Paper

Sensation of Brightness for a Living Room with Downlights

Wataru Iwai

Matsushita Electric Works, Ltd.

243, Togasaki 2-chome, Misato-shi, Saitama, 341-0044, Japan

Yoshinori Saito

Matsushita Electric Works, Ltd.

1048, Kadoma, Kadoma-shi, Osaka, 571-8686, Japan

Sadahiro Sumi

Matsushita Electric Works, Ltd.

2-3-1, Nishi Shinjuku, Shinjuku-ku, Tokyo, 163-0918, Japan

Toshihiko Sakaguti

Matsushita Electric Works, Ltd.

243, Togasaki 2-chome, Misato-shi, Saitama, 341-0044, Japan

Paper originally published in Japanese in J.IELJ, Vol.83, No.2, 1999

ABSTRACT

The sensation of brightness perceived in a living room with downlights was investigated by psychological experiments with seven observers. Three positions and four types of downlight reflector were examined. The method of magnitude estimation was adopted to measure the sensation of brightness. In addition, the luminances of areas related to the sensation of brightness were measured with a CCD camera. The relationships between these luminances and the sensation of brightness are discussed. The results showed that the sensation of brightness for a living room with downlights was strongly affected by the average luminance within the area of the front wall and by the luminance in the corners of the room".

KEYWORDS: sensation of brightness, living room, downlight, luminance

1. Introduction

Brightness is an important factor in the selection of lighting, since an illuminated space that is perceived to be dark is not preferred. When the subject is limited to the lighting of a residential living room, it can be assumed that the brightness required is brightness as an impression of the overall room space or the sensation of brightness, since the working surface of a desk is unlikely to be regarded as important, as is the case in an office space. Furthermore, it is considered important to establish a method to quantitatively evaluate the sensation of brightness, since it is predicted that it will become increasingly necessary to create the sensation of brightness with as little energy as possible in the future due to environmental conservation requirements. However, it is known that this sensation of brightness can not be explained only by the illuminance of the horizontal planes of a desk or floor surface ¹⁾.

2. Psychophysical Factors Affecting the Sensation of Brightness

There have been many reports in the past on studies that were made in an effort to clarify the factors that affect the sensation of brightness or the impression of the brightness of an overall room space. The psychophysical factors relating to the sensation of brightness that were determined by these studies can be broadly categorized as the average luminance of specific areas and the luminance of the visible portion of the luminaire.

2.1 Average Luminance of Specific Areas

Although it is obvious that, when apparatuses of the same luminous intensity distribution are used, there is the perception of greater brightness when the average luminance of the whole visual field at the time of the observation of a space illuminated by apparatus is higher, Kobayashi et al. ²⁾ showed that this relation is roughly valid among luminaires of different luminous intensity distributions. Also, the study by Loe et al. ³⁾ concluded that the average luminance in the range of 40 degrees vertical visual angle best explains the sensation of brightness, and it

suggests the existence of an observation area that is closely related to the sensation of brightness.

Furthermore, in a study regarding the gloom of a room, which is related to the sensation of brightness of a room space, Shepherd et al.⁴ carried out an experiment to verify an assumption from a series of past studies and concluded that an absence of brightness at the corners of a room causes gloom in a room. Since the relationship between the sensation of gloom and the sensation of brightness is very close⁵, it can be predicted that the sensation of brightness will be lower when the brightness at the corners of a room, that is to say the luminance at the corners of a room, is insufficient.

By summarizing the descriptions above, it can be predicted that the sensation of brightness of a room space will become higher in parallel with an increase in the average luminance of a specific observed area of the room.

2.2 Luminance of the Visible Portion of the Luminaire

Bernecker and Mier⁶ clarified that the sensation of brightness increases when the luminance of the visible portion of the luminaire gets higher in the range of 1000–4100cd/m² (the luminance in the direction of the line of vision when an observer looks at the luminaire). Also Akashi et al.⁷ clarified that the sensation of brightness increases when the luminance of the visible portion of the luminaire radiates at the level of the luminance that gives the sparkle effect.

From the above, it can be forecasted that the sensation of brightness is increased when the emitting surface of the apparatus emits at an appropriate luminance level.

3. Purpose

However, each of the above studies can not explain the sensation of brightness in an actual room space where there is a mixture of various factors as described above, since the experiments in each study were devised so that the influence of certain specific factors, which were selected as objects, on the sensation of brightness could be studied. Also, almost all of the spaces selected in the above mentioned studies were office spaces, and to date there have been essentially no studies applicable to living spaces.

Hence, we have surveyed in this study how the psychophysical factors of the average luminance of specific areas and the luminance of the visible portion of the luminaire, which were studied in the past studies, affect the sensation of brightness in an actual living room where these factors exist in a mixture. The final purpose of this study was to quantitatively evaluate the sensation of brightness of the living space. In the experiment reported here, the lighting plan used a ceiling light together with downlights of types that are widely used these days, and these were selected as the objects of the study.

4. Experiment

4.1 Experimental Space and Objective Luminaires to be Evaluated

Fig. 1 shows the plans of the living room used for the experiment. The upper plan shows the locations of the furniture and the lower plan shows the locations of the luminaires. The experiment was carried out using the left side of the space or the living room with a width of 3.5m, a depth of 3.7m, and a height of 2.4m. In the space, lightly colored curtains, a sofa, a table, and so on were placed and a ceiling light was located in the center of the ceiling with four downlight units set at the four corners of the ceiling. During the experiment, the lights in the dining room on the right side were off.

Four types of downlights, as shown in Fig. 2, were used for the downlights that were the objects of evaluation. These types are for general lighting, have diameters of 125mm, and are commonly used. They will each be called luminaire A, B, C, and D, respectively. These downlights differ from each other in the design of the reflection plate. luminaire A has a mirrored reflection plate; luminaire B has a reflection plate finished with white paint; luminaire C has a mirrored reflection plate with a white painted baffle attached at the opening; and luminaire D has a mirrored reflection plate with a black painted baffle attached at the opening. The downlights at the side of the front wall were set at three positions of 30cm, 60cm, and 90cm away from the wall. This means that the experiment in this study was implemented over twelve conditions in total with four kinds of downlights and three positions for them. Also, the light source of the ceiling light was a three-band fluorescent lamp of 72W with a correlated color temperature 3000K, and the light source common to all of the downlights was an incandescent lamp of 2800K at 60W.

4.2 Procedure

The experiment consisted of an experiment to evaluate the sensation of brightness and an experiment to measure each luminance level corresponding to the psychophysical factors as described before. The degree of influence of each psychophysical factor on the sensation of brightness of the actual lighting space was studied through analysis of the corresponding relationship between the luminance level corresponding to each factor that was obtained through the measuring experiment for each experimental condition and the evaluated level of the sensation of brightness that was obtained through the evaluating experiment for the sensation of brightness.

The evaluation of the sensation of brightness was made using magnitude estimation. It was considered that the sensation of brightness evaluation is made at the moment when the room is first seen after it is entered, and the observers were required to do the evaluation while standing at a position 3.6m from the room wall, which was an

Fig.1 Plans of the living room. The upper plan shows the location of the furniture and lower plan shows the location of the luminaires. The left side of the room is living room used in these experiment

equivalent to a room entrance. The observers were instructed to regard the sensation of brightness felt in the whole standard lighting space with lighting by the ceiling light alone as 100, and then they were required to compare and assign a numerical value to the sensation of brightness felt in the evaluating lighting space with the standard lighting space and the additional four lit downlights versus the former standard lighting space. For example, when the sensation of brightness felt in the whole evaluating lighting space that was illuminated by both the ceiling light and the down lights is felt to be 1.3 times higher than the standard space with the ceiling light alone lit, the observer evaluated it as 130. The standard lighting space and the evaluating lighting space were demonstrated for 10 seconds each alternately until the observer gave an evaluation. The

Fig.2 View of the downlights

number of observers was 18 and the number of the repetitions of the evaluation was one.

Measurement of the luminance level corresponding to each psychophysical factor was made by the method⁸⁾ of analyzing the image data (Fig. 3 – Fig. 5) of 640×480 dots (about 105×80 degrees in visual angle), which were photographed at the observation position of the observers from roughly average eye-level (1.5m) using a CCD camera. For the luminance level corresponding to the factor of the average luminance of specific areas, the average luminance level of three kinds of areas were measured: the average luminance of the whole image (area A) as shown in Fig. 3; the average luminance of the area equivalent to the front wall as shown in a black frame in Fig. 4 (area W) which is considered to be carefully viewed by the observers at the time of evaluation; and the average luminance of the area corresponding to the corners of the room as shown in black frames in Fig. 5 (area C). Furthermore, the average luminance of the reflection plate areas of the downlights that could be seen from the observation position (area R) were measured, so that they were regarded as the luminance level corresponding to the factor of the luminance of the visible portion of the luminaire.

4.3 Results

Fig. 6 shows the variance by downlight and the variance by location of the downlights as well as the relationship of the evaluation of the sensation of brightness obtained through the experiment with the average for all observers. The horizontal axis shows the different apparatuses, the vertical axis shows the evaluated values of the sensations of

Fig. 3 Image of Living room taken by CCD(Area for calculating average luminance within area A)

Fig. 4 Area for calculating average luminance within area W

Fig. 5 Area for calculating average luminance within area C

Fig. 6 Sensation of brightness for different downlights and locations. The bars shows the standard error

Table 1 Average luminance of each calculating area

Luminaire	Setting Position (cm)	Average Luminance of Each Area (cd/m ²)			
		Area A	Area W	Area C	Area R
Luminaire A	30	53.9	46.9	31.2	520
	60	53.7	43.6	30.6	680
	90	52.2	39.5	29.0	740
Luminaire B	30	50.1	40.3	30.0	4500
	60	49.3	37.2	28.1	4300
	90	49.2	36.1	27.3	4800
Luminaire C	30	53.2	45.2	32.6	5600
	60	52.4	41.7	31.3	5900
	90	51.7	38.8	29.3	6000
Luminaire D	30	50.1	40.8	28.6	180
	60	49.8	38.4	28.0	190
	90	49.5	36.4	28.0	200
Ceiling Light Alone		43.7	28.2	21.3	

brightness, and the different symbols indicate the different locations of the apparatuses. Fig. 6 shows that the sensation of brightness increases when the luminaire location is closer to the wall, and it shows that luminaire C when set at 60cm or 90cm and that luminaire A when set at 30cm give the highest sensation of brightness.

Also, the average luminances of the four kinds of areas measured in each experimental condition are shown in Table 1.

5. Consideration

As the result of this experiment, as shown in Fig. 7 and Fig. 8, the average luminances of area W and area C showed high correlations with the evaluated level of the sensation of brightness and the correlation coefficients were 0.79 and 0.82, respectively.

Fig.7 Relationship between the average luminance within area W and the sensation of brightness

Fig.9 Relationship between the average luminance within area A and the sensation of brightness

Fig.8 Relationship between the average luminance within area C and the sensation of brightness

Fig.10 Relationship between the average luminance within area R and the sensation of brightness

Through multiple regression analysis of the logarithmic values of the evaluated values of the sensation of brightness while putting the logarithmic values of these two psychophysical quantities as the explanatory variables, the logarithmic values of the evaluated values of the sensation of brightness could be approximated by the following equation (1).

$$\log_{10} Br = 0.36 \cdot \log_{10} Lw + 0.77 \cdot \log_{10} Lc + 0.46 \dots \dots \dots (1)$$

Here, *Br*: Evaluated value of the sensation of brightness
Lw: Average luminance of area W [cd/m^2]
Lc: Average luminance of area C [cd/m^2]

The multiple correlation coefficient in this case is as high as 0.92, and this result indicates that the contribution of the average luminance of the front wall and the average luminance of the room corners to the sensation of brightness of the living room space with downlights installed were high.

On the other hand, as shown in Fig. 9 and Fig. 10, the average luminances of area A and area W showed low correlations to the evaluated values of the sensation of

brightness compared to the cases of area C and area D. The correlation coefficients were 0.56 and 0.13, respectively.

Here, we would like to further discuss the average luminance of area R that corresponds to the luminance of the visible portion of the luminaire. Fig. 11 shows, similar to the graph in Fig. 7, the plotted relationship between the logarithmic value of the average luminance in area W and the logarithmic value of the evaluated level of sensation of brightness, in which the size of the diameter of the plotted point expresses the magnitude of the average luminance value in area R. Fig. 11 shows a tendency that, when the average luminance in area W is almost the same in the range of low logarithmic values of average luminance in area W or 1.55 – 1.65, the sensation of brightness gets higher when the diameter of the plot is larger or, in other words, when the average luminance of area R gets higher. Since it can be assumed that the average luminance of area W strongly influences the adaptation of eyes because the area occupies the center of the visual field, this tendency can be regarded as consistent with the conclusion of the study by Akashi et al. ⁷⁾ that the effect of increasing the sensation of brightness by the existing luminance in the room space is higher when the adaptation luminance is

Fig. 11 Influence of the luminance of the visible portion of the luminaire

lower. Furthermore, we consider that the correlation of the luminance of the visible portion of the luminaire to the evaluated level of the sensation of brightness was low, as mentioned before regarding Fig. 10, because it has the character of contributing to the sensation of brightness under the strong influence of another factor or the adaptation luminance. As discussed above, the study results shown in Fig. 11 suggest that the luminance of the visible portion of the luminaire affects the sensation of brightness. However, a more elaborate study on this point is necessary in the future because the number of data points on hand is small.

Also the average luminance in the range of 40 degrees in the vertical visual field angle (here in after called the 40-degree band) that was reported to influence the sensation of brightness in the study by Loe et al.³⁾ was calculated based on the image data per Fig. 3, and its relation with the sensation of brightness is shown in Fig. 12. The coefficient of correlation is 0.65, which is a level lower than the cases of area W and area C. Since the measured range of the 40-degree band in this study had a narrower horizontal arc compared to the measured range in the study by Loe et al., a complete comparison with the study results by Loe et al. is impossible. However, the area outside the measured range in Fig. 3 is the area mainly illuminated by the ceiling light in the experimental condition in this study, and the difference in its average luminance is small between the experimental conditions. Therefore, the tendency shown in Fig. 12, by which analysis was made on the average of 40-degree band as calculated based on Fig. 3, can be regarded to show the same tendency as the measured results in the range of the 40-degree band by Loe et al. that had a wider measuring arc in the horizontal direction. And, as the results in Fig. 12 indicate, contrary to the results reported in the study by Loe et al., the average luminance in the 40-degree band alone can not explain the sensation of brightness.

The analysis of the 40-degree band, which was judged to

Fig. 12 Relationship between the average luminance within the horizontal 40 °C band area and the sensation of brightness

have a low correlation with the evaluated value of the sensation of brightness as described in the above, as well as the analysis results in this study on the average luminance of area A with the visual angle of 105×80 degrees that was shown in Fig. 9, support the report by Nakamura⁹⁾ which concluded that “the area for calculating the average luminance, such as the 40-degree band, is difficult to fix” through analysis of the relation between the average luminance within the 40-degree band and the sensation of brightness in the office space.

When we observe an illuminated space, we have a natural tendency to unconsciously separate and recognize, quickly and naturally, the brightness of each object in the space and the intensity of the lights illuminating the objects. Regarding the recognition of the light intensity, which is significantly related to the lighting among them, Kosaki took this up as psychological quantity and called it the impression of illumination¹¹⁾. When the reflectance of the parts composing a room, such as the ceiling, walls, floor, and furniture remains unchanged and only the lighting condition is changed, it can be said that changes in this impression of illumination are generated. In this regard, the authors hypothesize that the sensation of brightness of a room space is considerably affected by this impression of illumination and that the sensation of brightness gets higher in parallel with an increase in its perceived quantity. When the reason why the average luminance of the front wall and the room corners highly contribute to the evaluated values of the sensation of brightness in this experiment is assessed, it is considered that each of these areas are the areas linked to the recognition of the impression of illumination in the living room, such as “How much intensity of light is radiated on the wall?” and “What level of light reaches to the room corners?”, and that they are the areas that must be noticed because they give the necessary information for recognizing the sensation of brightness of the room. Furthermore, the authors consider

that, for evaluating the sensation of brightness, it is effective to adopt the areas noticed by observers at the time of evaluation that are related to the recognition of the illumination impression of the space, such as the front wall and the room corners, as adopted in this experiment, and not a fixed area such as the 40-degree band as described before.

In the future, we plan to implement experiments to study the relation between the impression of illumination and the sensation of brightness and to verify the authors' hypothesis that the sensation of brightness of an illuminated room space gets higher in parallel with an increase in the perception of the impression of illumination. In addition, we would like to study the sensation of brightness of spaces as provided by illumination based upon the impression of illumination.

6. Conclusion

In this study, the sensation of brightness of a residential living room space with downlights installed was evaluated, and its corresponding relationship with the luminance of the areas that were assumed to influence the sensation of brightness was analyzed. As a result, it was clarified that the average luminance of the front wall and the average luminance of the room corners contributed highly to the sensation of brightness in the residential living room space with downlights.

In the future, we plan to study illuminated spaces with luminaires other than downlights.

References

- (1) A.R.Bean: Impression of Brightness of Object and Interiors, *Light. Res. Technol.*, 9-2, pp.103-106(1977)
- (2) S. Kobayashi, T. Kizu, Y. Nakamura and M. Inui: The Assessment of Brightness in the Interior Lighting Environment Part 2. Relationships between Brightness and Luminance Distribution, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, pp.1157-1158(1993)(in Japanese)
- (3) D. L. Loe, K. P. Mansfield and E. Rowlands: Appearance of Lit Environment and Its Relevance in Lighting Design : Experiment Study, *Light. Res. Technol.*, 26-3, pp.119-133(1994)
- (4) A. J. Shepherd, W. G. Julian and A. T. Purcell: Gloom as a Psychophysical Phenomenon, *Light. Res. Technol.*, 21-3, pp.89-97(1989)
- (5) M. Miyamoto: "Effects, which the Light Source and the Color of Carpet Produce on the Atmosphere in the Living Room", *Research Journal of Living Science*, 36-1, pp.35-42 (1989) (in Japanese)
- (6) C. A. Bernecker and J. M. Mier: The Effect of Source Luminance on the Perception on Environment Brightness , *J. Illum. Engng. Soc.*, 15-1, pp.253-271(1985)
- (7) Y. Akashi, I. Akashi, Y. Tanabe and S. Kanaya: "The Sparkle Effect of luminaires on the sensation of brightness, Proceedings of the 23rd CIE, pp.176-179 (1995)
- (8) T. Murakami and T. Sakaguchi: "A Measurement System of Luminance Distribution using Image Processing Technic", *Proc. 1992 Annual Conf. IEI Jpn.*, p.122 (1992) (in Japanese)
- (9) Y. Nakamura: "The Effect of Luminance Distribution on Subjective Assessments in an Office", *Proceedings Lux Europa '97*, pp.102-115(1997)
- (10) M. Ikeda and F. Kaneko: "Effect of Initial Visual Information on the Recognized Visual Space of Illumination -The Case of Lightness and Saturation", *J. Illum. Engng. Jpn.*, 80-5, pp.319-323 (1996) (in Japanese)
- (11) A. Kozaki: "Perception of Lightness and Brightness of Achromatic Surface Color and Impression of Illumination", *Japanese Psychological Research*, 15-4, pp.194-203(1973)