Preferred Illuminances on Surrounding Surfaces in Relation to Task Illuminance in Office Room Using Task-ambient Lighting

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Abstract
Comfortableness in various spaces is recently gaining priority. For comfortable lighting in a desk work area, visual comfort in the environment as well as good visual performance are required during a long desk work with visual tasks such as reading and writing documents.
Preferable illuminance and luminance on surrounding surfaces in relation to the task (on the desk) illuminance should be determined appropriately.
Since general lighting is usually used as office lighting, the previous paper clarified the preferred wall illuminance and luminance in relation to desk illuminance. On the other hand, task-ambient lighting has been proposed to save energy. In this paper, the following items are clarified with respect to the task-ambient lighting.
(1) Preferred ambient illuminance in relation to task illuminance
(2) Preferred wall illuminance in relation to task illuminance
Further, with the use of task-ambient lighting based on the results above, even with energy-saving ambient illuminance, the ratio of consumed wattage per worker between general lighting and task-ambient lighting, is obtained through a simple calculation; the result revealed that the power saving amount to as much as 40-55%.

1. Introduction
Comfortableness in various spaces is recently gaining priority, which of course is common to public and productive space like an office. Although comfortableness in an office has been an important need, the measure has not urgently been taken against it, while improving productivity of office works always is a substantially important task, and in addition, the following new purpose have come up in this severe business environment:
(1) Increase in capacity and efficiency of treating routine information through office automation
(2) Improvement in intellectual productivity

Conventional routine works have been considerably improved in their efficiencies with the introduction of OA systems, and further improvements in decision-making in important aspects of management such as creating a new business are becoming more and more important; to find a way out of the present confusion of business environment, improvement in comfortableness of lighting, which promote inventive and intellectual activities, is becoming more and more important.

An office includes several areas different in their purposes, among which is a desk work area. There are a number of people working there for a long duration of time, and therefore, an improvement in comfortableness is most important; this desk area was taken up as a subject of this study.

For comfortable lighting in a desk work area, visual comfort in the environment as well as a good visual performance are required during a long desk work with visual tasks such as documents. Even glancing for a short duration, a desk worker may feel safety and comfort with a preferable environment, and it may have a considerable effect on intellectual productivity.

Preferable luminance and illuminance on surrounding surfaces in relation to the illuminance on a desk with visual tasks on it, are required for a comfortable environment.

Since general lighting is usually used as office lighting, the previous paper clarified the preferred wall luminance and illuminance for the case in relation to the visual tasks on a desk surface.
On the other hand, task-ambient lighting\(^5\) has got underway primarily to save energy, in which ambient illuminances sometimes are found too low for a comfortable visual work on a desk; that is, the ambient illuminance should be appropriate in relation to the illuminance on the desk. In this paper, a preferable ambient illuminance will be clarified regarding the task-ambient lighting.

Further, the data previously reported in Japanese\(^6\)\(^7\) were partially revised, and the effect on saving energy were calculated and added in this English version.

2. Background of This Study

2.1 Definition of Task-ambient Lighting

Task-ambient lighting was proposed around 1975 with the oil crisis as a momentum\(^10\), and some examples have been reported\(^11\)\(^12\), but with decreasing numbers per annum since then. Energy-saving, however, is an urgent need at present, for which an appropriate lighting technique should be developed and commercialized. Traditionally, a highly sophisticated idea for comfortable task-ambient lighting is to integrally combine independent lighting techniques that has been designed most effectively for the task and the ambient, respectively, while the basic conception has not been established yet.

There are a variety of possibilities for task-ambient lighting; the most basic concept is to get a fundamental illuminance with general lighting for the entire room, which is combined with local lighting for a higher illuminance to improve visual performance for the task.

IES Lighting Handbook defines “task-ambient lighting” as “a combination of task lighting and ambient lighting within an area such that the general level of ambient lighting is lower than and complementary to the task lighting”\(^13\).

“Task” means, according to the Collins' English-English dictionary, “a specific piece of work required to be done as a duty or chore”\(^14\), while IES Lighting Handbook defines “visual tasks” as “those details and objects that must be seen for the performance of a given activity, including their immediate background”\(^15\), and “task lighting” as “lighting directed to a specific surface or area that provides illumination for visual tasks”\(^16\).

Generally, a “visual task” indicates an individual visual object, while the examples of task-ambient lighting show that “task” for “task lighting” indicates “the area in the vicinity of an operation site” against the entire room, which substantially means a “task area”; in this paper, therefore, the term "task" means the “task area”.

Also, “ambient” does not have a clear definition. Ambients may include whole of the surrounding surfaces, among which adjacent desks of absentees' and a front wall are most important. Only adjacent desks will be hereafter simply regarded as ambient, according to conventional idea. A front wall will be treated separately. Ambients and a wall will be, hereafter, as important surrounding surfaces.

2.2 Former Studies

Bean and Hopkins studied minimum illuminance of general lighting in a room and the visually satisfactory task illuminance v.s. ambient illuminance relationship, revealing that the task and ambient illuminances at the same level are preferred\(^19\). On the other hand, Fischer clarified that, under a constant task illuminance of 1000 lx, a preferred illuminance of an ambient (general lighting is 50% or above of task (local) lighting, and interestingly, most evaluators preferred sole general lighting to task ambient lighting\(^20\).

These results on a preferred ambient illuminance in relation to the task illuminance showed various inclinations, and few steps of task illuminances were set\(^10\)\(^16\).

Balder investigated a preferable task illuminance, and clarified the preferable luminances on front and side walls in relation to the task illuminance or luminance\(^21\). Fischer showed the wall reflectance v.s. wall luminance relationship with the task illuminance as a parameter\(^18\). Tabuchi et al. (previous paper) clarified a preferred wall illuminance in relation to the task illuminance, with general lighting\(^22\); these studies were based on a premise that an ordinary office uses general lighting; if a task illuminance different from the ambient illuminance is preferred, the preferable wall illuminance cannot be determined.

2.3 Purpose of This Study

In consideration of the background mentioned above, the following items will be clarified in this study:

(1) A preferable ambient illuminance in relation to the task illuminance
(2) A preferable wall illuminance in relation to the task illuminance

In the previous paper, both of preferable wall illuminance and luminance in relation to the task illuminance were treated\(^20\). In this paper, the illuminance, which is used for lighting designs, was solely discussed for both the ambient and the wall surface; for the ambient, the desks and the ambient (adjacent desks) having the same reflectance, the luminance is proportional to the illuminance, while for the wallsurface, the illuminance v.s. luminance relationship, from the standpoint of “preference”, has a tendency similar to that in the previous paper, only the values being slightly different.
3. Preferred Ambient Illuminance in Relation to Task Illuminance

3.1 Equipments

The same equipments, as those in the previous studies \(^{12}\), were used in this study, which will be described again, since the description was made in Japanese in the previous paper.

3.1.1 Selection of Spatial Conditions as Visual Stimuli

Among the experimental conditions, a layout of the visual objects or the visual stimuli, such as shape of the office and layout of the desks, were decided according to the following idea:

Typical Japanese office buildings have a variety of sizes, but normally, an appropriate front width (a longer side) is considered to be 50-70m \(^{19}\), at the longest, an appropriate depth from a window mostly 10-15m \(^{20}\), and a ceiling mostly 2.5m high \(^{21}\). These large rooms are sometimes partitioned and sometimes not; when partitioned, a preferable number of partitions may be 3-4 \(^{18}\) with a standard module of approximately 3m, while a small office is sometimes used as a room \(^{22}\).

A worker sits at a free position in a room, sometimes sitting close to the front wall and sometimes far from it; in an extreme case, the desk may be in contact with a wall, while normally, there may be other workers’ desks between the worker’s desk and the wall which will make the mean distance from the wall approximately 3m. The farthest may be approximately 50-70m, which is the distance equal to the front width mentioned above.

When a worker looks at a surface after another, and when luminances of these surfaces are almost the same, his eyes might immediately be adjusted to the luminance of each surface. On the other hand, the subjective impression of the worker is affected by a solid angle of another surface; as an extreme case, we estimated a long room, which was mentioned above.

A worker will rarely sit as far as 70m from a wall, and let’s assume the longest distance to be 50m, while the shortest distance may be 3m. With these assumptions, solid angles for respective surfaces were calculated at the level of the worker’s eyes. Assuming that a worker’s desk generally used is 1m × 0.7m in the surface area and 0.7m high \(^{22}\), and the worker’s eyes are 1.1m high \(^{23}\), the solid angle for the worker’s desk surface was calculated as approximately 1sr. Also assuming that the surfaces of the ambient (adjacent desks) are continuous since they are closely laid in the space, the solid angle for the ambient was calculated by deducting the solid angle for the worker’s desk from that for the assumed large desk consisting of all the desks in the room; actually, the total solid angle for the ambient actually should be slightly smaller than the solid angle of this assumed integrated desk surface, since the desks are not really closely laid.

Table 1 shows the solid angles for the front wall, the entire desks’ surface in the room, and for the ambient.

Table 1. Solid Angles (sr) for Surfaces in an Office with evaluator sitting on the center line extending toward interior Room size: 10m (width) × 50m (depth)

<table>
<thead>
<tr>
<th>Objects</th>
<th>Distance (m)</th>
<th>Near from Evaluator</th>
<th>Far from Evaluator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Surface</td>
<td>3</td>
<td>1.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Desk (entire) Surface</td>
<td>50</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Ambient (entire) Surface</td>
<td>1.8</td>
<td>1.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

When the surfaces have similar luminances, the solid angle for each surface has little effect. Hopkinson showed, on one hand in his study on discomfort glares, where the worker is looking straight at a light source with a area, that a solid angle had a considerable effect, with a background luminance of 30-150 cd/m\(^2\), a solid angle for the light source of 0.003-3 sr, and with a “just uncomfortable glare”. On the other hand, the same investigation revealed, supporting the comment mentioned above, that a solid angle had little effect with a similar luminance of each surface and with a “just perceptible glare” \(^{24}\). A person looking straight at a surface, therefore, may obviously have an impression independent of solid angles of respective surfaces, and this experimental result with the solid angles selected within the range mentioned above, may apply to other cases.

3.1.2 Conditions of Laboratory and Each Surface

Too large a laboratory, having too large ambient, may give a lonely and uncomfortable feeling to the worker. For this reason, a middle-sized laboratory, 6.3m × 5.8m, with a ceiling of 2.5m high, and with interiors similar to those of normal offices, was employed. The room had, as mentioned later, relatively large solid angles for the walls. As the ambient, four desks, 2 × 2 rows, were used in front of the worker.

An outline of the laboratory is shown in Fig.1, the layout of desks in the room and of luminaires on the ceiling in Fig.2(a), and a section of the laboratory in Fig.2(b).

As the visual task on the desk, a page of a magazine was used.
Reflectances of respective surfaces are shown in Table 2. Two grades of wall reflectance, the lower (0.3) and the upper (0.8) limits, were selected, which are the reflectance of an office, recommended by the CIBS Code of British IES (1984). These wall surfaces will hereafter be simply called a "low reflectance" and a "high reflectance" walls. The laboratory wall was used as a high reflectance wall, and a flat diffuse painted board fixed on a wall was used as a low reflectance wall.

Table 2. Reflectances of Respective Surfaces

<table>
<thead>
<tr>
<th>Surfaces</th>
<th>Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>0.85</td>
</tr>
<tr>
<td>(Front) Wall</td>
<td>0.3 or 0.8</td>
</tr>
<tr>
<td>Floor</td>
<td>0.15</td>
</tr>
<tr>
<td>Desk (with a Task on it)</td>
<td>0.3</td>
</tr>
<tr>
<td>Page of Magazine</td>
<td>0.7</td>
</tr>
</tbody>
</table>

The evaluator sat 4.8 m from the wall.

The wall, covering the level from desk to ceiling, was a rectangle of approximately 6.3 m x 1.8 m, and the solid angle for the wall at the level of evaluator's eyes was approximately 0.15 sr. The solid angles for the adjacent desks were 0.03 sr and 0.006 sr, respectively, totaling to 0.07 sr.

These solid angles are within the range shown above.

3.1.3 Lighting Installations

The lighting conditions were selected as follows:

In a normal office, a task illuminance lower than the ambient illuminance has been considered to be unfavorable. In a restaurant with decorative interiors, however, sometimes an umbrella is put up above a dining table to imitate an outdoor atmosphere. In this case or under the shade of a tree, the ambient illuminance is higher than the task illuminance, which sometimes might be preferred, while in this study on a normal office lighting, a higher ambient illuminance was omitted for the purpose of saving energy.

The following lighting fittings mounted with white 4200K fluorescent lamps are most widely used for an office lighting.

(1) Ambient Lighting (General Lighting)

As shown in Figures 2 (a) and 2(b) mentioned above, glare-limiting lighting fittings, with a recessed diffuse reflector and with two 40W fluorescent lamps (shielding angle: 15°), were placed at 1.74m intervals, which were connented with a dimmer. Fig.3 shows a task illuminance distribution with an undimmed lighting, where the mean illuminance was approximately 1000 lx.
(2) Task Lighting (Local Lighting)

In this experiment, a uniform illuminance distribution of the ambient lighting was to be obtained by general lighting only, as reported in the previous paper, while local lighting for the desk surface was combined to obtain an illuminance higher than on the ambient. Two lighting fittings, with a 40W fluorescent lamp each, were hung parallelly 1.6m above the floor to illuminate the desk surface, and were connected with a dimmer. The mean undimmed task illuminance with these lighting fittings only was approximately 1200 lx; the illuminance distribution is shown in Fig.4. The illuminance uniformity was moderately good.

(3) Wall Lighting

As shown in Figures 2(a) and 2(b), three rows, four in each row, of 40W lighting fittings with a fluorescent lamp each were placed parallelly close to walls, and also were connected with a dimmer.

Fig. 5 shows the undimmed illuminance distribution on the wall surface. As the point of chief observation for evaluating the wall illuminance, the center of wall in front of the evaluator and 1.1m from the floor, was selected. The maximum/minimum ratio or the uniformity of the vicinity of this point was approximately 2.1, which is small enough; the point of evaluation was located at the center of nine sections, 2.1m wide and approximately 0.85m high, made by dividing each of the vertical and horizontal sides into equal three parts. The geometrical mean of the maximum and the minimum levels was approximately 1450 lx, which roughly coincides with the illuminance at the center.
3.2 Experimental Procedure

The procedure taken were almost the same as in the previous paper\textsuperscript{12).}

The evaluator repeatedly compared the ambient (test surface) with the visual task (reference surface), a magazine page that had the reflectance of approximately 0.7 was placed on the desk as a reference surface, through alternating observations to the evaluator's satisfaction. The wall illuminance was adjusted so that the wall surface was felt fit to the grades described below, where the evaluator was free to give priorities to the sections according to his/her degree of concentration or interest. This is a comparison different from a time-lapse comparison, where the luminance of the watched evaluation surface is changed from outside; that is, this is another type of time-lapse comparison, where the evaluator freely compares the respective surfaces, and will hereafter simply be called "alternating comparison", comparably to the "simultaneous comparison" and the "time-lapse comparison``.

The worker's desk was lit with given luminance with both task and ambient lightings. The illuminance was in the range of 300-1000 lx, which meets the design illuminance for a common office area, and which was changed by four steps upward, from 300lx via 500 and 700lx to 1000lx.

The evaluator adjusted the ambient illuminance by dimming the ambient light. To maintain the task illuminance constant during the dimming, the investigator dimmed the task lighting.

With a preliminary experiment on the wall illuminance, a preferable wall illuminance with general lighting was employed at first in relation to the desk surface, which was discussed in the previous paper\textsuperscript{11, 12).} We put out the wall lighting later, however, feeling that the wall surface was slightly too bright, despite another feeling that the ambient illuminance can be lower than the task illuminance; i.e., the ambient illuminance could not be decreased, affected by the wall illuminance.

The two evaluation grades, excluding the upper limit for the reason shown above, were proposed as follows:

1. Lower limit (too dark)
2. Optimum (just preferable)

Number of evaluators was eight including two women. The eye-sights of the evaluators were not measured, but were necessarily corrected.

The evaluation was repeated three times at each step.

3.3 Results of Experiment

At each task illuminance, the relationship between adjusted ambient illuminances and their appearing rate were plotted, with logarithms of the illuminances on the horizontal axis, and with cumulative appearing rate on the vertical axis, assuming that the appearing rate of each adjusted value was 4.2%. Fig. 6 shows the results with the task illuminance of 700lx, and with the wall reflectance of 0.8 (a high-reflectance wall).

![Fig. 6 Cumulative Appearance Rate of Adjusted Ambient Illuminance](image)

Since the adjusted lower limit of ambient illuminance was considerably lower than the task illuminance, the former drew a lenient S-shaped curve. The optimum adjusted values lower than the task illuminances also drew an S-shaped curve. The ambient illuminance lower than the task illuminance, which is the premise of this experiment, resulted in an upper limit equal to the set task illuminance. The ambient illuminance at a cumulative appearance rate of 50% is slightly lower than the task illuminance. The cumulative appearance rate of the optimum of equal levels of the ambient and the task illuminances was 30%, which is relatively high; namely, it can be said a relatively preferable condition.

From the figures, each adjusted optimum and lower limit level at 50% cumulative appearance rate as well as each "energy-saving level" were obtained.

A "energy-saving level" is an evaluation grade for a combination of comfort and energy-saving, for which a lower limit at 90% cumulative appearance rate was employed. Since a general lighting has always been used in conventional offices, where people are accustomed to the equal levels of task and ambient illuminances, and the worker might feel reluctant to use an ambient illuminance lower than the task illuminance, while the designed illuminance should be reduced at least to undisatisfying levels to save energy even by a small margin. In general, the lower limits at 50% cumulative appearance rate may be dissatisfactory, while the 90% cumulative appearance rate rarely gives us a feeling of a lower limit, which may be a level moderately good.
Since a wall illuminance, which will be discussed in the next section, does not have an existing reference value, we obtained a lower limit just for a reference, and did not obtain a energy-saving level. When an energy-saving level was required, a geometric mean of the optimum and the lower limit levels will be used, which is considered to be practically appropriate because of a level of the cumulative appearance rate higher than 50%, which is the safer side against dissatisfaction.

From these assumptions, the optimum, lower limit, and energy-saving levels for preferable ambient illuminances were plotted against the task illuminances in Fig. 7, with black circles for a low-reflectance (0.3) wall and with blank circles for a high-reflectance (0.8) wall. Since the effect of wall reflectance is small with few exceptions, the mid-points of the black and blank circles were connected with solid lines.

The lower limits and the energy-saving illuminances almost are on respective straight lines, which are nearly parallel to each other and have similar inclinations. On the other hand, the line for the optimum level is bent, which differs from others. Above 500 lx of the task illuminance, the straight line is nearly parallel to those for the lower limit and the energy-saving levels, similarly to others, while the task illuminance becomes equal to the ambient illuminance at 500lx and below.

In designing actual office lighting, the task illuminances of 500lx or the higher levels are selected; hereafter, only the optimum value of 500lx or the lower levels will be discussed.

Exponents for the ambient illuminance in relation to the task illuminance is 0.4-0.5, while those for the wall illuminance was 0.6-0.8 (see the previous paper). The former exponents are slightly smaller, and the allowable range for the preferable ambient illuminance (Optimum/lower limit : 3) is slightly larger than that for wall surfaces (Optimum/lower limit : 2).

Accordingly, as the task illuminance increases, the optimum level becomes lower than the ambient illuminance, and especially when the task illuminance is 1000 lx, the preferred ambient illuminance is considerably lower than the task illuminance. This is different from Fischer's result that most evaluators favor an ambient illuminance equal to the task illuminance.

3.4 Discussion

The line for the optimum values in Fig.7 is bent, which differs from others. Above the task illuminance of 500lx, an extension of the line toward the lower side, parallel to the lines for the lower limits and energy-saving levels renders the task illuminance lower than the ambient illuminance. As mentioned earlier, it never happens when a usual task-ambient lighting is used, and also may be unfavorable commonsensibly, while in the range of a considerably lower task illuminance, there might be a possibility that the ambient illuminance only should be preferably higher, even if the task illuminance becomes lower than the ambient illuminance. An actual impression in the experiment showed that regardless of the level of ambient illuminance, the task illuminance of 500lx or below was felt unfavorably dark; if so, a lower ambient illuminance than the task illuminance may be still more unfavorable, and also, either the task or the ambient illuminance below 500 lx was felt unfavorable. At a task illuminance of 500 lx or below, therefore, the task and the ambient illuminances become equal to each other under the conditions of this experiment, forming another straight line, resulting in an occurrence of an intersection of the two straight lines with different inclinations at a task illuminance of 500 lx.

Further, the line for the lower limits might have a bending point below the task illuminance of 300 lx, and the ambient illuminance considerably decreases with the decreasing task illuminance, which were not clarified in the range of this experiment.
The exponents, 0.4-0.5, for the preferable ambient illuminance in relation to the task illuminance (see Fig. 7), are slightly smaller than those, 0.6-0.8, for the preferable wall luminance in the previous paper, and the allowable range (optimum/lowest : 3) for the ambient illuminance was slightly higher than that (optimum/lowest : 2) for the wall luminance. This means that the preferred luminance becomes constant and the allowable range becomes wider, when the test and the reference surfaces are similar in their materials and the evaluator has a higher interest toward the surface.

The same is true, as in the previous paper, in selection of levels for the design surface, under an appropriate ambient illuminance, an allowable range for the design task illuminance is considerably wider than the ambient illuminance, and also wider than the allowable range for the design task illuminance in relation to the wall illuminance.

3.5 Recommendable Ambient Illuminance

Table 3 shows the recommendable ambient illuminance obtained from Fig. 7 at 500, 750, and 1000 lx of task illuminance.

Table 3. Recommended Ambient Illuminance in Relation to Task Illuminance

<table>
<thead>
<tr>
<th>Task Illuminance (lx)</th>
<th>Evaluation Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimum</td>
</tr>
<tr>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>750</td>
<td>580</td>
</tr>
<tr>
<td>1,000</td>
<td>670</td>
</tr>
</tbody>
</table>

4. Preferred Wall Illuminance in Relation to Task Illuminance

4.1 Experimental Conditions

The conditions of this experiment differ from those reported in the previous paper, in the nonuniformity of interior task illuminance over the entire desksurface, resulting in the difference of illuminance on the task and the ambient. In this paper, the ambient illuminance was given by ambient lighting only, and the task illuminance was given by both task and ambient lighting. As an ambient illuminance, the energy-saving level, explained in 3.5, was employed. Strictly, to obtain the optimum or the lower limit wall illuminance, we should use the optimum or the lower limit ambient illuminance, uniting the evaluation grades for the design illuminances. In this paper, however, to clarify the difference caused by the difference in the evaluation grades for the wall illuminance in relation to the same ambient illuminance, we selected the energy-saving level, which is most widely used in a lighting design.

4.2 Experimental Procedure

As in 3.2, the same task was used as a reference, and the test wall illuminance was evaluated and adjusted through alternating comparison with the reference by the evaluator, which was repeated twice for each measurement.

The desk illuminance was changed, as in 3.2, through four steps upward from 300, via 500 and 700 to 1000 lx.

The grades used for evaluation were as follows:

1. Lower limit (too dark at this level and below)
2. Optimum (most preferable)
3. Upper limit (too bright at this level or above)

The evaluation was made by the same evaluator as in the previous section.

4.3 Results of Experiment

As in the previous section, logarithms of the adjusted wall illuminances (the horizontal axis) v.s. cumulative appearance rates (vertical axis) relationship at each level of the task illuminance was plotted on a graph, assuming the appearance rate of each adjusted value to be 6.25%. Fig. 8 shows an example at a task illuminance of 500 lx on a high-reflectance (0.8) wall.

Fig. 8 Cumulative Appearance Rate of Adjusted Wall Illuminance

From these results, as in the case of a general lighting only, the task illuminance (log) v.s. preferred wall illuminance (log) relationships are shown in Fig. 9 with blank circles for a high-reflectance wall, and with black circles for a low-reflectance wall, as well as with dotted lines for the upper limit, solid lines for the optimum illuminance, and with broken lines for the lower limit.

The figures show the following:
Fig. 9 Preferred Wall Illuminance in Relation to task Illuminance

(1) The task illuminance v.s wall illuminance relationship is not linear; the wall illuminance tends to saturate with the increase of task illuminance. In the case of general lighting discussed in the previous paper \(^{120}\), the wall illuminance v.s task illuminance relationship was linear; the relationships are slightly different. This may be, as shown in Fig.7, due to a smaller increase of energy-saving ambient desk illuminance than the increase of the task illuminance.

(2) The curves for respective evaluation grades are parallel to each other.

(3) The wall reflectance affects the wall illuminance the least for the upper limit, and the most for the lower limit, the optimum level being in the middle. Fig.10 shows the wall reflectance (horizontal axis) v.s. wall illuminance (vertical axis) relationships with the task illuminance as a parameter, which shows the effect of wall illuminance on the preferred wall illuminance. These graphs show an inclination almost the same as in Fig.12 in the previous paper \(^{120}\) (Effect of wall reflectance on preferable wall illuminance). In more detail, the slopes of the straight lines for the wall

Fig. 10 Effect of Wall Reflectance on Preferred Illuminance (Optimum)

reflection v.s. preferred wall illuminance relationships depended on the task illuminance, while in this paper, these slopes are almost the same, which is similar to the Fischer's result \(^{16}\), which was compared in the previous paper \(^{120}\).

4.4 Comparison with General Lighting (see the previous paper \(^{120}\))

Fig.11(a) shows the preferred wall illuminances v.s. task illuminance relationship with a low-reflectance wall, while Fig.11(b) the same with a high-reflectance wall; all the grade levels (upper limit, optimum, and lower limit) are shown with solid lines for the present experiment, and with broken lines for the previous experiment.

A lower ambient illuminance gave a lower preferable illuminance in relation to the task illuminance with a low-reflectance wall, while with a high-reflectance wall, the optimum preferable wall illuminance gave the same preferable illuminance in relation to the task illuminance, and a lower wall illuminance gave a lower preferable illuminance. For the upper limit, a lower ambient illuminance sometimes gave a higher preferable illuminance, which may have been caused by dispersion of the data.
4.5 Recommendable Wall Illuminance

Table 4. Recommendable Ambient and Wall Illuminances

<table>
<thead>
<tr>
<th>Task Illuminance (lx)</th>
<th>Ambient Illuminance</th>
<th>Wall Illuminance (lx)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy-saving</td>
<td>Optimum</td>
</tr>
<tr>
<td></td>
<td>Wall Reflectance</td>
<td>0.3 - 0.8</td>
</tr>
<tr>
<td>500</td>
<td>220</td>
<td>270</td>
</tr>
<tr>
<td>750</td>
<td>270</td>
<td>340</td>
</tr>
<tr>
<td>1,000</td>
<td>320</td>
<td>380</td>
</tr>
</tbody>
</table>

For reference of a lighting design as in the previous paper, the task illuminance v.s. recommendable wall illuminance relationships were obtained from Fig. 9, and are shown in Table 4. For reference, energy-saving levels of the ambient illuminance, set in the experiment on the wall illuminance, also are shown. The "good" and "fair" levels mean the same as in the previous paper, and the data are shown in the following manner:

1. The "just preferable" level was decided and shown for each wall reflectance.

2. The wall illuminance obtained with actual luminaires are never uniform, and also changes with time. Further, the difference in preferred wall illuminances in relation to the respective wall reflectances is slight, which made us not to think strictly about it, and we conveniently used the geometrical mean of the levels for the two walls, which may give us the levels that is close to the "preferable", when the wall reflectances were between 0.3 and 0.8.

This level will hereafter be called a "preferable level".

3. For the convenience of design, "fair" levels of the wall illuminance are shown for arbitrary wall reflectances in the range shown above. The fair level here may not be the optimum in relation to an arbitrary reflectance, while being between the upper and the lower limits, the lower limit with a high-reflectance (0.8) wall (not to be higher than the upper limit) and the upper limit with a low-reflectance (0.3) wall (not to be lower than the lower limit) were employed.

In an actual design, the wall reflectance is mostly decided in the design of interiors, and the illuminance is generally decided in the design of lighting; e.g., use of the task illuminance of 750 lx, which is described in...
the "Guide on office lighting" \textsuperscript{26}, results in the energy-saving level of the ambient illuminance of 270lx, the preferable level of the wall illuminance of 380lx, and the fair level of 230-670 lx.

5. Study on Energy-saving

From above, when the task illuminance is 750lx or higher, the ambient illuminance, even the optimum level, is slightly lower than the task illuminance, and the energy-saving level is further lower. By employing task-ambient lighting, therefore, we may be able to save energy; a simple calculation will be made about it.

Desks are assumed to be placed in an working area at two levels of density: 5 and 10m\(^2\)/person, simply for examples of high density and low densities, respectively.

The task illuminance was 750 or 1000 lx, for a standard and a high level, respectively, the latter making use of the advantage of combining local lighting. Energy-saving levels are used as the ambient illuminances.

As a wattage consumed for general lighting, 0.032W/m\(^2\) /lx is used, which is the upper limit of the standard consumed wattage for a working space shown in the "Energy-saving Standard for Buildings "\textsuperscript{27}. The illuminance of task lighting is obtained by deducting the ambient illuminance from the design illuminance, and the consumed wattage is decided with the assumption of a task light corresponding to this illuminance.

A wattage consumed per worker is calculated for a general and a task-ambient lightings, and then the ratio is calculated, which are shown in Table 5. This table shows that the wattage saved is approximately 40-55%, depending on the design illuminance and the area occupied by the worker; that is, a considerable amount of energy would be saved.

6. Conclusion

Recently, the task-ambient lighting is being introduced for the improvement of visual task performance. This paper clarifies the following terms with respect to the relations of the ambient (adjacent desks) and the wall illuminance to the task illuminance:

1) Preferable ambient illuminance in relation to task illuminance
2) Preferable wall illuminance in relation to task illuminance

Further, the recommended ambient and the wall illuminances in relation to the task illuminance are evaluated, and the following values are clarified in this study.

(a) Optimum, energy-saving, and lower limit levels of the illuminance in relation to the task illuminance.
(b) The optimum wall illuminance as a function of the wall reflectance and the energy-saving ambient illuminance employed in relation to the task illuminance. For a convenience of design, the preferable and appropriate wall illuminance for arbitrary wall reflectance of 0.3-0.8, in relation to the task illuminance.

When the design task illuminance of 750 lx is adopted as an example according to the Lighting Standards \textsuperscript{30}, the energy-saving ambient task illuminance is 270 lx, the preferable wall illuminance is 380 lx, and the fair level of illuminance is 230-670 lx. The results obtained in this study can be widely used as a guide to design proper task-ambient lighting.

Further, the task-ambient lighting based on the results of this study, for the reason that the energy-saving ambient illuminance can be considerably lower than the task illuminance, will contribute to accomplish energy-saving. The ratio of consumed wattages per worker, i.e. the ratio of general lighting to task-ambient lighting, is estimated through a simple calculation; the result revealed that the power saving rate amounted to as much as 40-55%.

To conclude this paper, we would like to express our gratitude for the cooperation extended by the members of the Corporate Engineering Group, especially Mr.Hideki Beppu.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Design Illuminance (Ix) & 750 & 1000 \\
\hline
Recommended Illuminance (Ix) & Task & 470 & 680 \\
Ambient & 280 & 320 \\
\hline
Electric Power (Ix) & Task (W/Worker) & 30 & 45 \\
Ambient (W/m\(^2\)) & 24 & 32 \\
\hline
Area occupied by Worker (m\(^2\)/Worker) & 5 & 10 & 5 & 10 \\
\hline
General Lighting (W/Worker) & 120 & 240 & 160 & 320 \\
\hline
Task-ambient Lighting & Task & 30 & 30 & 45 & 45 \\
Ambient & 43.2 & 86.4 & 51.2 & 102 \\
Total & 73 & 116 & 96 & 147 \\
\hline
Energy-saving Rate (Task-ambient Lighting/General Lighting) & 0.61 & 0.48 & 0.60 & 0.46 \\
\hline
\end{tabular}
\caption{Energy-saving by Task-ambient Lighting (Energy-saving Level)}
\end{table}
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