Paper

Relationship between Illuminance/Color Temperature and Preference of Atmosphere

Hajimu NAKAMURA and Yoshinori KARASAWA

Engineering Planning Department
Matsushita Electric Works, Ltd.,
1048 Kadoma Osaka 571-8686, Japan


ABSTRACT

A residence is a place for various living activities, for which a variety of lighting conditions should be studied, including the general lighting illuminance, illuminance distribution, luminance, luminance distribution, color rendering properties, and color temperature, to achieve an appropriate atmosphere with suitable lighting. Selecting the two factors of illuminance and color temperature, their effect on the atmosphere was scientifically studied. The experimental study of subjective appraisal was carried out with the semantic differential method, using experimental equipment developed to simulate various combinations of illuminance and color temperature. Observers were asked to make their appraisals by first participating in an imaginary scene involving an enjoyable conversation with family and/or friends and next by imagining themselves in a relaxed state drinking coffee alone. The first scene applies to a state that we shall refer to as the communal state, and the second scene to the solitary state. Analysis was performed on the result of how the preference changed with the adjustments of illuminance and color temperature. For the communal state, atmosphere preference grew with the increase of illuminance within the range between 100 lx and 400 lx, and was saturated at higher illuminance levels. For the solitary state, preference was not as closely related to illuminance, and observers expressed a slightly greater dislike for higher illuminance levels in comparison with low illuminance. The first activity showed a preference for higher illuminance levels, and the second activity showed a preference for lower illuminance levels. The results above were compared with Kruithof's.

1. Introduction

A good lighting plan can be said to be a plan that creates an illuminated environment that has function and atmosphere appropriate to the purpose and the use of the facility. As objects of evaluation for the development of a lighting plan, it is necessary to consider carefully the main lighting factors, such as the general lighting illuminance, illuminance distribution, luminance, luminance distribution, color rendering properties, and color temperature. In the design of the general lighting for the interior of a house, in general, the type of luminaire and its placement is planned so that the necessary illuminance for the whole room be obtained and, furthermore, lighting factors such as color temperature are considered. There are various kinds of light sources that may be used for interior lighting with different color temperatures and wattages. It is desirable to have basic data for a lighting procedure to improve comfort by means of selecting the appropriate illuminance and color temperature, sufficiently taking into consideration the purpose of the lighting environment as well as the characteristics of the life activities of the residents. In this study, illuminance and color temperature were picked as subjects and a lighting system that can vary them independently was developed. Using this system, an experiment for psychological evaluation was implemented in order to clarify the effects of illuminance and color temperature on preferences of atmosphere in lighting for a residential living room.

2. Past Studies

There have been various studies on the relationship of illuminance and color temperature on preference of atmosphere, of which representative ones are introduced in below.

A. A. Kruithof showed that the "upper and lower limits of comfortable illuminance vary depending on color temperature of the light source" based upon experimental data 1. According to his study, the atmosphere is calm and warm in a room of low color temperature, and low illuminance is appropriate. At the same time, in a room of high color temperature, low illuminance creates a cold and dismal atmosphere and, instead, high illuminance is appropriate. However, the light sources used in that experiment were an incandescent lamp for the area of low color temperature and a fluorescent lamp with low color
rendering properties for the area of high color temperature. Thus, it was pointed out that there was the problem that the color rendering and the diffuse properties of the light changed simultaneously with the changes in the color temperature \(^2\). Hence, a lighting control system that can vary the two lighting factors of color temperature and illuminance independently was developed and used for this study. In this paper, this system will be called the color control lighting system. Bodmann also carried out a similar experiment and reported that the results of Kruithof were not valid in a specific range of illuminance \(^3\).

R. G. Davis et alia implemented a psychological appraisal experiment by the SD method, in which the illuminance and color temperature were changed in a room \(^5\). According to its results, illuminance affected the preference of atmosphere but color temperature did not. Illuminance was varied in three levels, or low, middle and high illuminance, and the middle and high illuminance were preferred over low illuminance. The level of preference was almost the same between the middle and the high illuminance. The Construction Materials Test Center assumed conditions allowing the combination of the preferable illuminance and color temperature by the psychological appraisal experiment and compared the outcome with Kruithof's results \(^9\). There was a report by the Construction Materials Test Center of experimental results regarding the relationship between illuminance and preference of atmosphere \(^6\). Ishikawa et alia reported the test results on the relationship between color temperature and preference of atmosphere \(^7\). Also Miyamoto et alia obtained the preferred level of illuminance for the communal state by the adjustment method \(^8\).

A residential living room was selected as an object space for this study. In a living room, various kinds of activities are performed, such as the regular gathering of the family, drinking coffee or tea, reading newspapers or books, watching TV, listening to music, cheerful chattering among family members, and conversation with guests. Tabuchi et alia classified these activities into two categories of life activities by characteristics, i.e. personal relation life (communal state), of which the main subject is communication (contact) among family members, and personal private life (solitary state). Then they reported that the preferred atmosphere for each category is different \(^9\). However, in the other experiments mentioned before, little attempt was made to evaluate the preference of atmosphere assuming specific life activities. Hence, in this paper, the communal state and the solitary state were adopted as life activities for the basis of psychological appraisal. Then, after instructing to subjects so that they are mentally concentrated, psychological appraisal data were obtained and then analyzed.

There are various patterns in human behavior in a residence. There are cases in which a person stays in a living room for a long time but, in other cases, a person stays there only for a short time. It happens often that a person moves from the living room to the dining room, or from a corridor to the living room. Since in the latter case the impression immediately after entering a living room is also important, we decided to make it a goal to clarify this impression in our study. This impression was measured by a method of comparing it consecutively by changing the illuminance and color temperature in the living room for this experiment. Therefore, the experimental method in this study is slightly different from the appraisal method used in the previous experiments which assumed a long stay in a room.

3. Experimental Method

3.1 Facilities for Experiment

The living room for this experiment as shown in Fig. 1 is located on the first floor of a two-floor residence. A table and sofas were set around the center of the room. The reflectance of the ceiling, wall and floor were 0.75, 0.5 and 0.25, respectively. The dimensions were 4.2m x 4.2m, which is equivalent to approximately 10 mats, a common size for a room. Its interior was in western design and the height of the ceiling was 2.4m. Color of ceiling and wall was off-white and an off-white carpet was laid on the floor.

![Fig. 1 Sectional Diagram for Laboratory.](image1)

![Fig. 2 System to Control Color Temperature and Illuminance.](image2)
total. Although the details will be described later, the illuminance and color temperature could be varied by independently adjusting the light from lamps with three different color temperatures. The maximum illuminance on the table surface was 1200 lux and the range of color temperature was from 3000K to 6700K. The average color rendering index of each lamp was 88.

![Fig. 3 Illuminance and Color Temperature Presented.](image)

Illuminance and color temperature are controlled by dimming each lamp in the color control lighting system as shown in Fig. 2. By the way, the color temperature of the light, as described above, was measured at the surface of the table after it passed through the milk-white panel. The setup data of a lighting scene (the level data for each fader for dimming, illuminance, and color temperature) could be stored in the memory of a personal computer for the main control. Furthermore, the stored contents of a lighting scene could be reproduced. As shown in Fig. 3, there were 17 combinations of illuminance and color temperature that were presented to the observers. For these combination, 3000K, 3400K, 3900K, 4600K and 5600K were adopted for the color temperatures and 100 lx, 200 lx, 400 lx and 800 lx for the illuminance levels, which are levels with equal intervals for human perception. The lighting scene of 200 lx and 3900K was taken as the standard among them and the preferences of the remaining 16 scenes versus the standard were evaluated based upon the appraisal method, which will be described later. The experiments were implemented at night in December.

### 3.2 Appraisal Method

The observers stayed in the room for 30 minutes for adaptation after entering. Since the 3900K color temperature and 200 lx of illuminance were in the middle of the range, they were regarded as the standard scene. After simple instruction was given, the standard scene (3900K, 200 lx) was initially shown for one minute and then the test lighting scene was shown, and the observers evaluated the “like—dislike” of the test scene versus the standard scene on a scale of seven steps. After the test scene was shown for 30 seconds after switching from the standard scene, a light-off period of one minute was set. Observers repeated this cycle 16 times. During the first repetition of the 16 cycles, observers were requested to imagine a space for a communal state. Then, in the next session, they were requested to imagine solitary state and to make a similar appraisal. The required time for the test was 40 minutes for each 16 cycles.

The following instructions were given to the observers:

1. Please evaluate the atmosphere of the overall space imagining a communal state in which you are cheerfully conversing with your family. (The case of the communal state.)
2. Please evaluate the atmosphere of the overall space imagining a solitary state in which you are relaxed, alone, and drinking a cup of coffee. (The case of the solitary state.)

Observers were seated on a sofa and evaluated their preference of the space's atmosphere. Light music was presented so that an environment similar to an actual living space could be realized as far as possible. Cheerful conversation was held among the observers during the test of the communal state, and appraisal was made while drinking a cup of coffee in the test of the solitary state. Number of lighting conditions for the test scene was 16.

The level of color temperature and illuminance to be demonstrated to the observers were replayed at random from 17 combinations, which were stored in the memory of the lighting control system, so that the effect of a sequence could be avoided. The presented combinations are shown in Fig. 3.

The dimming level of each lamp was set so that the chromaticity of the illuminating light was changed in accordance with the locus of blackbody radiation and its distance from the blackbody locus remained unchanged as far as possible. The xy chromaticity coordinates of the illuminating light from the lighting control system in Fig. 2 measured at the center of the upper surface of the table is shown in Fig. 4. Also the chromaticity points of the trichromatic warm white, neutral white, and daylight fluorescent lamps are shown in Fig. 4.
3.3 Observers

The purpose of this experiment was to clarify the general relationship between color temperature and preference as well as between illuminance and preference by numerical values based upon data, which were obtained by successive comparisons with the defined life activities. Therefore, the observers selected were not many but a limited number of people who had excellent sensitivity for the evaluation of preference of lighting atmosphere. The observers consisted of six -- four males and two females -- aged from the 20's to 50's, with normal color and visual perception. In this study, the intervals between the seven categories by the SD method were assumed to be equal from the view point of sensitivity and each grade was converted to an index to calculate the average for the six observers.

4. Results of Experiment

4.1 Results of Appraisal of Preference

How the preference of atmosphere changed with the combination of illuminance and color temperature as demonstrated in the test is shown in Fig. 5 and Fig. 6. The case of the communal state is shown in Fig. 5 and that of the solitary state in Fig. 6. It is noted that preference largely changed depending on the illuminance and color temperature. Thus, the effect on preference of each factor of illuminance and color temperature will be quantitatively discussed in the following.

4.2 Relationship between Illuminance and Preference of Atmosphere

The relationship between illuminance and preference of atmosphere in the case of the communal state with color temperature as a parameter is shown in Fig. 7. The following statements are obvious from Fig. 7. Preference increases in parallel with an increase in illuminance in the range from 100 lx to 400 lx. Preference is saturated or decreases at 800 lx. All color temperatures are on the “dislike” side of the range at 100 lx. At 100 lx, the degree of dislike increases in parallel with an increase in color temperature. Also a tendency is shown that lower color temperature is preferred in the other conditions of illuminance. Since all curves have similar trends against changes in illuminance, it is assumed that the influence of illuminance on preference is larger than that of color temperature. Four hundred lx is required at 5600K to realize “like slightly” but about 200 lx at 3000K or 3400K. Therefore, if color temperature is lowered, the level of “like slightly” can be maintained even if the illuminance is set at low level.
The appraisal results in the case of the solitary state is shown in Fig. 8. The tendency for preference to increase in parallel with increases in illuminance is not so conspicuous as was the case with the communal state. Also preference reaches its peak at a lower illuminance than the case of the communal state. The most preferred condition in the solitary state was a combination of 200 lx and 3000K.

4.3 Relationship between Color Temperature and Preference of Atmosphere

The relationship between color temperature and preference of atmosphere in the case of the communal state is shown in Fig. 9. Illuminance is a parameter. It is observed that lower color temperatures are preferred over higher ones in any illuminance conditions. Since it is considered that color and the reflectance of the interior materials in a room affect the overall atmosphere of the room, this tendency might be different when conditions are different from the arrangement used in this study. The relationship of color temperature to preference of atmosphere in the case of the solitary state is shown in Fig. 10. There is the tendency that lower color temperatures are preferred.

4.4 Statistical Analysis

An analysis of variance was made based on two-dimensional position without repetition in order to statistically check if illuminance and color temperature affect the average scores of preference. The results are shown in Tables 1 and 2. In the case of the communal state, both illuminance and color temperature were statistically significant and, accordingly, it can be said that they affect preference. The case of solitary state also showed similar results.

Table 1 Analysis of Variance (“Communal” state).

<table>
<thead>
<tr>
<th>Change factor</th>
<th>Changes</th>
<th>Grades</th>
<th>Variance</th>
<th>Observed Variance Rate</th>
<th>F(0.05)</th>
<th>F(0.01)</th>
<th>F(0.001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person(Times)</td>
<td>20.85</td>
<td>2</td>
<td>10.42</td>
<td>1.22*</td>
<td>4.46</td>
<td>6.68</td>
<td>18.29</td>
</tr>
<tr>
<td>Factor (color temperature)</td>
<td>7.22</td>
<td>4</td>
<td>1.80</td>
<td>1.01**</td>
<td>3.84</td>
<td>7.01</td>
<td>14.39</td>
</tr>
<tr>
<td>Errors</td>
<td>2.25</td>
<td>8</td>
<td>0.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30.32</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significance level 5%
** Significance level 1%

Table 2 Analysis of Variance (“Solitary” state).

<table>
<thead>
<tr>
<th>Change factor</th>
<th>Changes</th>
<th>Grades</th>
<th>Variance</th>
<th>Observed Variance Rate</th>
<th>F(0.05)</th>
<th>F(0.01)</th>
<th>F(0.001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person(Times)</td>
<td>4.54</td>
<td>2</td>
<td>2.27</td>
<td>1.41*</td>
<td>4.45</td>
<td>6.65</td>
<td>18.49</td>
</tr>
<tr>
<td>Factor (color temperature)</td>
<td>5.84</td>
<td>4</td>
<td>1.46</td>
<td>1.01**</td>
<td>3.84</td>
<td>7.01</td>
<td>14.39</td>
</tr>
<tr>
<td>Errors</td>
<td>1.33</td>
<td>8</td>
<td>0.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11.71</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Significance level 1%

In order to compare the degree of influence illuminance and color temperature have on preference, an analysis of type I quantification was made, taking the average score as a target variable (outside standard) and the illuminance and color temperature as explanatory variables (items). For this analysis, the range was used as an index to show the degree of the effect of an item on the outside standard. The range is to show the range of quantities (scores) corresponding to categories under each item, and it is used as one of rough
indicator of effect level. The cases of communal state and solitary state are shown in Tables 3 and 4, respectively. Positive scores show an increase in the level of preference and negative ones show a decrease in the same. The range was greater in illuminance in the case of the communal state and greater in color temperature in the case of the solitary state.

**Table 3 Effect of Illuminance and Color Temperature ("Communal" State).**

<table>
<thead>
<tr>
<th>Item</th>
<th>Category</th>
<th>Range</th>
<th>Score</th>
<th>Score (graph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Illuminance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>200 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>400 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>800 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>3000 K</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>3400 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>3900 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>4600 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>5600 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4 Effect of Illuminance and Color Temperature ("Solitary" State).**

<table>
<thead>
<tr>
<th>Item</th>
<th>Category</th>
<th>Range</th>
<th>Score</th>
<th>Score (graph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Illuminance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>200 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>400 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>800 lx</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>3000 K</td>
<td>1</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>3400 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>3900 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>4600 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
<tr>
<td>5600 K</td>
<td>2</td>
<td>0.000</td>
<td>-1.384</td>
<td></td>
</tr>
</tbody>
</table>

4.5 Comparison of Preference by Life Activities

In order to compare preference in the life activities of the solitary state and the communal state, the average score for each scene was plotted on two-dimensional co-ordinates with preference for the solitary state plotted on the horizontal axis and preference for the communal state plotted on the vertical axis as shown in Fig. 11. The parameters are illuminance and color temperature. The preference of atmosphere are the same for the communal state and the solitary state with combinations located on the dotted line.

Combinations above the dotted line are preferred for the communal state rather than for solitary state. Combinations below the dotted line are preferred for the solitary state rather than for communal state. First, it will be described how the evaluation was changed by illuminance with a constant color temperature. In the range from 100 lx to 400 lx, a tendency that the plotted points shift upward in parallel with an increase in illuminance is noted, and it is considered that the preference for the communal state increases simultaneously.

Many lighting scenes with high illuminance are located above the dotted line, while those with low illuminance are located below the same. This indicates that low illuminance is preferred in the solitary state, while high illuminance is preferred in the communal state. Therefore, the need to change illuminance in correspondence with the communal state or the solitary state was suggested by the result.

Next, how the evaluations was changed by color temperature under constant illuminance will be described. For example, when the color temperature was changed under the condition of 100 lx of illuminance, there was a tendency that the plotted point shifted toward the upper right when the color temperature was lowered. For example, among the five points of 100 lx, 3000K is positioned at the highest, while 5600K at the lowest. In this experiment, a tendency for the preferred color temperature to vary by life activities was not observed. Overall, there was a tendency for low color temperature to be preferred over high color temperature.
5. Comparison with the Past Studies

5.1 Comparison with Kruithof's Results

Kruithof found that there was a range of illuminance to be felt comfortable for each color temperature through an experiment and demonstrated the comfortable zone in two-dimensional coordinates with color temperature on the x-axis and illuminance on the y-axis. This indicated that, as described before, low illuminance was comfortable in the case of low color temperature and high illuminance was comfortable in the case of high color temperature. The border line of the comfortable and uncomfortable areas was also demonstrated.

In the lower uncomfortable area, the results of this study were "neither like nor dislike" or below. Therefore, the evaluation results in this study were similar to Kruithof's results. In the case of the solitary state in Fig. 13, the combinations of illuminance and color temperature in this study that are in Kruithof's uncomfortable area were not much preferred. This indicates that these two results resemble each other. Among the combinations of illuminance and color temperature in this study that are in Kruithof's comfortable area, lighting conditions at 800 lx were not preferred. This is the point in which the results in this study were different from Kruithof's to some extent.

Fig. 12 Color Temperature and Illuminance vs. Preference ("Communal" State)

Comparisons of the results in this study and Kruithof's are shown in Fig. 12 and Fig. 13. White and shadowed areas represent Kruithof's comfortable and uncomfortable areas respectively. In the evaluation of the communal state in Fig. 12, the sizes of the circles are small in the case of 100 lx and large in the case of 400 lx. In Kruithof's comfortable area the results in this study showed a preference of "neither like nor dislike" and above.

Fig. 13 Color Temperature and Illuminance vs. Preference ("Solitary" State)

5.2 Comparison with Other Appraisals of Preferred Illuminance or Color Temperature

The effect of the two lighting factors of illuminance and color temperature on the comfort level of lighting for a living room was clarified in this study. As an example of studies that clarified the effect of illuminance alone on lighting, an appraisal experiment implemented by the Construction Materials Test Center will be taken up and compared with the results of this study. The experiment was performed in a living room that was set to be similar to an actual living space. In this experiment, four levels of
illuminance were chosen as experimental conditions with four kinds of light sources. Evaluation was made based on a scale of “too bright,” “appropriate,” and “too dark”. The evaluation data for the case of a color temperature 5000K and an average color rendering index of 92 (by the way, the spectral distribution was of the full-spectrum type) was shown in Fig. 14. In addition, among the evaluation data in this study, those of color temperature nearest to 5000K were shown in Fig. 14. According to the results by the Construction Materials Test Center, the appropriate illuminance in a living room was about 400 lx, which was comparatively similar to the results obtained in our current study.

According to this study, the desirable illuminance was about 400–500 lx, which was roughly similar to the results found in our current study.

Ishikawa et alia did a psychological experiment evaluating the relationship of the lighting atmosphere and the color temperature using a Japanese style room 7). Now, among the experimental conditions of the current study, those with the closest conditions to theirs are compared in Fig. 15. According to our results, a tendency is noted that the level of preference is saturated when the color temperature is lowered, while there is a tendency for the preference to decrease especially at 3000K in the results of Ishikawa et alia. Therefore, a small difference is observed in the case of a color temperature of 3000K. The difference in seasons when the experiments were performed might be a reason for this difference; i.e. we implemented our experiment in winter but Ishikawa et alia did it in summer. That is to say, a low color temperature has a warm atmosphere and is not much disliked in a cold winter, but it may have a tendency to be disliked in a warm summer.

6. Summary

The main experimental results of this study are summarized as follows.

(1) In the case of the communal state, preference of atmosphere increases when illuminance gets higher in the range from 100 lx to 400 lx, but it saturates or decreases when the illuminance exceeds the range. In the case of the solitary state, the proportional relationship between illuminance and preference is not so strong. Also, preference reaches its peak in low illuminance. In either case, there is a strong tendency for lower color temperature to be preferred over higher color temperature under the experimental conditions for this study. The evaluation was an impression of preference immediately after switching from the standard scene to the test scene, for which the adaptation time was short. If an evaluation is made after a long time period of adaptation, it is possible that a clear difference in preference by illuminance and color temperature as observed in this experiment may not be detected. However, it is believed that the basic tendency will be similar even under such conditions. Since it is considered that the preferred color temperature is related to color, reflectance and so on of interior materials in a room, their quantification is a subject for the future.

(2) There is the tendency that high illuminance is preferred in the communal state and low illuminance is preferred in the solitary state. According to the results of the evaluation of the necessary atmosphere for the solitary state and the communal state 9), a calm and restful atmosphere, which is somehow removed from daily life, is desirable for the solitary state, while a relaxed, informal, and lively atmosphere is desirable for the communal state. It is considered that the required illuminance is different between the two states because the desirable atmosphere is different for each life activity as mentioned in the above. It is conceivable a device could be developed that would...
enable the easy change illuminance by operating a switch for each luminaire, on which the necessary brightness has been pre-set using dimming equipment with memory, as a method to effectively use the luminaire so that the required illuminance can be produced depending on the life activities.

(3) The results in this study are similar to Kruithof's results in the case of the communal state but somehow different in the case of the solitary state. One of reasons for the difference between the results of the current study and those of Kruithof that has been discussed from time to time is that the incandescent lamps have been used for a long time in European homes, while fluorescent lamps (mainly daylight color, 5000K) have been widely used for home lighting in our country and, accordingly, people here are accustomed to lights of high color temperature. However, since the difference exists only in the case of the solitary state in this study, it is considered that the difference in the required atmosphere for the corresponding life activities may be one of the major reasons rather than the above. It has been experienced in our daily life that the preferable illuminance and color temperature vary by the activities of the users of a lighting environment.

As described before, it has been reported that Kruithof's results are not valid in a specific range of illuminance 3). However, Kruithof's results still have been used from time to time since they are useful to qualitatively explain the effect of illuminance and color temperature as experienced in our daily life. Detailed studies in the future are desirable to check if Kruithof's results are valid in a lighting environment under certain compositions of conditions in the house or outdoors as well as with different types of life activities. Furthermore, since various items such as illuminance distribution, luminance distribution, and the directional property of light are conceivably factors determining preferred illuminance and color temperature, it may be necessary to systematically study them.

7. Conclusion

It is considered that there are two major purposes of lighting: to produce a comfortable atmosphere and to provide a good environment to facilitate visual tasks. For a place of complicated and varied life activities, such as living rooms in residence, it is important to have basic information for lighting design that not only satisfy visual utility as a matter of course, but also additionally satisfy atmosphere needs corresponding to life activities. Before-mentioned lighting factors other than illuminance and color temperature have been checked from time to time in the practice of lighting design. Thus, it is desirable to promote the development of studies to the point that rough levels or objective indications of preferable conditions for such other factors can be given.

8. Acknowledgement

We would like to express our sincere thanks to Ms. Mari Miyata and Mr. Mineo Suzuki of Electrotechnology Application R & D Center of Chubu Electric Power Company, Dept. Manager Mitsuo Yokoyama, Section Head Hidemi Kashiwagi, Section Head Isao Maeda of Interior Lighting Business Dept. of our company, Supervisor Tadashi Kuwata of Lighting Chubu Engineering Central Dept., and all other persons supported this study. Also, we would like to express our thanks to Prof. Masato Oki of Ashikaga Institute of Technology, who fully supported the translation of our paper from Japanese to English, and General Manager Yasuhiro Tomita of Lighting Chubu Engineering Central Dept. of our company, who fully supported implementation of this assigned study in various aspects.

Reference

(1) A.A.Kurithof: Tubular Luminescence Lamps for General Illumination, Philips Technical Review 6, pp.65-96(1941)
at General Conference of Japan Society of Architecture, 40220 (1995 August)
