Usefulness of OLED Task Lighting in Office Space

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OLED (Organic Light-Emitting Diode) lighting has the advantage of being not only environmentally-friendly, but also human-friendly, and therefore has the potential to bring about great innovation to the illumination of spaces in the future. On this occasion, we targeted office space and used our newly developed OLED task lighting to verify its usefulness for the environment and humans. As a result, it became clear that OLED task lighting is effective for establishing a comfortable, low illuminance space where it is possible to achieve both energy efficiency and comfort and that has the potential to bring about positive effects for intelligent productivity. This paper presents this usefulness of OLED task lighting in office space.

1. Introduction

One of the lighting methods used for office spaces is task ambient lighting that combines task lighting and ambient lighting. Task lighting locally illuminates a desk and its surroundings using a desktop desk light or another task light, while ambient lighting illuminates an entire office space using ceiling lights, etc., Task ambient lighting is considered to be effective as a lighting method that achieves both the reduction of lighting power consumption and a comfortable visual environment for workers, because it allows them to manually adjust the lighting environment around the desk. Although actual implementation examples have shown a sufficient reduction in power consumption, the realization of comfortable desk work has been hardly reported. Some cases where decreasing the ambient lighting illuminance causes uneven space illuminance distribution and results in decreased concentration and increased fatigue during work have been reported.[1] In addition, while an increasing amount of LED task lighting is being introduced quickly, discomfort caused by glare, flicker, etc., is still frequently pointed out. On the other hand, OLED lighting is attracting attention as lighting that can offer a comfortable visual environment.[2] In the past, the use of OLED lighting as task lighting was very limited because of its insufficient illuminance and other factors. In recent years, however, the need for OLED lighting has been increasing steadily as its basic performance has been enhanced.

We used OLED task lighting developed jointly by Mitsubishi Heavy Industries, Ltd. (MHI), Taisei Corporation and Okamura Corporation to verify the achievement of both energy efficiency and comfort in an office space, as well as the effect of OLED task lighting on intellectual productivity. This paper presents the results of the verification.

2. Development of OLED lighting panel

OLED lighting is next-generation lighting that casts uniform and soft light due to its surface light emission and has the innovative material properties of being very thin and lightweight. In January 2011, Lumiotec Inc. (a subsidiary of MHI) started, ahead of anyone else in the world, the mass production and delivery of the OLED lighting panels that are the light source of OLED lighting.

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Figure 1 shows the progress of OLED lighting panels manufactured by Lumiotec Inc. until today. Basic products are available in three kinds of colors: warm white, neutral white, and daylight white. Unlike LED, the designed efficiency of an OLED lighting panel can be further enhanced when the color temperature is lower. As a major feature, the OLED lighting panels of Lumiotec Inc. can simultaneously realize high luminance, long life, and high color rendering property by using multi-photon emission (hereinafter referred to as MPE) device technology.[3, 4] The MPE device has a structure where light-emitting units consisting of a series of organic layers including an organic light emitting layer are connected in series and laminated in multiple stages via charge generation layers. Based on this MPE device technology in combination with high-efficiency organic light-emitting material, high-efficiency light-extraction technology, etc., the luminous efficacy of warm white OLED lighting panels achieves 60 lm/W, equivalent to a commercially available LED bulb with a high color rendering property. In addition, the lifetime of OLED lighting panels is approaching that of LEDs, at 40,000 hours.[5]

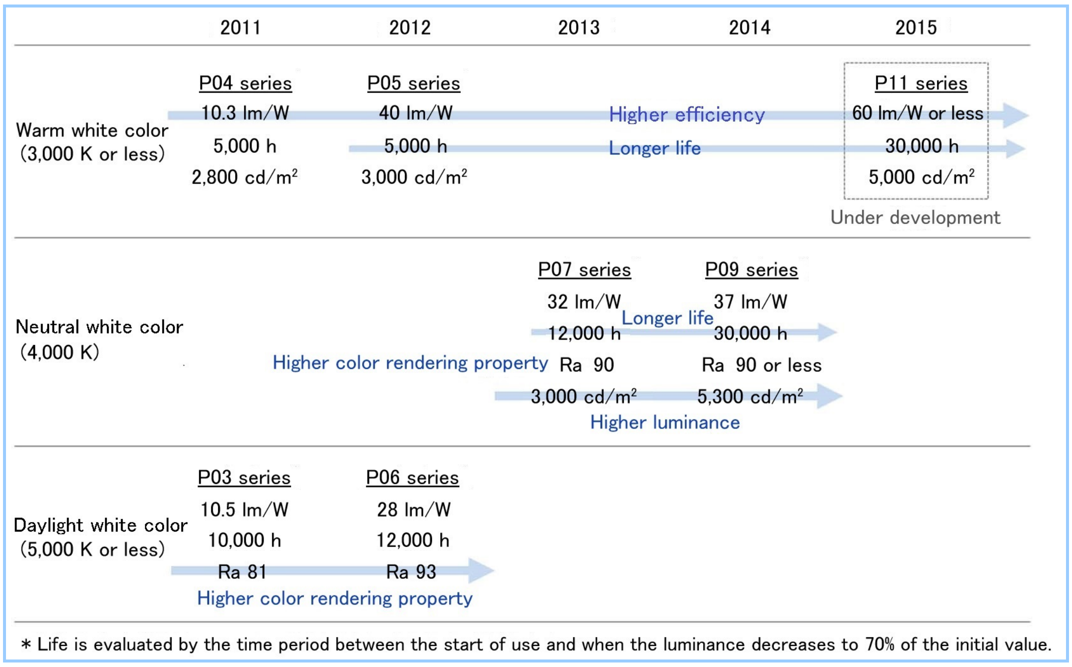

Figure 1 Progress of OLED lighting panels manufactured by Lumiotec Inc.

3. Development of OLED task lighting

The greatest feature of OLED lighting is the softness of its light, which does not make a user feel glare even when the lighting is placed close to him or her. In addition, the user can feel higher illuminance than the actual illuminance due to the wide spread of the light toward him or her. Furthermore, OLED lighting does not include ultraviolet rays and therefore is friendly to the human body. It can be said that OLED lighting is indispensable for the realization of comfortable desk work. In addition, OLED lighting has the potential to enhance energy efficiency. It is important for the reduction of lighting power consumption to focus on the overall efficiency of the luminaire, not the efficiency of a single light source. It is said that the efficiency of a single LED light source decreases by approximately 70% because of the effect from heat generation and through the diffusing process of the light. OLED lights sources are almost free from such efficiency loss because they do not generate heat and can emit diffused light directly.[6] For both LED and OLED, additional efficiency loss of approximately 10% occurs in the driving circuit. However, OLED can attain a higher final efficiency of the luminaire despite this loss, which is a significant advantage of OLED lighting.

On this occasion, MHI, Taisei Corporation and Okamura Corporation jointly developed OLED task lighting with the potential for both energy efficiency and comfort. **Figure 2** shows an external view. OLED task lighting employs the neutral white (4,000 K) P07/P09 series panel. Task lighting with the high-luminance P09 series panel provides desk top surface illuminance of up to approximately 500 lx and satisfies the AA-type illuminance standards specified in "JIS C 8112 Table study lamps with LED light source or fluorescent lamp." This task lighting is designed in a shape making the most of the great features of OLED lighting, its thinness. Desk mount types and partition mount types are available. In Taisei Corporation's ZEB (Zero Energy Building) demonstration building, approximately 40 of these task lighting units are used. This is one of the world's largest implementations of OLED task lighting in an office space.

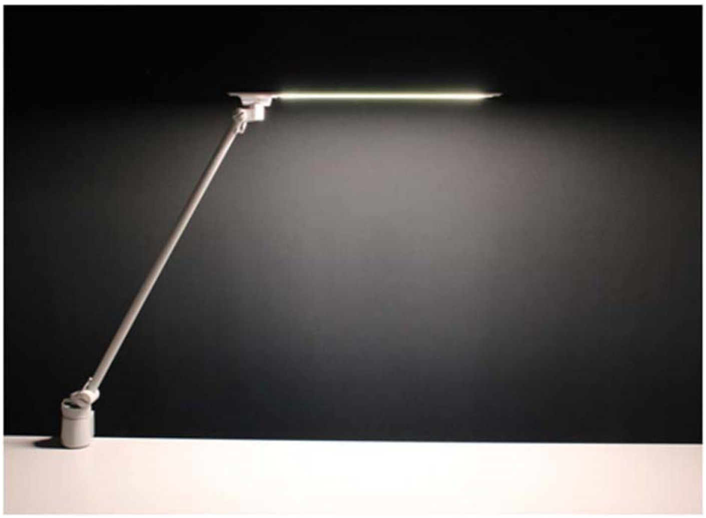

Figure 2 External view of OLED task lighting

4. Demonstrative verification of OLED task lighting

4.1 Evaluation of lighting environment and energy in office space

(1) Experimental room

The experiment was implemented in part of an office space[7] in Taisei Corporation's ZEB demonstration building. **Figure 3** shows a plan view of the experimental room and the locations of the subjects. All the windows in the room were shielded by blinds in order to avoid the effects of light from the outside. Dimming type LED luminaires (custom ordered, 4,000 K) were used as ambient lighting. OLED task lighting (with Lumiotec P07/P09 series panels, 4,000 K) or LED task lighting (commercially available, 4,000 K) was used as the task lighting. The task lighting was mounted at a position where an illuminance of up to 500 lx could be attained at the desk top surface illuminance setting point 230 mm behind the front of a desk. A partition was installed between the desks of the subjects in order to avoid the effects of task lighting on adjacent subjects. The computers and keyboards on the desks were the same for all subjects and the luminance of the computer screen was set to approximately 230 cd/m^2.

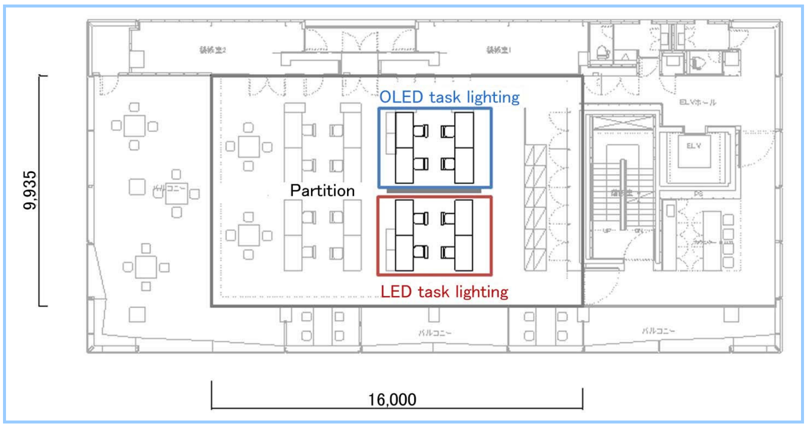

Figure 3 Experimental room in ZEB demonstration building

(2) Experimental conditions and procedures

Table 1 shows the experimental conditions of the evaluation of the lighting environment and energy. The illuminance of the ambient lighting was set to 700 lx for general lighting and 200 lx or 300 lx for task ambient lighting. The illuminance of the task lighting for task ambient lighting was either of the two rough classifications: illuminance that was fixed at a certain illuminance in the range of 200 to 500 lx (the fixed condition) and illuminance that was arbitrarily adjustable during work (the dimming condition). As the experimental procedures shown in **Figure 4**, the evaluation of the impression of the brightness, workability, and lighting environment was performed using questionnaires after a certain period of computer work (typing of English texts) or work on paper (kanji discriminating test) for the fixed condition or after finishing all of the computer work or work on paper (the same as that of the fixed condition) for the dimming condition. The experiments were implemented separately on August 22 and 26, 2014 and November 21, 2014. On each day, the experiment was started after sunset in order to avoid the effects of daylight. For all experiments, eight subjects (men and women with the average age of 23.6 years) were employed. In August, experiments of two fixed conditions and one dimming condition, or three conditions in total were implemented. In November, experiments of five fixed conditions and two dimming conditions, or seven conditions in total were implemented.

Table 1 Experimental conditions of evaluation of lighting environment and energy

Condition	Implementation timing	Illuminance			T/A rate
		Ambient (A)	Task (T)	Overall	
Fixed condition	November	300 lx	200 lx	500 lx	0.67
	November	200 lx	300 lx	500 lx	1.50
	August and November	700 lx	0 lx	700 lx	0.00
	November	300 lx	400 lx	700 lx	1.33
	August and November	200 lx	500 lx	700 lx	2.50
Dimming condition	November	200 lx	Arbitrarily adjustable		
	August and November	300 lx	Arbitrarily adjustable		
	August	700 lx	Arbitrarily adjustable		

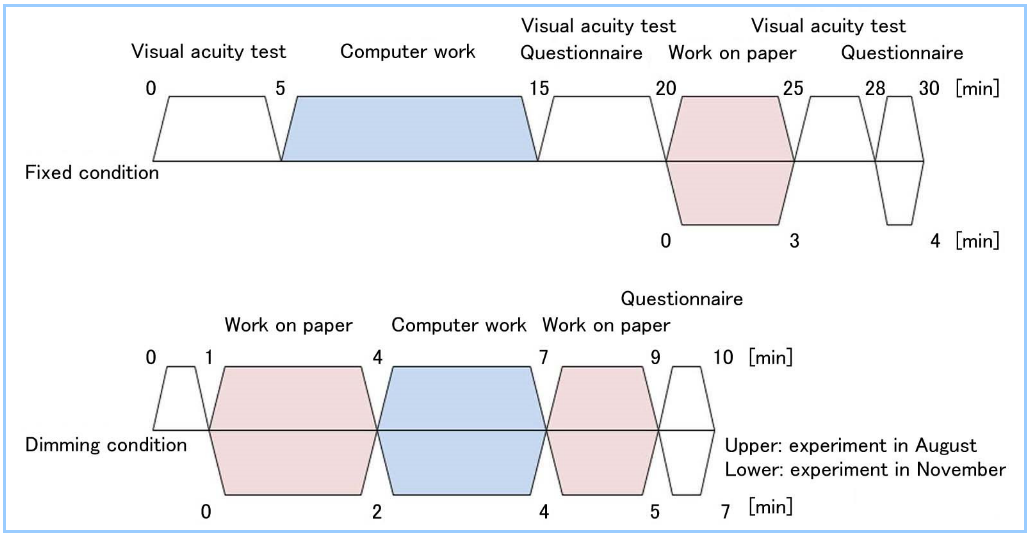

Figure 4 Experimental procedures of evaluation of lighting environment and energy

(3) Experimental results

Figure 5 shows the evaluation results of comfort around the desk top surface under the fixed condition and the dimming condition. These are the evaluation results for the case where the ambient illuminance was fixed at 200 lx and the task illuminance was changed. The condition where the task illuminance was fixed at 500 lx satisfied the recommended illuminance in “JIS Z 9110 General rules of recommended lighting levels.” Normally the task ambient lighting in an office space is set to illuminance like this in many cases. However, the results show, for all task lighting used, a tendency where the comfort is enhanced when the task illuminance was further lowered. In the case of OLED task lighting, this tendency seems to be particularly strong under the dimming condition. This implies that there is potential to attain sufficient comfort even when the task illuminance is set lower.

Therefore, additional evaluation of the relationship between the desk top surface illuminance and the comfort in changing the ambient illuminance under the dimming condition was implemented in this experiment. **Figure 6** shows the results. When the ambient illuminance was 300 lx, a tendency where the use of LED task lighting was avoided is shown, and it seems that the exposure of subjects to glare could be avoided as a result and therefore the comfort of the LED task lighting was evaluated highly. When the ambient illuminance was 200 lx, on the other hand, OLED task lighting produced a more comfortable work environment despite the task illuminance being set low.

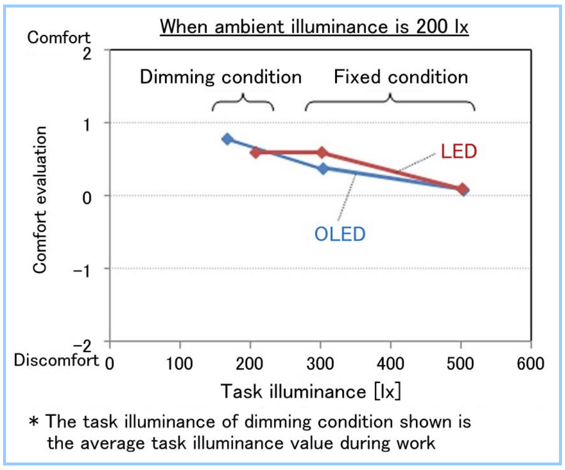

Figure 5 Evaluation results of comfort around desk top surface under fixed condition and dimming condition

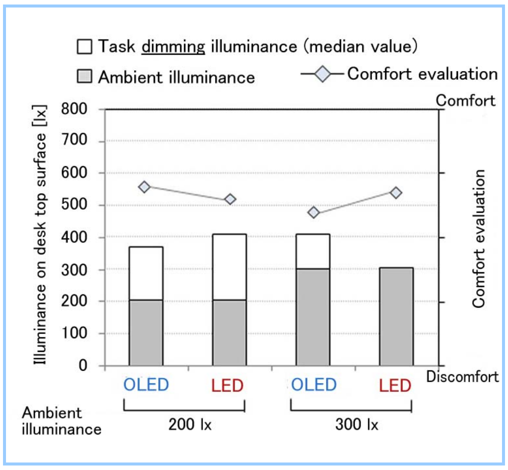

Figure 6 Evaluation results of illuminance on desk top surface and comfort under dimming condition

Figure 7 shows the evaluation results of luminous flux per unit area consumed in the experimental space (hereinafter referred to as consumed luminous flux), as well as the comfort around the desk top surface under the dimming condition. In this experiment, because the relationship between the light quantity in the entire space and the workers' evaluation was focused on, the energy consumption is indicated as consumed luminous flux in the entire space, not as the illuminance of the same physical unit. When LED task lighting was used, a tendency where a condition with a smaller amount of consumed luminous flux led to more deterioration of comfort was shown. When OLED task lighting was used, however, the potential to maintain comfort even in a low consumed luminous flux environment was implied.

Figure 8 shows the evaluation results of individual factors of comfort under the dimming condition. This implies the high possibility that OLED task lighting's light quality such as warmness and softness, and the uniformity of light distribution on the desk top surface due to diffusion of light, or in the other words, uniform light spread around the hands, lead to the enhancement of comfort. In addition, the potential to establish not only the improvement of the lighting environment described above, a favorable work environment such as ease of viewing paper and ease of performing work was indicated.

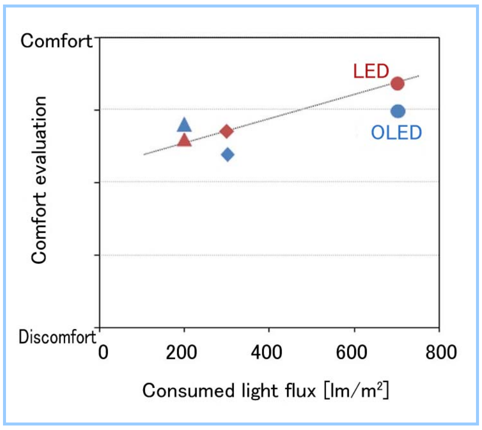

Figure 7 Evaluation results of consumed light flux and comfort around desk top surface under fixed condition

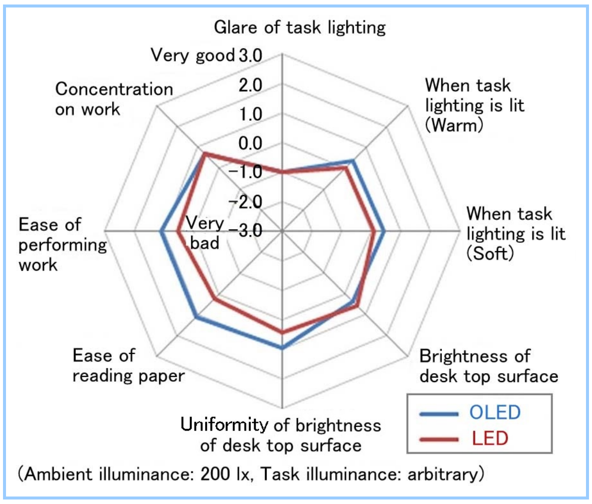

Figure 8 Evaluation results of individual factors of comfort under dimming condition

4.2 Evaluation of effects on intelligent productivity

(1) Experimental room

The experiment was implemented in a room at the Research Center for Human Environmental Adaptation of Kyushu University. This room is a closed space without windows, and therefore has a structure where the effects of light from the outside can be eliminated. Ceiling embedded type fluorescent lamp luminaires (commercially available, combination of 3,800 K and 4,200 K) were used as ambient lighting. OLED task lighting (with Lumiotec P07 series panels, 4,000 K) or LED task lighting (commercially available, 4,000 K) was used as the task lighting. The task lighting was mounted at a position where an illuminance of up to 450 lx could be attained at the desk top surface illuminance setting point 230 mm behind the front of a desk. Two desks were placed in the experimental room and the subjects were located back to back to prevent light emitted by the task lighting of the other subject from coming into sight.

(2) Experimental conditions and procedures

Table 2 shows the experimental conditions of the evaluation of intelligent productivity. The illuminance of the ambient lighting was set to 700 lx for general lighting (the use of ambient lighting only) and 250 lx for task ambient lighting (the combined use of task lighting and ambient lighting). The illuminance of the task lighting for task ambient lighting was fixed at 450 lx (the fixed condition) and the total illuminance that is a combination of the task lighting and the ambient lighting was set to 700 lx. As the experimental procedures shown in **Figure 9**, the task set of the experiment basically consisted of work on paper (Kraepelin test for measuring calculation speed), computer work (mental rotation task (hereinafter referred to as MRT) for testing space perception) and the measurement of alpha waves. The subjects repeated the task set five times a day. Immediately after the start of and just before the end of each task set, and after each task on paper (Kraepelin test) and each computer task (MRT), the evaluation of the impression of the brightness, the workability, and the lighting environment was performed using questionnaires. The experiment was implemented from the end of August to November in 2014. Eight subjects (only men with the age of 22.6 +/- 1.4 years) were employed. In the selection of the subjects, whether the subject was active at night or in the morning was investigated by questionnaire and individuals who were determined to be active at night were not selected as subjects.

Table 2 Experimental conditions of evaluation of intelligent productivity

Condition	Implementation timing	Illuminance			T/A rate
		Ambient (A)	Task (T)	Overall	
Fixed condition	August to November	250 lx	450 lx	700 lx	1.80
	August to November	700 lx	0 lx	700 lx	0.00

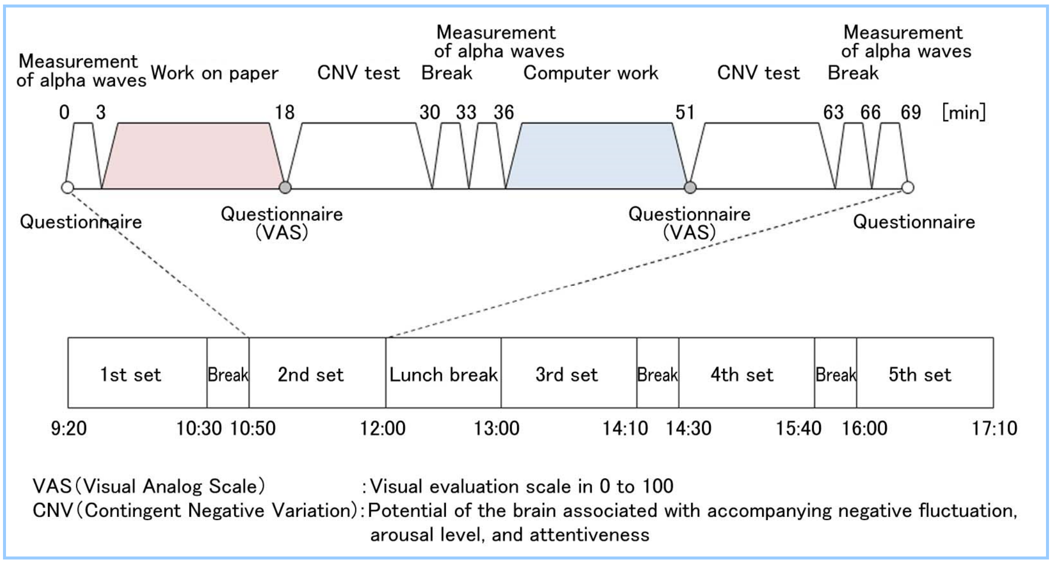

Figure 9 Experimental procedures of evaluation of intelligent productivity

(3) Experimental results

Figure 10 shows the results of the relationship between the arousal level and the intelligent productivity represented as the correlation between the alpha wave rate and the MRT correct answer rate. When the alpha wave rate is lower, the arousal level is considered to be higher. In this experiment, each of the eight subjects repeated the same task set five times under identical conditions, and therefore 40 data points per condition were obtained. Figure 10 shows the distribution of the 40 data points for each condition. Under the condition of general lighting where only ambient lighting was used, a significant negative correlation between the alpha wave rate and the MRT correct answer rate was obtained. Therefore, it is considered that the accuracy of answers is enhanced when the arousal level increases. In many cases, office spaces still use ambient lighting only. In such a lighting environment, there seems to be potential for enhanced intelligent productivity along with the enhancement of the arousal level. A similar correlation distribution occurred when OLED task lighting was used, but a significant difference that determined the same potential for enhanced intelligent productivity was not obtained. Regardless of the arousal level, however, an MRT correct answer rate of higher than approximately 90% was obtained. When LED task lighting was used, on the other hand, a completely different correlation distribution was shown and a significant positive correlation between the alpha wave rate and the MRT correct answer rate was obtained. It is considered that the accuracy of answers decreases when the arousal level increases. The evaluation results of LED task lighting have a significant variation and therefore it can be said that the suitability of its use varies from individual to individual.

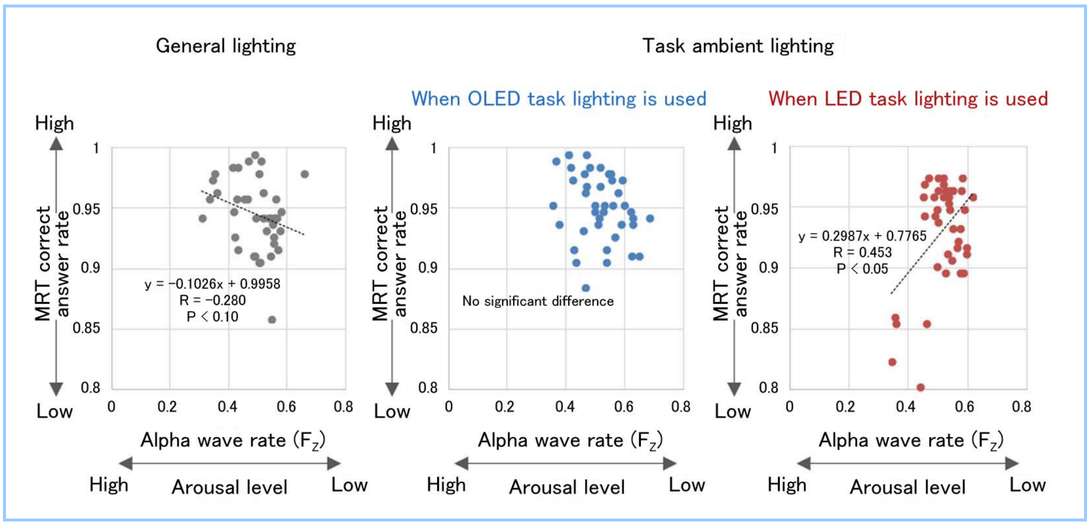

Figure 10 Alpha wave rate and MRT correct answer rate

Figure 11 shows the results of the relationship between the arousal level and the intelligent productivity represented as the correlation between the alpha wave rate and the MRT answer time. Figure 11 can be viewed similarly to Figure 10. Under the condition of general lighting where only ambient lighting was used, a significant positive correlation between the alpha wave rate and the MRT answer time was obtained. Therefore, it is considered that the speed of answering is enhanced when the arousal level increases. Based on the results shown in Figure 10 and Figure 11, it can be said that enhancement in the arousal level in an office space where only ambient lighting is used may lead to simultaneous improvement in the speed and accuracy of answers, resulting in a contribution to enhanced intelligent productivity. As the use of OLED task lighting also resulted in a similar correlation distribution where a significant positive correlation was obtained, it was implied that the use of OLED task lighting may result in enhanced intelligent productivity in an office space similarly to that of a conventional lighting environment where only ambient lighting was used. When LED task lighting was used, the resulting MRT answer time had a significant variation and difference that determined the possibility of effects for enhanced intelligent productivity were not obtained. Although some data points showed quicker answer times, this is considered to be no more than individual differences in the suitability of its use.

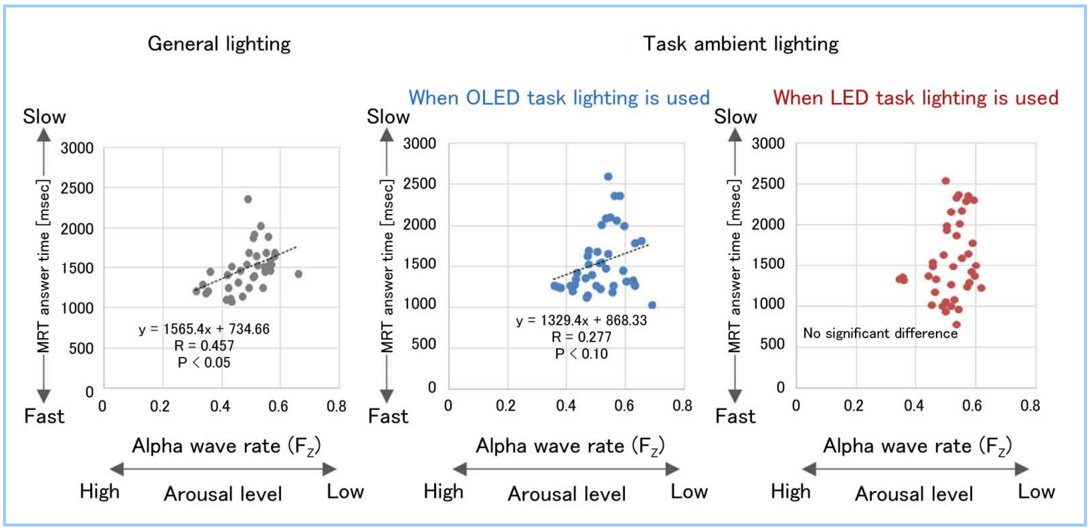

Figure 11 Alpha wave rate and MRT answer time

As shown in **Figure 12**, it is known that an inverted U model exists between the daily persistent (tonic) arousal level such as alpha waves and intelligent productivity.[8] The summit of the inverted U and its periphery where the intelligent productivity nearly reaches its peak is the optimal arousal level zone for the given task. The results shown in Figure 10 in which the use of LED task lighting is located on the right side of the summit of the inverted U indicates the possibility that an unnecessary nervous state occurred and resulted in a decrease of intelligent productivity. On the other hand, the results shown in Figure 11 in which the use of OLED task lighting is located near the left side of the summit of the inverted U indicates the possibility that intelligent productivity could be maintained with a moderate nervous state.

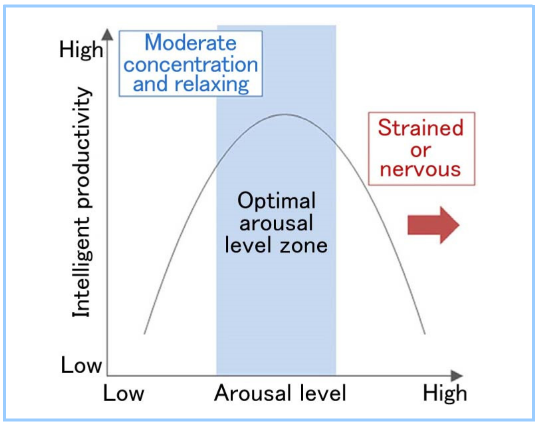

Figure 12 Inverted U model

5. Conclusion

In these experiments, the possibility of OLED task lighting to establish a comfortable desk work environment in an office space even when both the ambient illuminance and task illuminance were set lower was found. In addition, it is indicated that OLED task lighting also has a positive effect on intelligent productivity. **Figure 13** shows the presentation of this usefulness at Lighting Fair 2015 (promoted by Nikkei Inc.), one of the largest lighting exhibitions in Japan. In that exhibition, we demonstrated a comfortable work environment with accompanying prototype OLED task lighting with a sophisticated design for future commercialization. This was a good opportunity for wide recognition of the usefulness of OLED task lighting in an office space. As OLED lighting is undergoing rapid technological evolution and is expected to attain significant enhanced efficiency, expectations for its energy-saving effects have increased recently. Furthermore, it is believed that OLED lighting will attract an increasing amount of attention as next-generation lighting when the additional advantages of enhanced comfort and intelligent productivity reported in this paper are realized.

Figure 13 OLED task lighting presented at exhibition

Acknowledgements

We received guidance from Prof. Etsuko Mochizuki of the Chiba Institute of Technology and significant cooperation of then students Daisuke Oikawa, Gen Akishige, and Kenta Yoshiki for the experiment in section 4.1, and guidance from Prof. Akira Yasukouchi of Kyushu University and significant cooperation of then student Tomoaki Hirata for the experiment in section 4.2. In addition, we received considerable cooperation of Kazuyoshi Harimoto, Maki Ichihara, Hiroaki Takenobu, and Nobusato Kobayashi of Taisei Corporation and Yoshiyuki Fukatsu of Okamura Corporation in environmental arrangement and the summarization and analysis of the results of both experiments. We would like to express our appreciation.

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