impression could be explained on the psychological average of each portion. In comparison with, the space is illuminated uniformly, even if its reflectivity is not uniform, separate impression of brightness would not be exist. So, the overall impression of brightness would be explained on the quantitative average of luminance.

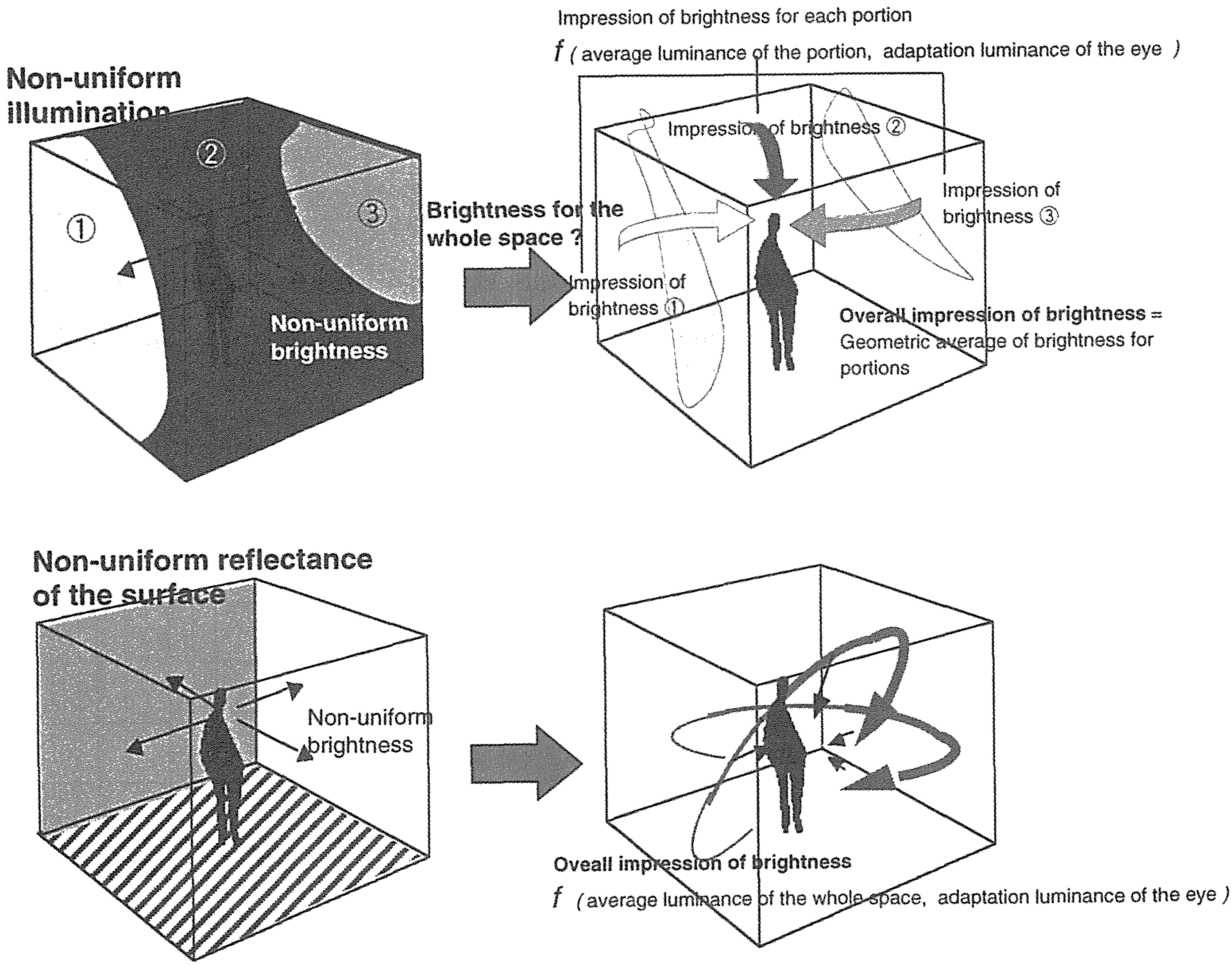


Fig.12 Overall Impression of brightness in non-uniform luminance spaces

4 Conclusion

In this study, two experiments were conducted to assess impression of brightness of whole spaces those were illuminated non-uniformly. In the first experiment, luminance distribution images of an interior space were used as stimuli. In the second experiment, real interior spaces of non-uniform lighting were used as stimuli and results obtained approximately supported the analysis of the first experiment.

The experiment showed that the greater the degree of non-uniform illumination, the darker the interior space as a whole was evaluated, despite equal average luminance. The overall impression of brightness of the interior space cannot be explained on the basis of the average luminance of the interior space, however it was found that the impression of brightness for each level of illumination in the interior space resembled the psychological average. While the average luminance is a calculated average, the perceived average is a value close to the geometric average. As the latter is always less than the calculated average, the impression of brightness for a non-uniformly illuminated space cannot be explained in terms of average value of luminances.

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