博士論文（要約）

A Study on Brightness and Allowable Illuminance in Working Space

(執務空間における明るさと許容照度に関する研究)

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ABSTRACT

Global warming which the rise in the average temperature of Earth's atmosphere and oceans since the late 19th century is projected to continue. The greenhouse effect and the urban heat island is a metropolitan area that is significantly warmer than its surrounding rural areas due to human behaviors. In order to avoid these effects, global sustainability has aroused wide public concern. Sustainability is the potential for long-term maintenance of well being, which includes ecological, economic, political and cultural dimensions. The easy way for sustainability is power-saving in daily life.

During the Great East Japan Earthquake in 2011, the Fukushima first nuclear disaster was an energy accident at the Fukushima I Nuclear Power Plant, caused by the tsunami. Because of misgiving and politics factor, all nuclear power plants were already shut down for a periodic inspection now in Japan. However, all nuclear power plants switch-off occurred power shortage. Japan government decided to require that companies or institutions with above 500kW consumption companies or institutions should reduce 15% power from 1st July to 9th Sept. in 2011 benchmark for the same time in 2010. The other institutions or residence houses were asked reduce power consumption as more as possible. After 2011, up to now, shortage power still affects our daily life in summer.

According to the Illuminating Engineering Institute of Japan reported that lighting consumes approximately 16~19% of the electrical energy supplied to office buildings in Japan, there is a lot of space for power-saving in lighting environment. There are so many methods and researches about power-saving in lighting environment, but reducing lighting consumption and lighting management are two of convenient method for power-saving in normal office building, especially after the Great East Japan Earthquake.

Therefore, this study is starts from the influence of reducing lighting consumption and the influence of low task illuminance and ambient brightness. On the other hand, visual healthy is an important issue which should be concerned. VDT work has become the main working style in office, and the critical correlation of lighting environment is screen luminance. Because of above statement, this study is also discussed the influence of VDT screen luminance in low task illuminance and ambient lighting environment.

Chapter 1 presents the background related to power-saving in lighting environment. While the current lighting environment task horizontal illuminance is too high and the evaluation standard is incomplete. To respond the requirement of energy save, it is necessary to discuss again.

Chapter 2 is discusses the influence of visual fatigue and productivity in 200lux and 500lux task horizontal illuminance in VDT work. The result is mentioned that better working performance occurs in the lower illumination environment of 200lux in this study, which means that the contrast of luminance between the surrounding environment and the low-luminance monitors for VDT use are suggested to be smaller in order to minimize the sources of reflected luminance, thus influencing visual fatigue.

Chapter 3 deals with office lighting environment survey in Japan after the Great East Japan Earthquake and normal situation in Taiwan. The almost horizontal average central task plane illuminance in 13 offices is almost between 400lux and 600lux in Japanese office. The result shows, although the task plane illuminance reduces, or even far below 750lux in JIS standard, workers can still work and did not feel dissatisfied. On the other hand, Taiwanese and Japanese are almost the same for brightness feeling. Because Taiwanese can bearable low illuminance and have good productivity in working space, through the result of survey, Japanese maybe be the same feeling with Taiwanese.

Chapter 4 is continued the result from chapter 2. To the need of power-saving, the experiment of minimum allowable horizontal illuminance in reading and VDT work is proceeded. Natural light is used as lighting resource, and horizontal task illuminance decreases with sunset. The subjects are required to reading or done VDT work through task horizontal illuminance decayed until they cannot tolerate it. Finally, the average minimum allowable task horizontal illuminance is 67lux in reading work; the average minimum allowable task horizontal illuminance is 57lux in VDT work. These results are very impressive what subjects can tolerate such low task horizontal illuminance.

Chapter 5 works on the minimum allowable task horizontal illuminance and vertical illuminance in eyes' position get from chapter 3. There are 5 different vertical illuminance conditions of ambient lighting environment and the subjects should adjust the minimum allowable and appropriate task horizontal illuminance for each pattern. The result indicates when the ambient lighting gets brighter, subjects adjust the minimum allowable and appropriate task illuminance horizontal lower than when the ambient lighting gets darker.

Chapter 6 discusses the correlation of luminance uniformity of ambient space and the minimum allowable and appropriate task horizontal illuminance. Using spotlights to change uniformity of ambient space as independent variable, and asks the subjects to adjust the minimum allowable and appropriate task horizontal illuminance. The experiment in this chapter is founded when the average luminance keeps identical and uniformity is good, minimum allowable and appropriate task horizontal illuminance can be adjusted lower.

The study finds that the minimum allowable and appropriate task horizontal illuminance may affected by ambient lighting environment. The brightness and uniformity is adopted to be independent variables for experiment in this study and required subjects adjusted the minimum allowable and appropriate task horizontal illuminance. According to experiments and survey, the minimum allowable and appropriate task horizontal illuminance in this study present that subjects can tolerate lower task horizontal illuminance and work smoothly.

Viewed generally, this study is one of concept for power-saving in lighting environment. The main methodology in this study is adjustment. Although there are another methods and measures to solve shortage power, likes new lighting exploitation. The most important is that everyone should adjust our environment appropriately and get sustainability.

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CHAPTER 1 INTRODUCTION

CHAPTER 1 INTRODUCTION

1-1 Background and Motivation

In recent years, with rapid changes in global climate and environment deterioration, the concept of global sustainability has aroused wide public concern. Pursuing a healthy and comfortable living environment through advanced technologies has become the critical issue in the 21st century. In order to reduce CO_2 or the other greenhouse gas emission, the clean power is necessary. The nuclear power is the most important and the most efficient energy in commercial operation now.

During the Great East Japan Earthquake in 2011, the great tsunami severely damaged the nuclear power plant in Fukushima which caused three large explosions and radioactive leakage accidents. In order to avoid radioactive leakage, the Japan government decided to close every nuclear power plants. For the security problem of nuclear power, nuclear power plant will not restart in short time, thus, power shortage won't take short time, until the problem solved or new power type developed and operated commercially. The thermal power plants or natural gas power plants is used to replace nuclear power plants, but these power plants is unable to provide enough power and make power cost raised rapidly. At the same time, the thermal power plants and natural gas power plants may emission more CO_2 to make greenhouse effect severely. Shortage power change Japanese daily life egregiously, especially in Tokyo in which central government is located and contains important and prosperous business of the world. This abrupt impact will be a long time until new and clean power is found.

Meanwhile, as the era of the knowledge economy has arrived, pursuing healthy and comfortable indoor environments and ensuring good productivity have already become one of the most important issues in the21st century. Saving energy and getting a health lighting environment should be considered together.

1-2 Solutions and Shortages

1-2-1 Policies of Government and Civil

Because of shortage power, Japan government decided to require that above 500kW consumption companies or institutions should reduce 15% power during AM9:00~PM8:00 in 1st July to 9th Sept. in 2011 benchmark for the same time in 2010. The other offices or residence houses were asked reduce power consumption as more as possible.

According to questionnaires form office building managers in 16 administrative divisions in Japan after earthquake, there were 75% office buildings reducing power of lighting facility consumption and 69% reducing power of air conditioner facility consumption. In lighting environment, schedule management, using day-lighting and reducing lighting facility was the top three measures for power-saving (Mochizuki et al. 2013).

Lighting environment is one of main energy consumption in office building. Based on the survey about 35000m^2 type office building in Japan conducted by ECCJ (the Energy Conservation Center Japan), the result shows heat resource occupy most energy consumption in 31.1%, the secondary most is lighting in 21.3%, the detail percentage shows in Fig. 1-1[1].

[1]財団法人　省エネルギーセンター（オフィスビルの省エネルギー）

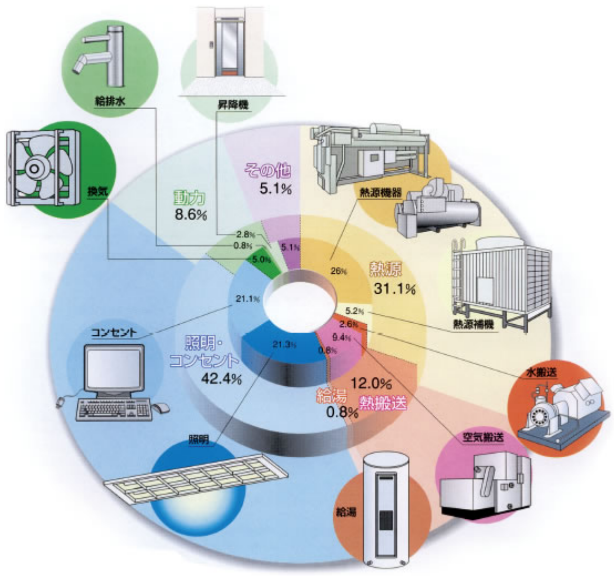

Fig. 1-1 Energy consumption in office building in Japan

If only analysis the electronic consumption situation in office, the consumption of lighting occupies 40% more than air-condition, the secondary is air-condition occupies 28%[2]. It can be seen if the power used for lighting can be saved essentially so that the whole office building energy consumption can be reduced rapidly, it will be a big help to regard overall building electronic saving. Therefore, in order to power-saving, there is a lot of space in lighting environment.

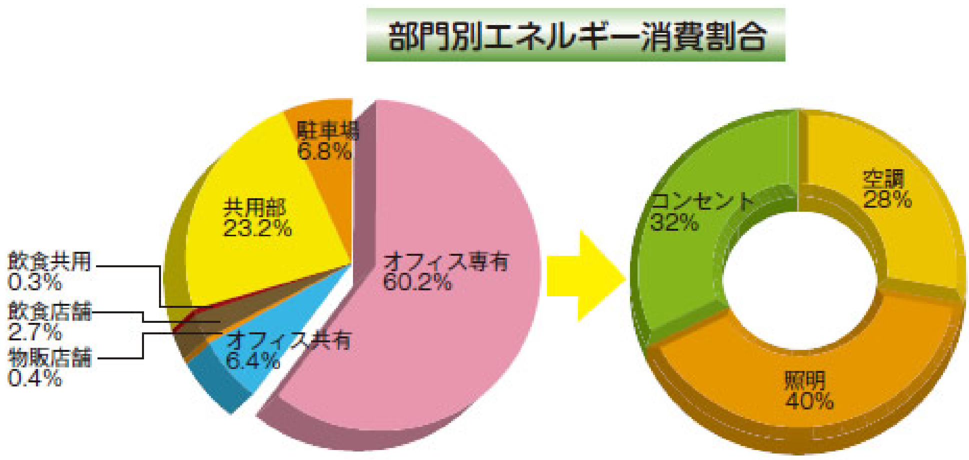

Fig. 1-2 Energy consumption of each section in office space

2財団法人　省エネルギーセンター（オフィスビルの省エネルギー）

1-2-2 Recommended Levels of Illuminance of JIS

Before earthquake, the JIS Z9110:2010 (照明基準総則), for the office carries on the normal working space, the Recommended Levels of Illuminance(推奨照度) was 750 lux. In order to achieve power-saving policies and reduce consumption of lighting, the recommended illuminance should be reconsidered. However, for energy-saving policy, 750 lux is too high for present building lighting. In order to reduce more power, JIS was corrected from 500 lux to 1000 lux, as the Fig. 1-3 shows[3].

主な作業領域・活動領域の照度範囲

JIS Z9110:2011

単位:lx

領域、作業又は活動の種類	推奨照度	照度範囲
設計、製図	750	1000～500
キーボード操作、計算	500	750～300
事務室	750	1000～500
電子計算機室	500	750～300
集中監視室、制御室	500	750～300
受付	300	500～200
会議室、集会室	500	750～300
宿直室	300	500～200
食堂	300	500～200
書庫	200	300～150
倉庫	100	150～ 75
更衣室	200	300～150
便所、洗面所	200	300～150
電気室、機械室、電気・機械室などの配電盤及び計器盤	200	300～150
階段	150	200～100
廊下、エレベータ	100	150～ 75
玄関ホール(昼間)	750	1000～500
玄関ホール(夜間)、玄関(車寄せ)	100	150～ 75

Fig. 1-3 JIS Z9110 for illuminance in office space

3 JIS Z9110

1-2-3 Shortage of Lighting Standard

Even the Recommended Levels of Illuminance is reconsidered to be a range, but the upper limit is recommended to 1000 lux in normal space is very few in the world. Regard of lower limit illuminance, 500 lux sometimes is the other countries' upper limit standard. Bright lighting can let users more awakening and concentrating, over bright lighting will make users feel uncomfortable glare and other negative effects. Face on work efficiency and comfortable, whether over bright lighting can create better use environment or not should be contemplated. On the other hand, several problem emerged due to illuminance standard used, for example, the inappropriate design caused high illuminance or low brightness, it does not only waste energy but also cannot improve environmental quality. The most important is this range is not useful for power-saving.

There is no directly relationship between brightness and vertical illuminance, if evaluate space brightness only by horizontal illuminance, it is difficult to show the effects of wall and roof. Due to the electronic save policy, it is hard to achieve the purpose if we follow the illuminance standard, thus, it is need to discuss whether the horizontal illuminance should keep such high. The standard formulated by fluorescent lump or other old lump, with the development of science and technology, many new lighting resource and lighting examine equipment have been developed and improved, for example, LED has low heat, long life, high impact resistance, high luminance and other characteristics, besides these, the light color from LED is easy to control, some light color which traditional light resource cannot make can be made through light mix, it can benefit to save energy and make lighting freely, light equipment can be designed for different space in future to make lighting space pluralistic. Therefore, the research related with LED and brightness has the research value.

On the other hand, with the development of internet, in present office, VDT (Visual Display Terminal) work has been used widely, even many work type should be carried on VDT long time. Lighting environment affects VDT work, over bright lighting or high luminance display may make users' eyes fatigue or even make pathological change, or cause contrast glare, reflect glare and other problems, users' sight maybe damaged and unrecoverable. Some present researches suggest appropriate VDT display luminance, but discuss less on the relationship between brightness and luminance of VDT display.

Consequently, for the sight protection and comfortable of users, satisfied visual environment has a significant influence. How to make lighting comfortable, bright and work efficiently while even let them achieved energy save is the most important subject in this study. The first stage of this study is investigation about how actual office deals under the electronic saving condition and analysis the psychological evaluation in lighting environment. Continually, under the condition of not affect the normal work and vision, when use laboratory method to explore ambient-task lighting way for reading and general office VDT work required minimum allowable horizontal illuminance and appropriate horizontal illuminance to review present lighting standard. Finally, set the office lighting brightness and uniformity as independent variables, explore correlation of task horizontal minimum and appropriate illuminance, proposes the recommend task horizontal illuminance which is needed in office work under electronic save condition. Besides, the correlation of appropriate luminance of VDT screen and brightness in lighting space also explored in this study.

1-3 Literature Review and Problems

The follows are discussed the reference of energy-saving for lighting office lighting environment, brightness and influence of VDT work.

1-3-1 Electronic Consumption of Lighting Environment

The majority admitted 80% or more of their workers engage in VDT works. Four hours of VDT work per day was widely used as a criterion for the eligibility to the VDT health examination. Some specific measurement was performed at health examination among 54.8% of the companies. According to reported that around 25% of the total electricity used in the commercial sector is consumed by lighting systems (Bleeker 1993). Consumption ranges greatly from country to country and is due to not only climatic and design conditions, but also due to cultural habits. In China, the lighting end-use in commercial buildings is 15% (Min et al. 1995); in the USA, 39%[4]; in the Netherlands, 55% (Sliepenbeek et al. 1995); and in the UK it ranges from 30% to 60%[5]. In Brazil, the lighting end-use in commercial buildings with air-conditioning is about 24%; but in commercial buildings without air-conditioning, the lighting end-use can reach 70% of the energy consumption of the whole building (Procel et al. 1993). Lighting consumes approximately 25% of the electrical energy supplied to office buildings in Japan[6], and 24.8% in Taiwan (S.C. Hu et al. 2004). According to “It is generally assumed that about 30% of the energy consumption of office buildings come from artificial lighting”, even if those estimations are difficult to verify and might not be completely consistent, these figures lead to one important finding: around the world, the scientific community seems to agree that discussing the artificial lighting loads of buildings is extremely important and that energy-efficient lighting solutions have to be adopted (Franzetti et al. 2004).

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4 EIA, Energy end-use intensities in commercial buildings, Energy Information Administration, US Department of Energy, Washington, September 1994.

5 BS 8206-2, Lighting for buildings-Part 2: Code of practice for daylighting, British Standard, 1992.

6 Recommendations of lighting apparatus renewal, Japan lighting manufacturers association, p. 3, 2005

1-3-2 Problems in Present Lighting Standard

In order to guarantee an appropriate visual comfort in office rooms, the horizontal illuminance (especially on the working plan) must be sufficiently. In JIS(2011), the required horizontal illuminance in 500~1000 lux on the working plan in normal offices. But according to CIE, it is suggested to be 200 lux to 500 lux in offices, and CNS [7] (Chinese National Standards, Taiwan) is 500 lux in Taiwan's offices. Therefore, Japan seems to have higher horizontal illuminance level in office. On the other hand, did a survey and questionnaire to lighting designers which showed horizontal illuminance is not the same with brightness (Kimura et al. 2004). Illuminance can ensure the task light for work but cannot describe the users' brightness effect, therefore, nowadays pluralistic lighting cannot satisfied if only use illuminance as evaluate factor.

Table 1-1 Office illuminance standard in the world

Office Illuminance Standard	Illuminance (lux)
JIS Z9110:2011 (Japan)	500lux~1000lux
CNS 12112 (Taiwan)	300lux ~750lux
GB 50034-2004 (China)	300lux~500lux
BS EN 12464-1:2002 (Britain)	500lux
DIN 5035 Part2 (Germany)	200lux ~500lux
CHNII23-05-95 (Russia)	300lux
Finland	150lux~300lux

[7] CNS 12112

1-3-3 LED for Power-saving

A light-emitting diode (LED) is a semiconductor light source[8]. Efficient lighting is needed for sustainable architecture. In 2009, a typical 13-watt LED lamp emitted 450 to 650 lumens[9], which is equivalent to a standard 40-watt incandescent bulb. In 2011, LEDs have become more efficient, so that a 6-watt LED can easily achieve the same results. A standard 40-watt incandescent bulb has an expected lifespan of 1,000 hours, whereas an LED can continue to operate with reduced efficiency for more than 50,000 hours, 50 times longer than the incandescent bulb. In the US, one kilowatt-hour of electricity will cause 1.34 pounds (610g) of CO_2 emission[10]. Assuming the average light bulb is on for 10 hours a day, one 40-watt incandescent bulb will cause 196 pounds (89kg) of CO_2 emission per year. The 6-watt LED equivalent will only cause 30 pounds (14kg) of CO_2 over the same time span. A building's carbon footprint from lighting can be reduced by 85% by exchanging all incandescent bulbs for new LEDs.

1-3-4 Brightness

Presently, many researchers used luminance to evaluate brightness. Stevents who is the first researcher created that luminance and brightness had power correlation (Stevens 1961). $Feu=1.5\times lg^{0.7}$ (lg = geometric mean of luminance)is one of formula to described brightness of space (IWAI 2008). Ko et al.in 2013 created another brightness formula: Brightness = [21.5-8.4*SD of log (luminance)] × average luminance. It is combined the luminance of uniformity and magnitude of luminance in space to described brightness. The former researches shows luminance as evaluate factor is closer the brightness feeling of users, while the brightness is affected by lighting energy and distribution. When the light distribute is not uniformity, the uses' brightness evaluation reduces, thus magnitude of luminance and uniformity are the main factors which determine users' brightness evaluation.

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8 "LED". The American heritage science dictionary. Houghton Mifflin Company. 2005. ledand LED

9 DOE Solid-State Lighting CALiPER Program Summary of Results: Round 7 of Product Testing (PDF). U.S. Department of Energy. February 2009.

10 US DOE EIA: Electricity Emission Factors. Eia.doe.gov. Retrieved on March 16, 2012.

1-3-5 Problems in Task-ambient

Task-ambient lighting systems proposed in the 1970s (P.L. Shellko et al. 1976, N. Florence et al. 1978, C.L. Amick et al. 1978). The concept behind task-ambient lighting is that as long as enough light is provided to fulfill the visual requirements of the work, the ambient light level in the office can be reduced significantly, thereby saving energy. However, task-ambient lighting was never widely adopted, for two reasons, one technical, and the other perceptual. The technical reason was the difficulty of providing electrical power to every desk. This is no longer a problem, the widespread use of personal computers having necessitated a solution. The perceptual reason was the concern that many occupants would object to the gloomy appearance of the office. Mochizuki, Ujigawa et al. in 1996 shows compare with the whole space illuminance keep 750lux recommended in JIS, if the ambient illuminance slightly lower than task illuminance, users feel satisfied easier. The research of Slater, A.l.g. Perry, A.J. and Varter, D.J in 1993 points the ratio of own task illuminance over neighboring task illuminance is more than 0.7, the users will feel more comfortable. The research of Inanuma et al. explained in office with partition, when Task illuminance/Ambient illuminance=0.7, the users feel better (Inanum 2002). The researches above pointed out that when ambient illuminance is lower than task illuminance, the users have a better feeling, and benefits for energy save as while. However, the researches so far still used illuminance T/A, for brightness not involve with the research relate with task-ambient.

Table 1-2 Task-ambient[11]

Task Plane Illuminance (lux)	Ambient Illuminance (lux)
≧750	500
500	300
300	200
≦200	The same with task plane

[11] ISO 8995-2002:CIES008

1-3-6 Influence of VDT Work

With the progress in Information and Communication Technology, information equipments are now used widely, such as PC, smart phone, tablet PC. Based on the survey investigated by Ministry of Internal Affairs and Communications in 2009, at the end of 2008, PC hold rate was 85.9%, internet use rate was 91.9%[12]. The survey investigated by Ministry of Labor shows long-time VDT work can cause fatigue, especially visual fatigue[13].

Table 1-3 VDT subjective symptoms of fatigue from employee

VDT TIME	Ratio of employee (%)	Subjective Symptoms of Fatigue from Employee (%)					
		Headache	Visual Fatigue	Wrist and Fingers	Back	Waist	Foot
~1 hour	39.5	12.8	90.5	8.4	51.3	15.7	1.6
1~2 hours	31.6	15.6	90.1	11.9	66.2	18.1	2.1
2~4 hours	19.5	20.9	92.7	19.2	70.6	23	4.3
4 hours~	8.9	30.2	91.9	27.2	76.9	34.7	10.5

Besides Japan, an investigation conducted by The Hong Kong Polytechnic University (2003) surveyed 915 office workers in Hong Kong and discovered that the work performance of 80% of the interviewees with improper lighting in the working environment was affected, and 48% of them further expressed that they felt eye discomfort as a result of the poor lighting. Continuous computer operation and visual load caused operators visual fatigue, such as blurred vision, double images, teary eyes and nearsightedness, as well as eye pain resulting from over-high intraocular pressure. Furthermore, in terms of working performance, phenomena such as scattered attention, increased error ratios and reduced working speed resulted in lower productivity. The reason was found to be visual fatigue caused by the long-term use of eyes in an improper lighting environment[14].

The above may know operate on VDT for a long time will be a very tremendous influence to eyes. However, many researches so far concentrated on the fatigue from

[12]總務省 2009：平成 20 年通信利用動向調査報告書（世帯編)6/24

[13]労働省：技術革新と労働に関する実態調査、平成 10 年

[14]The Hong Kong Polytechnic University, Centre for Social Policy Studies, Visual health and working performance for office illumination, Philips Lighting, 2003

font size, distance between display and eyes, angle of display and etc, lack of discuss on the relationship between lighting space and display luminance. Lin and Huang in 2006 said that character identification under relatively high ambient illumination might be more sensitively affected by background luminance of the screen rather than contrast ratio or contrast sensitivity. Further, considering the screen luminance combination and contrast ratio simultaneously may be more appropriate than considering the contrast ratio alone. Helander and Rupp mentioned that the specifications for an ambient illuminance standard would become even more confusing in the future as LCDs and other flat panel displays (FPDs) become more popular (Helander 1984). Therefore, it is necessary to explore the relationship between lighting brightness and display luminance.

1-3-7 Conclusions of Reference

This study beaded on the consequences of the resource above, under the electronic save condition with ambient-task lighting system, discusses the minimum and appropriate illuminance in office lighting and corresponding appropriate VDT display luminance. Table 1-4 is the questions proposed by this study directs above resources.

Table 1-4 Issues of reference

Factors	Issues
Energy	■ Lighting environment consume very big part energy in office building, it is worth to develop some measures for saving energy.
Illuminance	■ Enough horizontal illuminance can ensure work smoothly on task plane, but it can not describe brightness in ambient space. ■ JIS et al. standards are too high for task horizontal illuminance in saving energy condition.
Brightness	■ Magnitude of luminance and uniformity in the ambient space are important factors for brightness.
Task-ambient	■ Task-ambient system in the office can be reduced energy significantly. But horizontal illuminance is not a good estimate factor for ambient space.
VDT	■ VDT screen luminance is affected by Ambient lighting space significantly.

1-4 Position of this thesis

Sustainability has become more and more popular issue in the world. In order to reduce CO_2 and greenhouse gas emission, power-saving and new clean power exploitation is necessary. In the office building, lighting environment energy consumption is 40%. If lighting environment consumption can be reduced, it may help to lessen greenhouse gas emission and get sustainability. Reducing lighting consumption, renew high efficiency lighting facilities, lighting management and adopting day-lighting are employed for power-saving now. Because of power shortage after earthquake, the offices have no enough time and fund to handle it, for example, renew all high efficiency lighting facilities immediately. On the other hand, adopting day-lighting is restricted by architecture design and area of office, if the office is deep and long, day-lighting will be unable to adopt. Reducing lighting consumption and lighting management are two of convenient method for power-saving. This study is discussed the influence of reducing lighting consumption and correlation between task illuminance and ambient brightness. All lightings which is used in this study are LED lightings.

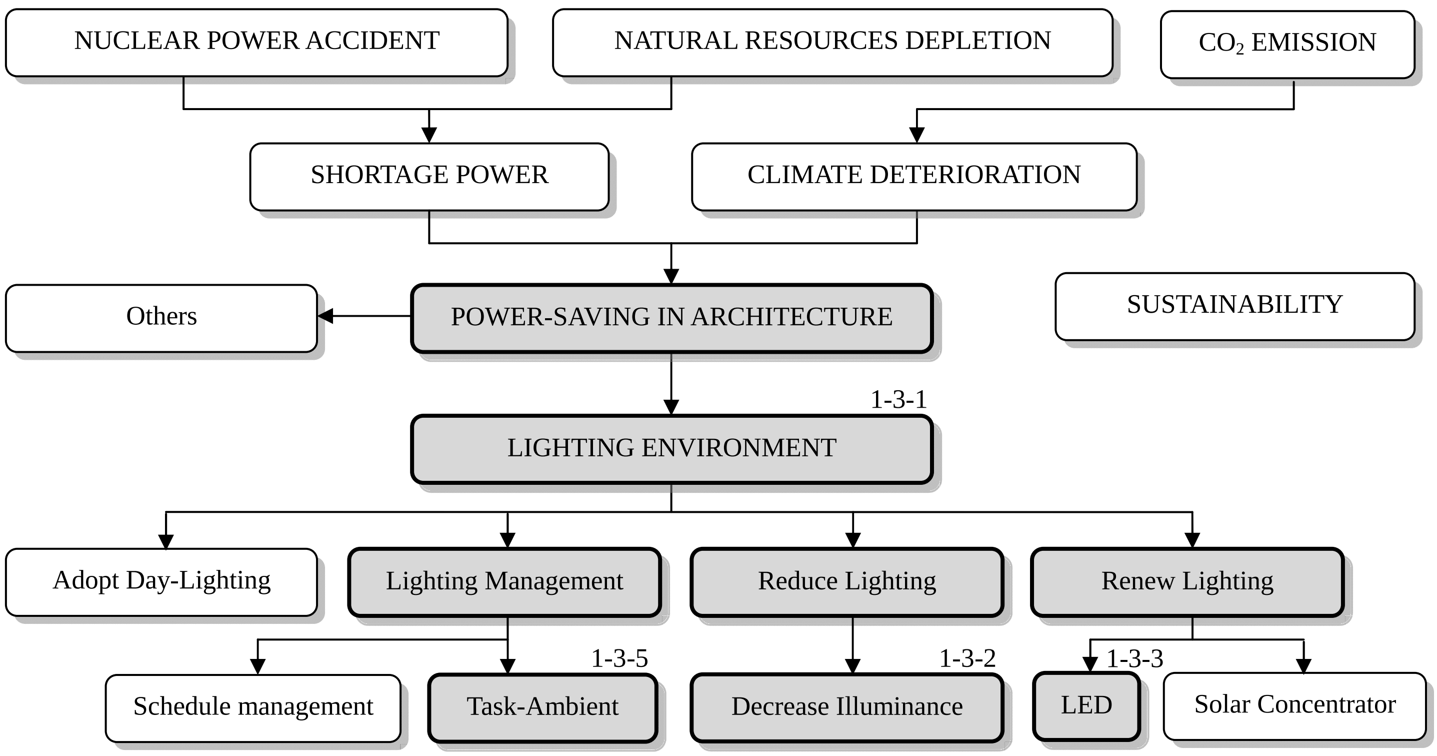

Fig. 1-4 Position of research in the power-saving field in lighting environment

1-5 Purposes

This study starts from the power save caused by East Japan earthquake, from the manager's perspective, around task-ambient lighting way in office, under the prerequisite for comfortable and brightness of visual space, furthermore, find the appropriate brightness of indoor lighting. Besides, the relationship of appropriate luminance of display in VDT job and lighting space is also explored in this study. As shown in the following, the three points are specific objectives of this study:

1. **How are influences of lower task illuminance for VDT work for Taiwanese.**

In order to power saving, reducing lighting facilities is the simplest method, so the task illuminance will be decreased at the same time. In principle, the standard task illuminance may ensure employees' visual healthy and keep a good productivity, but how is employees' visual fatigue and productivity under lower task illuminance is worth to research. In this study, visual fatigue and productivity are discussed under three kind of lighting facilities in VDT work for Taiwanese.

2. **How is the employee' psychology evaluation and situation of lighting environment office in Taiwan and in Japan after great earthquake**.

Because the office building should make the energy consumption meet the government requirements compares the preceding year to reduce 15%, it is necessary to explore the whole building energy use, lighting use is second highest lower than air-condition, accounts for 20%, even for 40% in office. After the great earthquake, the offices in Japan should saving energy, therefore, how is the situation of task horizontal illuminance, vertical illuminance and luminance in office is the start of this study explores the office lighting energy save in Japan. At the same time, according to experiment result of influence in lower task illuminance for Taiwanese, trying to find out some differences from Japanese and Taiwanese. If there are not too many differences between Japanese and Taiwanese psychology and brightness, the experiment result from Taiwanese can be referred to Japanese.

3. **Influence on minimum, appropriate task horizontal illuminance in different brightness and uniformity of lighting environment**

To energy save, task-ambient ensures the necessary lighting, table lump makes up the need of task surface illuminance. When the lighting changes, due to the surround environment brightness changes, it may affect the need of workers for the task surface illuminance. This study based on the brightness formula, uses vertical illuminance instead of average luminance in space and task horizontal illuminance instead of brightness to discuss when the space average luminance and luminance uniformity are different, makes the subjects adjust the light to find the minimum allowable horizontal illuminance and appropriate horizontal illuminance on task plane and space lighting effect.

4. **Influence on appropriate VDT display in different lighting environment**

With the development of internet, mobile phone, tablet and desktop display have been integrated with everyday life closely, and present display luminance lighting standard does not revise contrary to ambient lighting changes. Inappropriate display luminance causes contrast glare resulting visual fatigue so that make work efficiency low. This study sets average luminance changes of brightness and uniformity of luminance as control variables, ask subjects to adjust the luminance of display, discuss the relationship between appropriate VDT screen luminance and ambient luminance.

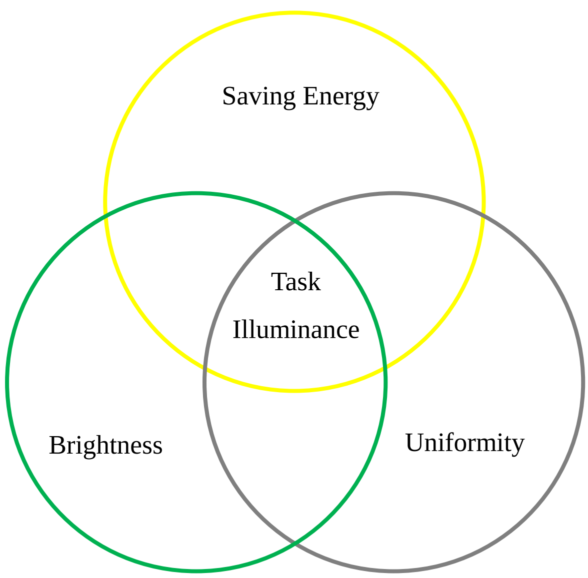

Fig.1-5 Research composing

1-6 Construction

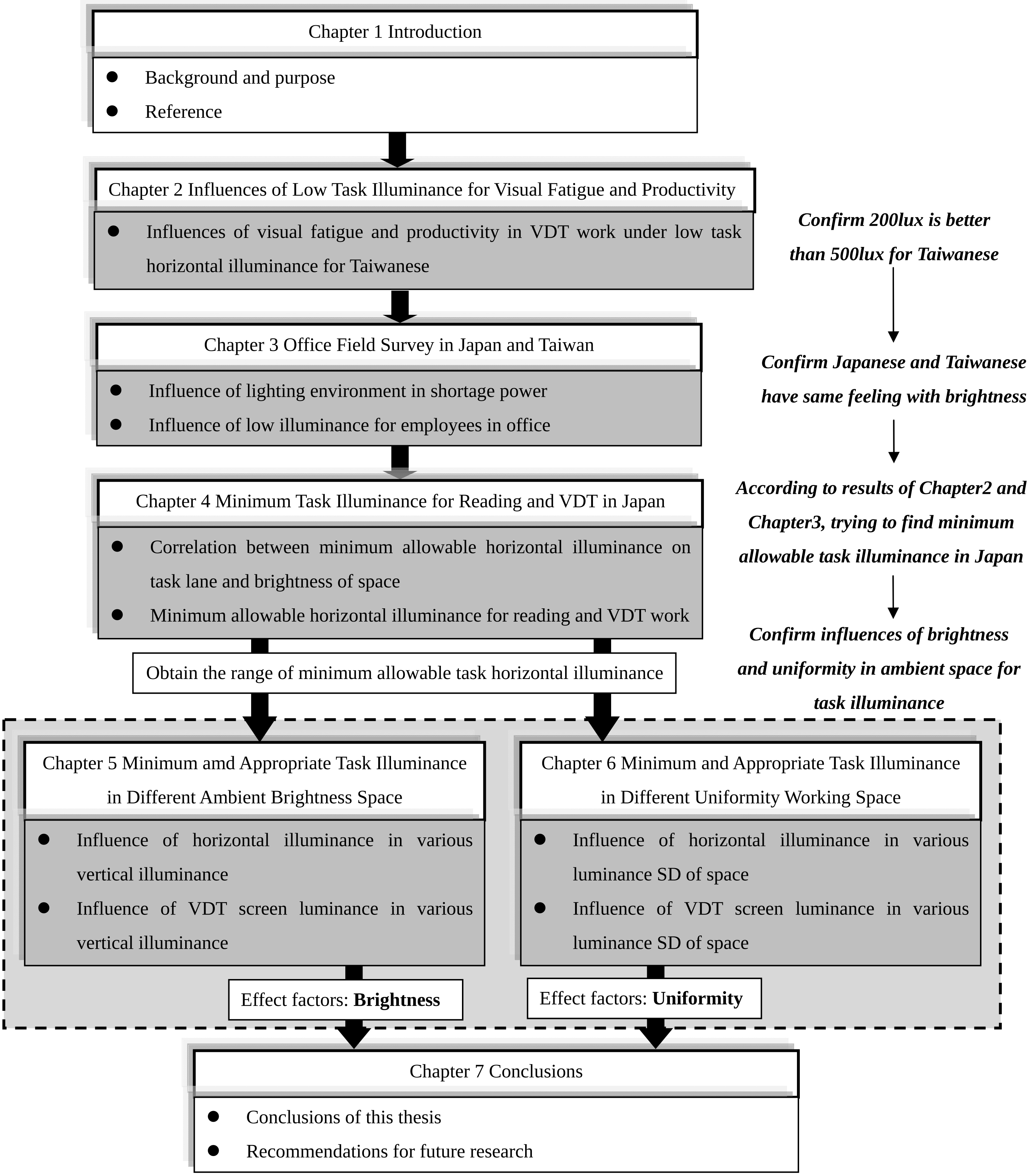

Fig. 1-6 Research flow

This study discusses the task illuminance for power saving in working space. In chapter2, 200lux and 500lux is used in experiment to exam inflince of visual fatigue and productivity for Taiwanese before the Great East Japan Earthquake in 2011. After the Great East Japan Earthquake in 2011, in order to confirm Japanese can tolerate low illuminance in working space because of shortage power, the office survey of lighting environment in Japan office should be discuss. At the same time, this study also discusses the survey in lighting environment in Taiwan office. There are two reasons for office survey in Taiwan:

1. Taiwanese recommended level of illuminance (推奨照度) is lower than Japanese

According to JIS Z9110:2010, the recommended level of illuminance is 750lux in working space. But after the Great East Japan Earthquake in 2011, the standard was reconsidered and proceeded amendment that the range from 500lux to 1000lux is recommended. But Taiwanese recommended level of illuminance in CNS12112 is 300lux to 750lux for working space. The recommended level of illuminance in Taiwan is lower than Japan. Therefore, this study would like to discuss what differences between Taiwanese and Japanese employees' psychology evaluations for lighting environment.

2. If there is no difference between Taiwanese and Japanese, the illuminance for working might be reduced in Japan.

According to result of Chapter2, 200lux is better than 500lux in visual fatigue and productivity for Taiwanese. If the influences of Japanese and Taiwanese are almost the same in lighting environment, through the surveys, it can be confirmed that Japanese can tolerate lower illuminance than recommended level of illuminance.

Therefore, doing the surveys in Taiwan and Japan is important and significant.

In chapter4, after surveys, the employees can tolerate lower task illuminance is be confirmed. Next study would like to exam how much minimum illuminance can be employed for VDT and reading and the correlation between task illuminance and ambient brightness. This experiment indicates that different ambient brightness may cause different minimum allowable task illuminance for VDT and reading. Therefore, next experiment will discuss the correlation between ambient brightness, ambient uniformity and task illuminance.

According to Brightness formulas in Chapter 1-3-4:

1. Feu=1.5×lg0.7

2. Brightness = [21.5-8.4*SD of log (luminance)] × average luminance

Human brightness has the relationship with ambient luminance and uniformity. In chapter 5 and chapter 6 are discuss the correlation between:

1. Minimum allowable task illuminance, ambient brightness and ambient uniformity.

2. Appropriate task illuminance, ambient brightness and ambient uniformity.

1-7 Methodology

This study is one of brightness research systems, start from energy save, discuss efficient electronic save way in lighting environment and visual comfort. So far, though the loss due to earthquake and tsunami has been reduced, when summer power use peak coming, Japan cannot escape the dilemma of energy shortages. With LED imported, it helps for energy save but difficult to achieve the power save propose. It is still need work with fine lighting equipment and adjust to appropriate lighting energy to make the power save effect significantly. Therefore, this study starts from real office survey, and discuss how the current office building managers take measures to save power. Simulate office task-ambient by laboratory experiment way to discuss VDT display luminance and power save range of minimum and appropriate illuminance in reading and VDT work under different lighting environment and uniformity.

- Chapter 2

By means of applying critical flicker frequency to the quantitative assessment of objective visual fatigue, and using a visual fatigue questionnaire to evaluate subjective visual fatigue, this study attempts in 500lux and 200lux lighting environments, to investigate the influence of visual fatigue on working performance when using visual display terminals. Changes in productivity as a result of subjective and objective visual fatigue under different artificial lights have been analyzed.

- Chapter 3

This chapter includes actual investigation and survey about office lighting environment in Tokyo (after earthquake) and Taiwan. The target of investigation are 13 office in Tokyo and 5 in Taiwan as sample to proceed the physical factors measure includes task horizontal illuminance, vertical illuminance, window surface illuminance, space luminance etc, questionnaire to power save for building managers and psychological evaluation questionnaire of lighting environment for office works. The objective of this investigation is to understand how the common office environment takes measure to save power, the situation of office operation area lighting physical factors change after power save and evaluation of power save environment.

- Chapter 4

The indoor brightness decreases with sunset, whether the subjects have different the minimum allowable task horizontal illuminance in different bright background. The luminance camera is adopted for luminance distribution of ambient space. The concept in chapter 2 is continued in this chapter, to the need of power-saving, the experiment of minimum allowable horizontal illuminance in reading and VDT work is proceed. Natural light (not direct sunlight) was used as lighting resource, and horizontal task illuminance decreases with sunset. The minimum allowable horizontal task illuminance under the premise of the subjects can see clear when they deal with reading and VDT work was measured and, the two objectives of the experiment shows as follow,

1. Find the minimum allowable task horizontal illuminance and corresponding luminance in working space in office work.

2. Find the difference of the minimum allowable task horizontal illuminance in reading and VDT work.

The indoor brightness decreases with sunset, whether the subjects have different the minimum allowable task horizontal illuminance in different bright background.

- Chapter 5

This chapter based on the minimum allowable task horizontal illuminance and vertical illuminance in eyes' position get from chapter 3, set up different vertical illuminance environment in 5 groups to ask subjects to adjust the minimum allowable and appropriate task horizontal illuminance. After the subjects adjust the task lighting, proceed in different lighting environment and adjust the display luminance to find VDT work display luminance in different bright environment. Environment psychological evaluation is also discussed in this chapter. According to the SD method, environment psychological evaluation is classified to 7 levels, after task lighting and display luminance adjusted enquire subjects about brightness, comfort, satisfaction and productivity of task plane and ambient space. Finally, according to the task illuminance adjusted, take luminance photo of experiment space (includes task plane and ambient space) at eyes' position with Luminocan luminance camera to record average luminance and distribution of luminance as database for continues analysis. In this study, assumes when under brighter lighting environment, task horizontal in minimum and appropriate patterns lower than dark lighting environment, in other words, when the ambient lighting improved, works' task lighting can reduce to achiever power save. In VDT work, this study assumes when the lighting environment get brighter, to avoid users' visual fatigue and uncomfortable caused by contrast luminance of display, the luminance need improved reasonable.

- Chapter 6

The minimum allowable and appropriate task horizontal illuminance is not only affected by brightness, uniformity of ambient lighting also is one of factors. The former chapter use different vertical illuminance of ambient lighting environment as independent variables, this chapter use average luminance $5cd/m^2$ when vertical illuminance at eyes' position get from former chapter as control variable, use 1~4 spotlight to change uniformity of ambient space as operate variable, and asking the subjects adjust the minimum allowable and appropriate task horizontal illuminance. The experiment in this chapter assumes when the average luminance keeps identical and uniformity is good, minimum allowable and appropriate task horizontal illuminance can be adjusted lower.

The experiment method in chapter 4 continues in this chapter, use Luminocan luminance camera to record average luminance and ambient luminance distribution (SD) after adjusted. The same with chapter 4, after adjusted the task illuminance, proceed the display luminance adjust to find the appropriate luminance in different uniformity ambient lighting in VDT work. Environment psychological evaluation is also discussed in the experiment of this chapter, includes brightness, comfort, satisfaction, glare, sense of opening and work efficient. Finally, find the formula of the minimum allowable and appropriate task horizontal illuminance based on the ambient brightness and uniformity of luminance as impact factors.

- Chapter 7

Chapter 6 is the summary from chapter 2 to 5, proceeds the proposal for research related with ambient lighting brightness and power save environment in the future.

CHAPTER 2 INFLUENCES OF LOW AND NORMAL TASK ILLUMINANCE FOR VISUAL FATIGUE AND PRODUCTIVITY

CHAPTER 2 INFLUENCES OF LOW TASK ILLUMINANCE FOR VISUAL FATIGUE AND PRODUCTIVITY

2-1 Introduction

In recent years, with rapid changes in global climate and deterioration of the living environment, the concept of global sustainability has gradually become more valued and greatly promoted. Meanwhile, as the era of the knowledge economy has arrived, pursuing healthy and comfortable indoor environments and ensuring good productivity have already become two of the most important issues in the 21st century. In Taiwan, people work daily for 8–12 h on average, generally using visual display terminals (VDTs) (Wu 1985).

This has a huge influence on visual health. An investigation conducted by The Hong Kong Polytechnic University surveyed 915 office workers in Hong Kong and discovered that the work performance of 80% of the interviewees with improper lighting in the working environment was affected, and 48% of them further expressed that they felt eye discomfort as a result of the poor lighting[15]. Continuous computer operation and visual load caused operators visual fatigue, such as blurred vision, double images, teary eyes and nearsightedness, as well as eye pain resulting from over-high intraocular pressure. Furthermore, in terms of working performance, phenomena such as scattered attention, increased error ratios and reduced working speed resulted in lower productivity.

The reason was found to be visual fatigue caused by the long-term use of eyes in an improper lighting environment. Hanne and Changes (1994) randomly selected 102 office workers using VDTs and 102 who did not use VDTs for a five-year follow-up and comparison. The research discovered that visual fatigue was significantly correlated to daily working duration for the VDT condition, and the fatigue resulting from working for more than six hours daily was different from that resulting from working for less than six hours daily. Besides, during VDT operation, the set-up of

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[15] The Hong Kong Polytechnic University, Centre for Social Policy Studies, Visual health and working performance for office illumination, Philips Lighting, 2003

the computer monitor has also been found to have a significant influence on visual fatigue. Ryoji and Koichi in 1986 indicated that the optimal luminance of a computer screen is 30cd/m^2, the glare of which should be reduced to the minimum.

2-1-1 Research Purpose

There is 90% of the time in the human's life to stay in the indoor environments, so this is a very important issue to ensure the healthy and comfortable interior environment for human. This study is explored about visual fatigue and productivity with different types of artificial light in the indoor space. Through the results of this study, users can choose the lightings that could make them feel more comfortable and raise their productivity.

2-1-2 Evaluation of Human's Visual Fatigue

As computer technology advances, whether moving or still able to use visual display terminal (VDT) to show information, so in VDT is increased rapidly.

However, computer operations eyes from the screen is mainly used to obtain the necessary information and communicate with the machines, and judging by the brain to complete the work, so the work of the physiological workload switch to human visual and mental. Therefore, it also brings many problems of the visual fatigue and visual adjustment.

Continuous computer operation and visual load would make workers have blurred vision, double vision, tears, continue or short discomfort and make high intraocular pressure. In Taipei, the third highest in the work of occupational injury is about using computer too long and make dry eye in the air-conditioned environment[16]. In general air-conditioned environment, because watching computer screen in the long time, and reduce the frequency of blinking, it may cause the water of eye surface evaporation excessively. Therefore, in order to protect computer user, many country are legislating and starting the research to improve the visual fatigue in VDT working space.

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16 Department of Health, Taipei City Government, 2007.

2-1-3 Reason of Visual Fatigue

No single research method or objective measure has yet emerged that consistently and accurately correlates with visual fatigue. No doubt this effort is hampered by the lack of a coherent definition. However, many techniques have been devised that do measure certain contributing factors to visual fatigue.

These methods span a wide range of fields. From a human factors engineering perspective, these methods can generally be grouped into two categories: those that deal with medical and optometric measurements (e.g., EMG and contrast sensitivity) and those that are of greater practical interest to the human factors/ergonomics researcher and practitioner (e.g., performance and surveys).

More formally, Megaw's (1990) review of visual fatigue does not offer an actual definition of the affliction, instead listing some key points that should be included in any formal definition. Briefly, those points are:

- Visual fatigue does not occur instantaneously

- Visual fatigue should be distinguishable from mental workload demands

- Visual fatigue can be overcome by rest

- Visual fatigue should be discernible from any adaptive response of the visual system

- Symptoms of asthenopia are the main reason for assuming the existence of visual fatigue

- Symptoms of asthenopia can be caused by nonvisual factors.

2-1-4 Assessment Methods of Visual Fatigue in Lighting Environment

Megwa (1990) suggested five measures of visual fatigue: (1) accommodation, convergence, etc.; (2) vision measure, including critical flicker frequency (CFF), changes in visual sensitivity, etc.; (3) the measure of visual fatigue; (4) the measure of subjective visual fatigue (SVF); and (5) other indexes relevant to vision, such as changes in visual range8). Additionally, Chi and Lin (1998) designed seven measures: (1) the capability of visual accommodation; (2) eye sharpness; (3) the diameter of the pupil; CFF; (5) the revolving speed of the eyeball; (6) the subjective comfort of visual fatigue; and (7) the experiment of subjective comfort9). According to the aforementioned, CFF could be applied to measure visual fatigue, and some research results indicate that CFF is significantly sensitive to visual fatigue caused by VDT behaviour. Tetsuya and Masaharu (1994) also studied the correlation between the duration of VDT and CFF. These results indicated that visual alertness deteriorates, indicated by a decrease in CFF changes, when subjects had 60min of continuous VDT interaction.

There are five methods that can be used to measure SVF: ranking methods, rating methods, questionnaire methods, interviews and checklists (Salgado 1997). The questionnaire method is the most commonly used by general studies because it is the measure that shows most directly the subjects' feelings of visual fatigue.

Heuer et al. (1989) developed a subjective scale for measuring visual fatigue as a result of subjects' VDT interaction, which includes the following six items:

1. I have difficulties in seeing.

2. I have a strange feeling around the eyes.

3. My eyes feel tired.

4. I feel numb.

5. I have a headache.

6. I feel dizzy looking at the screen.

However, Toi and Dumery (1997) argued that "My eyes feel dry" was one of the major symptoms of visual fatigue. In line with this, other research provided by the Department of Health, Taipei City Government (2007)[17], indicates that "My eyes feel dry" is also a major symptom for VDT workers in Taiwan. Consequently, the questionnaire for subjective visual fatigue measures in this study includes "My eyes feel dry" as the seventh item in addition to the original six items for measuring SVF.

In this study, the subjective measure scale shows the degree of each question in terms of a 9-point scale, in which '1' indicates 'no feeling at all' and '9' indicates 'extremely tired'(Yoshitake 1975). Simultaneously, Weber et al. indicated that the P-value of the correlation between CFF and the subjective measure scale is higher than 0.817.

In this study, critical fusion frequency is used to measure VDT users' visual fatigue under different indoor artificial light types.

When the frequency of a flash is higher than 60Hz, the human eye generally cannot differentiate if the light flashes. However, when the flash frequency is gradually reduced to the level that the eye no longer feels that the light is continuous, it is called critical flicker frequency or CFF for short, and is used as a measure of objective visual fatigue (OVF). When the frequency of a continuous light is higher than the CFF value, human eyes will regard the light as continuous, the brightness I of which is

$$\mathrm{I} = \frac{1}{T}\int_{0}^{T} L(t)dt \qquad \text{Equation 1}$$

CFF is the index of the human eye's distinguishing capability when stimulated by light, the value of which is influenced by the intensity of light; it forms a direct ratio with log I, and can be indicated by means of Equation 2:

$$\mathrm{n} = \alpha \log I + \beta \qquad \text{Equation 2}$$

[17] Department of Health, Taipei City Government, 2007.

2-2 Experimental Purposes

This chapter is described the experimental laboratory setting and determination for different interior light environment of human response, including weather conditions, lighting conditions, illumination, artificial light source and testing, laboratory processes and visual fatigue. Table 2-1 is the project-oriented type of experimental design.

The purpose of this study is investigated the indoor environment which there are different artificial lighting at 26 ℃ to the human's visual response and productivity. In this study, experimental Method is measured for the visual fatigue of psychological (SD Method) and physiological (CFF). In the other hand, using VTS test to assess the productivity.

Table 2-1 Experimental setting items of indoor lighting conditions space

Experimental Plan		Test contents	Test items
Laboratory		Laboratory scale	Measurements of Laboratory
			Equipment performance
			Interior decoration materials
Physics factors	Lighting factors	lighting	Lighting features, glare control
			Lighting location, height, angle
		Lighting source	type, line number, character, purpose, size
			Luminous efficiency, power consumption
			Luminous flux, color temperature, color rendering
			Illumination ,uniformity
	Heat factors	Climatic conditions	Temperature, humidity setting, wind
VDT space		LCD Screen	Size, brightness, screen frequency
Subject		Date base	Name, sex, age, education
			Height, weight, vision, color blindness, history of disease
		Experimental data	Behavior patterns, col
			Chair position, with the lamp distance, source location
			CFF、Questionnaire, VTS

2-2-1 Experimental Room Setting

According to Horikoshi and Oomine, the prerequisite of an indoor space for experiments on human physical reactions to a lighting environment includes air conditioning facilities (which can maintain constant temperature, humidity and stable climate conditions) and maintaining the indoor background noise under 55dB (Horikoshi and Oomine 1999). By considering the feasible conditions therefore, a full-scale laboratory meeting the experimental requirements was selected as the experimental location. The testing space of the laboratory (L: 4.2m; W: 3.9m; H: 3.3m) was installed with black opaque curtaining and materials in order to avoid interference from other lights during the experiment and to reduce the albedo released by the surrounding walls inside the laboratory.

Because the light reflected might change the frequency and combination of the spectrum, it was important to ensure that subjects using VDTs were not affected by reflections from the surroundings or by vertical glare. The arrangement of the lights and the size of the experimental location are shown in Fig. 2-1.

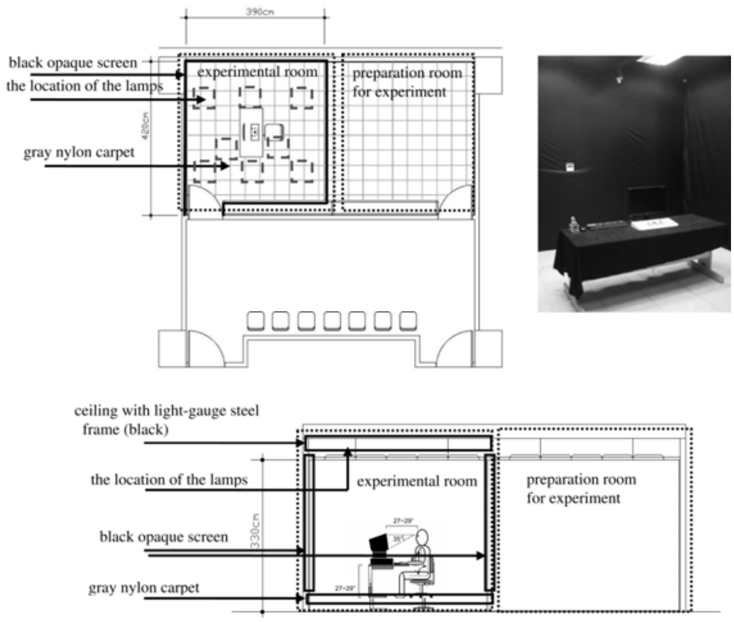


Fig. 2-1 The size of the laboratory and the arrangement of lights

The results of the measurement of the average illumination and uniformity of the indoor operational level were between 0.67 and 0.86, all more than the standard value of 0.5, which is regulated by the International Commission on Illumination. Focusing on T5 fluorescent lamps and white LED lights, this experiment measured the average illumination on the desktop in the indoor operation area. The method to measure the average horizontal illumination of indoor space divided the level of experimental space that is equal to the height of the desktop (the height of the operational level: 75cm) into 16 testing spots, as indicated in Fig. 2-2.

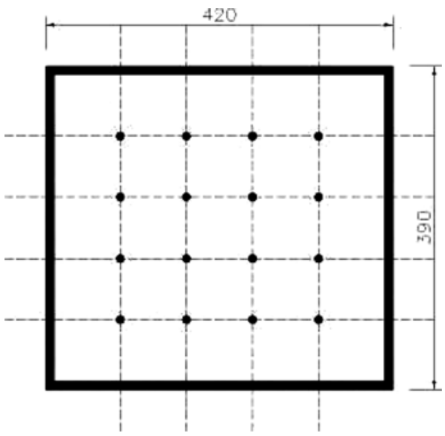
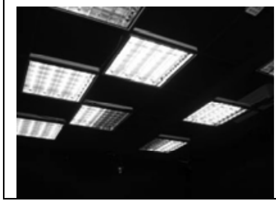
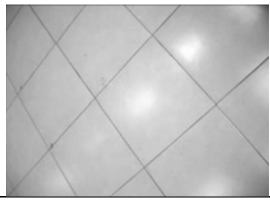
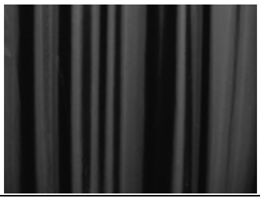


Fig. 2-2 Average measuring point for illumination in the laboratory

To prevent the phenomena of refraction and reflection caused by the interior materials used in the testing room, which might influence the accuracy of the experiment, black opaque curtaining with rough screens needed to be installed in the experimental room, and also measurement of the interior materials' albedo needed to be known to understand the illuminant's reflection in the area. According to the Munsell brightness diagram, the albedo of perfect black is 0; however, it is not possible to reach albedo 0 in real situations. In this study, the CNS C3068 luminance measurement was used to measure the surroundings of room, with the luminance of the surrounding wall rated between 2 and 5cd/m^2 (as shown in Table 2-2).

Table 2-2 Pictures of the surroundings

Ceiling	Floor (plastic carpet)	Wall (screen)	Operation desk (table cloth)
			

2-2-2 VDT Operation Standards

The desks and chairs used were all OA furniture employing ergonomic design meeting the ISO9241-3 VDT Operation Standards, as indicated in Fig. 2-3.

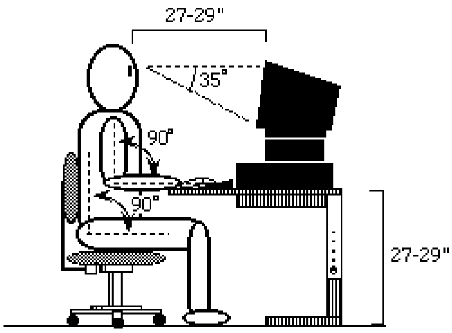


Fig. 2-3 VDT operation standards

The subjects were required to have their working efficiency evaluated through the computer system by VDT; therefore, the eyes of the subjects could not leave the screens, and thus the influence of the surrounding environment was minor. Undoubtedly, both direct glare and reflected glare have a significant influence on visual fatigue. Generally speaking, the influential coverage caused by direct glare is the direct illumination of beams at a ±30° horizontal line of human sight, while reflected glare is at a ±25° vertical line of sight (Shiau 1996), as shown in Fig. 2-4.

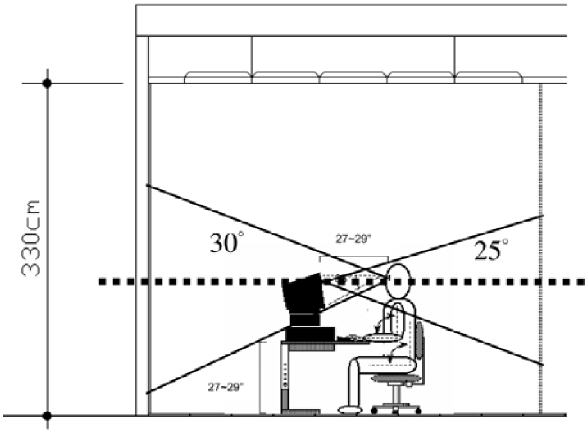


Fig. 2-4 No illuminant of the glare is within the subject's visual sight

This study proves that no illuminant of the glare existed within the subjects' visual sight; hence it can be concluded that subjects were not easily influenced by the glare. Besides, the set-up of anti-glare grilles on the lamps by using the low-reflection material mentioned above in the surroundings reduced the influence of veiling reflection with luminance $30cd/m^2$ of the VDT display monitors.

22"LCD monitors were used, with specifications of a 16:10 wide screen, a maximum contrast of 1000:1 and a maximum luminous intensity of $300cd/m^2$. For the luminous intensity test of the computer monitor, the literature mentions that $30cd/m^2$ is the optimal luminance; hence a luminance meter was used to directly measure the LCD monitors and adjust the value to $30cd/m_2$ before the experiment was conducted.

Table 2-3 VDT screen

Name	LG W2234S-BN	Photo
Response time	5ms	
Screen ratio	16:10	
Contrast	1000:1(Max)	
Brightness	$300cd/m^2$(Max)	
Screen scale	22″	

2-2-3 Equipment Type and Specifications

The human response to lighting conditions, all as required by the relevant experimental equipment can be divided into the following four types of items.

1. Lighting measurement items

2. Indoor climate measurement items

3. Background noise measurement items

4. Human visual response measurement

Table 2-4 Experimental equipment items

No.	Items	Range	Precision	Propose
No.1	Illumination	0.01 ~ 299900Lux	±2%	Illumination on working face
No.2	Temperature	-40 ~ 115℃	±0.1℃	Interior temperature
No.3	Humidity	0 ~ 100%	±0.1%	Relative humidity
No.4	Wind velocity	0 ~ 30m/s	±2%	Wind velocity
No.5	Noise	10 ~ 130dB(A)	±1dB(A)	Background noise
No.6	Lluminosity	0~99900 cd/m^2	±1 cd/m^2	Screen luminosity
No.7	CFF	20~60Hz		Visual fatigue

2-3 Experimental Factors

The experiment was divided into two modules with four variations (as indicated in Table 2-5), in order to evaluate and investigate the influence of physical reactions, and the psychological effects on working efficiency when using VDTs with white light emitting diode (LED) lights in an indoor environment.

Table 2-5 The experimental module set-ups with four variations

	T8 fluorescent lamp	T5 fluorescent lamp	LED lights
500Lux	A	C	E
200Lux	B	D	F

2-3-1 Work Surface Illumination

This study investigates the influence of visual fatigue on productivity in an environment of artificial lighting. It considered the T8 fluorescent lamps, extensively used today, and T5 fluorescent lamps, extensively also used today and efficient in energy saving and environmental protection, as the control group. 200 and 500lux illuminations were chosen as the suggested standard under different regulations of operating environments by the Illumination Engineering Society (IES) and Central Nervous System (CNS). Recommended Levels of Illuminance of Japanese Industrial Standards (JIS Z9110:2011) is higher than them. (Table 2-6).

Table 2-6 CNS and JIS regulations for illumination for different attributes of indoor space

<table>
<tr><th rowspan="2">Luminance (Lux)</th><th colspan="5">The effects of spatial attributes</th></tr>
<tr><th colspan="3">CNS</th><th colspan="2">JIS (recommended levels of illuminance)</th></tr>
<tr><td>1000Lux~</td><td rowspan="2">Design room, Lobby(day)</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>750</td><td colspan="2" rowspan="2">Regular office, manager room, meeting room, print room, control room, information</td><td rowspan="2">Design room, regular office, lobby(day) ,</td><td></td></tr>
<tr><td>500Lux</td><td rowspan="3">Guest room, rest room, meeting room assembly hall, guardroom , reception room, auditorium</td><td>Keyboard task, calculate, control room, meeting room</td></tr>
<tr><td>300Lux</td><td rowspan="2">Electric room, air conditioning facilities, elevator</td><td></td><td></td><td rowspan="2">Information, restaurant</td></tr>
<tr><td>200Lux</td><td rowspan="3">Toilet, bathroom, stair, corridor</td><td>Stack room, fitting room, toilet, electric room</td></tr>
<tr><td>150Lux</td><td colspan="2" rowspan="3">fitting room, warehouse, rest room, tea room,</td><td></td><td rowspan="2">Stairs</td></tr>
<tr><td>100Lux</td><td rowspan="2">Corridor, lobby(night)</td></tr>
<tr><td>75Lux</td><td></td><td></td></tr>
</table>

2-3-2 Lighting Selection

According to references, the office space for indoor lighting are mostly used fluorescent lighting in Taiwan. In this study, choosing the current office space commonly used OA lighting (East Asian FVS-2441XT), electronic ballast and T8-T5 fittings . The basic information is as follows shown in Table 2-7.

Table 2-7 Basic lighting data

Standard	FVS-2441XT	Photo
Voltage	AC 220V	
Frequency	60Hz	
Current	0.42A	
Scale	2″ × 2″	

In this study, T8, T5 fluorescent tubes and LED lights were selected as the lighting factors of the experiment, and linear tubes were used as the light form. The width of tube of T8 is 8/8 inch, and T5 is 5/8 inch, so they are called T8 and T5. Because T8 is the most popular fluorescent tube which is used in office and house in Taiwan. T5 fluorescent tube is the new saving energy type in Taiwan. It costs higher than T8 but chapter than LED, so T5 fluorescent tube and LED are not very popular now. In the future, LED will be popular when price cost down. The basic lighting data are indicated in Table 2-8. The lights frequently used in indoor environments currently include three different color temperatures, namely 2700, 4000 and 6500K, among which 6500K generates a higher awakening of the human body[41] as well as better productivity according to the investigation results related to indoor operation general environments in Taiwan (Wang 2006).

Table 2-8 Basic lighting data

Category	T8	T5	White LED
Colour temperature (K)	6700	6500	6500
Colour rendition (Ra)	75	85	70
Length of tube (mm)	580	549	580
Width of tube (mm)	25 (8/8 inch)	16 (5/8 inch)	25
Lm	1440	1825	1800
W	20W	24W	18W
Efficiency	72Lm/W	81Lm/W	100Lm/W
Ballast style	Traditional ballast 低周波点灯専用安定器	Electrical ballast 高周波点灯専用安定器	No ballast
Image of light			

2-3-3 Experimental Setting

This study investigated the light of environmental factors on human psychological and physical effects, to provide a stable laboratory sites for the human response of full scale laboratory experiments, the experimental space and laboratory testing with external control room space, the outside chamber set a different temperature, humidity and wind speed, and the indoor temperature and humidity conditions and background noise control in a stable state of the state, for the control of the indoor physical environment with excellent results. The following will be measured against the results of the indoor boundary conditions for the discussion and determination of ways.

Table 2-9 Selected boundary for experimental set-ups

Experimental specimen	30 students aged between 18 and 29
Experimental environment	General lighting environment
Subject's behaviour	Operating a VDT while seated on a chair
Selected environmental lighting	500lux
Artificial lighting varieties	White LED lights and T5 fluorescent lamps
Temperature control	26^{o}C
Relative humidity control	70%
Wind speed control	Under 0.09m/s
Background noise control	55dB(A)
Colour temperature control	3000K, 4200K, 6500K
Monitor brightness control	30cd/m^{2}
Experimental method	CFF, the questionnaire for subjective visual fatigue, VTS for the examination of productivity

2-3-4 Assessment of Productivity

Past studies related to working performance used the 'correct answering rate' mathematical evaluation to quantify productivity (Tanabe 2006); however, in recent years, application of the 'Vienna Test System' (VTS) has become more popular in studies objectively evaluating the reaction of working efficiency in different situations (Salgado 1997). Consequently, the VTS, a neuropsychology system, is adopted in this study and is mainly administered for scientific and psychological diagnosis (as shown in Fig. 2-5) to conduct an evaluation of effectiveness, comprehensive ability and personality characteristics. The testing methods include psychological testing, ability testing, general ability testing and special ability testing. In this experiment, four items of general ability testing are exercised to examine the subjects' working efficiency: computing power (ALS), attention (Cognitrone, COG), reaction time (Reaction Test, RT) and vigilance (VIGIL) (as indicated in Table 2-10). The order of the operation steps is six minutes for COG I, six minutes for RT I, six minutes for COG II, six minutes for RT II, 10 min for ALS and 25min for VIGIL; 60min in total completes the process. Both COG and RT are tested twice and each time under different conditions, and then the T-score, which can be calculated by means of Equation (3), is shown as the statistical analysis for the outcome of the VTS resulting in working efficiency performance:

T= 50+(X- XA/S)10 Equation (3)

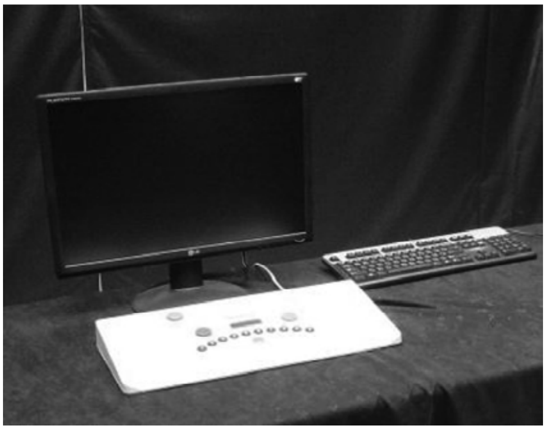
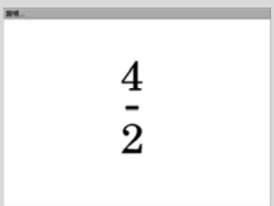
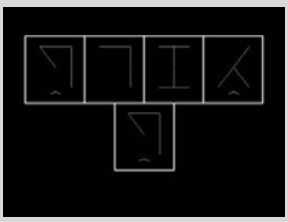
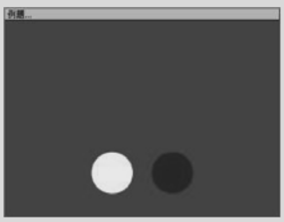
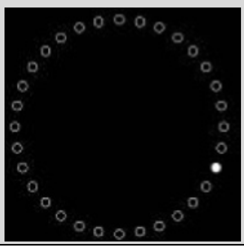


Fig. 2-5 Image of VTS

Table 2-10 Testing images of VTS productivity

ALS computational ability	COG concentrative ability	RT reaction time	VIGIL alert ability
Split-half reliability	Split-half reliability	Split-half reliability	Split-half reliability
0.91–0.99	0.67–0.98	0.84–0.95	0.77–0.84
			

2-4 Procedure

The experimental procedure (as shown in Fig. 2-6) consisted of three main stages: (1) acclimatization, (2) baseline measurement and (3) test condition measurement.

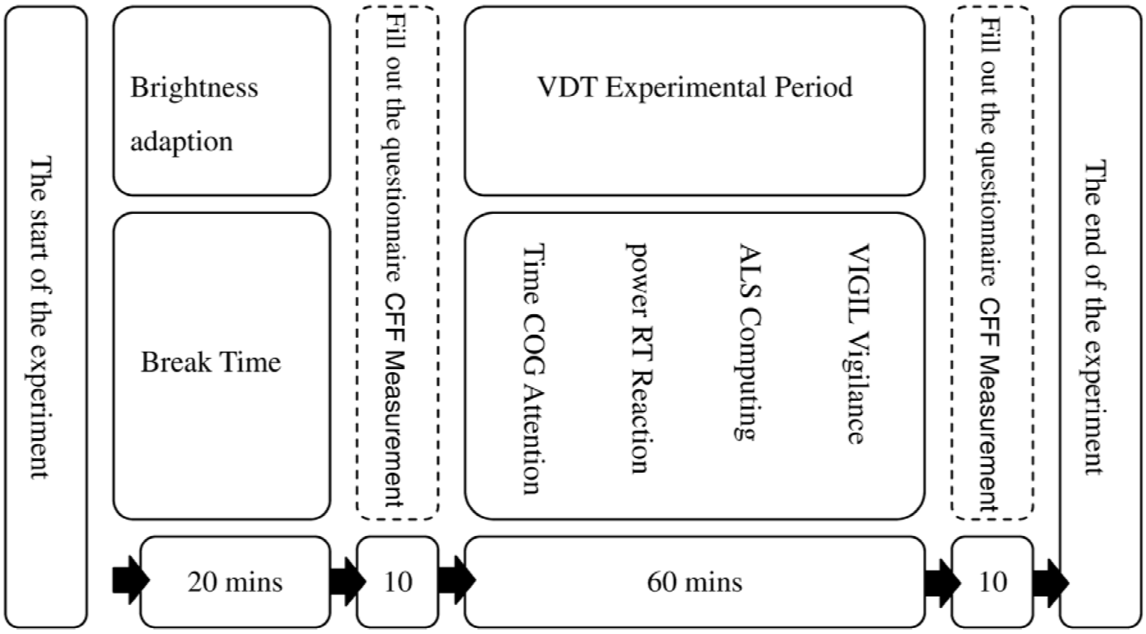


Fig. 2-6 Flowchart of the experiment

2-4-1 Acclimatization

A period of 20min prior to the start of the experiment was arranged as a resting period (brightness adaptation) (as shown in Fig. 2-7). During this 20-min period, the lights were on and the subjects were seated in order to avoid influences from external environmental factors interfering with the accuracy of the experiment. This was followed by 10min to complete the questionnaire. It was also required that subjects not use a VDT for one hour prior to the experiment. After the preparation period, the experiment was carried out for 60min in a lights-on situation.

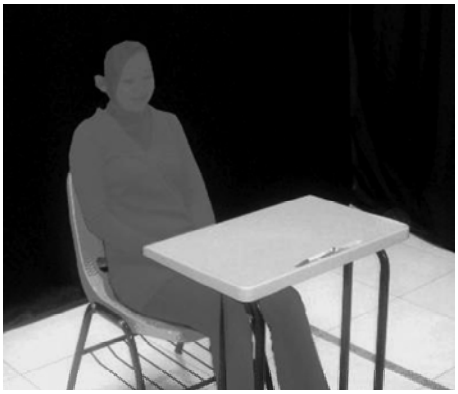


Fig. 2-7 The subjects' resting situation (brightness adaptation)

2-4-2 Baseline Measurement

During 10min of the preparation time before the start of the experiment, subjects were required to provide their personal information. It also had to be confirmed that they were not color blind and that their hearing was good. Besides, they could have no previous history of serious internal organ disease. The experimental procedure and the evaluation questionnaire were also explained at this time. Finally, CFF measurements were made and the subjects filled out the SVF questionnaire to be used as the standard for the following comparison. The differences shown before and after the experiment can be used to diagnose the level of the subjects' visual fatigue and the decrease in CFF when they feel tired. Thus it can be seen that the more the numbers decrease, the more serious the subject's visual fatigue.

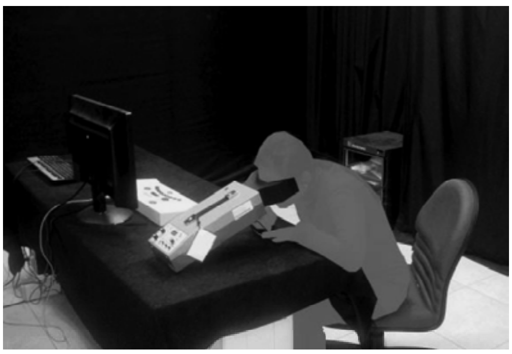


Fig. 2-8 CFF measurement before the experiment

Fig. 2-9 Filling out the questionnaire

2-4-3 Test Condition Measurement

VDT operation proceeded and evaluation of the VTS system was carried out after filling out the questionnaire. The subjects' working efficiency performance indicators were then examined. The CFF measurement was taken and the SVF questionnaire was completed when the VTS test finished. The experiment was completed once the questionnaire was finished.

Fig. 2-10 VTS productivity evaluation

Fig. 2-11 CFF measurement after the experiment

Fig. 2-12 Filling out the SVF questionnaire after the experiment

2-5 Experimental Results of Visual Fatigue

This chapter focuses on the part of the human's visual fatigue of psychological, physiological, and productivity which in three different artificial light modules. The experiments are comparative analysis in temperature 26 ℃, and the color temperature is 6500K, and the lights are T8, T5 fluorescent, and white LED light source. Each experiment costs 90 minutes which including 30 minutes for dark Adaptation and 60 minutes for VTS and VDT working. Before each experiment starting, the subject must take the CFF test and do the questionnaire and it also take after experiment ending. There are 30 subjects who are students in the college or graduate school, and age is between 18 to 29 years old.

There are 6 modules in this experiment. The modules are showed on next Table 2-11.

Table 2-11 Experimental Setting

	500lux	200lux
T8 fluorescent light	A	B
T5 fluorescent light	C	D
White LED	E	F

2-5-1 Results of Subjective Psychological Visual Fatigue

Experimental evaluation of the psychological perception questionnaire used Heuer, Hollendiek, Kroöger, Römer in 1989, who made the subjective visual fatigue questionnaire divided into nine scales, and then the use statistical software to analyze it. The psychological evaluation questionnaire of 9 scales for each question and subjects must circle "○" to make it. This research used the KS test by SPSS statistical software to determine whether the data in normal segment, T test is used to determine the subjective and objective visual fatigue test data at all whether there is significant difference between groups.

In the T8 fluorescent light modules, there are two modules which are A module (500lux) and B module (200lux).

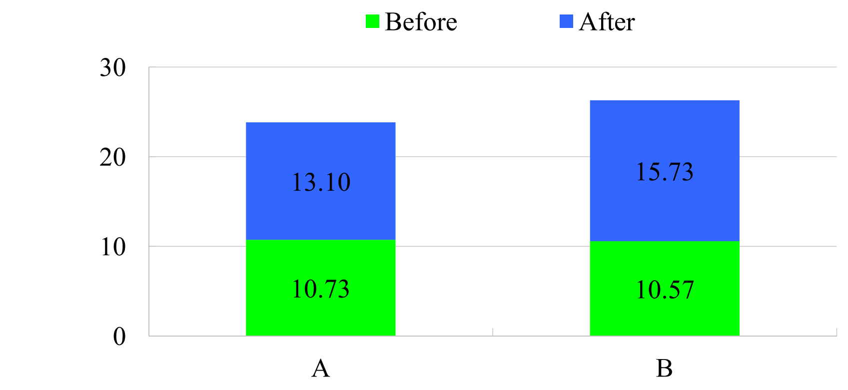
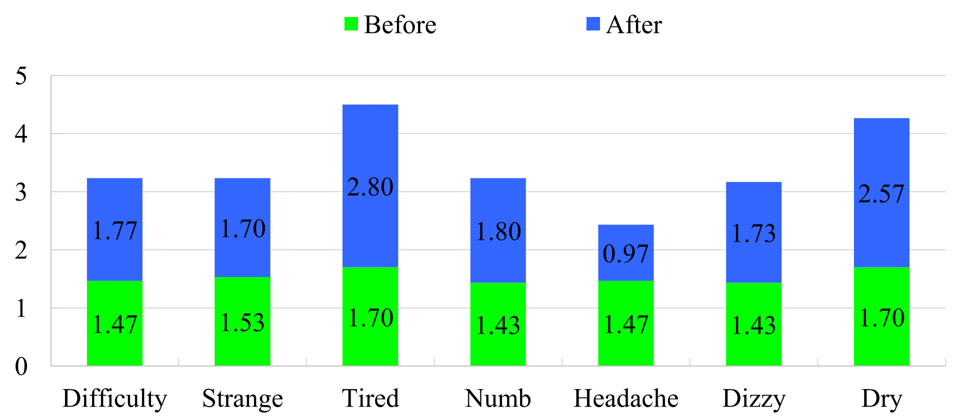
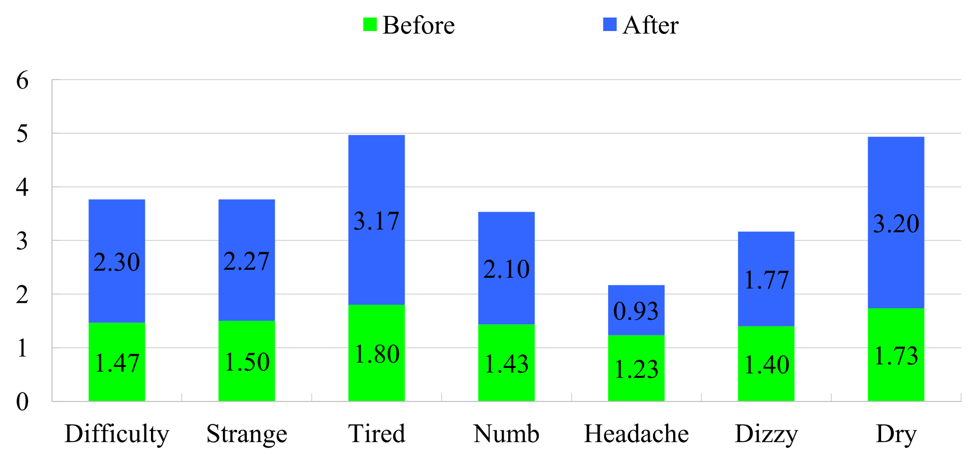
Table 2-12 T test of psychological visual fatigue in T8 fluorescent light

Paired-Sample test							
T8 fluorescent light	Variance					t	significance
	Arithematic mean	Standard deviation	Standard error	95% Confidence Interval			
				Lower	Upper		
A I - A II	-13.10000	9.26748	1.69200	-16.56053	-9.63947	-7.742	**
B I - B II	-15.73333	9.22864	1.68491	-19.17936	-12.28730	-9.338	**
A - B	-2.63333	3.59581	.65650	-3.97603	-1.29063	-4.011	**
*P<0.05 **P<0.01							

Results from the next Table 2-13 shows when indoor use of T8 fluorescent lamps as lighting, the psychological visual fatigue of B module (200lux) is obviously higher than A module (500lux). Before A module in the 500lux experiment starting, the average points in questionnaire of subjective psychological visual fatigue are 10.73, and the average points are 23.83 points after A module experiment end. Overall average of subjective visual fatigue increase 10.57 points in A modules. Before B module in the 200lux experiment starting, the average points in questionnaire of subjective psychological visual fatigue are 10.57, and the average points are 26.30 points after B module experiment end. Overall average of subjective visual fatigue increase 15.73 points in B modules.Through the experimental result between A and B modules, subjects considered B module generally getting more visual fatigue easily than A module, and the differentia is 2.63 points.

In each of the subjective psychological visual fatigue questionnaire, the subjects in the A and B module in the third question" I feel eye fatigue" and the seventh question "I have dry eyes ", the reaction are stronger than the other. The average of them increased 2.80 and 2.57 in the A module; 3.17 and 3.20 in the B module. In the fifth question: "I feel a headache", have the weak response with an average increase of 0.97 points in the A module; 0.93 points in the B module. Therefore, In T8 artificial light sources of A and B modules, subjects feel visual fatigue and have dry eyes, but they did not too much response for the headache.

Table 2-13 Questionnaire result of T8 fluorescent light

A and B module with T8 fluorescent light

Questionnaire result of A module with T8 fluorescent light

Questionnaire result of B module with T8 fluorescent light


2-5-2 Results of Subjective Psychological Visual Fatigue with T5

In the T5 fluorescent light modules, there are two modules which are C module (500lux) and D module (200lux).

Table 2-14 T-test in T5 fluorescent light

Paired-Sample test							
T5 fluorescent light	Variance					t	significance
	Arithmetic mean	Standard deviation	Standard error	95% Confidence Interval			
				Lower	Upper		
C I - C II	-8.10000	6.90002	1.25977	-10.67651	-5.52349	-6.430	**
D I - D II	-10.03333	7.69453	1.40482	-12.90652	-7.16015	-7.142	**
C - D	-1.93333	3.54219	.64671	-3.25601	-.61066	-2.989	**
*P<0.05 **P<0.01							

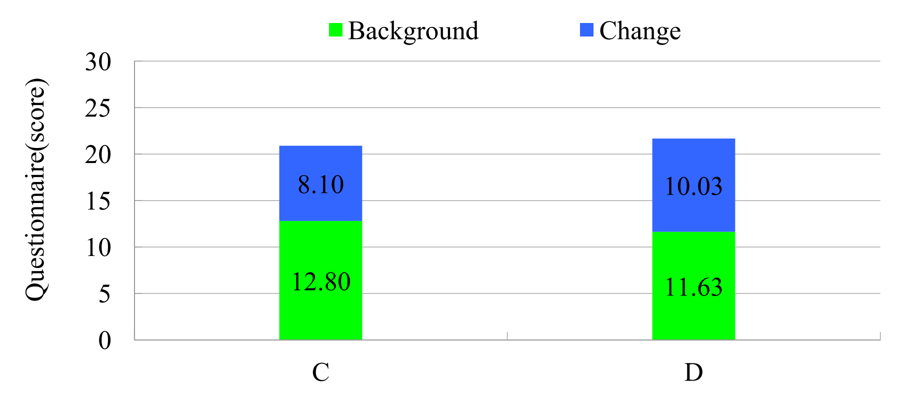
Results from the Table 2-14 shows when indoor use of T5 fluorescent lamps as lighting, the psychological visual fatigue of D module (200lux) is obviously higher than C module (500lux). Before C module in the 500lux experiment starting, the average points in questionnaire of subjective psychological visual fatigue are 12.80, and the average points are 20.90 points after C module experiment end. Overall average of subjective visual fatigue increase 8.10 points in C modules. Before D module in the 200lux experiment starting, the average points in questionnaire of subjective psychological visual fatigue are 11.63, and the average points are 21.66 points after D module experiment end. Overall average of subjective visual fatigue increase 10.03 points in D modules.

Through the experimental result between A and B modules, subjects considered B module generally getting more visual fatigue easily than A module, and the differentia is 1.93 points.

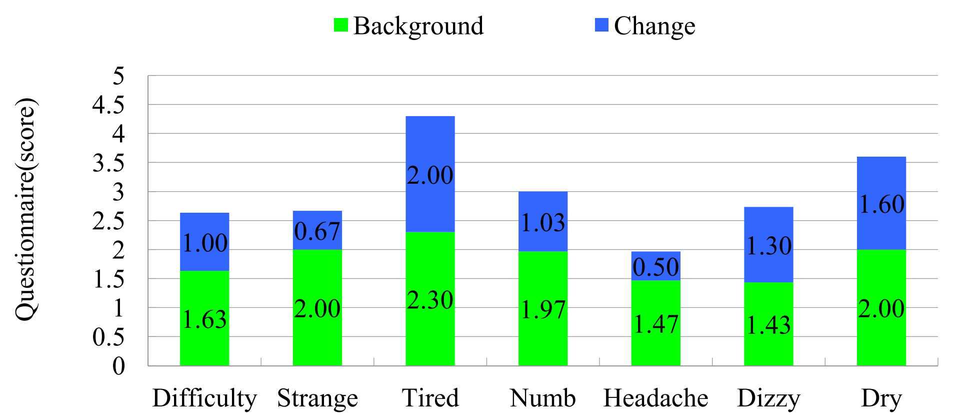
In each of the subjective psychological visual fatigue questionnaire, the subjects in the C and D module in the third question” I feel eye fatigue” and the seventh question “I have dry eyes “, the reaction are stronger than the other. The average of them increased 2.00 and 1.60 in the C module; 2.10 and 2.00 in the D module. And in the sixth question “I feel dizzy looking at the screen” in C modul also have stranger response, the average of them increased 1.3. In the fifth question: ”I feel a headache”, have the weak response with an average increase of 0.50 points in the A module; 0.70 points in the B module. Therefore, In T5 artificial light sources of C and D modules, subjects feel visual fatigue and have dry eyes, but they did not too much response for the headache.

Table 2-15 Questionnaire result of T5 fluorescent light

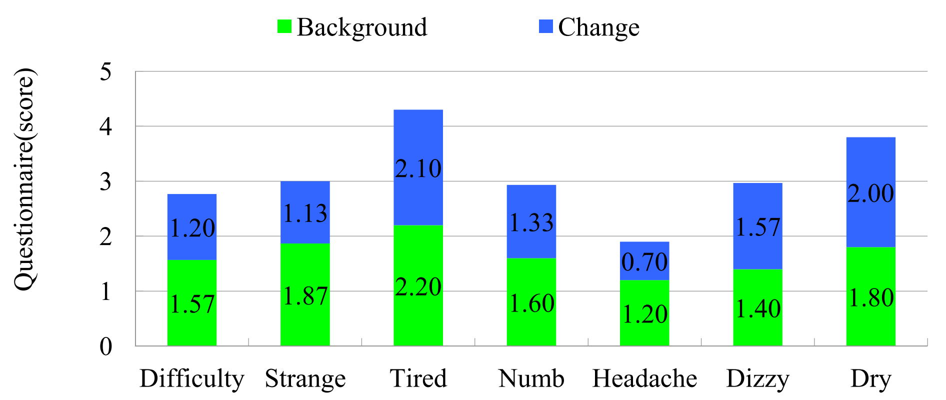
C and D module with T5 fluorescent light



Questionnaire result of C module with T5 fluorescent light



Questionnaire result of D module with T5 fluorescent light



2-5-3 Results of Subjective Psychological Visual Fatigue with White LED

In the white LED light modules, there are two modules which are E module (500lux) and F module (200lux).

Table 2-16 T-test in T5 fluorescent light

Paired-Sample test							
White LED	Variance					t	significance
	Arithmetic mean	Standard deviation	Standard error	95% Confidence Interval			
				Lower	Upper		
E I - E II	-7.50000	7.31437	1.33542	-10.23123	-4.76877	-5.616	**
F I - F II	-9.50000	9.20551	1.68069	-12.93739	-6.06261	-5.652	**
E - F	-2.00000	4.25886	.77756	-3.59029	-.40971	-2.572	*
*P<0.05 **P<0.01							

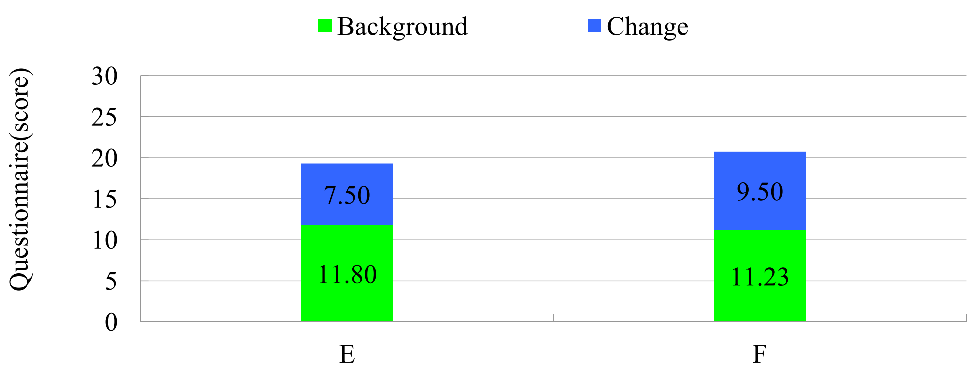
Results from the Table 2-17 shows when indoor use of T5 fluorescent lamps as lighting, the psychological visual fatigue of D module (200lux) is obviously higher than C module (500lux). Before C module in the 500lux experiment starting, the average points in questionnaire of subjective psychological visual fatigue are 12.80, and the average points are 20.90 points after C module experiment end. Overall average of subjective visual fatigue increase 8.10 points in C modules. Before D module in the 200lux experiment starting, the average points in questionnaire of subjective psychological visual fatigue are 11.63, and the average points are 21.66 points after D module experiment end. Overall average of subjective visual fatigue increase 10.03 points in D modules.

Through the experimental result between A and B modules, subjects considered B module generally getting more visual fatigue easily than A module, and the differentia is 1.93 points.

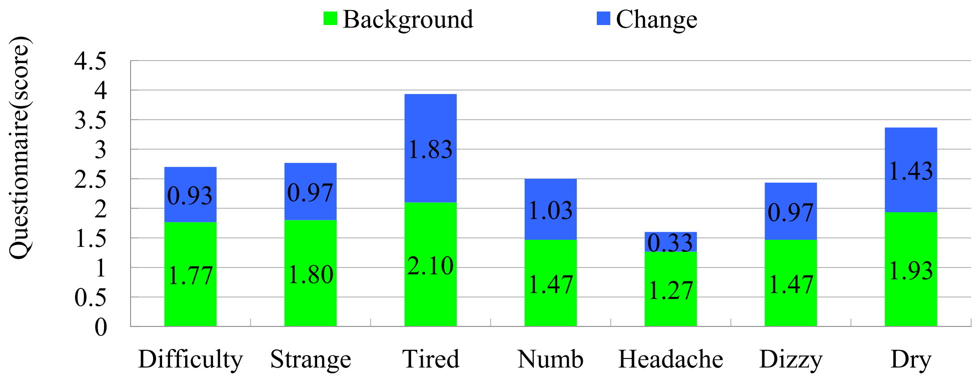
In each of the subjective psychological visual fatigue questionnaire, the subjects in the C and D module in the third question” I feel eye fatigue” and the seventh question “I have dry eyes “, the reaction are stronger than the other. The average of them increased 2.00 and 1.60 in the C module; 2.10 and 2.00 in the D module. And in the sixth question “I feel dizzy looking at the screen” in C modul also have stranger response, the average of them increased 1.3. In the fifth question: ”I feel a headache”, have the weak response with an average increase of 0.50 points in the A module; 0.70 points in the B module. Therefore, In T5 artificial light sources of C and D modules, subjects feel visual fatigue and have dry eyes, but they did not too much response for the headache.

Table 2-17 Questionnaire result of white LED light

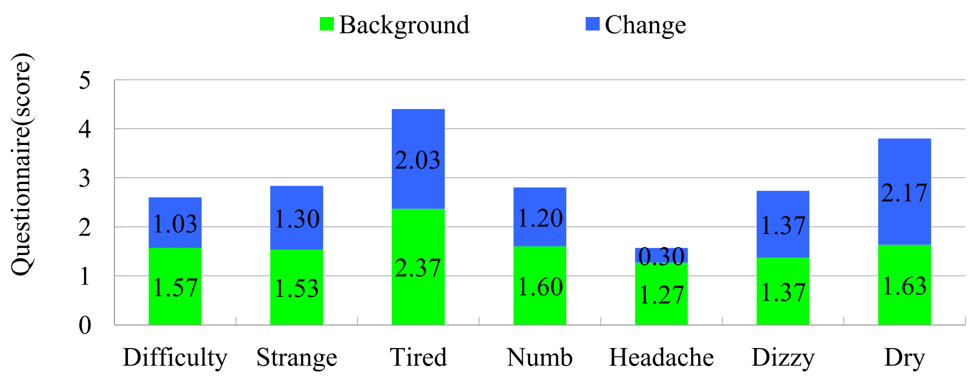
E and F module with white LED light



Questionnaire result of E module with white LED light



Questionnaire result of F module with white LED light



2-5-4 Subjective Psychological Evaluation of Visual Fatigue

This section will be comprehensive comparison of six modules of questionnaire data, and then find out subjects feel most comfortable modules. The following table is calculated by the SPSS software interaction in each group under comparison statistics.

Table 2-18 500lux modules of visual fatigue statistics

Paired-Sample statistics				
500lux	Average	Integer	Standard deviation	Standard error
A Questionnaire	13.1000	30	9.26748	1.69200
C Questionnaire	8.1000	30	6.90002	1.25977
E Questionnaire	7.5000	30	7.31437	1.33542

Table 2-19 Tukey HSD result of 500lux modules

Tukey HSD						
(I) Module	(J) Module	Average change (I-J)	Standard error	significance	95% Confidence Interval	
					Lower	Upper
T8	T5	5.00000*	2.03850	.042	.1392	9.8608
	LED	5.60000*	2.03850	.020	.7392	10.4608
T5	T8	-5.00000*	2.03850	.042	-9.8608	-.1392
	LED	.60000	2.03850	.953	-4.2608	5.4608
LED	T8	-5.60000*	2.03850	.020	-10.4608	-.7392
	T5	-.60000	2.03850	.953	-5.4608	4.2608
*<. 0.05 significance						

By the ANOVA analysis showed that both the illumination of 500Lux and 200Lux of indoor environment, the three artificial light modules groups are significant. Through Tukey test, T8 fluorescent light to T5 fluorescent light and white LED lights are significant difference; T5 fluorescent light and white LED light are no significant difference.

Next figure is the box figure. It shows the difference in the subjective psychological visual fatigue questionnaire. Most of the data are in non-deviation from the value between the maximum and minimum observed values, only a few samples a larger degree of dispersion.

Table 2-20 200lux modules of visual fatigue statistics

Paired-Sample statistics				
200lux	Average	Integer	Standard deviation	Standard error
B Questionnaire	15.7333	30	9.22864	1.68491
D Questionnaire	10.2667	30	8.04270	1.46839
F Questionnaire	9.5000	30	9.20551	1.68069

Table 2-21 Tukey HSD result of 200lux modules

Tukey HSD						
(I) Module	(J) Module	Average change (I-J)	Standard error	significance	95% Confidence Interval	
					Lower	Upper
T8	T5	5.46667*	2.28324	.049	.0223	10.9110
	LED	6.23333*	2.28324	.021	.7890	11.6777
T5	T8	-5.46667*	2.28324	.049	-10.9110	-.0223
	LED	.76667	2.28324	.940	-4.6777	6.2110
LED	T8	-6.23333*	2.28324	.021	-11.6777	-.7890
	T5	-.76667	2.28324	.940	-6.2110	4.6777
*<. 0.05 significance						

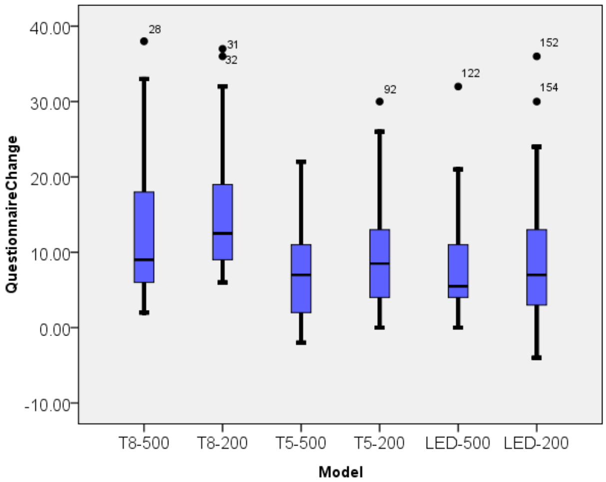


Fig. 2-13 Box of each module for subjective visual fatigue

Shown in Fig. 2-14, subjects generally agreed that the subjective visual fatigue in 200lux illumination environment higher than 500lux environment, each the difference between are 2.5, 1.64 and 1.80. In the lightings types T5 fluorescent and white LED lights have a higher rating in subjective visual fatigue, and T8 fluorescent light make the subjects feel most tired.

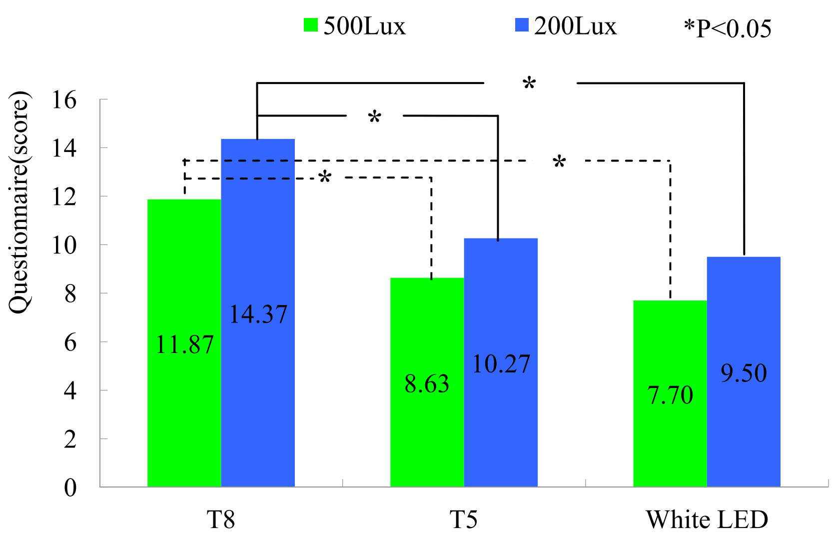


Fig. 2-14 Questionnaire result of each module change

Shown in Fig. 2-15, in the six modules, after one hour VDT working, subjects generally feel visual fatigue and dry eyes. Headache is not much response in these modules.

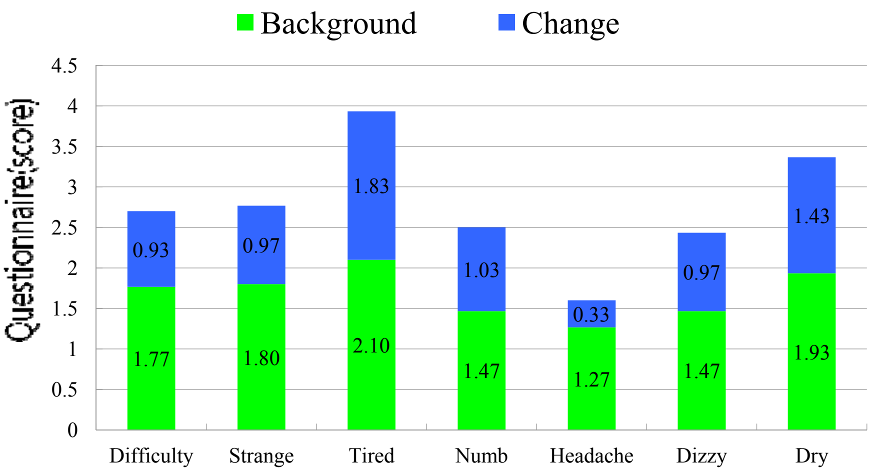


Fig. 2-15 Questionnaire result of each question

2-6 Results of Objective Physical Visual Fatigue

This section mainly discusses the different indoor artificial lighting environment for the users who are in VDT working of objective physiological VDT visual fatigue reactions. The previous section has considered the subjects psychological visual fatigue, and understand the different indoor artificial light environment on the psychological perception of the impact assessment. Now this section will further consider the reaction of the objective physiological differentia in visual fatigue.

In this experiment, this study is used the critical fusion frequency which make by SIBATA company. Each experiment costs 90 minutes which including 30 minutes for dark Adaptation and 60 minutes for VTS and VDT working. Before each experiment starting, the subject must take the CFF test, and it also take after experiment ending. There are 30 subjects who are students in the college or graduate school, and age is between 18 to 29 years old.

2-6-1 Objective Physiological Changes of Visual Fatigue with T8 Fluorescent Light

In the T8 fluorescent light modules, there are two modules which are A module (500lux) and B module (200lux).

Table 2-22 T-test of physical visual fatigue in T8 fluorescent light

Paired-Sample test							
T8 fluorescent	Variance					t	significance
	Arithematic mean	Standard deviation	Standard error	95% Confidence Interval			
				Lower	Upper		
A I - A II	2.39422	1.41769	.25883	1.86485	2.92360	9.250	**
B I - B II	1.31011	1.30493	.23825	.82284	1.79738	5.499	**
A - B	1.08411	1.42365	.25992	.55251	1.61571	4.171	**
*P<0.05 **P<0.01							

Results from the next Fig. 2-16 shows when indoor use of T8 fluorescent lighting, the physiological visual fatigue of A module (500lux) is obviously higher than B module (200lux). Before A module in the 500lux experiment starting, the average frequency in CFF of physiological visual fatigue is 45.52 Hz, and the average frequency is 43.13 Hz after A module experiment end. Overall average of CFF frequency decrease 2.39 Hz in A modules. Before B module in the 200lux experiment starting, the average frequency in CFF of physiological visual fatigue is 44.51 Hz, and the average points are 42.98 Hz points after B module experiment end. Overall average of CFF frequency decrease 1.53 Hz in B modules.

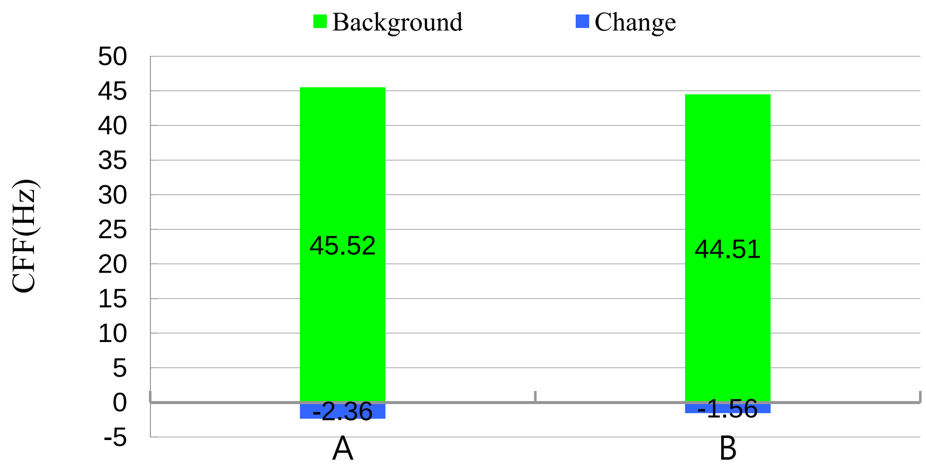


Fig. 2-16 CFF change of A and B module with T8

Therefore, under T8 fluorescent lighting illumination, after 1 hour of VDT working, there are significant difference between A and B module. Not only the CFF Hz of A module general difference higher than B module, but also that show the subjects feel more fatigue in 500lux than 200lux under T8 artificial lighting illumination.

2-6-2 Objective Physiological Changes of Visual Fatigue with T5 Fluorescent Light

In the T5 fluorescent light modules, there are two modules which are C module (500lux) and D module (200lux).

Table 2-23 T-test of physical visual fatigue in T5 fluorescent light

Paired-Sample test							
T5 fluorescent	Variance					t	significance
	Arithematic mean	Standard deviation	Standard error	95% Confidence Interval			
				Lower	Upper		
C I - C II	1.45706	1.33120	.24304	.95998	1.95414	5.995	**
D I - DII	.68706	1.75215	.31990	.03279	1.34132	2.148	*
C - D	.77000	1.69563	.30958	.13684	1.40316	2.487	*
*P<0.05 **P<0.01							

Results from Fig. 2-17 shows when indoor use of T5 fluorescent lighting, the physiological visual fatigue of C module (500lux) is obviously higher than D module (200lux). Before C module in the 500lux experiment starting, the average frequency in CFF of physiological visual fatigue is 44.54 Hz, and the average frequency is 43.08 Hz after C module experiment end. Overall average of CFF frequency decrease 1.46 Hz in C modules. Before D module in the 200lux experiment starting, the average frequency in CFF of physiological visual fatigue is 43.46 Hz, and the average points are 42.77 Hz points after D module experiment end. Overall average of CFF frequency decrease 0.69 Hz in D modules.

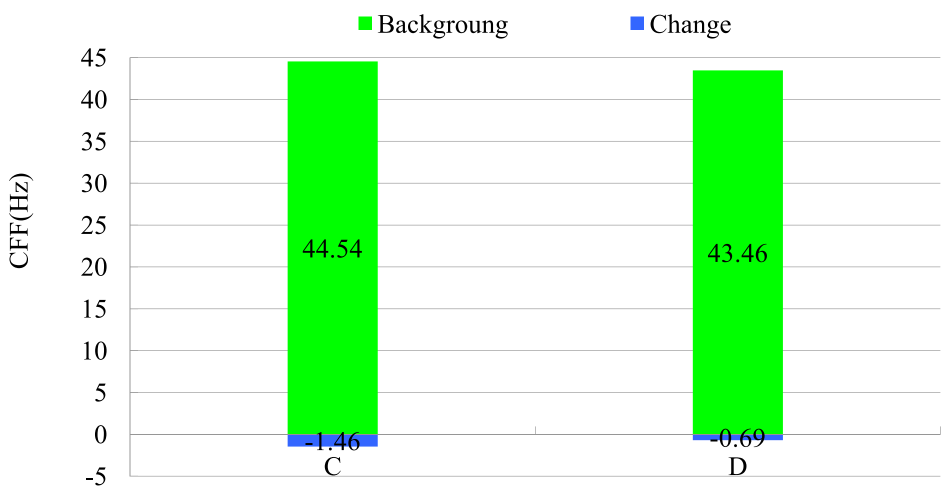


Fig. 2-17 CFF change of C and D module with T5

Therefore, under T5 fluorescent lighting illumination, after 1 hour of VDT working, there are significant difference between C and D module. Not only the CFF Hz of C module general difference higher than D module, but also that show the subjects feel more fatigue in 500lux than 200lux under T5 artificial lighting illumination.

2-6-3 Objective Physiological Changes of Visual Fatigue with White LED Light

In the white LED light modules, there are two modules which are E module (500lux) and F module (200lux).

Results from the Fig. 2-18 shows when indoor use of white LED lighting, the physiological visual fatigue of E module (500lux) is obviously higher than F module (200lux). Before E module in the 500lux experiment starting, the average frequency in CFF of physiological visual fatigue is 43.49 Hz, and the average frequency is 42.26 Hz after E module experiment end. Overall average of CFF frequency decrease 1.23 Hz in E modules. Before F module in the 200lux experiment starting, the average frequency in CFF of physiological visual fatigue is 43.79 Hz, and the average points are 43.21 Hz points after F module experiment end. Overall average of CFF frequency decrease 0.58 Hz in F modules.

Table 2-24 T-test of physical visual fatigue in white LED light

Paired-Sample test							
White LED	Variance					t	significance
	Arithematic mean	Standard deviation	Standard error	95% Confidence Interval			
				Lower	Upper		
E I - E II	1.23167	1.23962	.22632	.76879	1.69455	5.442	**
F I - F II	.58306	1.14078	.20828	.15708	1.00903	2.799	**
E - F	.63194	1.06683	.19478	.23358	1.03030	3.244	**
*P<0.05 **P<0.01							

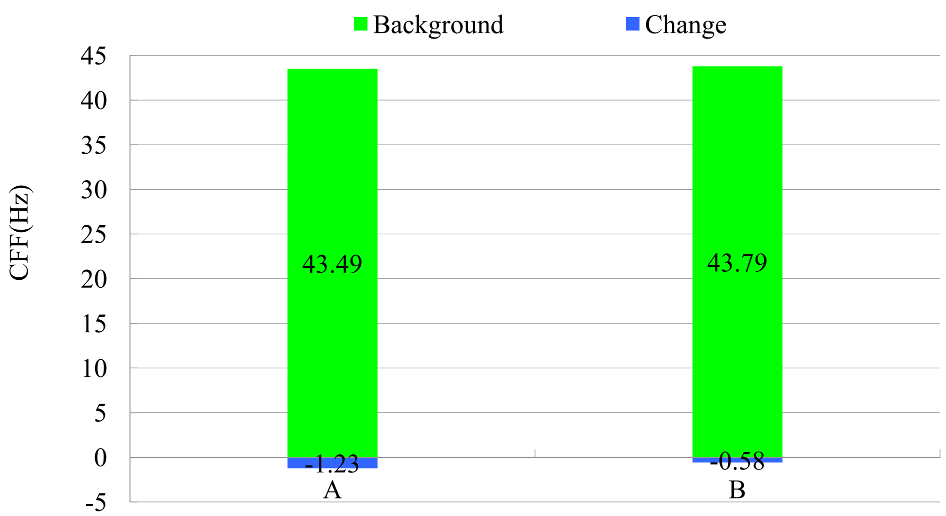


Fig. 2-18 CFF change of E and F module with white LED

Therefore, under white LED lighting illumination, after 1 hour of VDT working, there are significant difference between E and F module. Not only the CFF Hz of E module general difference higher than F module, but also that show the subjects feel more fatigue in 500lux than 200lux under white LED lighting illumination.

2-6-4 Objective Physical Evaluation of Visual Fatigue

This section will compare A, C, E modules of lighting illumination 500lux, and B, D, F modules of lighting illumination 200lux. By comparing the six modules, the most comfortable module will be found.

1. **Comparison statistics of 500lux module with T8 fluorescent light, T5 fluorescent light and white LED light.**

The following table is the results by SPSS ANOVA analysis software to calculate the A, C, and E modules.

Table 2-25 Tukey HSD result of 500lux modules

Tukey HSD						
(I) Module	(J) Module	Arithematic mean	Standard deviation	Standard error	95% Confidence Interval	
					Lower	Upper
T8	T5	.93717*	.34379	.021	.1174	1.7569
	LED	1.16256*	.34379	.003	.3428	1.9823
T5	T8	-.93717*	.34379	.021	-1.7569	-.1174
	LED	.22539	.34379	.790	-.5944	1.0451
LED	T8	-1.16256*	.34379	.003	-1.9823	-.3428
	T5	-.22539	.34379	.790	-1.0451	.5944
*<. 0.05 significance						

By the results, there is significant differentia in A module which compared with C and E modules, but C and E modules are no more different. According to the data show, the subjects feel physiological visual fatigue the most by using T8 fluorescent lightings in the 500lux environment. T5 fluorescent lightings and white LED lamp for 500lux environment are no significant difference.

2. Comparison statistics of 200lux module with T8 fluorescent light, T5 fluorescent light and white LED light.

The following table is the results by SPSS ANOVA analysis software to calculate the B, D, and F modules.

Table 2-26 Tukey HSD result of 200 Lux modules

Tukey HSD						
(I) Module	(J) Module	Arithematic mean	Standard deviation	Standard error	95% Confidence Interval	
					Lower	Upper
T8	T5	.84706*	.35404	.049	.0029	1.6913
	LED	.95106*	.35404	.023	.1069	1.7953
T5	T8	-.84706*	.35404	.049	-1.6913	-.0029
	LED	.10400	.35404	.954	-.7402	.9482
LED	T8	-.95106*	.35404	.023	-1.7953	-.1069
	T5	-.10400	.35404	.954	-.9482	.7402
*<. 0.05 significance						

By the results, there is significant differentia in B module which compared with D and F modules, but D and F modules are no more different. According to the data show, the subjects feel physiological visual fatigue the most by using T8 fluorescent lightings in the 200lux environment. T5 fluorescent lightings and white LED lamp for 200lux environment are no significant difference.

3. Results of objective physical visual fatigue with T8 fluorescent light, T5 fluorescent light and white LED light.

Through the 30 subjects’s average data and statistical test, it show that subjects feel physiological visual fatigue easier in 500Lux illumination environment than 200lux in the three different types lightings. In the evaluation of lightings, when the users are in VDT working, they feel the most fatigue in T8 fluorescent lightings, and the second is T5 fluorescent s, and white LED lighting is the best for users in VDT working space. Because the starter of T8 fluorescent is used traditional ballast, the lighting flicker frequency is lower than T5 fluorescent and LED and causes visual fatigue easily. It is called “strobe effect”. T5 frequency is used electrical ballast. The flicker frequency is very high that human cannot feel that. LED is used DC to make light continue, no flicker. Therefore, human feel visual fatigue under T8 lighting easier than T5 frequency and LED.

From the above table, all modules in CFF were significant less than 0.05, and almost of the data are in non-deviation from the value between the maximum and minimum observed values, only a few samples a larger degree of dispersion.

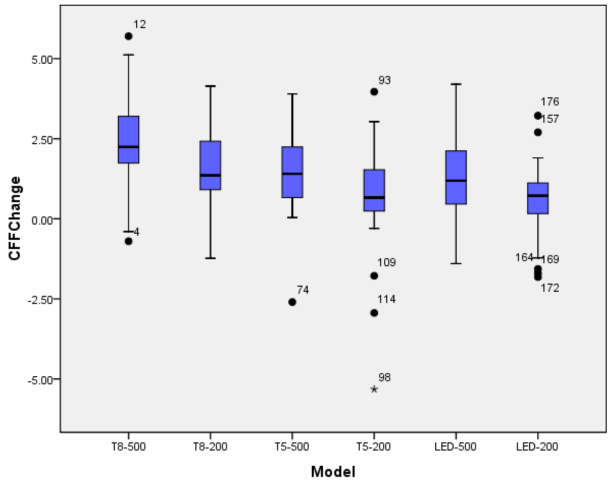


Fig. 2-19 Box of each module for CFF

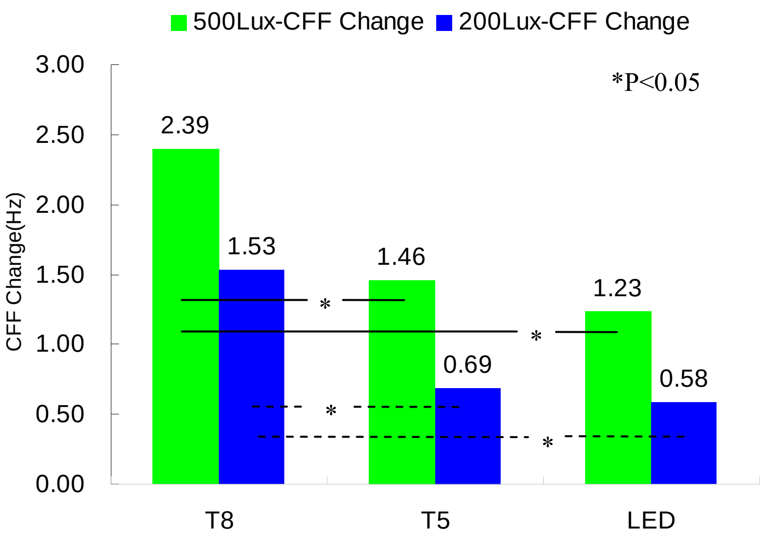


Fig. 2-20 CFF result of each module

2-7 Result of Productivity in Different Artificial Light Sources

This section study human's productivity under different artificial light sources in an hour VDT working. This study use VTS system software to test to assess subjects' performance of the work. The focus will be to COG, RT, ALS and VIGI.

2-7-1 Result of COG in Different Artificial Light Sources

During one hour VDT working, there are twice COG tests in this experiment. In order to make the score in the same scale, the raw score is converted to T score by standard deviation.

1. Result of COG in T8 fluorescent light

In the twice COG test, A module got 99.66 points and B module got 98.89 points. In terms of individual scores, A module in the first test was 49.63 points, the second was 50.03 points, B module in the first test was 47.83 points, the second was 51.06 points. A module performance is better than B module. Therefore, the performance of COG, , subjects have better performance of COG in 500Lux environment of T8 fluorescent lighting, but subjects may got attention raising in 200Lux.

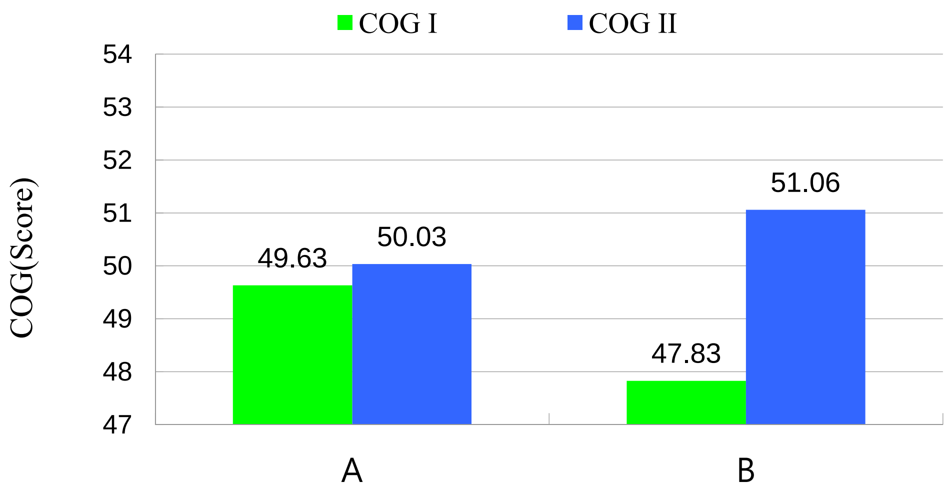


Fig. 2-21 Result of COG in T8 fluorescent light

2. Result of COG in T5 fluorescent light

In the twice COG test, C module got 97.96 points and D module got 97.42 points. In terms of individual scores, C module in the first test was 48.87 points, the second was 49.09 points, D module in the first test was 49.18 points, and the second was 48.24 points. C module performance is better than D module. Therefore, the performance of COG, subjects have better performance of COG in 500lux environment of T5 fluorescent lighting, and may got attention raising.

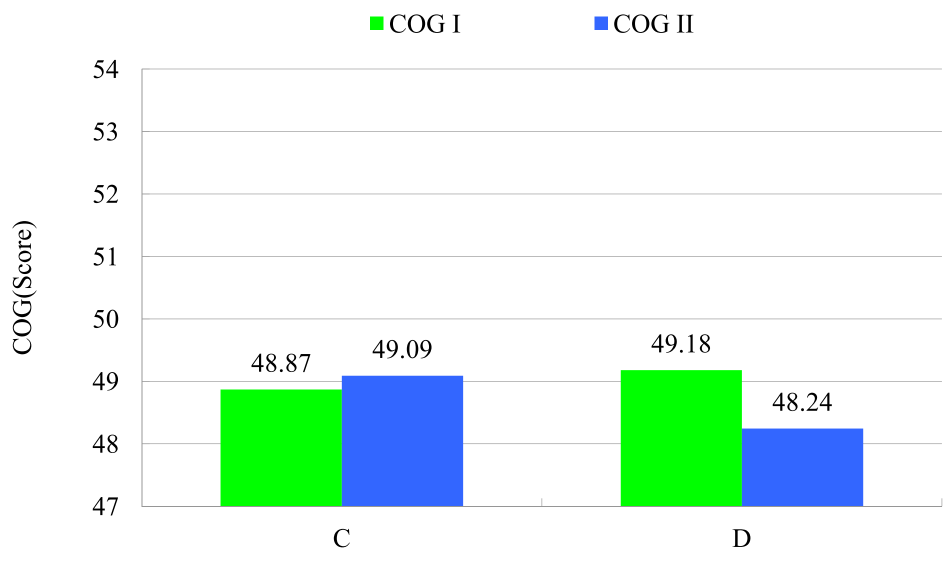


Fig. 2-22 Result of COG in T5 fluorescent light

3. Result of COG in white LED light

In the twice COG test, E module got 104.07 points and F module got 100.01 points. In terms of individual scores, E module in the first test was 51.72 points, the second was 52.35 points, F module in the first test was 49.37 points, and the second was 50.64 points. E module performance is better than F module. Therefore, the performance of COG, subjects have better performance of COG in 500lux environment of white LED lighting, but subjects may got attention raising in 200lux.

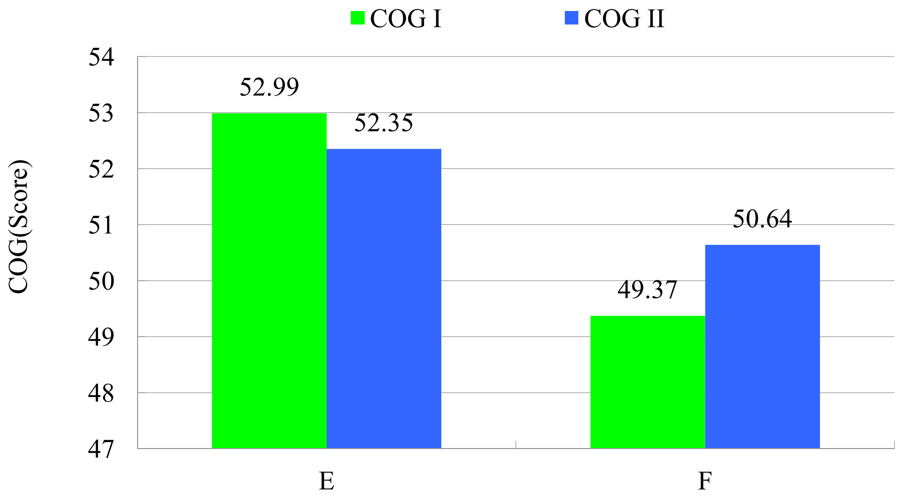


Fig. 2-23 Result of COG in white LED light

4. Comparison Result of COG in each module

COG use geometric transformations to test subjects' performance of the concentration. In the three lightings of study, white LED lights is the best lighting for COG, the second is T8 fluorescent lightings, T5 fluorescent lightings is the worst performance. However, only performance of white LED lightings is significant in T test, but T8 and T5 fluorescent lightings are not much difference in statistical. In the illumination, in addition to T5 fluorescent lightings, T8 fluorescent and white LED lightings both can improve the performance of concentration.

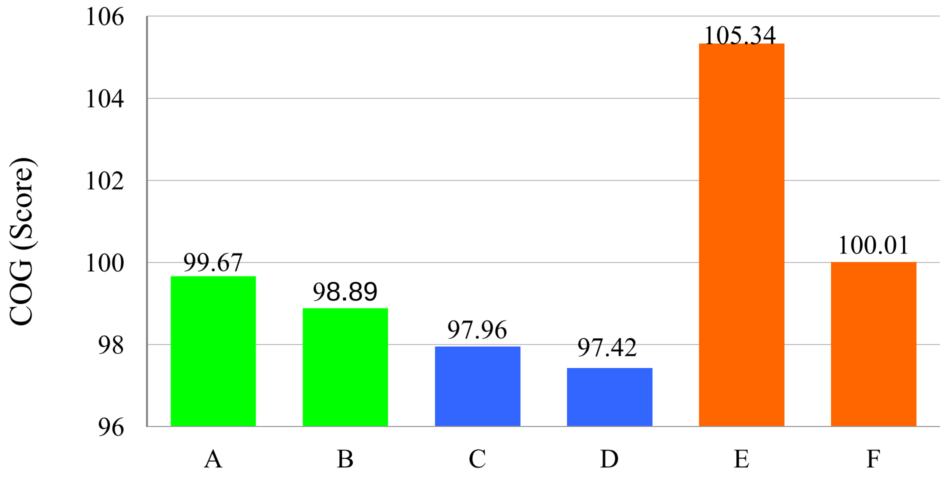


Fig. 2-24 Result of COG in each module

2-7-2 Result of COG in Different Artificial Light Sources

In one hour VDT working test, this study was preceded twice RT test.

1. Result of RT in T8 fluorescent light

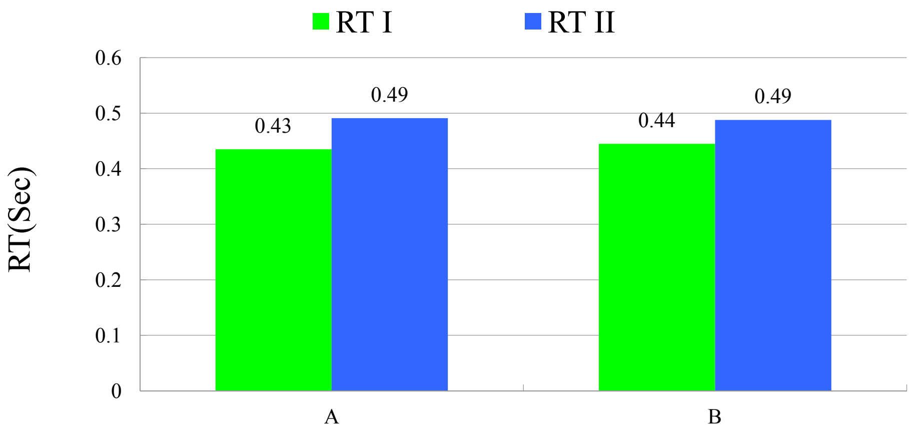


Fig. 2-25 Result of RT in T8 fluorescent light

The first stage in the A module and B module, the RT of A module is faster than B module. But after 6 min, A and B module both manifest later than before. A module is late for 0.06s and B module is late for 0.05. Therefore, whatever which modules, when the subjects are in the VDT working, the reaction time must be late, and in this study A module become a little later than B module, the average time is 0.01 sec.

2. Result of RT in T5 fluorescent light

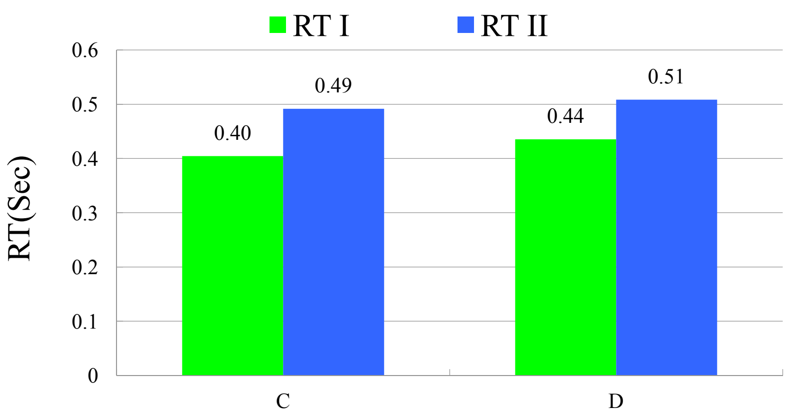


Fig. 2-26 Result of RT in T5 fluorescent light

The first stage in the C module and D module, the RT of C module is faster than E module. But after 6 mins, C and D module both manifest later than before. C module is late for 0.09s and B module is late for 0.07. Therefore, whatever which modules, when the subjects are in the VDT working, the reaction time must be late, and in this study C module become a little later than D module, the average time is 0.02 sec.

3. Result of RT in white LED light

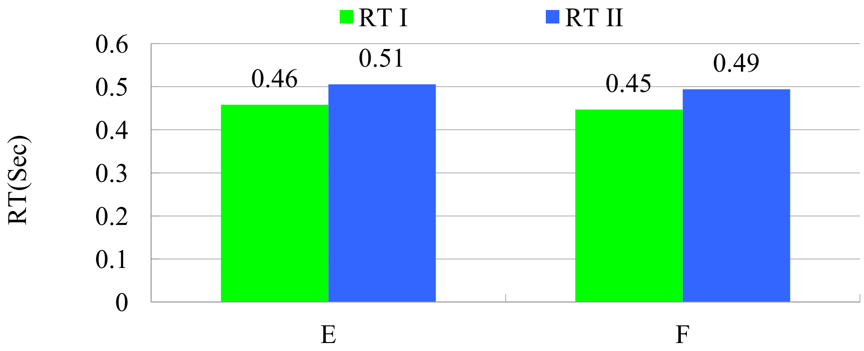


Fig. 2-27 Result of RT in white LED light

The first stage in the E module and F module, the RT of E module is faster than F module. But after 6 min, C and D module both manifest later than before. C module is late for 0.05s and B module is late for 0.04. Therefore, whatever which modules, when the subjects are in the VDT working, the reaction time must be late, and in this study E module become a little later than F module, the average time is 0.01 sec.

4. Comparison Result of RT in each module

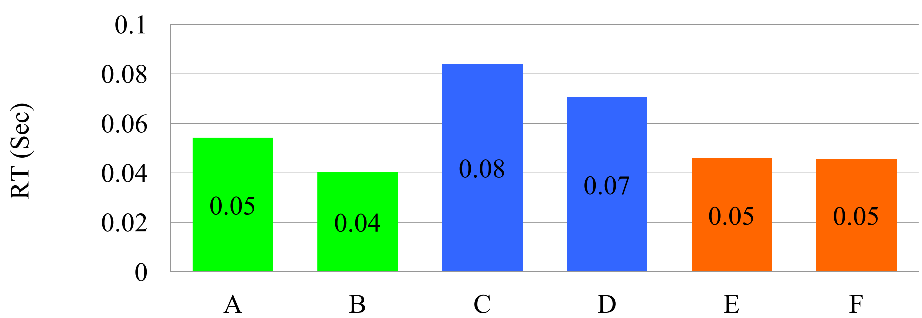


Fig. 2-28 Result of RT in each module

In the Fig. 2-28, C module become the lastest in this study, average time is 0.084. At the same time, 500lux modules are later than 200lux, it mean the subject's reaction time ability in the 200Lux got better. In the other hand, white LED is the best in reaction time, the second is T8, and the last is T5.

2-7-3 Result of VIGIL in Different Artificial Light Sources

During one hour VDT working, this study use VIGIL test in 25 minutes to assess the subject's alert ability.

1. Result of VIGIL in T8 fluorescent light

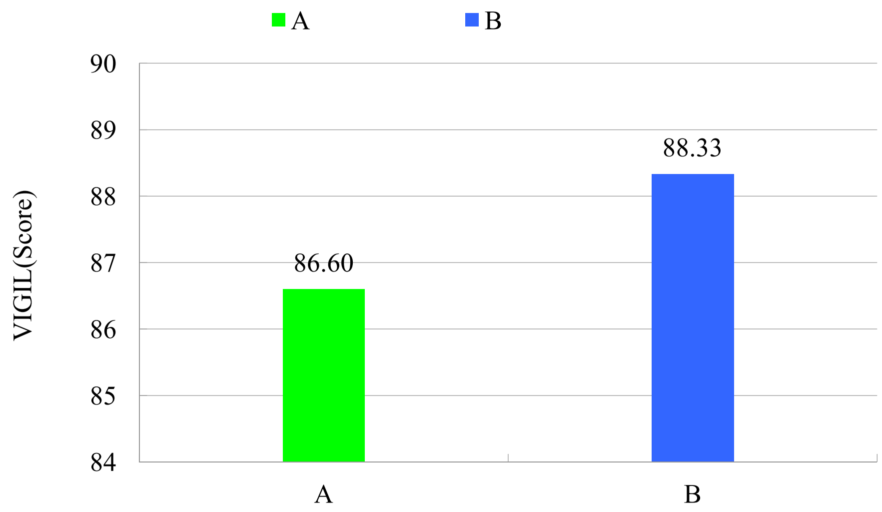


Fig. 2-29 Result of VIGIL in T8 fluorescent light

In this study with T8 fluorescent, B modules show the performance of correct responses than A module, with an average increasing 1.73%. In error response, A module has error 2.33 times of average and B module has error 1.34 times of average. In the reaction time, A module is 0.626 seconds of average, and B module is 0.584 seconds of average. B module is faster than A module with 0.042 seconds. Therefore, in the T8 fluorescent lighting space with 200lux, subjects have better performance than 500Lux in response accuracy, errors reaction, and reaction times.

2. Result of VIGIL in T5 Fluorescent Light

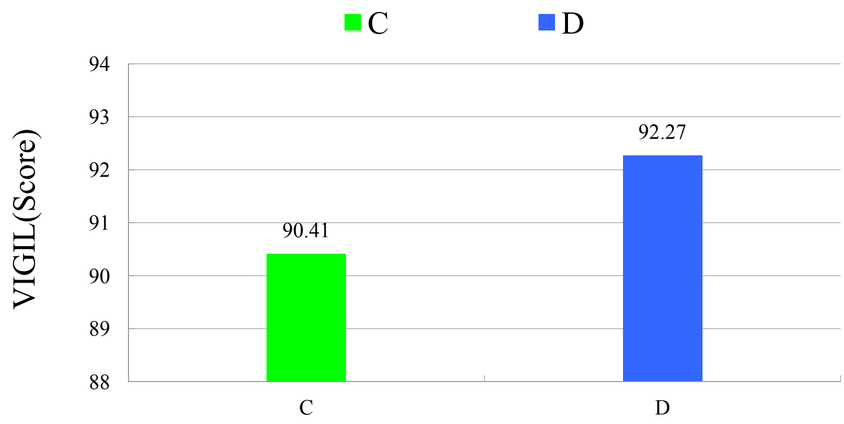


Fig. 2-30 Result of VIGIL in T5 fluorescent light

In this study with T5 fluorescent, D modules show the performance of correct responses than C module, with an average increasing 1.86%. In error response, C module has error 2.53 times of average and D module has error 2.37 times of average. In the reaction time, C module is 0.568 seconds of average, and D module is 0.499 seconds of average. D module is faster than C module with 0.069 seconds. Therefore, in the T5 fluorescent lighting space with 200lux, subjects have better performance than 500lux in response accuracy, errors reaction, and reaction times.

3. Result of VIGIL in white LED light

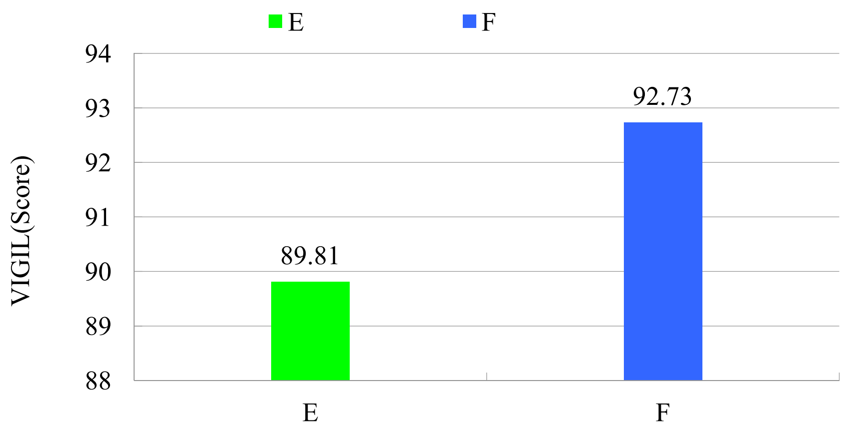


Fig. 2-31 Result of VIGIL in white LED light

In this study with white LED, F modules show the performance of correct responses than E module, with an average increasing 2.92%. In error response, E module has error 2.83 times of average and F module has error 2.79 times of average. In the reaction time, E module is 0.531 seconds of average, and F module is 0.524 seconds of average. D module is faster than C module with 0.007 seconds. Therefore, in the white LED space with 200Lux, subjects have better performance than 500Lux in response accuracy, errors reaction, and reaction times, but the range is too little.

4. Comparison Result of VIGIL in each module

In these six modules, F module (white LED lighting in 200lux) is the best choice in the VIGIL, and the response accuracy is 92.73%. A module (T8 fluorescent lighting in 500lux) is the worst choice in the VIGIL, and the response accuracy is 86.60%. Therefore, white LED light is the best choice in VIGIL in VDT working, and the working space with 200Lux is better than 500%.

2-7-4 Result of ALS in Different Artificial Light Sources

ALS test is operated in last ten minutes in VDT working. The question is simple single digit addition. In the ten minutes, subjects must do his best to finish the question until time is up. This study use ALS test to get accuracy ratio compare the productivity.

1. Result of ALS in T8 fluorescent light

Through the T-score translate, A module got 48.24 points, and is finished 466.59 of questions in ten minutes. B module got 49.23 points, and is finished 474.50 of correct question in ten minutes. In the in accuracy ratio, A module is 1.61% and B is 1.52%. Therefore, the ALS performance is better in 200lux than 500lux with T8 fluorescent lighting.

2. Result of ALS in T5 fluorescent light

Through the T-score translate, C module got 48.62 points, and is finished 447.59 of questions in ten minutes. D module got 50.02 points, and is finished 461.93 of correct question in ten minutes. In the in accuracy ratio, C module is 1.37% and D is 1.21%. Therefore, the ALS performance is better in 200lux than 500lux with T5 fluorescent lighting.

3. Result of ALS in white LED light

Through the T-score translate, E module got 48.91 points, and is finished 450.55 of questions in ten minutes. F module got 50.79 points, and is finished 469.93 of correct question in ten minutes. In the in accuracy ratio, E module is 1.49% and B is 1.40%. Therefore, the ALS performance is better in 200lux than 500lux with white LED lighting.

4. Comparison Result of ALS in each module

Depending on T-score, white LED is the best lighting in the ALS test, and T8 fluorescent is the worst. At the same time, 200lux space is better than 500lux in the ALS test.

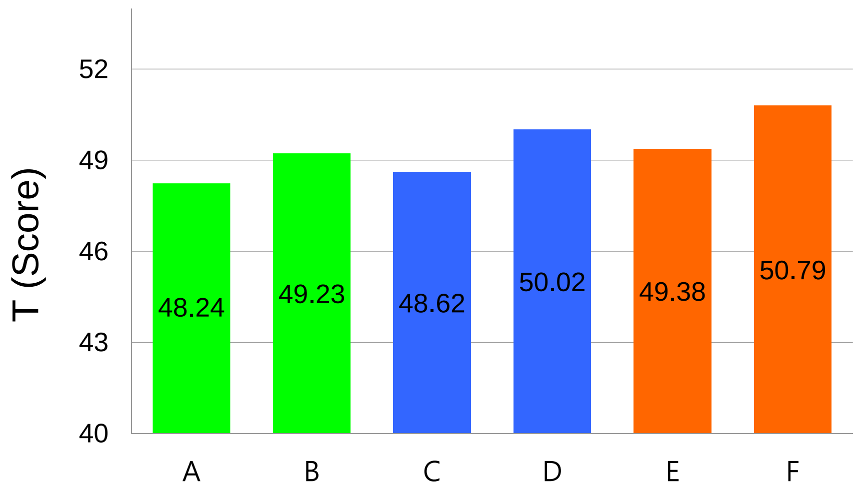


Fig. 2-32 Result of ALS in each module

2-7-5 Assess to Productivity of Different Artificial Light Sources

This study used VTS measures to evaluate productivity, in which reaction time was separated from COG, VIGIL and ALS, which were all transformed into a T-score for integrated evaluation of productivity under the same criterion, as indicated in Table 2-27.

Table 2-27 VTS performance scores

	COG			VIGIL	ALS	Sum	RT			
	I	II	Sum				I	II	III	Sum
A	49.63	50.03	99.67	46.54	48.24	194.45	0.435	0.491	0.626	1.552
B	47.83	51.06	98.89	48.29	49.23	196.41	0.445	0.488	0.584	1.517
C	48.87	49.09	97.96	50.39	48.62	196.97	0.405	0.492	0.568	1.465
D	49.18	48.24	97.42	52.27	50.02	199.71	0.435	0.508	0.499	1.442
E	51.72	52.35	104.07	49.77	48.91	202.75	0.458	0.506	0.531	1.495
F	49.37	50.64	100.01	52.43	50.79	203.23	0.447	0.494	0.524	1.465

The integrated comparison of each experimental variation for productivity in terms of COG, VIGIL and ALS (as shown in Fig. 2-33) indicated that the overall performance of the white LED module was better after summing up the performance of each item. For illumination performance, the 200lux indoor environment was generally better than the 500lux environment. There was a 2.74 difference between the 200lux and 500lux conditions for the T5 fluorescent lamps, whereas the white LED lights had a 0.48 difference.

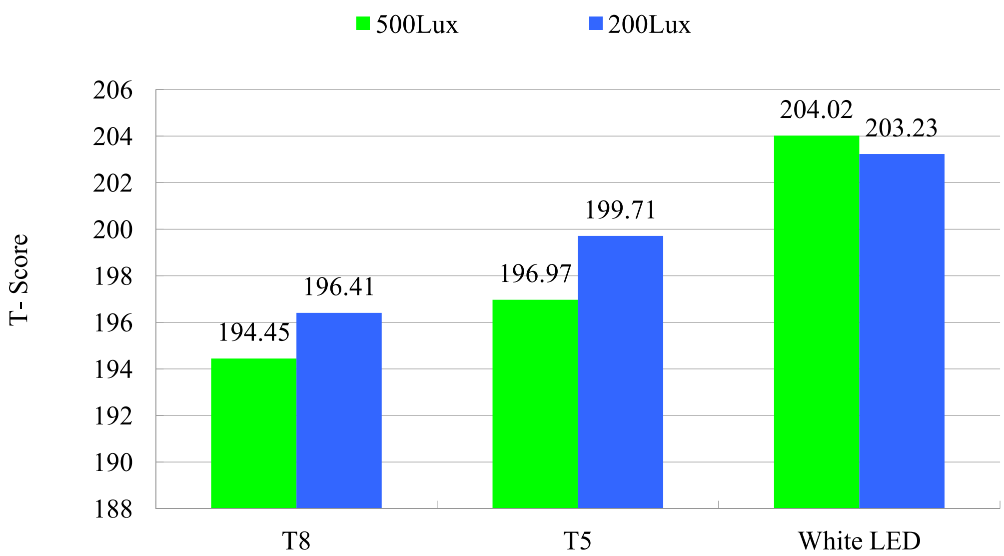


Fig. 2-33 Productivity comparisons of the four variations

This means that the white LED lighting environment can provide more stable productivity. The analysis of reaction time indicated that the white LED lights had better performance than the T5 fluorescent lamps, while for illumination performance, the 200lux indoor environments were also better than the 500lux environments, as indicated in Fig. 2-34.

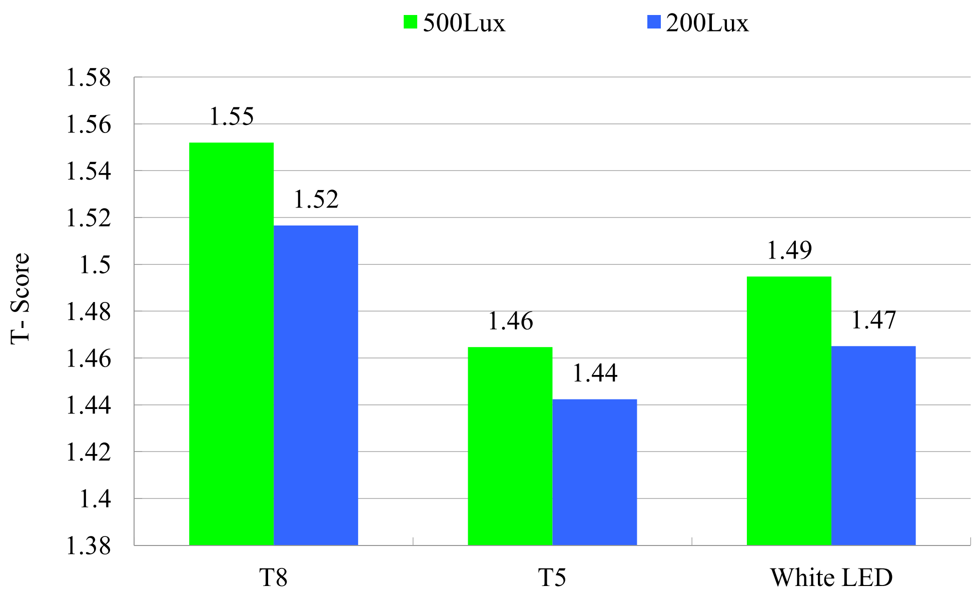


Fig. 2-34 Comparison of the reaction time of the four variations

2-8 Comprehensive Assessment and Conclusion

In the indoor environments of the two kinds of light mentioned in the SVF questionnaire, the values of 200lux were higher than those of 500lux, indicating that the subjects generally thought that it was easier for their eyes to become tired in the 200lux environment. However, the CFF values in the 500lux environment were much higher than those in the 200lux environment, which also indicates that it was easier for the subjects' eyes to become tired in the 500lux environment.

Consequently, the SVF and OVF results were totally different (as shown in Fig. 2-35).

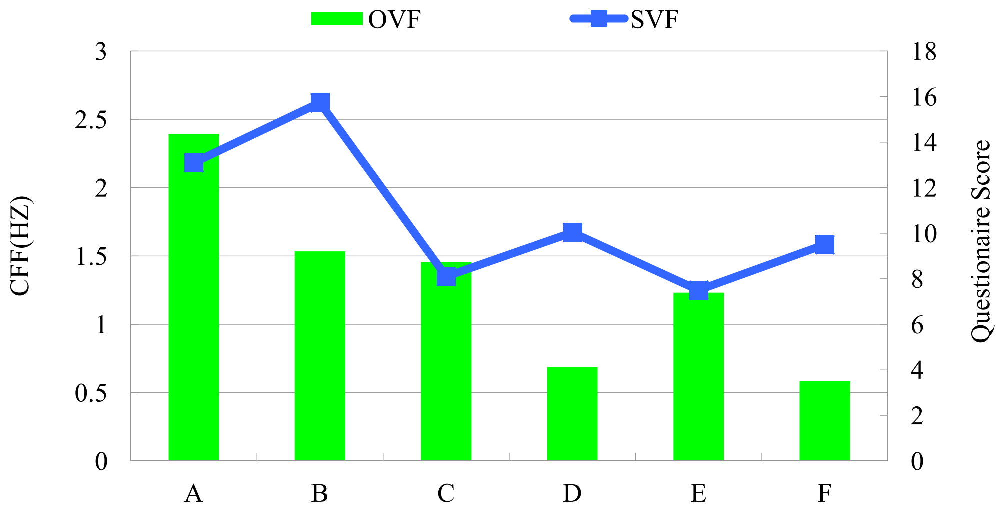


Fig. 2-35 Comparison of SVF and OVF for the four variations

For the two lighting categories, the correlation of the differences between the SVF questionnaire and VTS performance was consistent (as shown in Fig. 2-36). Performance under the T8, T5 fluorescent lamps and white LED lights was nearly equal in the subjective questionnaire. Moreover, the white LED lights produced better productivity than the T8 and T5 fluorescent lamps. In the 200lux indoor environment, however, productivity was better, but the difference of the SVF questionnaire was higher, indicating that productivity increased when SVF was more serious. The correlation of both shows an opposite tendency.

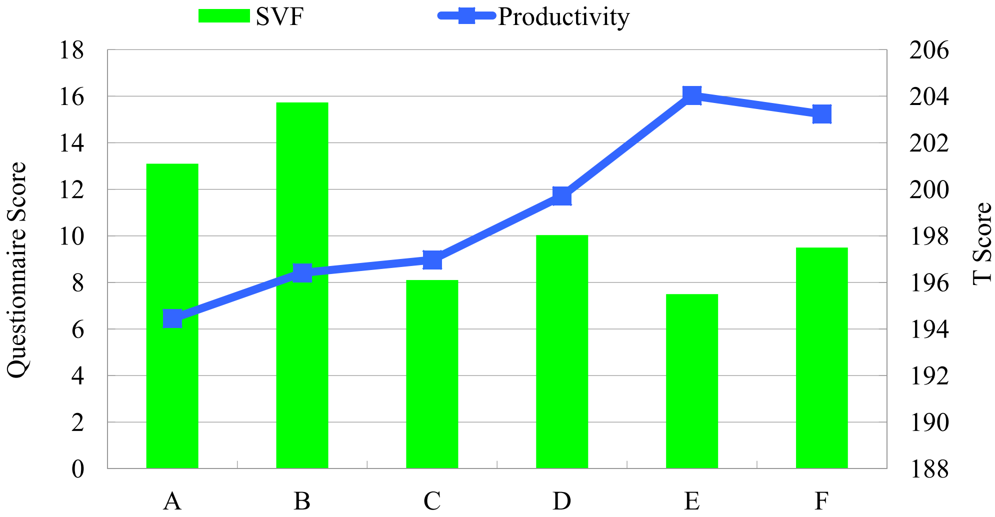


Fig. 2-36 Comparison of the SVF questionnaire and VTS performance

For reaction time, when the subjects felt that their fatigue increased, their reaction time slowed down accordingly. The illumination performance, however, still showed opposite results. The subjects subjectively felt that the 200lux indoor illumination was more tiring, although their reaction time did not slow down accordingly; in fact, they became faster and more effective (as indicated in Fig. 2-37). When the CFF values were higher, productivity was worse, also indicating that the subjects were more tired. Therefore, performance under the white LED lights was more outstanding than under the T5 fluorescent lamps.

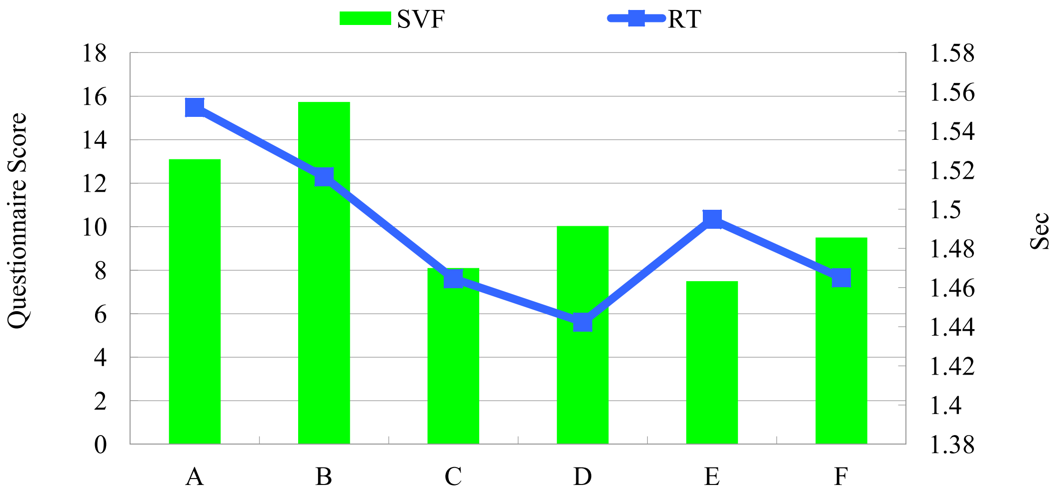


Fig. 2-37 Comparison of the SVF questionnaire and RT performance

However, performance was quite close in terms of CFF. The before and after experiment differences of white LED lights were slightly lower than those of T5 fluorescent lamps, but VTS performance for productivity increased dramatically (as indicated in Fig. 2-38).

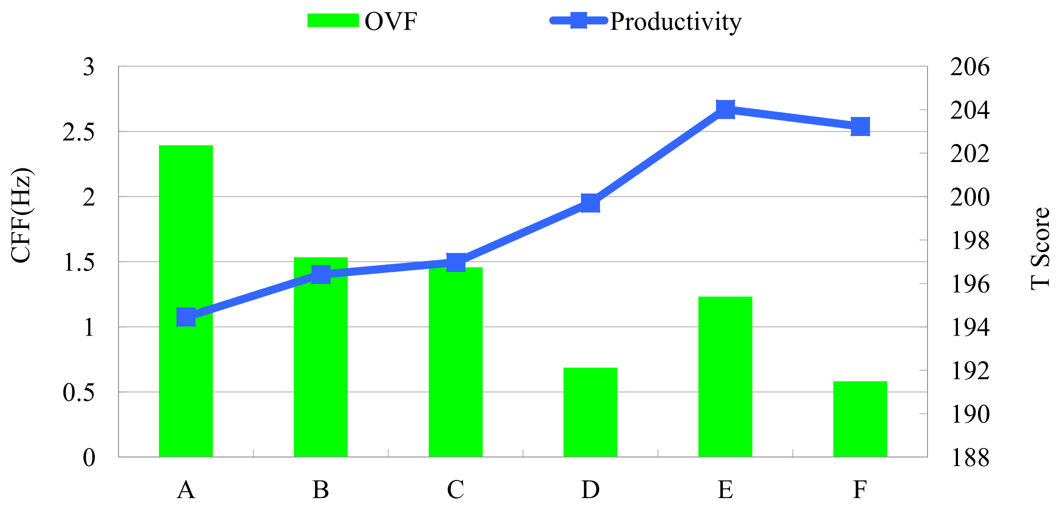


Fig. 2-38 CFF and VTS performance results

Reaction time increased when the CFF value increased. This shows that reaction time under the 200lux lighting was quicker than under the 500lux lighting (as indicated in Fig. 2-39).

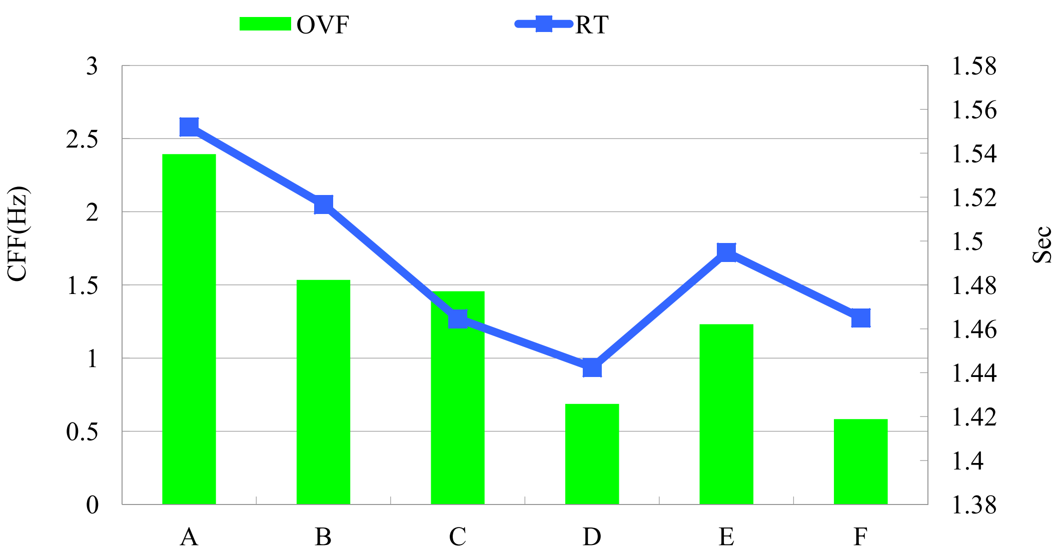


Fig. 2-39 CFF and RT performance results

The correlation analysis indicated that 0.469 was the correlation of the coefficient between the subjective and objective fatigue values, which is regarded as a medially positive correlation in statistics, indicating that both are positively correlated in the measurement of visual fatigue. Furthermore, the correlation coefficient between the SVF questionnaire and VTS performance was -0.641, which is regarded as a highly negative correlation in statistics, indicating that when SVF increases, productivity decreases accordingly. The correlation coefficient between CFF and VTS was -0.817, which is close to a completely negative correlation, and both are simultaneously significant. This indicates that productivity obviously decreased when CFF increased, as indicated in Table 2-28.

Table 2-28 Correlation of coefficients between visual fatigue and productivity

Correlation				
		CFF	Questionnaire	VTS
CFF	Pearson correlation	1	.469	-.817*
	Significance (two-tailed test)*		.348	047
Questionnaire	Pearson correlation	.469	1	-.641
	Significance (two-tailed test)*	.348		.170
VTS	Pearson correlation	-.817*	-.641	1
	Significance (two-tailed test)*	.047	.170	

Note: *The coefficient level reached 0.05 (two-tailed test).

2-9 Conclusions

When comparing subjective feelings in the 200lux and 500lux conditions, the visual fatigue of the 200lux environment is more serious than that of the 500lux environment in the experiment. However, we found that when working on a VDT for an hour with low luminance (30cd/m^2), the level of visual fatigue in the 200Lux lighting environment was not as serious as that in the 500lux environment, according to the CFF measurement. The results mentioned above highlight the conflict between subjective feeling and objective experiment, which is exactly the contribution made by this study regarding the influence on the productivity of VDT interaction from visual fatigue in the different artificial lighting environments. Therefore, better working performance occurs in the lower illumination environment of 200lux in this study, which means that the contrast of luminance between the surrounding environment and the low-luminance monitors for VDT use is suggested to be smaller in order to minimize the sources of reflected luminance, thus influencing OVF. On the contrary, a lighter environment creates higher luminance, and an increase in OVF might occur as a result. Our research also discovered that SVF does not directly result in OVF; hence, other measurements of visual fatigue are suggested for verification in the future. As for the choice of lamps and light bulbs, LED lighting causes less SVF than T8 and T5, and results in better productivity in a VDT working environment.

CHAPTER 3 OFFICE FIELD SURVEY IN JAPAN AND TAIWAN

CHAPTER 3 OFFICE FIELD SURVEY IN JAPAN AND TAIWAN

3-1 Introduction

There are 16~19% energy consumption for artificial lighting in office building[18]. According to result in Chapter 3, the 200lux horizontal illuminance is better than 500lux in visual fatigue and productivity for VDT working. Even the illuminance is low, but it is still good for visual and saving energy. But it is only in experiment space. As regards real lighting environment in Taiwanese offices and psychology evaluations have not research yet and there is no research recently in Taiwanese offices. On the other hand, after The Great East Japan Earthquake in 11th March, 2011, Japanese employees might be affected their psychology evaluations by the power-saving policies. The evaluations might be different between normal condition and power-saving condition. Therefore, in this chapter, the Taiwanese offices were used the same methods for survey and showed the results of Japanese offices and Taiwanese offices together. These results will be referred by next experiment in this thesis.

All results and data in Japanese office are referred from “The inpact of power-saving measures on office lighting in 2011” (Mochizuki et al. 2013) and “Field survey on light environment in office buildings under the limitation of electricity use due to the Great East Japan Earthquake” [19].

[18]照明学会：環境負荷低減と豊かな光環境の両立に向けて, JIER-104, 2009.
[19] 2011 年震災に伴うオフィス照明環境の実態調査 WG 2011 年夏期，中間期調査報告。

3-2 Measurement of Office Field Survey

This study was undertaken 12 offices in the Japan and 4 offices in the Taiwan. In Japan's data of the selected office buildings were collected from the original design documents including the building and floor layout drawings wherever possible. Further information was obtained through site visits and discussions with the members of Architectural Institute of Japan (AIJ). We tried to interpret what methods office used for energy saving and evaluate employees' perception in lighting environment after The Great East Japan Earthquake passing through 4 month.

Table 3-1 Summarizes the simple of survey

No.	A1	A2	B	C	D
Location	Kanagawa	Kanagawa	Tokyo	Tokyo	Tokyo
Date of survey	2011/7~8	2011/7~8	2011/8	2011/8~9	2011/9 月
No.	E	F	G	H	I
Location	Tokyo	Tokyo	Tokyo	Tokyo	Ibaraki
Date of survey	2011/9 月	2011/9	2011/9	2011/9~10	2011/10
No.	J	K	L	M	N
Location	Tokyo	Shizuoka	Tokyo	Hsinchu	Hsinchu
Date of survey	2011/9~10	2011/10	2011/11	2012/7~8	2012/7~8
No.	O	P	Q		
Location	Hsinchu	Hsinchu	Hsinchu		
Date of survey	2012/7~8	2012/7~8	2012/7~8		

3-2-1 Representative Day

In the real office, it was normal method to use daylight for energy saving. Zain-Ahmed et al. in 2002 mentioned that minimum energy savings of 10% can be achieved by using day lighting strategies alone and interior lighting environment might be affected by daylight via windows[61]. Therefore, verifying weather condition during measurement was confirmed. Regarding Japan Meteorological Agency and Taiwan Central Weather Bureau's climate statistics which was near meteorological station, this survey was divided into 3 parts(sunny day, cloudy day and night) due to the weather, cloudiness, sunshine duration, total solar radiation.

Sunny day is describe in sunshine duration above 9.2 hours, cloudiness above 7 and total solar radiation above 16.15MJ/m^2.

3-2-2 Illuminance Measurements

Illuminance measurements were recorded in each cubicle as possible. But some office was too big to measure it, we set zones in office and put illuminance meters in each zone. Illuminance measurements in this survey were horizontal illuminance, vertical illuminance and windows illuminance. These measurement was estimated illuminance automatically and continually per second in few days or two weeks until obtaining the datas of 3 kinds of weather in each office. Fig. 3-1 is a sample to show the site plane in survey.

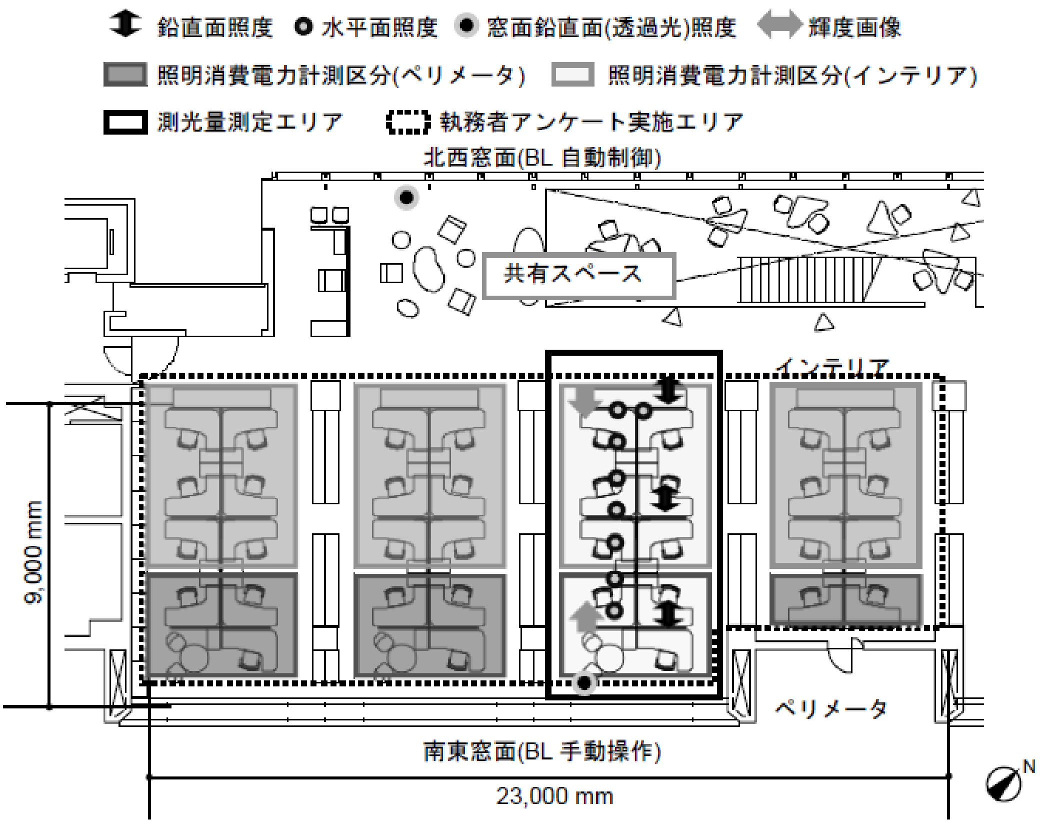


Fig. 3-1 Simple of survey for measurement zone and meter location

This thesis focus on horizontal illuminance, vertical illuminance and employees' psychology evaluations in Japanese office and Taiwanese office, luminance distribution and power consumption do not discuss in this chapter.

1. Horizontal illuminance

Measurement time was recorded in per minute during whole time in survey. It was difficult to put illuminance meter on each employee's task and obtained illuminance directly. There are two reasons: 1. Illuminance meters are not enough for each task plane. 2. Putting on task plane might make employees feel incontinent. In order to solve these two problems, illuminance meter was set on partition in front of each employee's task (If there is no partition in front of task, illuminance meter will be put on cube which is 40cm height). In principle, the nearest illuminance of illuminance meter will be adopted to replace illuminance on task plane. At the same time, task illuminance was also estimated by experimenter and created relation formula to describe task illuminance. Therefore, the speculation illuminance is calculated by relation formula.

2. Vertical illuminance

Vertical illuminance was also recorded in per minute during whole time in survey. It was set on the partition forward task plane to face the same direction and opposite direction with employees' sight.

3-2-3 Analysis Method for Illuminance

Representative illuminance was divided in sunny day, cloudy and night. Regarding night or office without windows, the illuminance was not affected by day lighting, so it was very stable. For representative illuminance at night adopted median horizontal illuminance in each hour. However sunny day and cloudy, horizontal and vertical illuminance changed very much in day, so median illuminance in each hour was also adopted and then chose median horizontal illuminance from last process in one day.

3-2-4 Questionnaire

There are five methods that can be used to measure subject's perceptual: ranking methods, rating methods, questionnaire methods, interviews and checklists. The questionnaire method is the most commonly used by general studies because it is the measure that shows most directly the subjects' feelings (Sinclair 1990). A simple and reliable questionnaire-based assessment method for occupant satisfaction regarding office lighting (Office Lighting Survey - OLS) was presented by Eklund and Boyce in 1996[51].

To Harvest employees' subject perceptual and energy saving, questionnaire was required and a good tool in the real office survey. Responses were made using 7-point scales in Brightness of task/Visibility of task /Visibility of monitor/Easiness of work/Satisfaction of task plan, Brightness of working space/Glare of windows/Glare of ceiling lighting/Glare of working space/ Satisfaction of working space and Productivity. Responses were made using 3-point scales in Utilization rate of task lighting, Visual fatigue/ weariness, Glare of windows/Glare of ceiling lighting/Glare of working space. The questions in the detailed questionnaire survey are in Table3-2:

Table 3-2 Questionnaire contents

Items	Contents
Subject's database	Responses date/Gender/Age
Environment of task plan	Category of work /Utilization rate of task lighting/Brightness of task/Visibility of task /Visibility of monitor/Easiness of work/Satisfaction of task plan
Environment of working space	Brightness of working space/Glare of windows/Glare of ceiling lighting/Glare of working space/ Satisfaction of working space
Effect of energy saving policy	Visual fatigue/ weariness /Productivity

3-3 Office Field Survey in Japan

3-3-1 Representative illuminance

Fig. 3-2 is the median horizontal illuminance in each office in sunny day, cloudy and night.

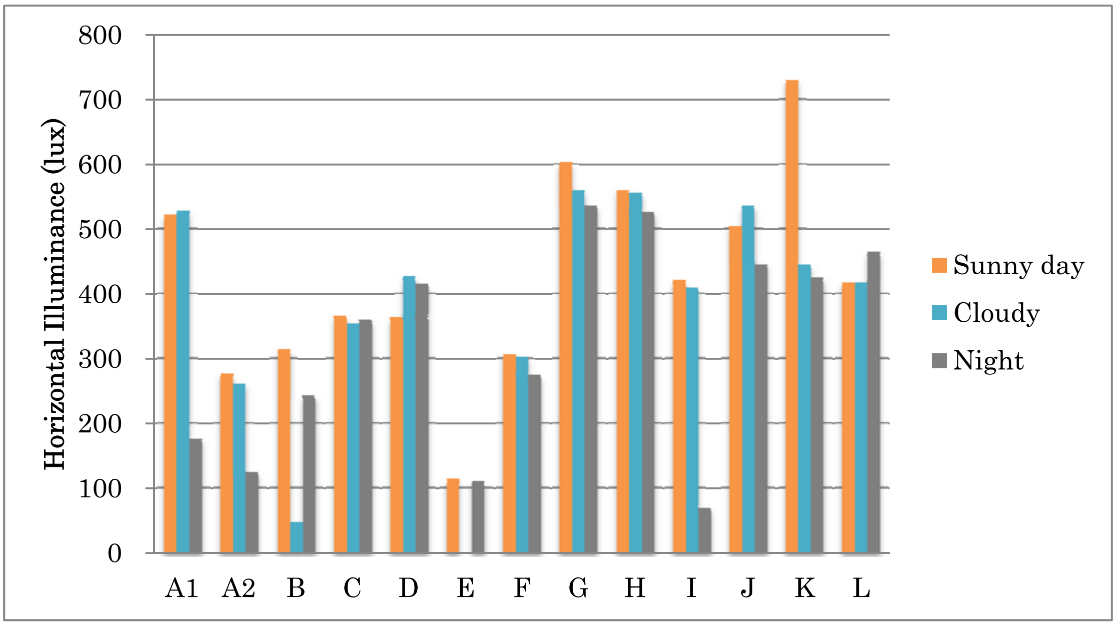


Fig. 3-2 Median horizontal illuminance in Japanese office

This result indicate that median horizontal illuminance on task plane in sunny day and cloudy is close in almost office, but median the horizontal illuminance in M office in sunny was higher than cloudy much. At night, median horizontal illuminance was lower than sunny day and cloudy in almost offices, but in L office was higher than sunny day and cloudy. The lowest median horizontal illuminance was 47lux in cloudy in B office, next was 68lux in at night I office. The highest median horizontal illuminance was 730lux in sunny day in K office, and next was 603lux in sunny day in G office. The others were between 200lux to 600lux.

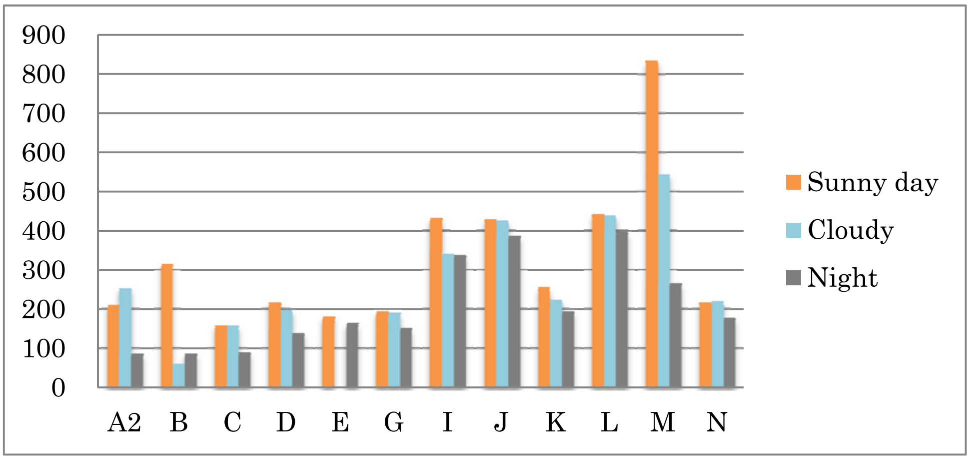


Fig. 3-2 Median vertical illuminance in Japanese office

Fig. 3-3 is the median horizontal illuminance on task plane in each office in sunny day. The median horizontal illuminance is arranged in order. The highest median horizontal illuminance was 730lux in K office, next is 603lux in G office, and the lowest median horizontal illuminance was 114.1lux in E office, next was 277lux in A2 office. The others were almost between 300ux to 500lux.

3-3-2 Result of Questionnaire in Japanese office

Table 3-2 is the employees' amount who answered the questionnaire in sunny day, cloudy and night. There were 619 employees to answer questionnaire in sunny day, 503 in cloudy, 527 at night and 76 unknown. They were total 1725 questionnaires in this survey. Fig. 3-4 is answerers' amount in each generation from 20 generation to above 50 generation. Because above 60 generation were very few, so they were combined with 50 generation.

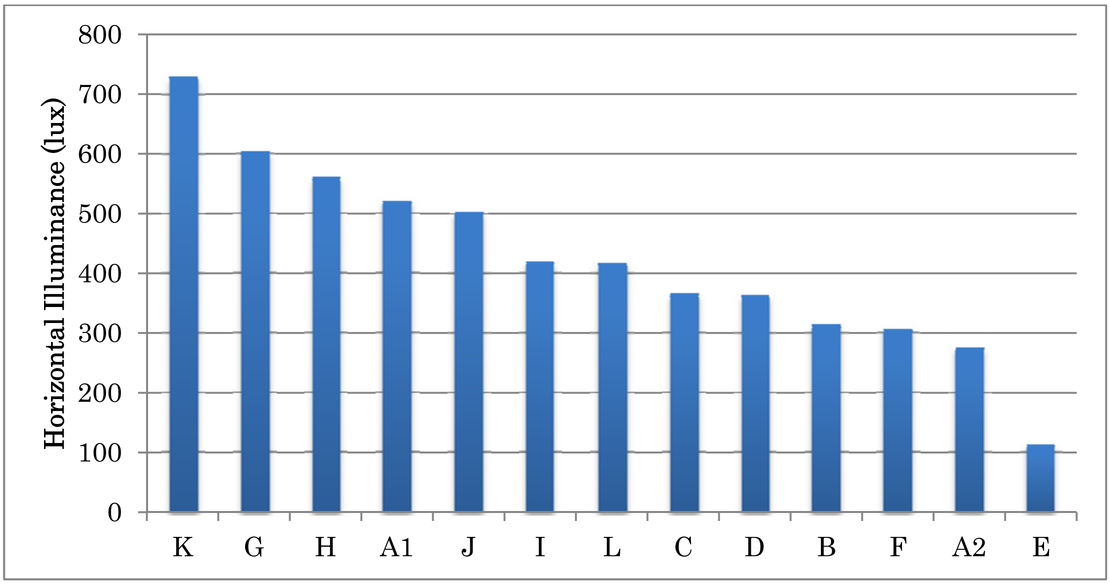


Fig. 3-3 Median horizontal illuminance in sunny day in Japanese office

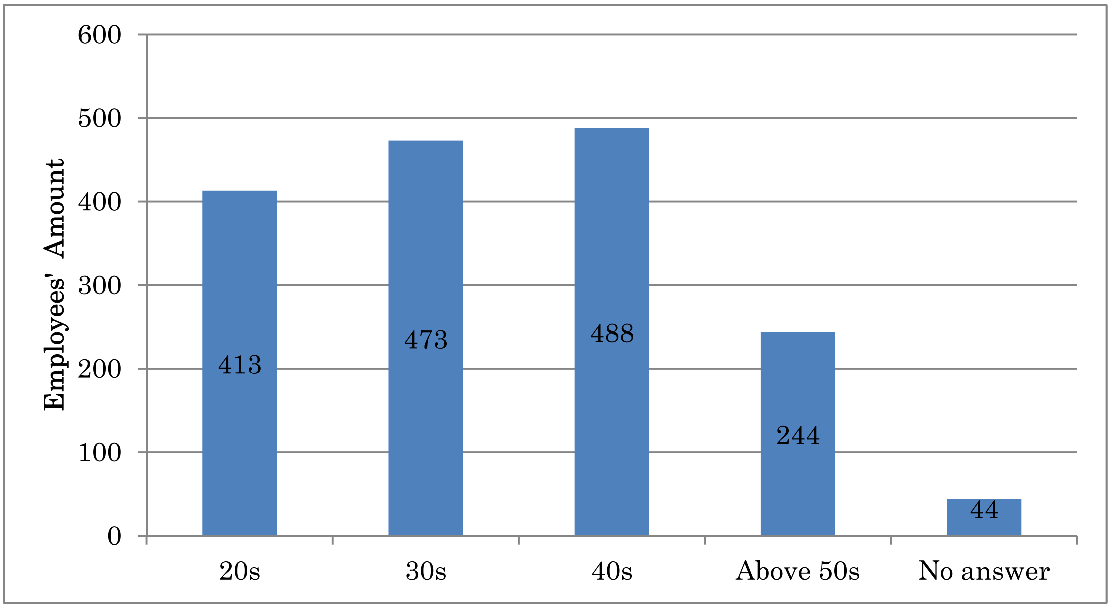


Fig. 3-4 Answerers amount in each generation in Japanese office

Regarding of questionnaire in sunny day, cloudy and night, it was depend on employees themselves or manager to decide it. The questionnaire was employed by WEB or paper. According to results, there were 619 employees to answer the questionnaire in sunny day, 503 in cloudy and 527 at night. There were 76 answers to be unknown. On the other hand, 40 generation was the most in this survey. There were 488 employees in 40 generation, 473 in 30 generation, 413 in 20 generation and 244 above 50 generation. From 20 generation to 40 generation amount were not too different, therefore, the survey in Japan represented employees from 20 generation to

40 generation.

Table 3-3 Answers amount for questionnaire in Japanese office

Weather	Answerers amount
Sunny day	619
Cloudy	503
Night	527
Unknown	76
Total	1725

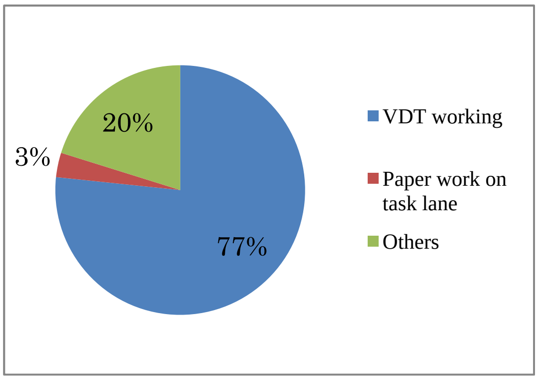


Fig. 3-5 Main behavior in Japanese office

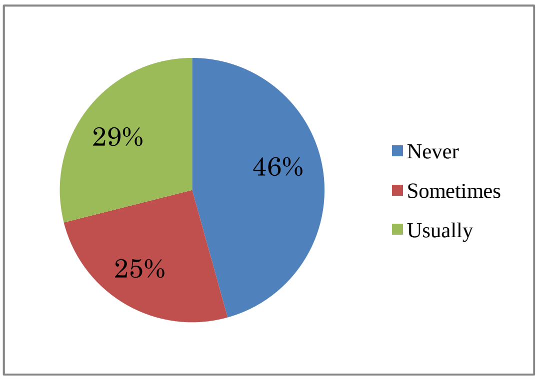


Fig. 3-6 Utility rate for task lighting in Japanese office

Fig. 3-5 shows main behavior in Japanese office. There were 77% employees' main work to be VDT working, 3% to be paper work, and 20% to be others. It indicated that VDT work is main work in normal office now. Regarding utility rate for task lighting in Fig. 3-6, in order to saving energy, ambient-task lighting was encouraged in office. There were 54% employees to use task lighting usually or sometimes. 46% employees did not use task lighting in office.

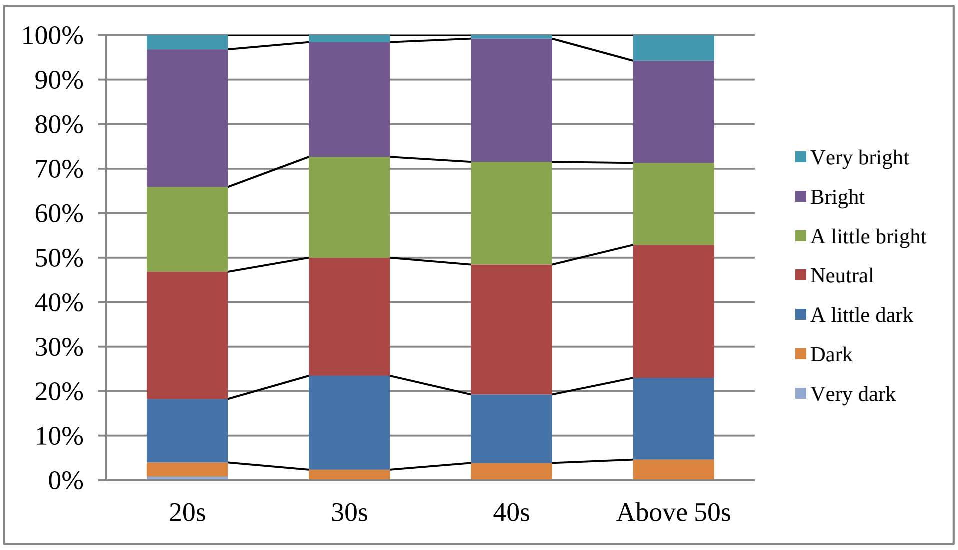


Fig. 3-7 Brightness of task plane in sunny day in Japanese office

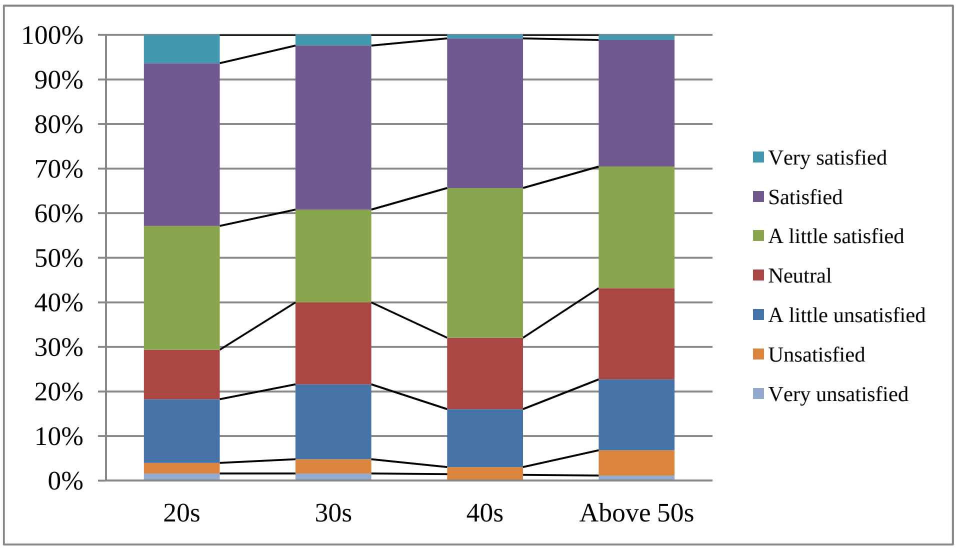


Fig. 3-8 Satisfaction of task plane in sunny day in Japanese office

Brightness and satisfaction are shown in Fig. 3-7 and Fig. 3-8. 20 and 40 generations evaluated above neutral over 20% for brightness. It meant that the employees thought their office bright enough. Above 50 generations evaluated "Dark" the most, next was 20 generation. It seems that brightness evaluations have no correlation with age. The same result with brightness, 20 and 40 generations evaluated above neutral over 20% for satisfaction. 40 generation is the most to evaluate above neutral. Except 40 generation, the other generations evaluated very unsatisfied very few.

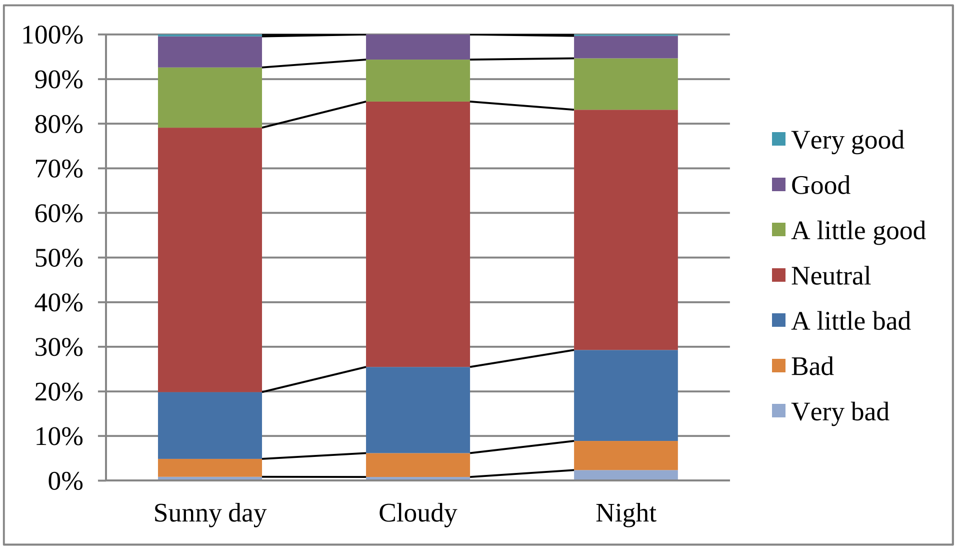


Fig. 3-9 Productivity in sunny day, cloudy and night in Japanese office

Fig. 3-9 shows employees had better productivity in sunny day than cloudy and night. Almost 80% employees thought their productivity was not bad in sunny day, but at night, almost 30% employees thought their productivity was a little bad or worse. One of reasons may be the employees felt tired for a long time working, so their productivity was not good.

Fig. 3-10 shows visual fatigue in each generation. Through the age becoming older, visual fatigue was occurred less and less. In 20 generation, 17% employees felt visual fatigue usually, 61% felt visual fatigue sometimes, and 22% employees never felt visual fatigue. But 29% employees in 30 generation never felt visual fatigue. 35% employees in 40 generation never felt visual fatigue. Above 50 generation, 32% employees never felt visual fatigue. It was indicated that elder employees never felt visual fatigue to increase. This result is different from reference or hypothesis. It should be more discuss.

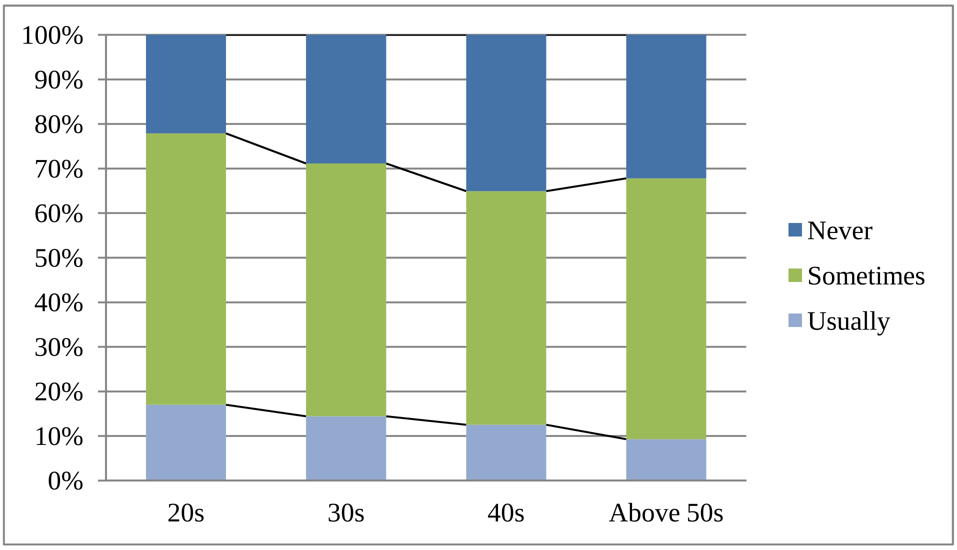


Fig. 3-10 Visual fatigue in each generation in Japanese office

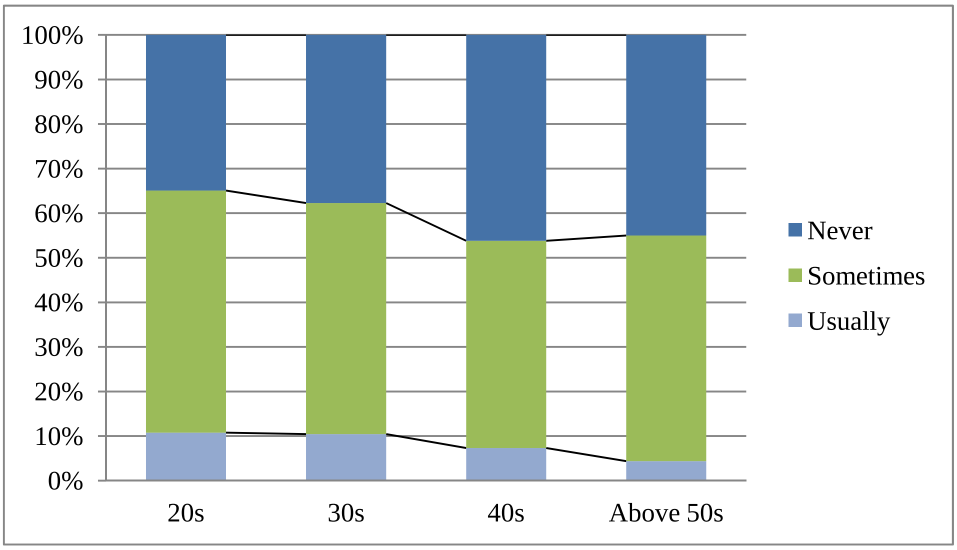


Fig. 3-11 Weariness in each generation in Japanese office

The same result indicated that elder employees might not feel tired easier than younger employees. Above 50 generations, only 4% employees felt tired usually, however 20 and 30 generations employees were 10% to felt tired usually. In 40 generation, 46% employees never felt tired, but 25% employees never felt tired in 20 generation.

Table 3-4 Correlation coefficient analysis of questionnaire

	Brightness of task	Visibility of task	Visibility of monitor	Easiness of work	Satisfaction of task	Brightness of space	Satisfaction of space	Productivity
Brightness of task		**0.72**	0.47	0.60	0.52	0.58	0.44	0.33
Visibility of task	**0.82**		0.62	**0.77**	0.67	0.54	0.53	0.43
Visibility of monitor	0.46	0.57		0.65	0.56	0.40	0.42	0.33
Easiness of work	0.67	**0.77**	0.65		**0.77**	0.56	0.61	0.51
Satisfaction of task	0.60	**0.73**	0.61	**0.79**		0.51	**0.72**	0.53
Brightness of space	0.49	0.53	0.42	0.51	0.50		0.58	0.43
Satisfaction of space	0.10	0.55	0.41	0.61	**0.71**	0.69		0.52
Productivity	0.40	0.48	0..46	0.50	0.55	0.43	0.55	

Table 3-3 shows correlation coefficient analysis of questionnaire. It is divided by two parts, right side is 20 to 40 generations, and left side is 50 to 60 generations. There were 1176 employees in 20 to 40 generations and 202 employees in 50 to 60 generations. Coefficient is used boldface to express above 0.7. In 20 to 40 generations and 50 to 60 generations both had high correlation between “brightness of task - visibility of task”, “visibility of task - easiness of work”, “satisfaction of task - easiness of work and “satisfaction of task - satisfaction of space. This result indicated that visual environment of task may affect employees’ easiness of work on task plane. On the other hand, task plane and ambient space had no strong correlation. It means visual environment can be divided by two parts, one is task plane, and another is ambient space.

3-4 Office field survey in Taiwan

3-4-1 Representative illuminance

Fig. 3-13 is median horizontal illuminance on task plane. Because P and O offices have no windows, their median horizontal illuminance on task plane would not be affect by weather or day lighting. Therefore, there were only night data in P and O office. The median horizontal illuminance on task plane were not so different in sunny day and cloudy, however because there was no day lighting, the offices had higher median horizontal illuminance at night, the highest median horizontal illuminance was 737lux, and the others were between 400lux~600lux. Fig. 3-14 is median vertical illuminance. Except O office, median vertical illuminance at night was higher than sunny day and cloudy. This result was the same with median horizontal illuminance on task plane. Therefore, according to this survey in Taiwan, the offices adopted higher energy consumption at night or for no windows office.

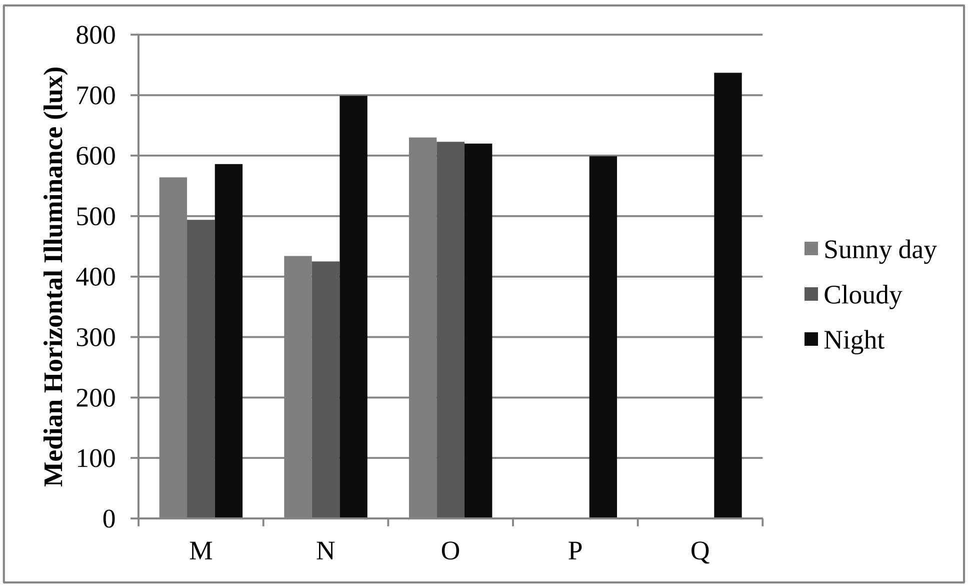


Fig. 3-12 Median horizontal illuminance in Taiwanese office

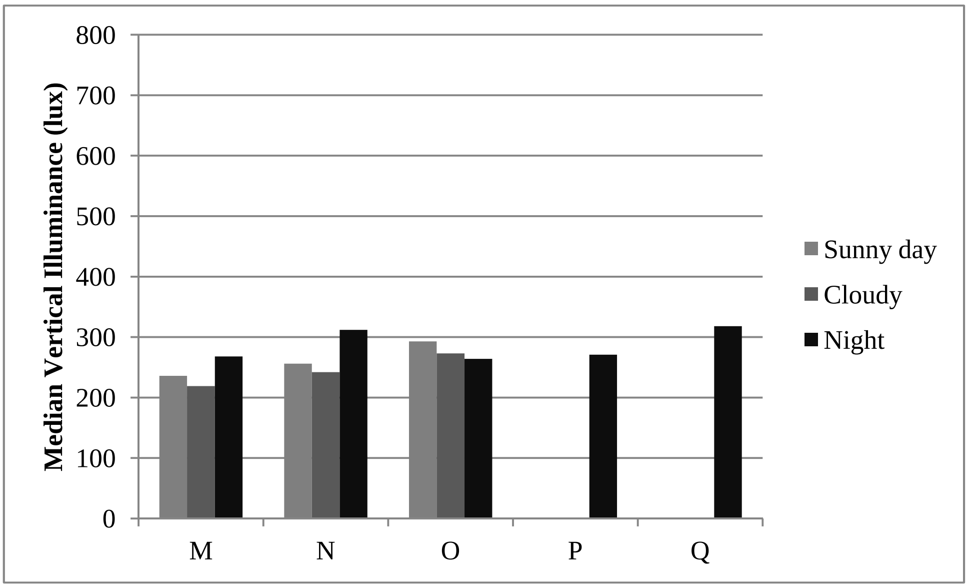


Fig. 3-13 Median vertical illuminance in Taiwanese office

3-4-2 Result of questionnaire in Taiwanese office

Table 3-4 is the employees' amount who answered the questionnaire in sunny day, cloudy and night. There were 42 employees to answer questionnaire in sunny day, 42 in cloudy and 70 at night. They were total 154 questionnaires in this survey. All questionnaires were employed by paper. Fig. 3-15 is answerers' amount in each generation from 20 generation to 50 generation. There was no generation over 50.

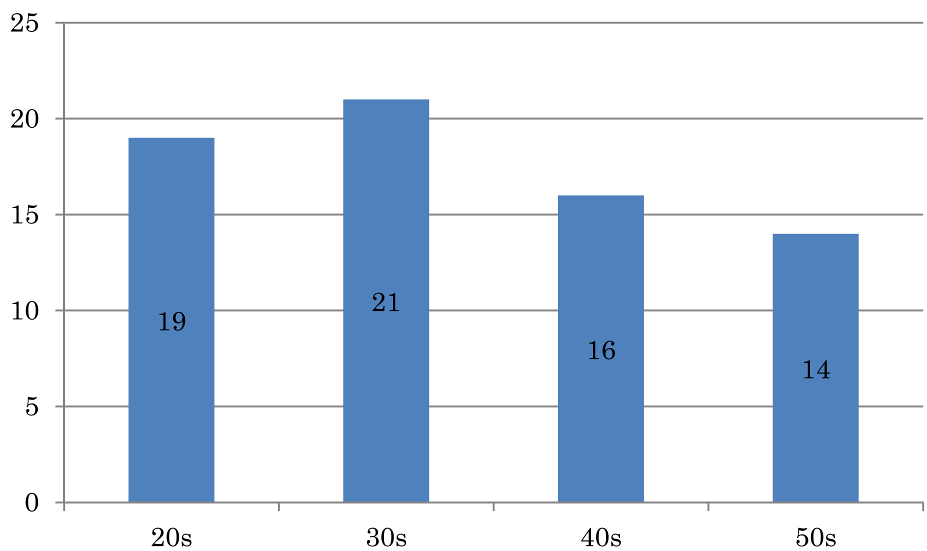


Fig. 3-14 Answerers amount in each generation in Taiwanese office

Table 3-5 Answers amount for questionnaire in Taiwanese office

Weather	**Answerers amount**
Sunny day	42
Cloudy	42
Night	70
Total	154

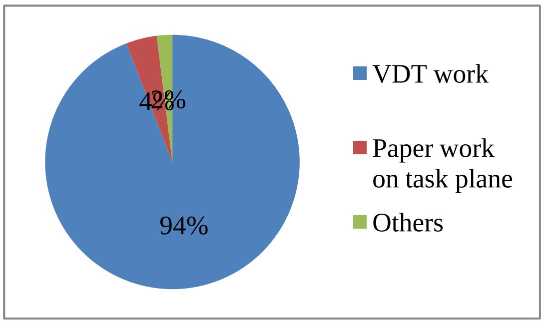


Fig. 3-15 Main behavior in Taiwanese office

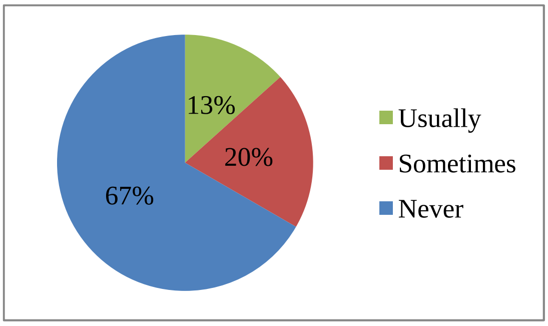


Fig. 3-16 Utility rate for task lighting in Taiwanese office

Fig. 3-15 shows main behavior in Japanese office. There were 94% employees' main work to be VDT working, 4% to be paper work, and 2% to be others. Because the office is located at Science Park, VDT work is very important and general work in Science Park. Regarding utility rate for task lighting in Fig. 3-16, in order to saving energy, ambient-task lighting was encouraged in office. There were 33% employees to use task lighting usually or sometimes. 67% employees did not use task lighting in office. According to interview, the reason was that the office did not set up task lighting in each task, so employees should bring it by themselves. Therefore, utility rate for task lighting was very low.

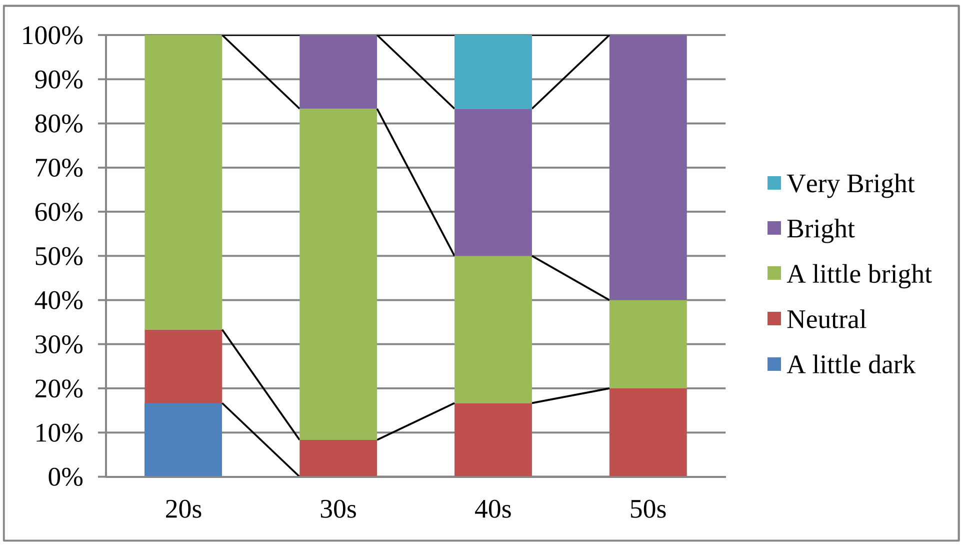


Fig 3-17 Brightness of task plane in sunny day in Taiwanese office

Fig. 3-17 is Brightness of task plane in sunny day in Taiwanese office. There were 17% employees in 20 generation who felt a little dark on their task plane, and the other generations did not feel dark. The 17% employees considered that their task plane was very bright in 40 generation, and 60% employees in 50 generation thought that their task plane was bright. But only 68% employees in 20 generation felt that their task plane was a little bright. No one felt bright or very bright in 20 generation. Therefore, young generations had higher criterion for evaluating brightness, and middle age employees thought that office was bright enough.

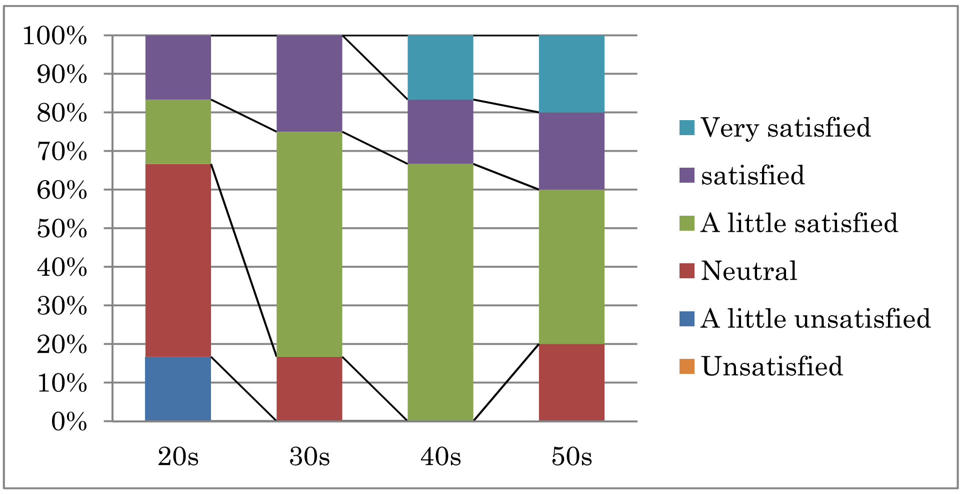


Fig. 3-18 Satisfaction of task plane in sunny day in Taiwanese office

Fig. 3-18 is the result of satisfaction on task plane in sunny day in Taiwanese office. 18% employees in 20 generation were unsatisfied with their task plane, and 33% employees were a little satisfied or satisfied with their task plane. The other generations were not unsatisfied their task plane. In 40 generation, 100% employees were above a little satisfied, and 20% employees were very satisfied with their task plane. This result is the same with brightness of evaluation. In the same condition, young generations evaluated unsatisfied easier than elder generations.

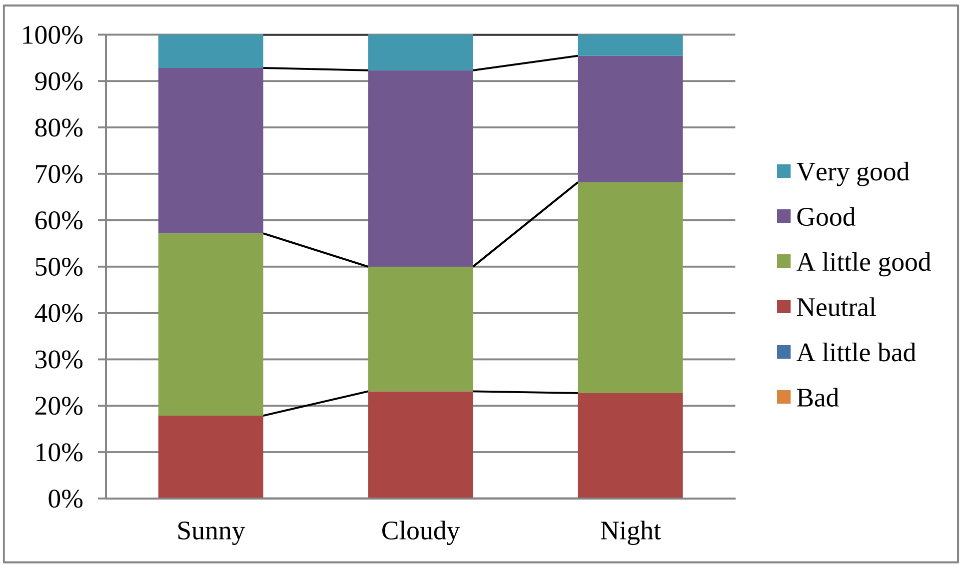


Fig. 3-19 Productivity in sunny day, cloudy and night in Taiwanese office

Fig. 3-19 shows employees had better productivity in sunny day than cloudy and night in Taiwanese office. There were no employees considering their productivity bad. 82% employees thought their productivity was above “a little good” in sunny day. In cloudy and night, 23% and 22% employees thought their productivity was neutral.

Fig. 3-20 shows visual fatigue in each generation in Taiwanese office. Through the age becoming older, visual fatigue was occurred more and more. In 20 generation, 12% employees felt visual fatigue usually, 38% felt visual fatigue sometimes, 50% employees never felt visual fatigue. But 26% employees in 30 generation never felt visual fatigue. 100% employees in 40 generation felt visual fatigue sometimes. 8% employees in 50 generation never felt visual fatigue. 92% felt visual fatigue sometimes. It was indicated that elder employees felt visual fatigue easier than young employees. This result is different from Japanese office.

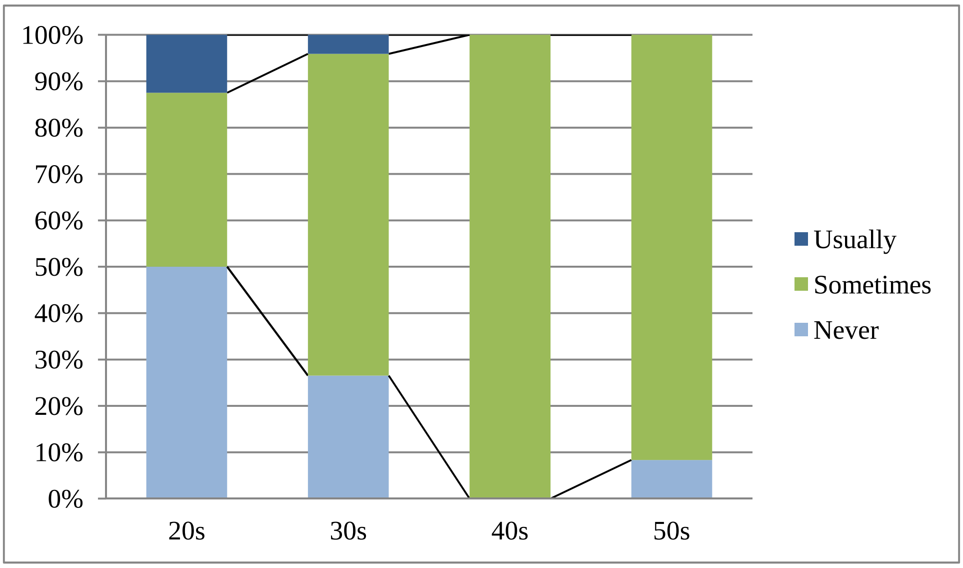


Fig. 3-20 Visual fatigue in each generation in Taiwanese office

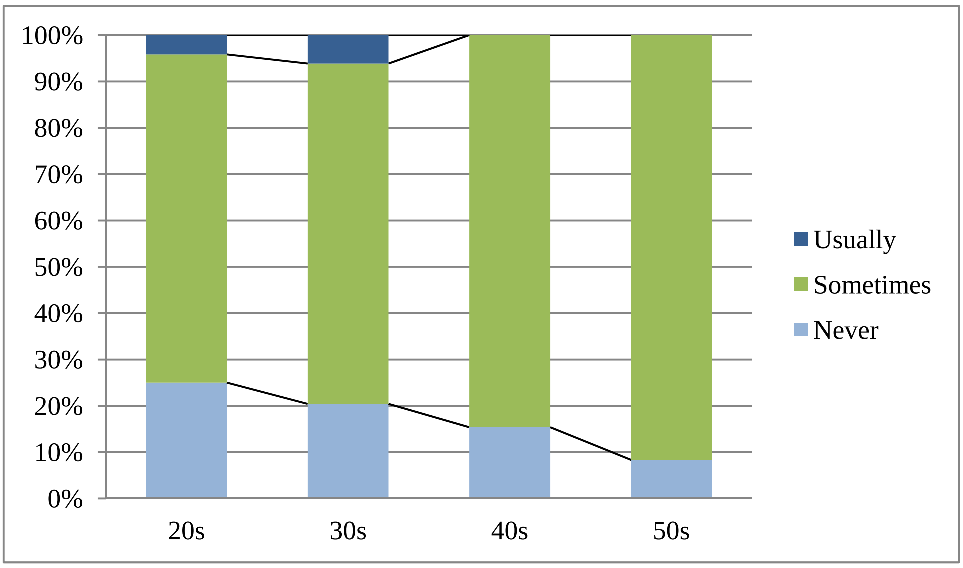


Fig. 3-21 Weariness in each generation in Taiwanese office

The same result indicated that elder employees might feel tired easier than younger employees. Above 50 generations, 92% employees felt tired sometimes. Even there were 24% and 20% employees who felt never tired, 4% and 6% were felt tired usually in 20 and 30 generations. In 40 generation, 85% employees sometimes felt tired.

Because there were too few employees in Taiwanese office survey, regarding of correlation coefficient analysis is not divided into different generations. Coefficient is used boldface to express above 0.7 in this table. This result shows that between “visibility of monitor - easiness of work”, “visibility of monitor - productivity”, "easiness of work - productivity" and "easiness of work - satisfaction of space" had high correlation. Because the main work in Taiwanese office is VDT work, visibility of monitor had direct correlation with productivity and easiness of work. On the other hand, task plane and ambient space had no strong correlation, like Japanese office.

Table 3-6 Correlation coefficient analysis of questionnaire in Taiwanese office

	Brightness of task	Visibility of task	Visibility of monitor	Easiness of work	Brightness of space	Satisfaction of task	Satisfaction of space	Productivity
Brightness of task		0.46	0.54	0.54	0.50	0.61	0.14	0.44
Visibility of task			0.45	0.58	0.53	0.34	0.21	0.43
Visibility of monitor				**0.730**	0.48	0.60	0.34	**0.77**
Easiness of work					**0.77**	0.57	0.49	**0.70**
Brightness of space						0.45	0.56	0.69
Satisfaction of task							0.46	0.58
Satisfaction of space								0.55
Productivity								

3-5 Conclusions

3-5-1 Discussion

Fig. 3-22 shows correlation between median horizontal illuminance on task plane, psychology evaluation of brightness of task plane and satisfaction of task plane in each Japanese and Taiwanese office in sunny day and night. The distribution is in order by median horizontal illuminance from highest to lowest in sunny day. A1 to L are Japanese offices, and M to O offices are Taiwanese offices. In principle, according to JIS, horizontal illuminance should be above 750lux in office and 300lux is minimum allowable horizontal illuminance in office in CNS (Taiwan's standard). After The Great East Japan Earthquake, Japanese government appealed for saving energy. In order to saving energy, except K office, median horizontal illuminanc of each office was below 750lux. Regarding brightness of task plane and satisfaction of task plane, expect E office, they were almost above 4(Neutral), even though median horizontal illuminance on task plane were below 300lux. Only brightness of task plane and satisfaction of task plane in E office were below 4(Neutral), because median horizontal illuminance on task plane was the lowest (114lux). At night, although there is no daylight, the horizontal illuminance of some offices in Japan and Taiwan is higher than sunny day. The reason is that there are windows in offices very general, and the daylight or skylight can be adopted in the office space. If the office is bright enough, the artificial lighting should not be used all in sunny day. Because of sunset, the daylight cannot supply lighting. The all or some artificial lightings are used in office. Therefore, the horizontal illuminance may be higher at night than sunny day in some offices. Fig. 3-23 shows designed task illuminance in each office. Accoeding to Fig. 3-22 and Fig. 3-23, the offices in Taiwan is over designed. The reason may be the energy cost in Taiwan is very cheap. The government reduces the energy cost for industrial in order to support them to cost down.

According to "Post Occupancy Evaluation of Office Lighting Design[39]" indicated that the office in Hsinchu in Taiwan, the lighting power density (LPD) is 23.3 W/m^2, and the average task horizontal illuminance is 800lux. For Future improvements, it is recommended lighting design should be lower than now for saving energy.

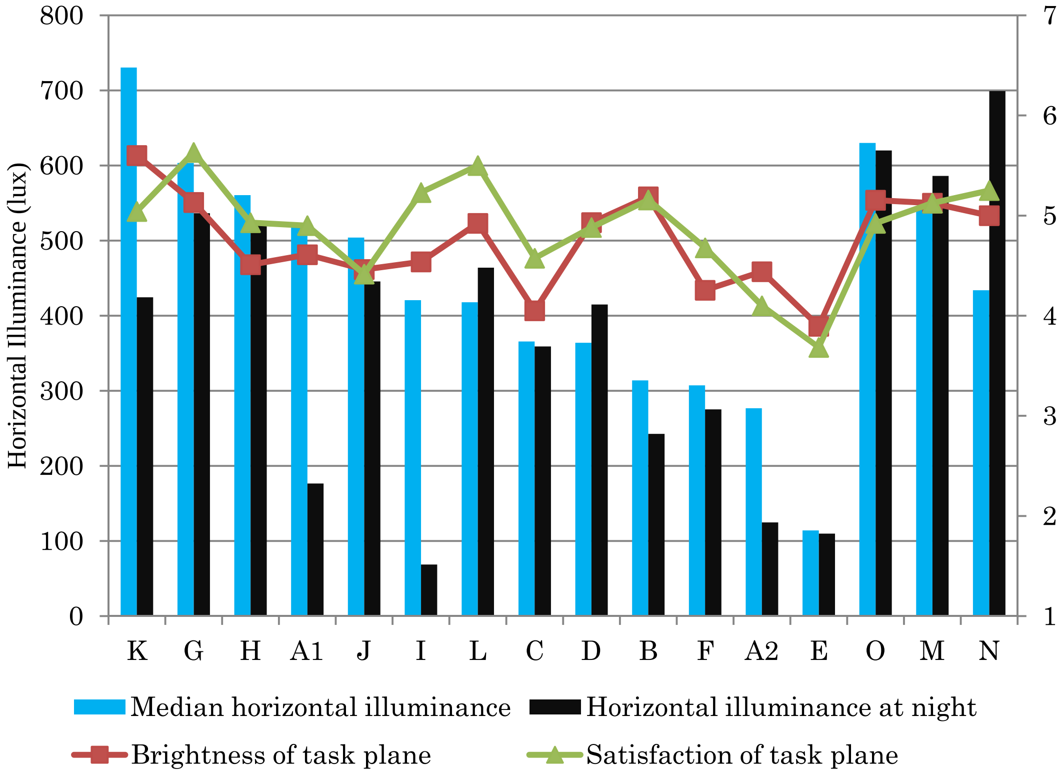


Fig. 3-22 Median horizontal illuminance, brightness and satisfaction of task plane in sunny day and night.

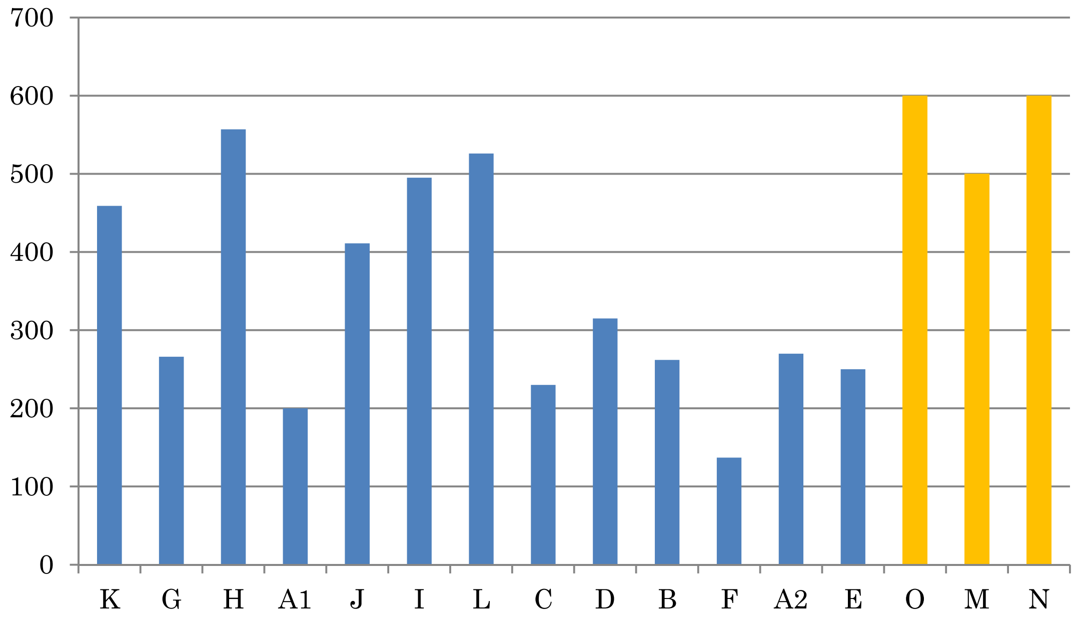


Fig. 3-23 Designed illuminance

Fig. 3-24 shows correlation between median vertical illuminance, psychology evaluation of brightness of ambient space and satisfaction of ambient space in each Japanese and Taiwanese office in sunny day. The distribution is in order by median vertical illuminance from highest to lowest. A1 to L were Japanese offices (blue bar), and M to O office were Taiwanese offices (orange bar). Regarding brightness of ambient space and satisfaction of ambient space, expect A2, E, J offices, they were almost above 4 (Neutral), even though median vertical illuminance were below 200lux. Median vertical illuminance of J office was 504lux, but satisfaction of ambient space belonged to a little unsatisfied. Median vertical illuminance of A2 office was 277lux and the brightness of ambient space belonged to a little dark. Median vertical illuminance of E office was 181lux. The brightness of ambient space and satisfaction of ambient space were very close 3(A little dark and a little unsatisfied). But focus on office C, the median vertical illuminance was 160lux which was the lowest in this survey, but the brightness of ambient space and satisfaction of ambient space were both above 4 (Neutral).

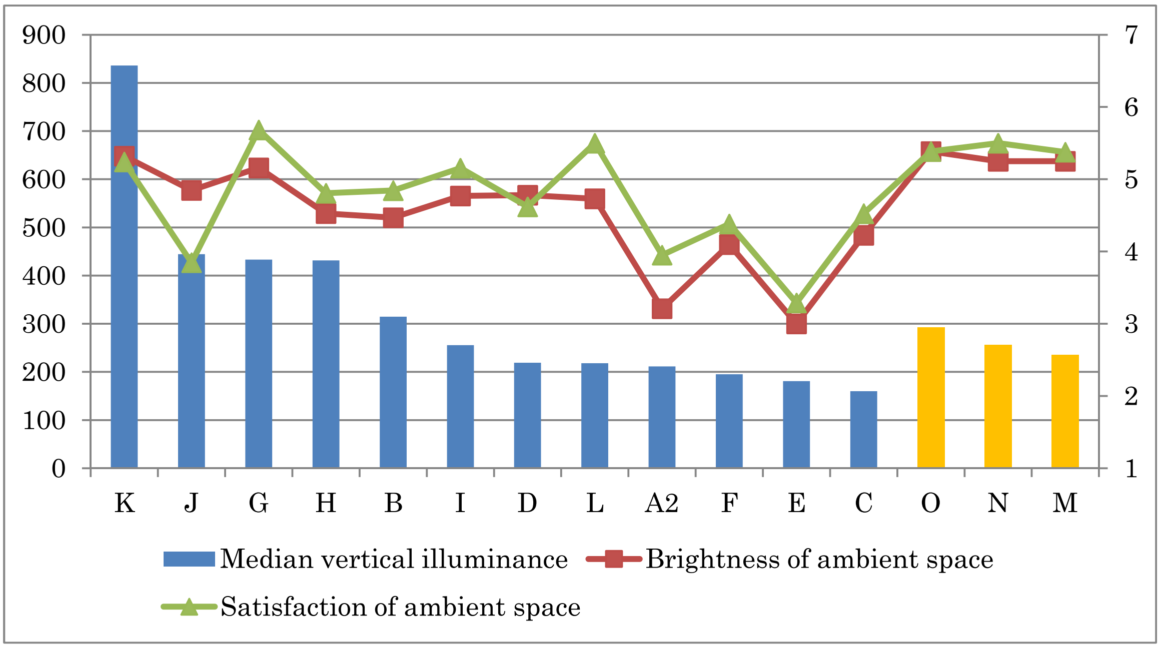


Fig. 3-24 Median vertical illuminance, brightness and satisfaction of ambient space in sunny day

3-5-2 Conclusion

According to result of office survey in Japan and Taiwan, the main conclusions point out that:

1. In order to saving energy, almost median horizontal illuminance offices in Japanese office were below 750lux (the minimum allowable JIS).

2. VDT work is the main work in Japanese and Taiwanese office.

3. Task-ambient lighting is adopted usually in Japanese office, but it is used sporadically in Taiwanese office.

4. According to analysis of brightness and satisfaction of task plane in sunny day in each generation, elder employees and young employees were not too different. Elder employees and young employees have the same evaluations of brightness and satisfaction of task plane.

5. Regardless of Japanese and Taiwanese office, young employees felt visual fatigue and tiredness easier than elder employees.

6. No.4 and No.5 indicated that generation may not be main factor to affect brightness, satisfaction of task plane, visual fatigue and tiredness of employees.

7. Because of median horizontal illuminance of task plane was below 750lux, further below 300lux, but evaluations of brightness and satisfaction of task plane were not too bad in Japanese office. It is indicated that in order to saving energy, horizontal illuminance of task plane might be decreased.

8. The result of offices in Japan and Taiwan were not too different. According to result of chapter 2, 200lux horizontal illuminance is better than 500lux for visual fatigue and productivity in VDT work for Taiwanese. Therefore, Japanese might have the same result with Taiwanese.

CHAPTER 4 MINIMUM TASK ILLUMINANCE FOR READING AND VDT

CHAPTER 4 MINIMUM TASK ILLUMINANCE FOR READING AND VDT IN JAPAN

4-1 Introduction

Horizontal illuminance always used in variety indoor and outside space in building for a long time, especially in office and school. To ensure visual comfort, avoid of visual fatigue and keep work efficient, world and CIE use horizontal illuminance as standard formulate recommended value. However, whether the value of horizontal illuminance can present the brightness and comfort of lighting environment is still a problem, several researches point out horizontal illuminance is not equal to brightness in space, therefore, more evaluation indictors should be added to express lighting situation in whole space.

Therefore, face the challenge of power shortage and energy issue cannot be solved in short-term, power saving is an inevitable trend. Whether the current Japanese office illuminate standard can meet with power save is still need discuss. On the other hand, power saving is the most pressing issue currently, but in order to power save to sacrifice healthy visual environment is not tolerate. In this chapter natural light imported laboratory, task illuminance indoor reduces with sunset, when the subjects carry on reading or VDT work, define the task illuminance is so low that unsatisfied work need as minimum illuminance, according to it to find the limit need illuminance in office environment.

4-2 Measurement of Minimum Illuminance Experiment

4-2-1 Experiment Purpose

The two objectives of this experiment shows as following:

1. To explore when subjects under the condition of natural light, task illuminance and luminance reduced due to sunset, the relationship between luminance of background and minimum illuminance.

2. In common office work type: whether minimum illuminance need of reading and VDT are different.

4-2-2 Measurement

The experiment is set in the office in the first story of Engineering Building No. 1 in University of Tokyo. There is only one window and face on the east. The site plane and section plane are shown on Fig. 4-1.

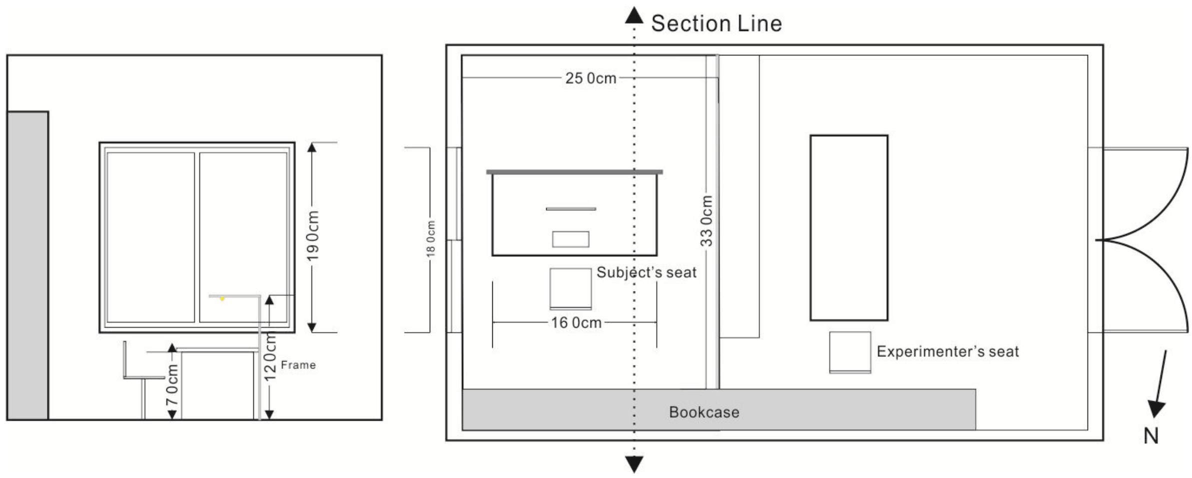


Fig. 4-1 Experiment space site plane and section plane

The physical quantity measured in this experiment includes: task illuminance, vertical illuminance at eyes' position, windows illuminance, luminance pictures. The equipments used in this experiment introduced as follows:

Horizontal Illuminance: 5 points on task measured by multi points Luxmeter and calculate the average, as Fig. 4-2shows:

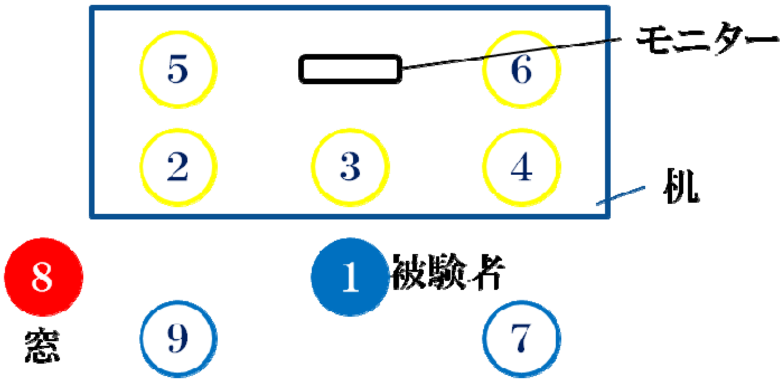


Fig. 4-2 Location of mult-illuminance meter

Vertical Illuminance: Vertical illuminance measured at the position of subjects' eyes by illuminance meter, the height is 120cm, the distance to VDT display is 63.4cm, as figure shows as follow:

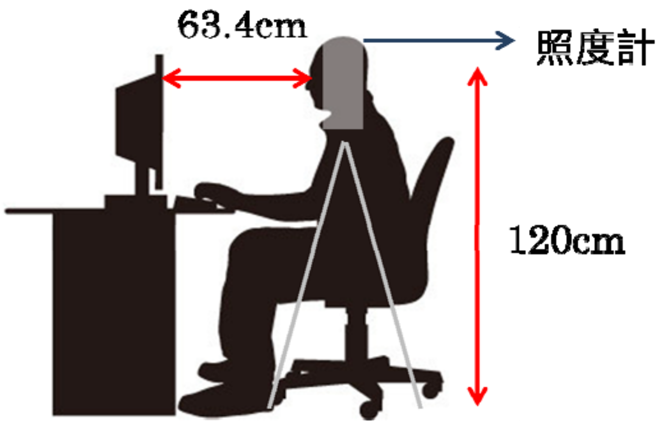


Fig. 4-3 Dimensions of VDT

Window Illuminance：Stick the light sensor on windows to measure the illuminance by multi-illuminance meter from sun enter indoor and find the relationship formula of windows and task illuminance.

Luminance camera : Use the Luminance camera Luminocam developed by KOZO KEIKAKU ENGINEERING to take space luminance photo.　Camera is set at 120cm as position of sujects' eyes and 63.4cm from VDT display, as Fig. 4-4 shows. In photography picture, the angle from right to left is 103.6°, from upon to down is 76.5°. In this experiment, the sight of subject is not limited and head can rotated freely, therefore, when taking space luminance photo, the range of subject's view should be consider, sets as face up to the front each 90° in left and right, altogether 180°. Limited to angle of luminance camera in left to right is 103.6°,the three pieces of photography are taken in this experiment at face up to the front, from lens to left 38.2° and to right 38.2°, respectively. When calculate the part of overlap in photography as sum of value in overlap/2, use average as final value. The synthetic photo shows as following figure:

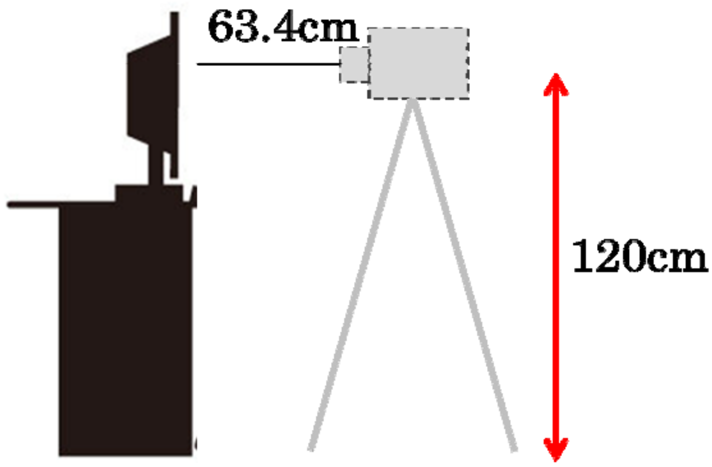


Fig. 4-4 Dimensions of luminance camera

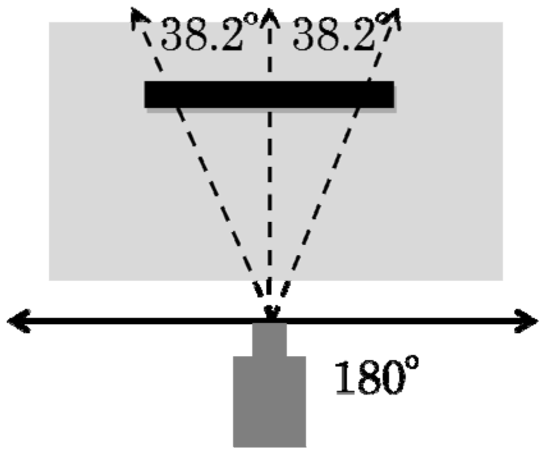


Fig. 4-5 Measurement angle of luminance camera

Fig. 4-6 Sample picture from luminance camera

Task lump: ERK8971W LED developed by ENDO lighting, module in 40w, the color temperature is 4000K. Light modulator attached: PWM signal controller (No. X-239W) is controlled from 15% to 100% light controllable range.

4-3 Experimental Plan

4-3-1 Preliminary Experiment

In order to get the task horizontal illuminance, consider the area of desk and reason why no limit on subject's behavior, horizontal illuminance on five points in desk proceeded to measure and use the average to analysis; vertical illuminance at the position of eyes in height is 120cm. In formal experiment, the desk keep clear, to ensure the measure points do not move and without prejudice to the experiment, the preliminary experiment proceeded at first to get the correlation equation of the task horizontal illuminance and vertical illuminance corresponding illuminance of window surface respectively and the correlation equation of the task horizontal illuminance and vertical illuminance corresponding artificial lighting to ensure the formal experiment proceed well. The location of illuminance meters on desk shows as below.

Fig. 4-7 Scene of experiment space

No.1 is the measure point of vertical illuminance, distance from desk is 15cm and the height is 120cm. No.2~6 is the task horizontal illuminance, measure the illuminance in each point and calculate the average, analysis the illuminance of window surface to find the correlation equation.

The preliminary experiment time is in Jan, 26th, 2013, from 3:00 pm to 5:00 pm and the weather is sunny (According to Japan Meteorological Agency).

The following figure is the correlation equation of illuminance of window surface of No.8 when artificial lighting turned off and task horizontal illuminance of No.2~6 on desk:

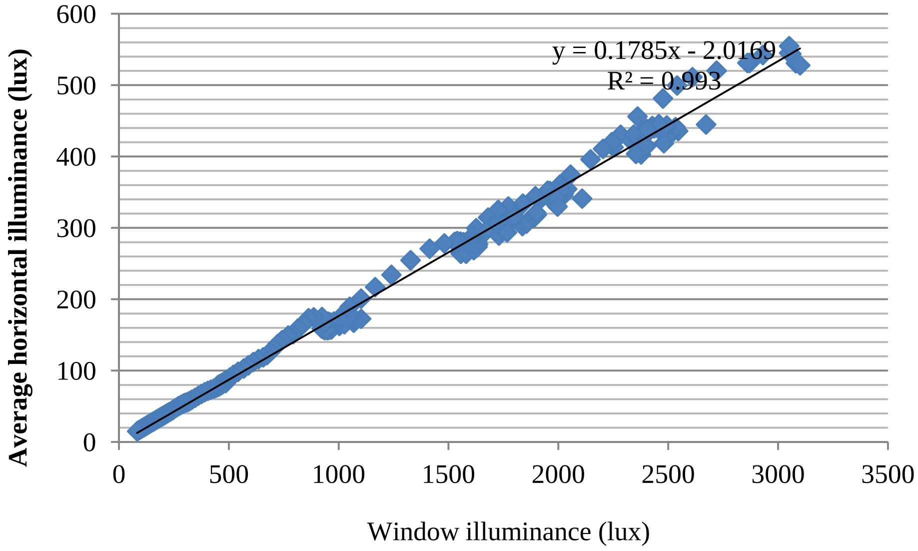


Fig. 4-8 Horizontal correlation equation previous adjust lighting

Correlation equation:

Average Task Horizontal Illuminance=0.1785 × Illuminance of window surface-2 (lux)
R^2=0.993

The following figure is the correlation equation of illuminance of window surface of No.8 when artificial lighting turned off and vertical illuminance at position of eyes of No.1:

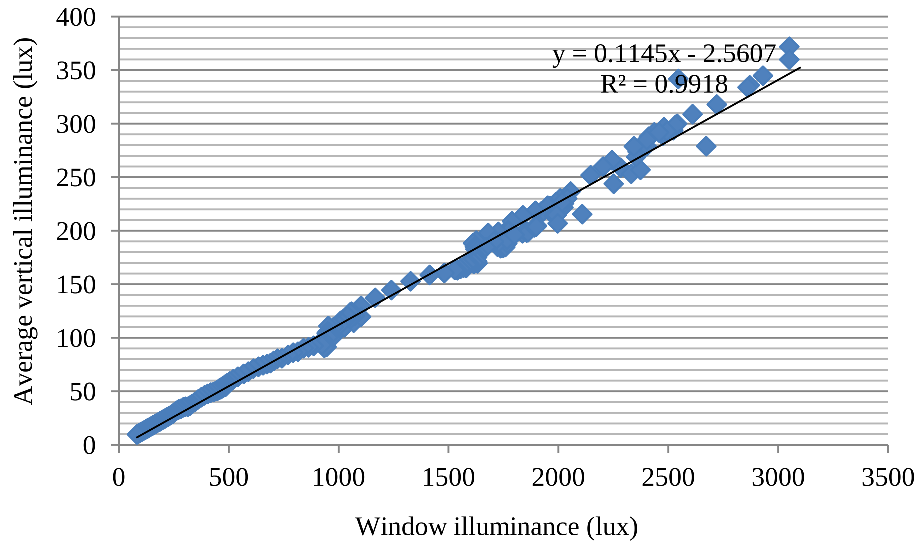


Fig. 4-9 Vertical correlation equation previous adjust lighting

Correlation equation:

Vertical illuminance at position of eyes =0.1145 × illuminance of window surface -2.6 (lux), R^2=0.9918

After sunset, illuminance of window surface influences task horizontal illuminance is small, but desk lump turned on influences task horizontal and vertical illuminance is big. Watt used in this experiment to measure the output of the desk lump, use watt as standard to estimate the correlate equation of task horizontal illuminance and vertical illuminance corresponding desk lighting.

The following figure is the correlation equation of task horizontal illuminance corresponding artificial lighting and illuminance of window surface when artificial lighting turned on.

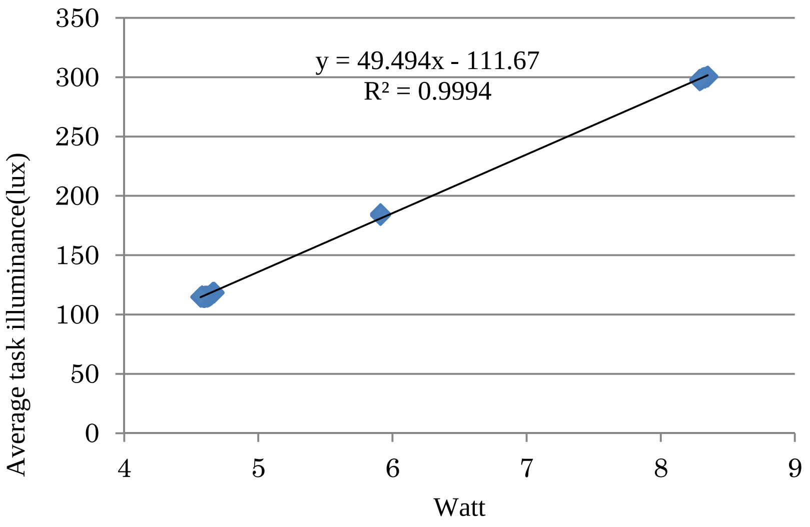


Fig. 4-10 Horizontal correlation equation after adjusting task light

Correlation equation:

Task Horizontal Illuminanc e= 49.494 × Power-111.7 (lux), R^2=0.9994

The following figure is the correlation equation of vertical illuminance at position of eyes corresponding artificial lighting and illuminance of window surface when artificial lighting turned on.

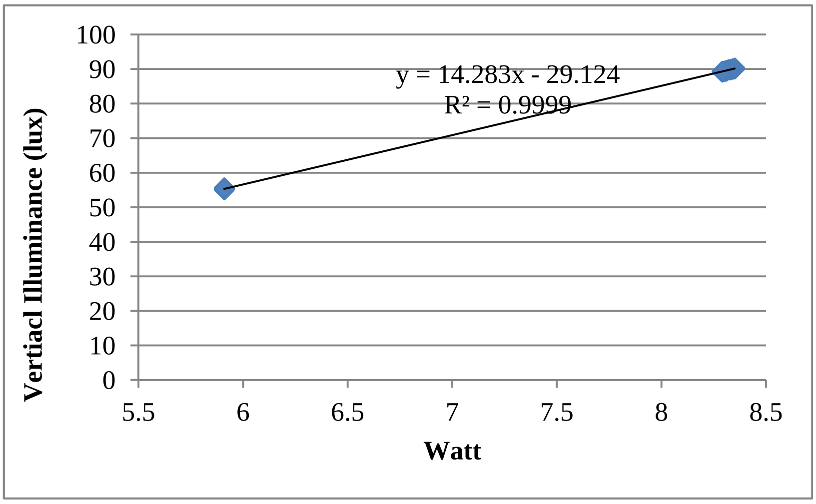


Fig. 4-11 Vertical correlation equation after adjusting task light

Correlation equation:

Vertical Illuminance at Position of Eyes = 14.283 × Power-29.1 (lux), R^2=0.9886

Integrates the natural and artificial lighting effects, the correlating equation about task horizontal illuminance and vertical illuminance at position of eyes：

Task Horizontal Illuminance = 0.1785 × Illuminance of Windows Surface -2+49.5 × Watt-111.7 (lux)

Vertical Illuminance at Position of Eyes = Illuminance of Windows Surface × 0.1145-2.6 + 14.283 × (Watt) -29.1 (lux)

Table 4-1 The background Correlation equation for horizontal and vertical illuminance

Correlative formula	Content
Horizontal illuminance (Working plant)	(illuminance meter No.2 ~ 6) =0.21x(No.8) (No artificial lighting)
	(illuminance meter No.2 ~ 6)=0.21x(No.8)+45.643x(watt)-87.782 (Using artificial lighting)
Vertical illuminance (Position of Subject's eyes)	(illuminance meter No.1) = (No.7 + No.9)/2x0.72 (No artificial lighting)
	(illuminance meter No.1) = (No.7+No.9)/2x0.72+7.8074x (watt)-11.146 (Using artificial lighting)

4-3-2 Experimental Setting

Table 4-2 Experimental summary

Experiment space	The office room with a window in east side
Experiment behavior	Reading or VDT
Experiment time	2 hours previous sunset
Subjects	10 male and 10 female (college student)
Weather	Sunny day
Date of experiment	2012.11~2012.12

The experiment space is controlled by sunset from bright to dark to measure the minimum allowable illuminance. Therefore, experiment time sets from 3 pm to sunset in 2012, besides, when the weather is cloudy, the change of sunlight is big, to avoid the error, the experiment only proceed in sunday. 20 subjects in this experiment totally, average age is 25, all are graduated school, 10 male and 10 female, no disease in eyes and vision is normal after correction.

4-3-3 Experimental Flow

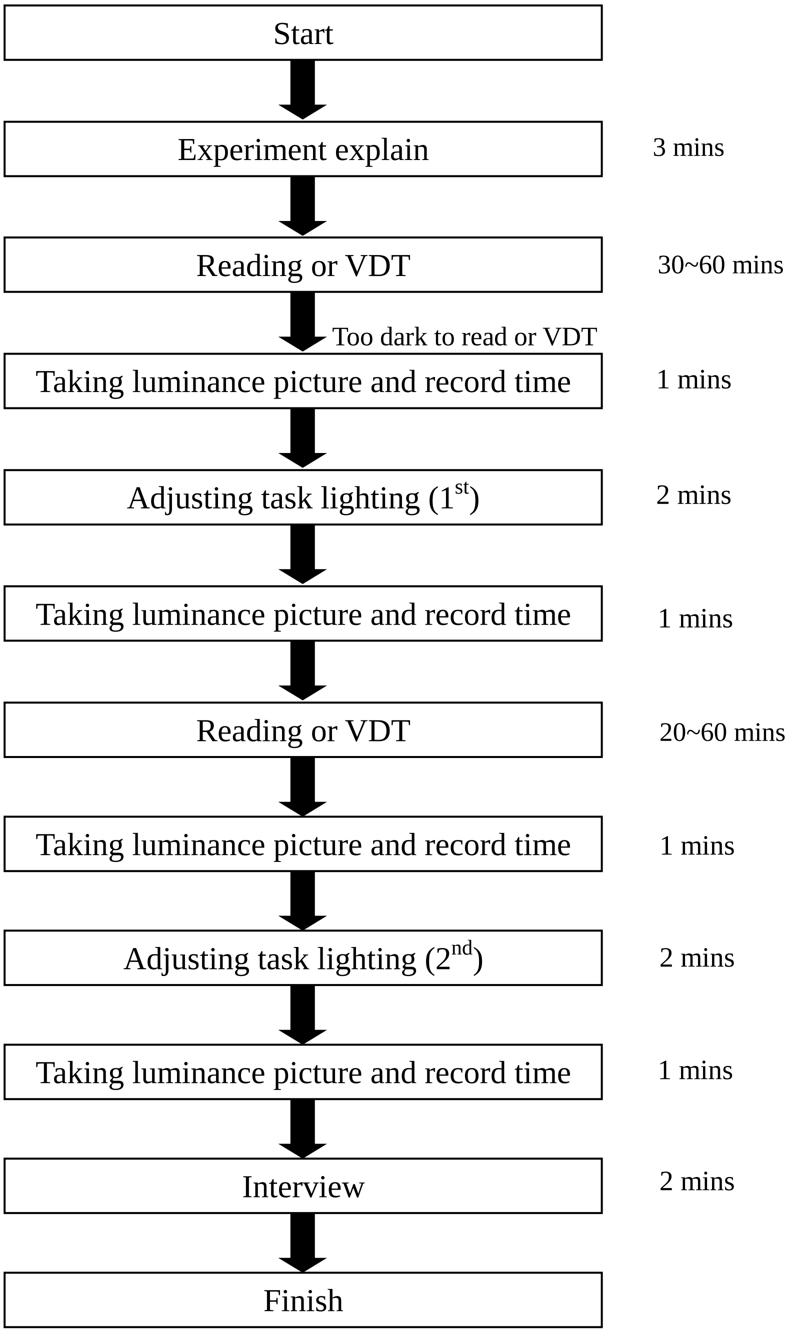


Fig. 4-12 Experimental flow

The experiment starts 2 hours before sunset. The experiment explanation is proceeded at first and adjust the height of chair to make height of eyes is 120cm. At the same, demonstrate the purpose of experiment, definition of minimum allowable task horizontal and practice use light modulator. After explanation, the formal experiment starts, subjects' can read or do VDT work, no limit in content and kind of work and adjust display to the appropriate light. The task horizontal illuminance when decreases the light for sun outside of windows decreases with sunset. Recording the time when the subject cannot stand the lighting to ask turn on artificial lighting to find the horizontal and vertical illuminance by correlation equation and take the luminance picture as well. After recorded the data, the subjects can go back and turn on the artificial light to appropriate, and record the time, watt of artificial light and take luminance picture. Before sunset, some subjects may adjust the artificial light again and experimenter should record the time, watt of artificial light and take luminance picture again. The experiment ends after sunset, the subject don't need change artificial light.

4-4 Result of Experiment

Through sunset and day-lighting decreasing, every subject are required to adjust task lighting when they are unable to bearable task horizontal illuminance in reading or VDT work. The task horizontal illuminance and vertical illuminance was measured and discussed. At the same time, the correlation of task horizontal illuminance and luminance of space is discussed in this chapter.

4-4-1 Correlation of Day-light and Minimum Allowable Horizontal Illuminance

Fig. 4-13~Fig. 4-16 are the examples which are correlation of task horizontal illuminance, vertical illuminance and illuminance of window for No. 1~No. 4 subject

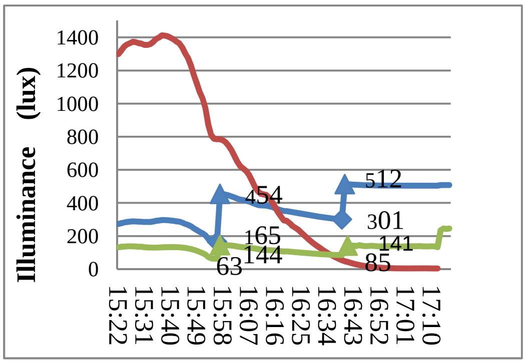


Fig. 4-13 No.1 subject performance

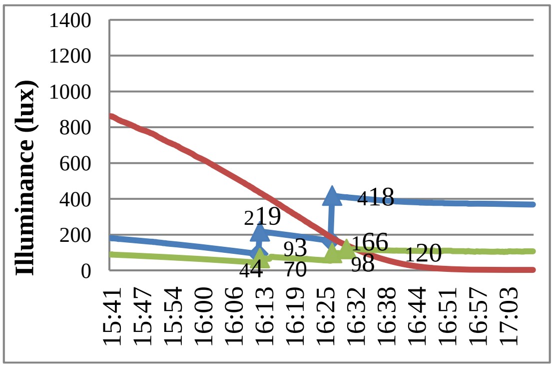


Fig. 4-14 No.2 subject performance

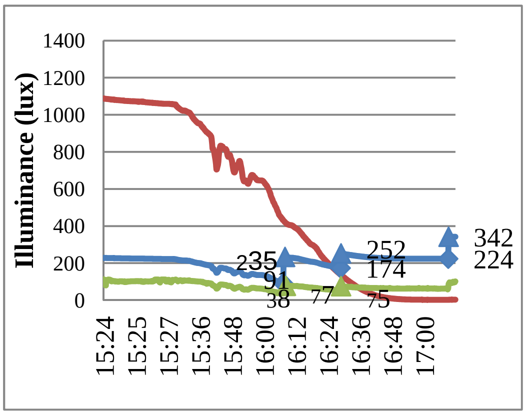


Fig. 4-15 No. 3 subject performance

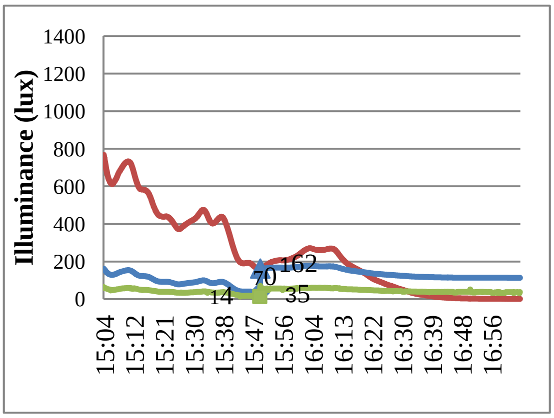


Fig. 4-16 No.4 subject performance

The red line is represented illuminance of window from day-lighting. Although the weather must be sunny day, the sun might shelter from cloud sometimes. Through the time went and sunset, illuminance of window was reduced. The blue line is task illuminance. When the subject adjusted task lighting, the blue line raised immediately. The green line is vertical illuminance. It is the same with blue line which raised immediately when the subject adjusted task lighting. From figures, No. 1, No. 2 and No. 3 Subject adjusted task lighting twice, but No. 4 subject adjusted only once.

4-4-2 Influence of Task Horizontal Illuminance and Task Lighting

Almost subjects adjusted task lighting twice, only 5 subjects adjusted once. Fig. 4-17 and Fig. 4-18 show difference task illuminance between previous and after adjusting task lighting in the 1st adjusting model and the 2nd adjusting model.

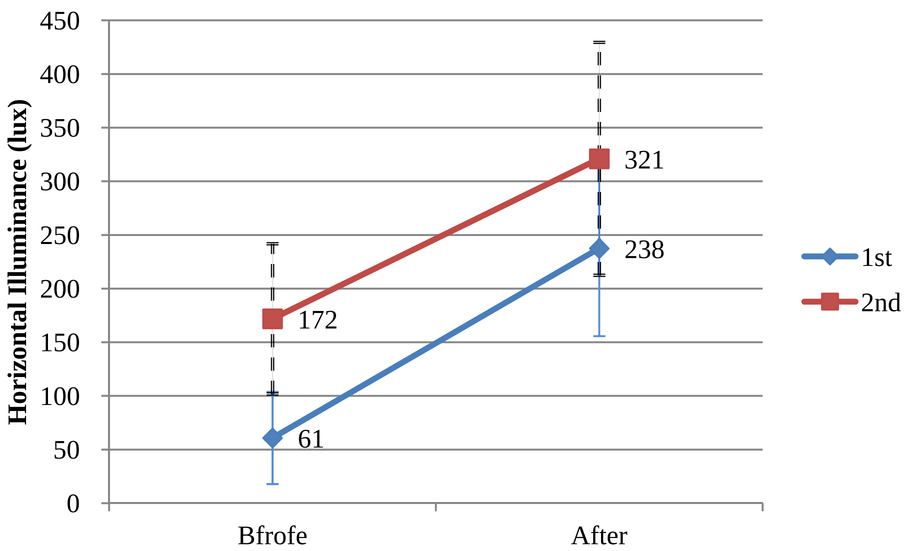


Fig. 4-17 Previous and after task illuminance difference in the 1st adjusting model

The task illuminance between the 1st adjusting model and the 2nd adjusting model are very different. In the 1st adjusting model, the task illuminance was from 61lux to 238lux, and SD was 42.9 and 81.7. In the 2nd adjusting model, the task illuminance was from 178lux to 321lux, and SD was 67.4 and 108.5. Vertical illuminance of subject's eye location was from 37lux to 78lux in the 1st model. In the 2nd model, vertical illuminance of subject's eye location was from 53lux to 89lux.

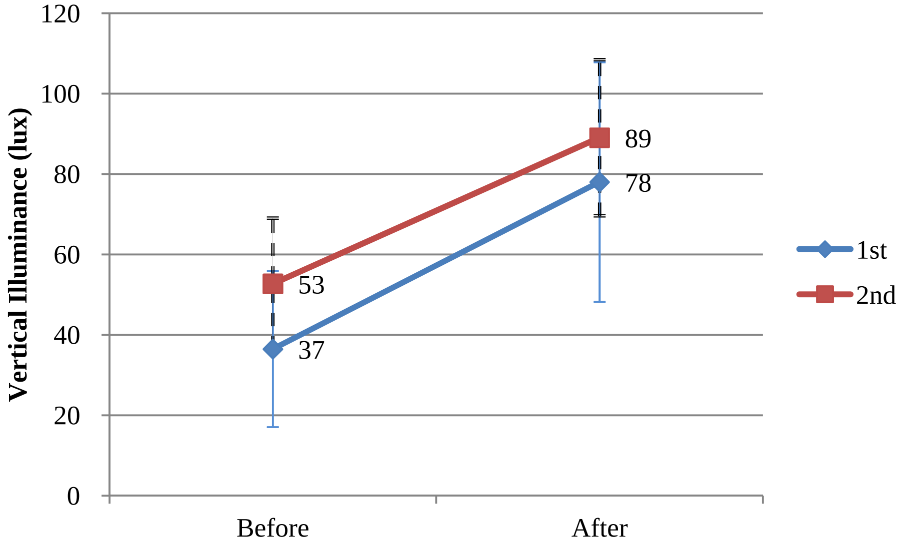


Fig. 4-18 Previous and after vertical illuminance difference in the 2nd adjusting model

Fig. 4-19 is shown that previous adjusting task illuminance difference in the 1st and 2nd.

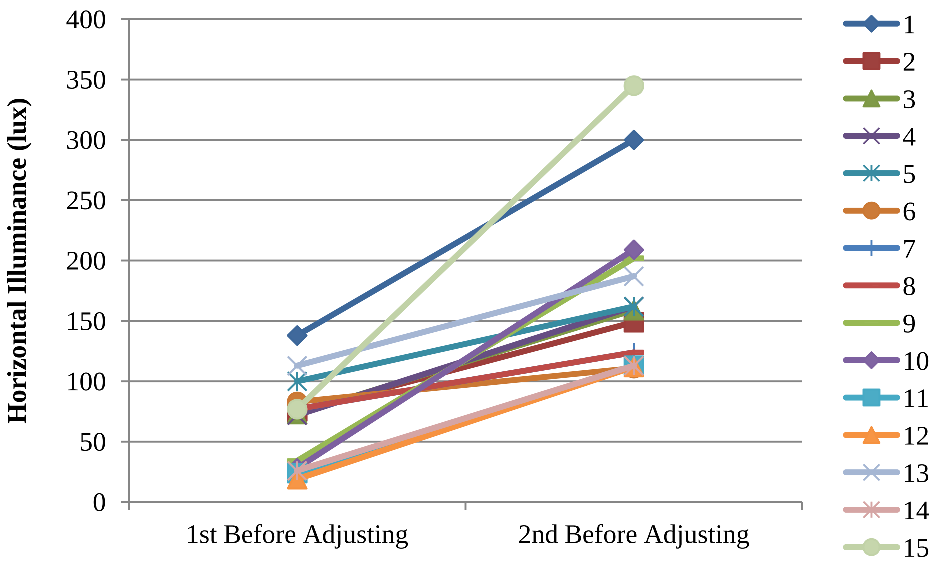


Fig. 4-19 Task illuminance previous adjusting in the 1st and 2nd

The task illuminance in "previous adjusting in the 2nd model" was higher than "the 1st model". The average increasing task illuminance is 117lux. According to paired samples statistics between previous and after adjusting task lighting, they are significant.

Table 4-3 Paired samples statistics between previous and after adjusting task light

	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower: Lower	Upper			
Previous - After	-76.65000	79.76959	17.83702	-113.98332	-39.31668	-4.297	19	.000

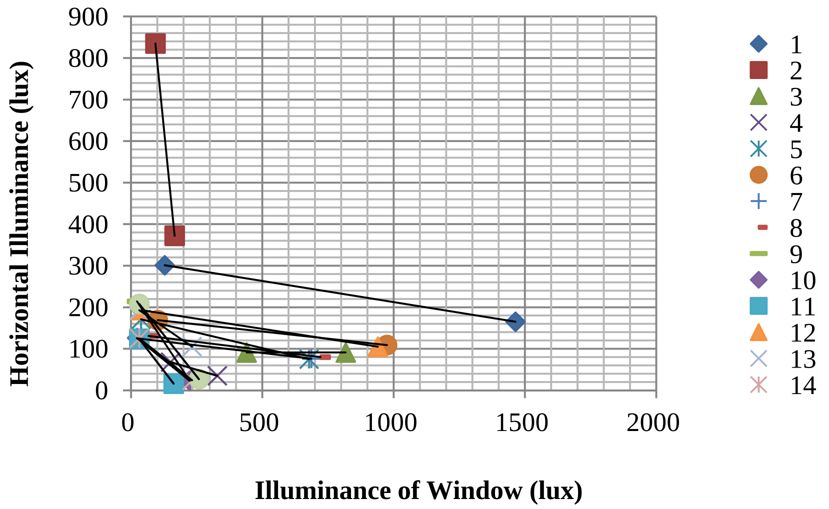


Fig. 4-20 Correaltion between task horizontal illuminance and window illuminance in the 1st model

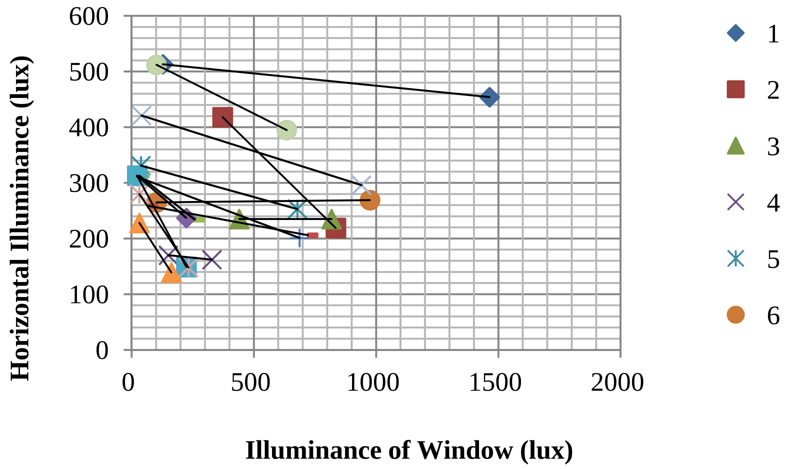


Fig. 4-21 Correaltion between task horizontal illuminance and window illuminance in the 2nd model

Comparing task horizontal illuminance and illuminance of window, when illuminanceof window is higher, the task horizontal illuminance previous adjusting is lower. In other words, when day-lighting of incidence from outside more “previous the 1st adjusting model”, the subject is able to bearable lower task horizontal illuminance for reading and VDT work previous adjusting task lighting. But when day-lighting decreased though sunset “previous the 2nd adjusting task lighting”, the subject is unable to bearable lower task horizontal illuminance like “previous the 1st adjusting” for reading and VDT work. The same result is occurred to “after adjusting task lighting model”. The task illuminance was adjusted higher in “after the 2nd adjusting task lighting model” than “after the 1st adjusting task lighting model”

4-4-3 Influence of Minimum Allowable Task Horizontal Illuminance and Luminance of Ambient Space

Fig. 4-22 shows the correlation of minimum allowable task horizontal illuminance and luminance of space.

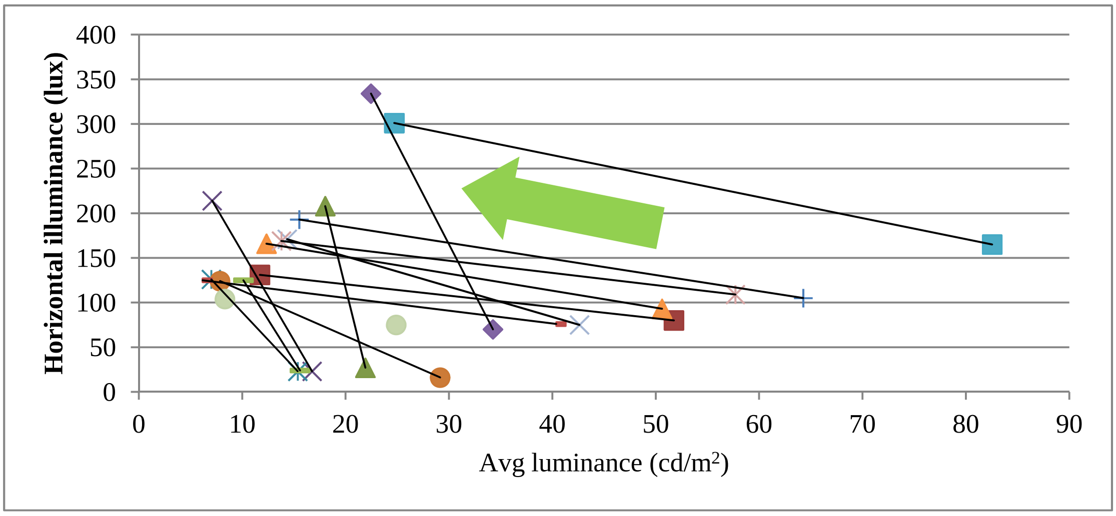


Fig. 4-22 Correlation of minimum allowable task horizontal illuminance and luminance of space

The same result with luminance of window is shown that luminance of space previous the 1st adjusting task lighting model was higher than the 2nd adjusting model. Because previous the 1st adjusting model was brighter than previous the 2nd adjusting model, the minimum allowable task horizontal illuminance was lower in the 1st adjusting model than the 2nd adjusting model. This experiment is only held in the afternoon and the luminance of experiment room has to decline through sunset. Because of weather limit (sunset) and difficult to hold experiment in the early morning, the subjects are all in the decreasing brightness space and adjust task lighting illuminance from unbearable task illuminance to appropriate task illuminance. Comparing 1st and 2nd previous adjusting task illuminance(unbearable task illuminance), when experiment space room becomes dark, the subjects' bearable ability of brightness is decreased. Therefore, previous task illuminance adjusting in 2nd is higher than 1st. Although ascending adjusting method is used, "previous task illuminance adjusting" is the key point in this diagram and it is not adjusted by the subject. Therefore, it is no correlation with adjusting method and the final result is reasonable. In the next chapter, the task lighting adjusting method will be ascending and descending both in the no day lighting room and average them for results and discuss effect between them.

Table 4-4 is correlation coefficient analysis between task horizontal illuminance, luminance of space and illuminance of window. The correlation coefficient of minimum allowable task horizontal illuminance, illuminance of window and luminance of ambient space are 0.115 and 0.004. The correlation coefficient is very low because each subject adjusted different task horizontal illuminance, they are no correlation. But the correlation coefficient of luminance of space and illuminance of window is 0.922. The result indicates that brightness of ambient space and the lighting of incidence from outside have direct correlation.

According to One-way ANOVA with task horizontal illuminance, luminance of space and illuminance of window previous adjusting task lighting, the F is 433.212 (p value=0.038<0.05) for task horizontal illuminance and luminance of space and 18467.242 (p value=0.006<0.05) in the 1st adjusting model. The F is 36.345 (p value=0.02<0.05) for task horizontal illuminance and luminance of space and 2399.177 (p value=0.000<0.05) in the 2nd adjusting model. Therefore, they are significant with task horizontal illuminance, luminance of space and illuminance of window both in the 1st and 2nd previous adjusting model. This result is mentioned that minimum allowable task horizontal illuminance is affected by ambient lighting environment.

Table 4-4 Correlation coefficient analysis between task horizontal illuminance, luminance of space and illuminance of window

		Horizontal Illuminance	Luminance	Illuminance of Window
Horizontal Illuminance	Pearson Correlation	1	.115	.004
	Sig. (2-tailed)		.481	.980
	N	40	40	40
Luminance	Pearson Correlation	.115	1	.922
	Sig. (2-tailed)	.481		.000
	N	40	40	40
Illuminance of Window	Pearson Correlation	.004	.922	1
	Sig. (2-tailed)	.980	.000	
	N	40	40	40

Table 4-5 One-way ANOVA test of minimum allowable task horizontal illuminance

1st Minimum allowable task horizontal illuminance		Sum of Squares	df	Mean Square	F	Sig.
Luminance of space	Between Groups	7533.088	18	418.505	433.212	.038
	Within Groups	.966	1	.966		
	Total	7534.054	19			
Illuminance of window	Between Groups	2659282.800	18	147737.933	18467.242	.006
	Within Groups	8.000	1	8.000		
	Total	2659290.800	19			
2nd Minimum allowable task horizontal illuminance		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Luminance of space	Between Groups	1057.887	15	70.526	36.345	.002
	Within Groups	7.762	4	1.940		
	Total	1065.648	19			
Illuminance of window	Between Groups	268707.789	14	19193.414	2399.177	.000
	Within Groups	32.000	4	8.000		
	Total	268739.789	18			

4-4-4 Influence of Horizontal Illuminance on Task Plane and Behavior in Office Space

The subjects are required read or VDT work in this experiment. In the first adjusting, there are 7 subjects in reading and 13 subjects in VDT work; in the second adjusting, there are 7 subjects in reading and 8 subjects in VDT work. The other 5 subjects do not adjust task lighting after the first adjusting. These 5 subjects all do VDT work. Fig. 4-23 and Fig. 4-24 show that difference of minimum allowable horizontal illuminance between the first adjusting and the second adjusting in reading and VDT work.

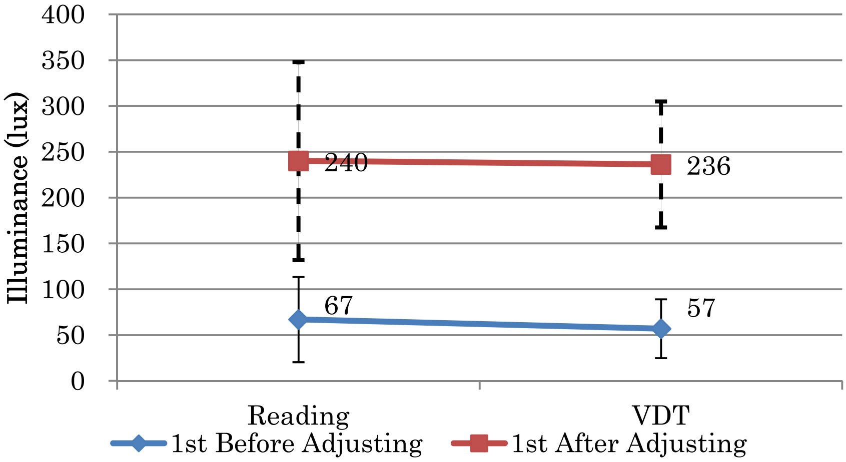


Fig. 4-23 Task horizontal illuminance for reading and VDT work in 1st adjusting

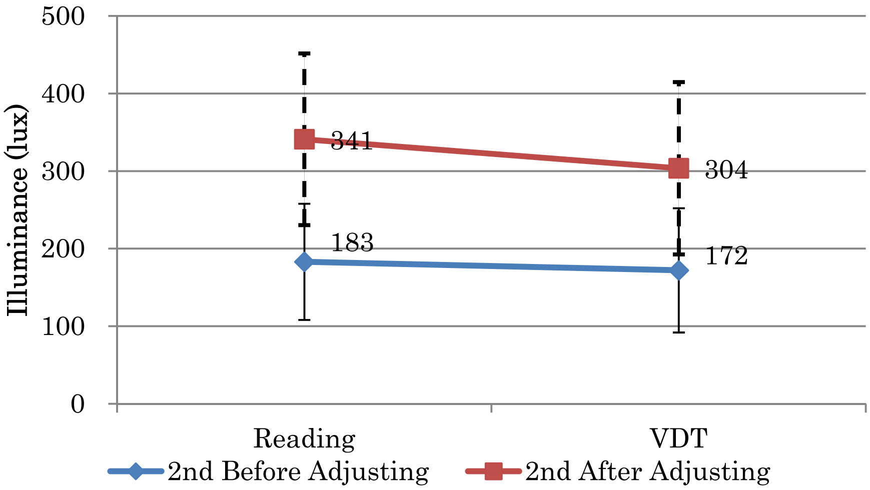


Fig. 4-24 Task horizontal illuminance for reading and VDT work in 2nd adjusting

The first adjusting task horizontal illuminance is from 67lux to 240lux, and SD are 46.5 and 108.1 in reading. The second adjusting task horizontal illuminance is from 183lux to 341lux, and SD are 74.9 and 110.62 in reading. The first adjusting task horizontal illuminance is from 57lux to 236lux, and SD are 32.1 and 80.1 in VDT work. The second adjusting task horizontal illuminance is from 172lux to 304lux, and SD are 68.72 and 111.03 in reading.

Table 4-6 Summary of task horizontal illuminance in reading and VDT work

Illumination	adjusting	N	Min(lx)	Max(lx)	Ave(lx)	SD
Reading	1	7	19	138	67	46.5
Reading	2	7	113	300	183	74.9
VDT	1	13	13	109	57	32.1
VDT	2	8	111	345	172	80.1

4-5 Conclusions

In this experiment, the subjects are required that when they are unable to bearable the task illuminance, they can adjust task lighting until they can read or do VDT work comfortably. Therefore, the task illuminance previous adjusting is called minimum allowable task horizontal illuminance, and the appropriate task horizontal illuminance is represented the task illuminance after adjusting in this experiment.

The main conclusions of the experiment are pointed out that:

1. Horizontal illuminance is affected by ambient lighting environment

In this experiment, horizontal illuminance and vertical illuminance is affected by two factors: 1. Sky light from window. 2. The task light is adjusted by subjects. The experimenter requires each subject adjust task lighting when each subject is unable to bearable for reading or VDT work. When luminance of ambient space was higher, the subjects will bearable lower horizontal illuminance on task plane because ambient space is brighter. In other words, when luminance of ambient space is lower, the subjects will not bearable lower horizontal illuminance on task plane because ambient space was darker. According to Brightness formula = [21.5-8.4*SD of log (luminance)] × average luminance, the next experiment will discuss that the minimum horizontal illuminance and appropriate horizontal illuminance in different ambient brightness (Chapter 5) and uniformity (Chapter 6).

Fig. 4-25 The next experiments after low task illuminance ensured in Chapter 4

2. Minimum allowable horizontal illuminance is lower than standard much.

The average minimum allowable task horizontal illuminance on task plane from 20 subjects is between 61lux and 172lux and the appropriate task horizontal illuminance is 238lux and 321lux. The average minimum vertical illuminance of subject's eye location is between 37lux and 89lux. This result will be referred to experiment setting in next chapter.

3. The horizontal illuminance on task plane for reading is higher than VDT work.

The results of minimum allowable task horizontal illuminance are divided to reading and VDT work in this experiment. Through 20 subjects adjusting task lighting, the results are shown that reading was needed higher horizontal illuminance than VDT work regardless of the first adjusting and the second adjusting. Besides the above-mentioned, there were 5 subjects only adjusting once for VDT work until sunset. This result is indicated that the subjects could bearable lower task horizontal illuminance.

CHAPTER 5 MINIMUM AND APPROPRIATE TASK ILLUMINANCE IN DIFFERENT AMBIENT BRIGHTNESS SPACE

CHAPTER 5 MINIMUM AND APPROPRIATE TASK ILLUMINANCE IN DIFFERENT AMBIENT BRIGHTNESS SPACE

5-1 Introduction

It is reported that around 25% of the total electricity used in the commercial sector is consumed by lighting systems (Bleeker 1993). Lighting consumes approximately 16~19% of the electrical energy supplied to office buildings in Japan[20], and 24.8% in Taiwan (S.C. Hu 2004). Even if those estimations are difficult to verify and might not be completely consistent, these figures lead to one important finding: around the world, the scientific community seems to agree that discussing the artificial lighting loads of buildings is extremely important and that energy-efficient lighting solutions have to be adopted.

According to survey on chapter 3, most office managers chose to reduce artificial lighting in office and tried to use daylight more. However, daylight is hard to be well controlled and necessary task-illuminance is also difficult to be ensured. On the other hand, there are only few researches for minimum and appropriate illuminance in office.

In order to guarantee an appropriate visual comfort in office rooms, the horizontal illuminance (especially on the task plan) must be sufficiently. According to chapter 4, the minimum allowable task horizontal illuminance in reading and VDT work was all below 750lux very much. Even appropriate task horizontal illuminance was also below 750lux.

In other way, visual display terminal (VDT) workplace becomes more and more popular in office now. When the display is placed in a light environment, surface reflections occur. Therefore, ambient illuminance is an important consideration in VDT workplace design. Therefore, the contrast ratio for a given TFT-LCD and the actual luminance of the screen towards the user were affected by the ambient

[21] 照明学会：環境負荷低減と豊かな光環境の両立に向けて，JIER-104，2009.

illuminance (Hori 1993). However, studies concerning ambient illuminance and luminance screen for VDT are rare. Helander and Rupp (1984) mentioned that the specifications for an ambient illuminance tolerateard would become even more confusing in the future as LCDs and other flat panel displays (FPDs) become more popular (Helander et al. 1984). Ambient illuminance and screen luminance combination are the key factors affecting character identification performance for VDT users. The results from this study may improve the visual conditions for VDT users.

In order to save energy, a convenient method of complying with the new power loads is to use the concept of task-ambient lighting which can be reduced significantly, thereby sappropriate vertical illuminanceng energy. The idea is not new but task-ambient lighting was never widely adopted. One of the main points is that many occupants would object to the gloomy appearance of the office. To overcome this problem, the brightness of ambient lightness is needed (P.L. Shellko 1976). Therefore, this study examined the minimum and appropriate illuminance which is adjusted by subjects in different ambient lighting for reading and VDT. Furthermore, the TFT-LCD is fast becoming the most optimal choice in VDT display today. Consideration correlation between appropriate screen luminance and ambient lighting environment is significant. It proposed a simple prediction formula for reference of different ambient lighting.

5-2 Experiment Plan

5-2-1 Purpose of Experiment

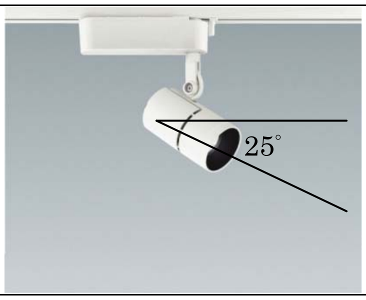
In order to undertolerate the minimum and appropriate illuminance of task under various ambient lighting, minimum and appropriate illuminance should be defined before starting the experiment. In this research, minimum illuminance means the limit low illuminance which can support subjects to read and do VDT work. In other words, if the task illuminance is below minimum illuminance, subjects will not be able to read. Appropriate illuminance is defined as the best lighting environment for reading in their point of view. This research adopted adjustable task lighting and each subject can adjust illuminance by themselves. The present study evaluated three independent variables: vertical illuminance of subject's eye position (to represent ambient illuminance), horizontal illuminance (to represent task plane illuminance) and screen luminance. There were five levels of vertical illuminance used in this study: 5lux, 10lux, 20lux, 50lux and 100lux.

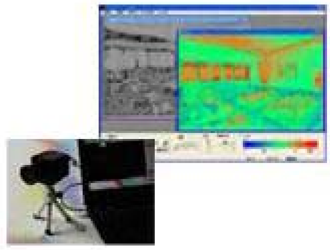
5-2-2 Experiment Equipment

Table 5-1 shows information of illuminance meter, task lighting, ambient lighting , spot lighting and VDT station.

Table 5-1 Experiment Equipment

Equipment	Model	Photo
Illuminance Meter	Konica MinoltaT-10 Measurement range:0.01 ~ 299,900 lx	

Luminance meter	BM-910D Measurement angle:1° f = 36mm　F2.5 Measurement range :0.1 ～ 1,999,000cd/m^2	
Task lighting	EndoERK8971W LED 4000K	
Ambient lighting	Endo ERK8117WC LED 4000K	
Spot lighting	Endo ERS3001WA 4000K	
Lighting Modulator	PWM X-239W (Power output 15~100％)	

VDT working screen	Acer ASPIRE 4810TG 14"LED LCD Adjustable, 10 luminance steps (20cd/m^2~200 cd/m^2)	
Luminance camera	Luminocam is made by KOZO KEIKAKU ENGINEERING	

The LED lighting in this experiment was made by Endo Lighting Corp, including ambient light and task light. Color temperature was 4000K. Task lighting was able to adjust horizontal illuminance on task plane from 20lux to 750lux. The illuminance meter was made by Konica Mimolta. The model was T-10 which was adopted for measuring horizontal illuminance and vertical illuminance. Luminance picture was taken by Luminocam which is made by KOZO KEIKAKU ENGINEERING(日本構造計劃研究所). The luminocam was set up height 120cm from floor and located in subject's eye. The distant from screen was 68cm. An lens angle of right and left side was 103.6° and up and down side was 76.5°.

In order to obtain minimum horizontal and appropriate illuminances for reading and VDT, article sample and VDT content should be defined. Letters in the article sample were font size 10 in single space in Times New Roman made by Microsoft Word in A4 paper. The VDT station was 14-in TFT-LCD notebook, and TFT-LCD luminance can be adjusted easily. The TFT-LCD with a 358mm diagonal screen provides an active viewing area of 311mm in horizontal and 175mm in vertical. The pixel resolution was 1366 in horizontal and 768 in vertical. The screen images were refreshed at a rate of 60 Hz. The maximal contrast ratio and maximal luminance of the TFT-LCD have 10 levels between 20 and 220 cd/m^2 and subjects were able to adjust to appropriate luminance which they felt well. Regarding chromaticity coordinates of the text and background color, it is shown in Table 5-1. The screen surface was coated with a polarizer to reduce glare and reflection. About VDT screen, according to ISO9241, English text 4mm row spacing 2mm was employed by Microsoft

PowerPoint, 6.11% of all screen pixels displayed text, 93.89% displayed background, and article content was the same with paper used for reading conditions. According to VESA FPDM (Flat Panel Display Measurements Tolerateard), using luminance-meter (TOPCON BM-9) measured 5~9 points and average those (Fig. 5-1).

Horizontal and vertical illuminance was measured by illuminance-meter (Konica Minolta T-10). Regarding of measuring position, horizontal illuminance was measured on the center of task plane, and vertical illuminance was measured in subject’s eye position (Height =120cm).

Table 5-2 CIE (1931) chromaticity coordinates of the text and background color

CIE(Lux,y)			RGB code value		
L(cd/m^2)	x	y	R	G	B
120	0.3166	0.3505	191	188	177
100	0.316	0.3503	176	167	158
75	0.3163	0.3485	158	145	140
50	0.3164	0.3496	144	130	121
25	0.3165	0.3486	117	101	91

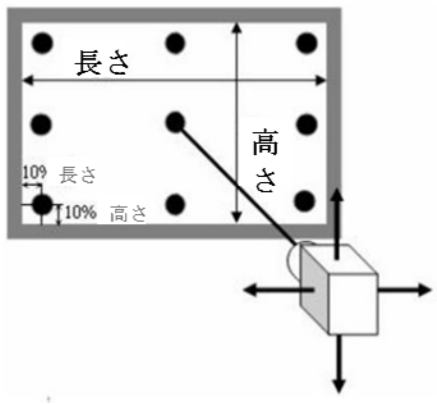


Fig. 5-1 Screen Luminance measurement

5-2-3 Questionnaire

At the same time, to obtain subject's opinions in this experiment, questionnaires are employed.

There are five methods that can be used to measure subjects' perception: ranking methods, rating methods, questionnaire methods, interviews and checklists. The questionnaire method is most commonly used by general studies because it is the measure that shows most direct subjects' feelings[54]. A simple and reliable questionnaire-based assessment method to evaluate satisfaction in office lighting was presented by Eklund and Boyce in 1996[50].

To know employees' point of view about energy sappropriate vertical illuminanceng, questionnaire work as a good tool in the experiment. Responses were made using 7-point scales. The questions used are listed below:

How bright dose the task plane look?
1: very gloomy, 2: gloomy, 3: a little gloomy, 4: neutral, 5: a little bright, 6: bright, 7: very bright.
How comfortable is the lighting on task plane?
1: very uncomfortable, 2: uncomfortable, 3: a little uncomfortable, 4: neutral, 5: a little comfortable, 6: comfortable, 7: very comfortable.
How satisfied is the lighting on task plane?
1: very unsatisfied, 2: unsatisfied, 3: a little unsatisfied, 4: neutral, 5: a little satisfied, 6: satisfied, 7: very satisfied.
How legible is the article on task plane?
1: very difficult, 2: difficult, 3: a little difficult, 4: neutral, 5: a little easy, 6: easy, 7: very easy.
How bright dose the space look?
1: very gloomy, 2: gloomy, 3: a little gloomy, 4: neutral, 5: a little bright, 6: bright, 7: very bright.
How comfortable is the lighting in space?
1: very uncomfortable, 2: uncomfortable, 3: a little uncomfortable, 4: neutral, 5: a little comfortable, 6: comfortable, 7: very comfortable.
Are you satisfied with the lighting in space?
1: very unsatisfied, 2: unsatisfied, 3: a little unsatisfied, 4: neutral, 5: a little satisfied, 6: satisfied, 7: very satisfied.
How is your productivity in this space?
1: very bad, 2: bad, 3: a little bad, 4: neutral, 5: a little good, 6: good, 7: very good.

Summary of questions used in the detailed questionnaire survey are in Table 5-2:

Table 5-3 Contents of questions

Items	Contents
Subject’s database	Response date/Gender/Age
Environment of task plane	Brightness/comfort/satisfaction/legible for reading
Environment of working space	Brightness/comfort/satisfaction/legible for reading
Effect of energy sappropriate vertical illuminanceng policy	Productivity

5-2-4 Experiment Arrangement

Table 5-4 Experimental summary

Experiment space	No windows, white wall space
Experiment behappropriate vertical illuminanceor	Reading and VDT
Experiment time	2 hours
Subjects	20 people (college student)
Method of lighting	Task-ambient
Date of experiment	2013.04~2013.05

The experimental space is 410cm in length, 290cm in width, and 270cm in height. Area is 11.9m^2. The perimeter and ceiling is white and there are no windows. The space contained a desk, a chair, a task-lighting and a frame. The ambient lighting is placed in front wall. There are 4 fluorescent tubes with color temperature of 4000 K installed on top of front wall. The chair in this experiment was able to adjust. Before the experiment starting, experimenter will ask the subject sit and adjust height of chair. The height is fixed to 120cm from floor to subject's eye. The desk of experiment is 180cm in length, 70cm in width. About task lighting, it is the same with ambient lighting as 4000 K and installed on the frame, height is 70cm above the task plane. The task lighting was able to adjust in the range of 0lux to 500lux in this experiment.

Fig. 5-2 and Fig. 5-3 are site plane and section plane for experiment space.

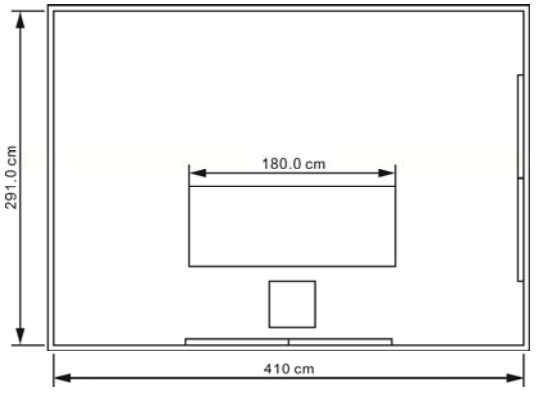


Fig. 5-2 Dimensions of experiment space

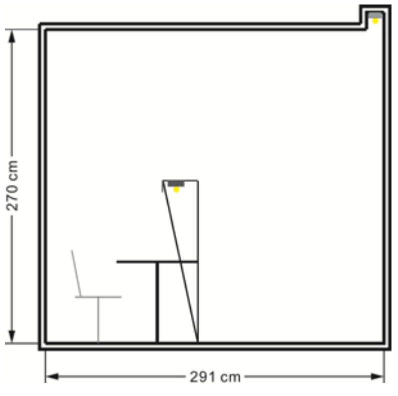


Fig. 5-3 Section of experiment space

There are 20 subjects to participate in this experiment. Each subject may spend 120 minutes for whole experiment. In experiment, reading and VDT work was done in turn. Regarding of reading paper, the size of paper was A4. Font and font size was adopted Times New Roma and Microsoft Word 10, single space, which was refer to English newspaper body text or book. Regarding to VDT work, the content on screen was the same with paper. According to ISO-9241, the font for VDT work is recommend to Times New Roma and font size is Microsoft Word 16. The height of letter was 4mm, and line-width is 2mm. ISO-9241 also recommend that distant between screen to user's eye should be 50~70cm. In this experiment, the distant between screen to user's eye was 68cm and a line of vision was kept to 90° on VDT screen[55].

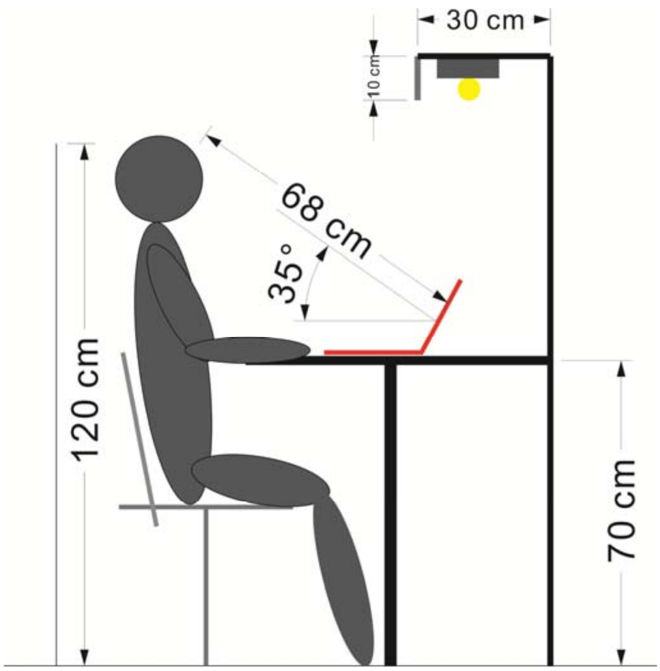


Fig. 5-4 Dimensions of VDT

5-2-5 Independent Variables in Experiment

There were five different independent variables in this experiment. According to the result of chapter 4, the vertical illuminance in the first adjusting task lighting and the second adjusting were 37lux and 53lux. Therefore, the independent variables were set in 5lux, 10lux, 20lux, 50lux and 100lux for vertical illuminance to be ambient light. Under these five independent variables, the horizontal illuminance on task plane were 5lux, 10lux, 20lux, 50lux and 100lux, luminance SD of space were 1,09, 1.36, 2.62, 7.41 and 15.03, maximum luminance of space were 21.73 cd/m^2、27.08 cd/m^2、33.53 cd/m^2、76.87 cd/m^2 and 111.91 cd/m^2.

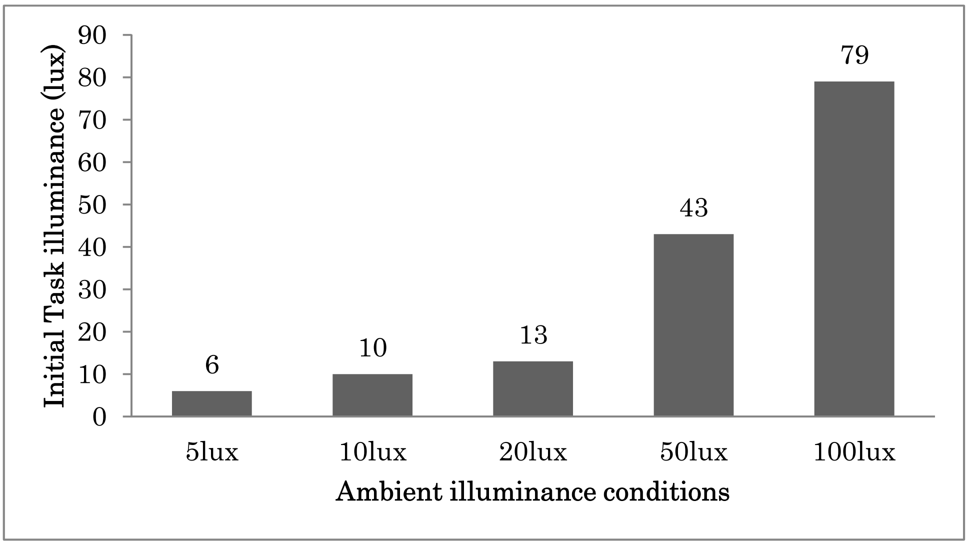


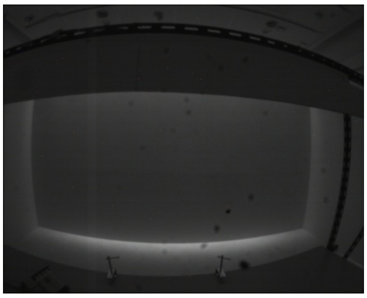
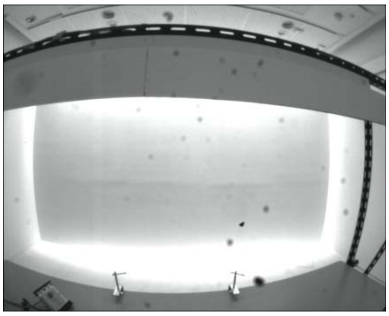
Fig. 5-5 Initial Task illuminance in each vertical illuminance pattern

Table 5-5 Independent Variables summary

Independent Factor	Vertical Illuminance	Horizontal Illuminance	Avg. Luminance of Space	Luminance SD of Space	MAX Luminance of Space
1	5 lux	6lux	2.11 cd/m^2	1.09	21.73 cd/m^2
2	10 lux	10 lux	3.33 cd/m^2	1.36	27.08 cd/m^2
3	20 lux	13 lux	4.98 cd/m^2	2.62	33.53 cd/m^2
4	50 lux	43 lux	14.41 cd/m^2	7.41	76.87 cd/m^2
5	100lux	79 lux	27.36cd/m^2	15.03	111.91 cd/m^2

Table 5-5 is pictures in each independent variable in next page.

Table 5-6 Picture of each independent variable

Independent variable	
1	2
	
3	4
	
5	
	

5-2-6 Subjects

The subjects were 20 college students, 10 male and 10 female. Average age is 28. All had at the least 0.8 corrected visual acuity and normal color vision.

5-2-7 Experimental Flow

Subjects were asked to adjust task illuminance in this experiment under 5 different vertical illuminances. At the beginning, each subject was in the dark adaptation in 5mins to adopt. At the same time, experimenter was explaining experiment process and some points for attention to each subject. After dark adaptation, subject were asked to do questionnaire and then experiment was started by adjusting task lighting until subjects can tolerate it for reading. Each subject was asked to read paper and adjust the task light from 0lux until they can identify each word well using. After adjustment, experimenter recorded illuminance of task lighting by illuminance meter. In this study, it is called minimum allowable task horizontal illuminance (MHI). Next step was adjusted appropriate VDT screen luminance (ASL). Experimenter moved notebook to the center of task desk and requested each subject to adjust screen luminance which they felt the best under minimum horizontal illuminance. Each subject should adjust screen luminance twice. One is ascending from lowest screen luminance (20cd/m^2) to appropriate. Another is descending for minimum allowable task horizontal illuminance highest screen luminance (220cd/m^2) to appropriate. Experimenter should record them both and average was used to analyze. The third step was adjusting appropriate task lighting illuminance in reading after notebook was removed. Each subject read the paper and adjusted task lighting from 0lux until they felt the best for reading. In this study, it is called appropriate task horizontal illuminance (AHI). After adjusting, experimenter should record illuminance of task lighting by illuminance meter again. The fourth step was the similar to the second step, adjusting appropriate screen luminance under appropriate horizontal illuminance. The fifth step was also adjusting appropriate task horizontal illuminance, but it adjusted starting from 500lux. The sixth step was adjusting appropriate screen luminance under appropriate task horizontal illuminance in fifth step. The seventh step was adjusting minimum allowable task horizontal illuminance from 500lux. Last step was adjusting appropriate screen luminance under minimum allowable task horizontal illuminance. After the last step, subjects could take a rest to wait for the next pattern. Therefore, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance was adjusted twice, one was ascending to minimum allowable task horizontal illuminance or appropriate task horizontal illuminance. Another was descending to minimum allowable task horizontal illuminance or appropriate task horizontal illuminance. ASL was adjusted four times in minimum allowable task horizontal illuminance and appropriate task horizontal illuminance individually in each vertical illuminance pattern. Doing the whole patterns took 120mins in total. The flow is showed in Fig. 5-6.

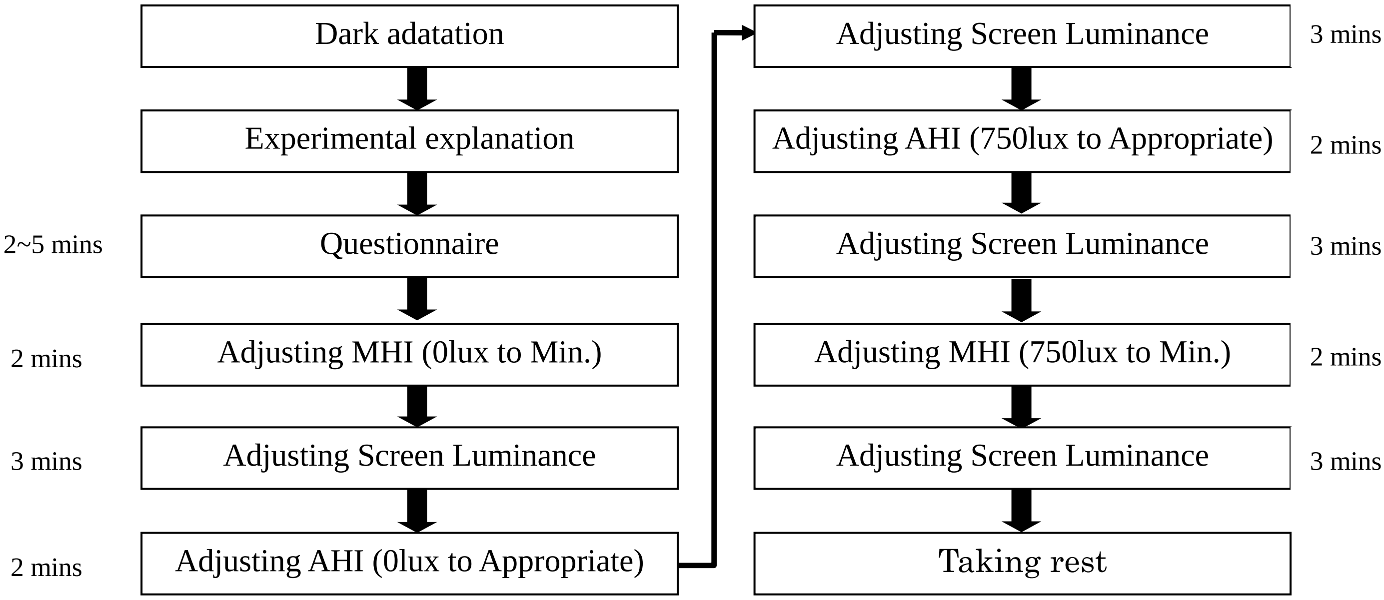


Fig. 5-6 Experimental flow

There are 5 patterns and 20 subjects in this experiment. In order to make random order in this experiment, the Latin Square design is adopted for 5 patterns.

1	2	3	4	5	1= No.1 pattern, 5lux
2	3	4	5	1	2= No.2 pattern, 10lux
5	1	2	3	4	3= No.3 pattern, 20lux
3	4	5	1	2	4= No.4 pattern, 50lux
4	5	1	2	3	5= No.5 pattern, 100lux

Fig. 5-7 Latin Square Design for 5 patterns

5-3 Result of Experiment

5-3-1 Illuminance

To compare minimum allowable task horizontal illuminance of each vertical illuminance model, the mean minimum allowable task horizontal illuminance in each model was needed. Fig. 5-8 and Fig. 5-9 show 1st and 2nd adjusting horizontal illuminance in each vertical illuminance pattern. According to T-test (Table 5-7) between 1st and 2nd in each pattern, they are not significant between ascending and descending. Another reason is that the difference is not too large between 1st and 2nd adjusting. Therefore, the final result is adopted 1st and 2nd adjusting average to analyze. The mean minimum allowable task horizontal illuminance is showed in Fig. 5-10. The mean minimum allowable task horizontal illuminance in 5lux model had the highest (79lux), next is 10lux (74lux), 20lux (71lux). In 50lux model, there were 7 subjects who did not adjust minimum allowable task horizontal illuminance, because they could tolerate it for reading without task light. Therefore, 50lux was divided into two groups in this study which 50lux stood for a group for adjusting minimum allowable task horizontal illuminance and 50lux' for the group which did not adjust. In appropriate model, all subjects adjusted in each condition. The appropriate task horizontal illuminance in each pattern was showed in Fig. 5-11.

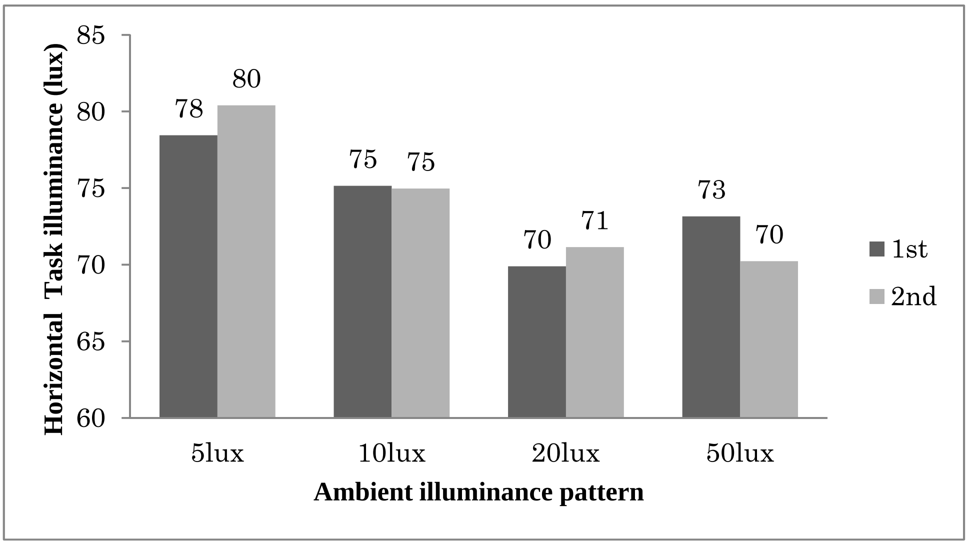


Fig. 5-8 1st and 2nd adjusting horizontal illuminance in minimum model

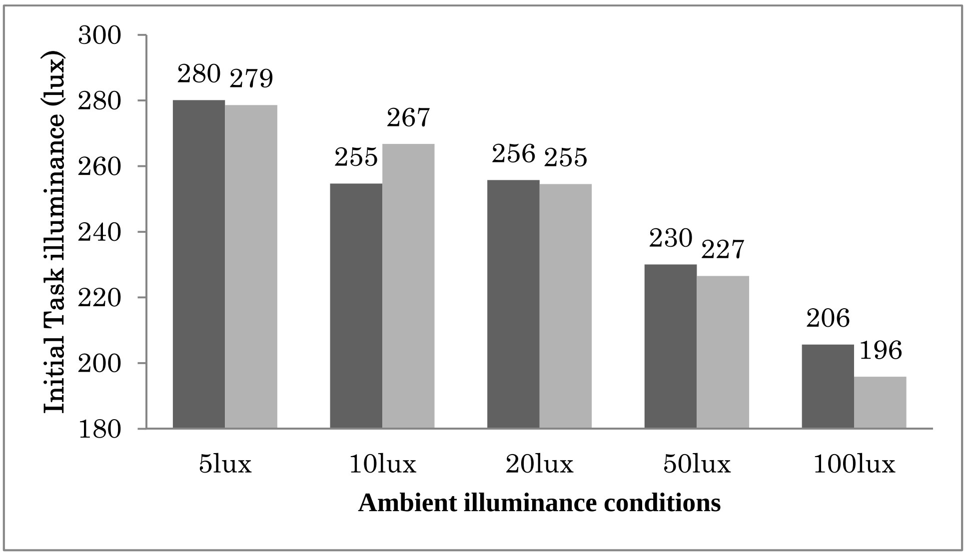


Fig. 5-9 1st and 2nd adjusting horizontal illuminance in appropriate model

Table 5-7 Paired samples test of 1st and 2nd adjusting in minimum and appropriate model

Model 1st - 2nd	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower: Lower	Upper			
Minimum	-.30685	19.06807	2.23175	-4.75576	4.14206	-.137	72	.891
Appropriate	.78800	34.43182	3.44318	-6.04402	7.62002	.229	99	.819

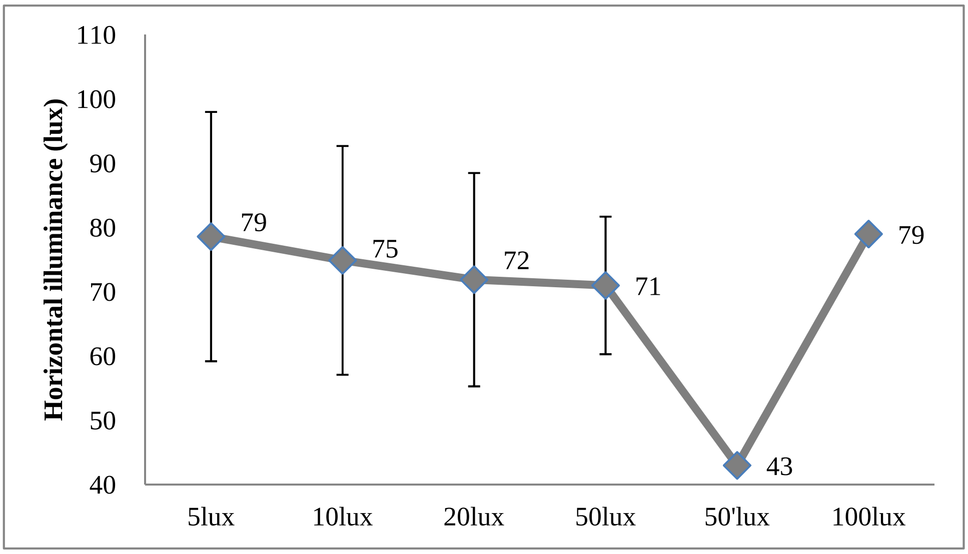


Fig. 5-10 Min. allowable task horizontal illuminance in each vertical pattern average of the subjects

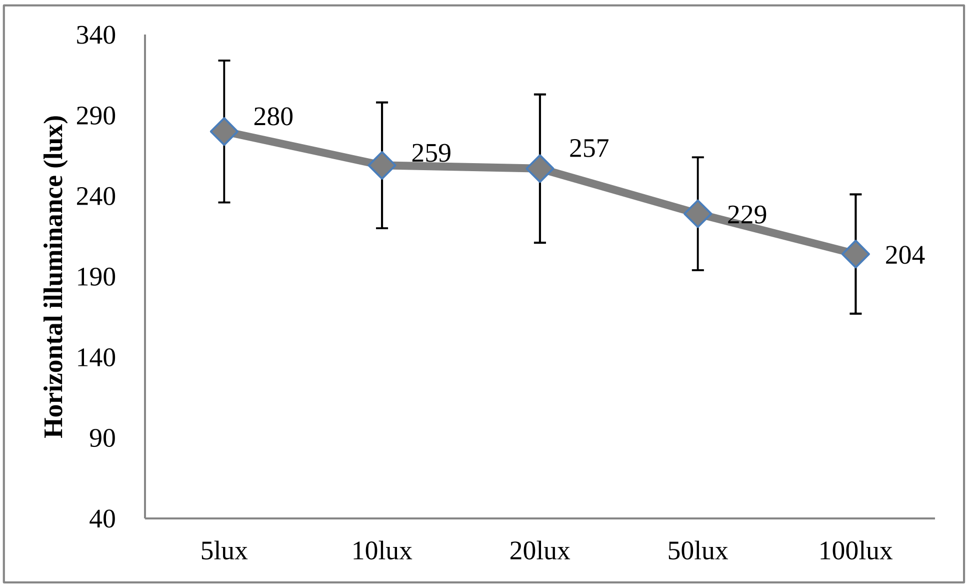


Fig. 5-11 Appropriate task horizontal illuminance in each vertical pattern average of the subjects

According to paired samples test, illuminance in each independent variable in minimum model and appropriate model are all significant (Table 5-8 and Table 5-9).

Table 5-8 Paired samples test of independent variables in minimum model

Minimum model	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower				
				Lower	Upper			
5lux – 10lux	5.51000	4.04187	.90379	3.61835	7.40165	6.097	19	.000
5lux – 20lux	10.04500	5.61309	1.25513	7.41799	12.67201	8.003	19	.000
5lux – 50lux	18.92000	3.76432	.84173	17.15824	20.68176	22.478	19	.000
10lux – 20lux	4.53500	4.36098	.97515	2.49400	6.57600	4.651	19	.000
10lux – 50lux	13.41000	4.49923	1.00606	11.30430	15.51570	13.329	19	.000
20lux - 50lux	8.875	6.04830	1.35244	6.04431	11.70569	6.562	19	.000

Table 5-9 Paired samples test of independent variables in appropriate model

Appropriate model	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower				
				Lower	Upper			
5lux – 10lux	18.63000	10.45834	2.33856	13.73534	23.52466	7.966	19	.000
5lux – 20lux	24.20500	9.62127	2.15138	19.70210	28.70790	11.251	19	.000
5lux – 50lux	51.05500	10.13641	2.26657	46.31101	55.79899	22.525	19	.000
5lux – 100lux	78.60500	13.46131	3.01004	72.30491	84.90509	26.114	19	.000
10lux – 20lux	5.57500	8.61039	1.92534	1.54521	9.60479	2.896	19	.009
10lux – 50lux	32.42500	5.19938	1.16262	29.99162	34.85838	27.890	19	.000
10lux – 100lux	59.97500	8.50770	1.90238	55.99327	63.95673	31.526	19	.000
20lux- 50lux	26.85000	9.02205	2.01739	22.62755	31.07245	13.309	19	.000
20lux – 100lux	54.40000	10.82589	2.42074	49.33333	59.46667	22.472	19	.000
50lux – 100lux	27.55000	7.43728	1.66303	24.06925	31.03075	16.566	19	.000

The minimum allowable task horizontal illuminance and minimum vertical illuminance correlation is showed in Fig. 5-12. Results show that, each point represented result of each subject adjusted task illuminance in minimum model and its corresponding vertical illuminance in each condition. In 100lux vertical model, there was no subject adjusting task lighting, that time, the task plane illuminance was 79lux which all subjects could tolerate for reading, therefore, it was not included. In addition to 100lux vertical model, 7 subjects also did not adjust task lighting in 50lux vertical model, so these results are not employed, too. In order to obtain correlation between minimum allowable task horizontal illuminance and minimum vertical illuminance, liner regression analysis was done using data of each subject's minimum allowable task horizontal illuminances and their corresponding minimum vertical illuminances. The result showed that each liner formula by regression analysis, 20 negative slopes could be obtained, and according to T test, they are not significant. In other words, these slopes showed the same tread which when subjects were in higher vertical illuminance space or in brighter ambient lighting space, subjects adjusted minimum allowable task horizontal illuminance lower. About constant, each line was different according to each subject had their own tolerateard for minimum allowable task horizontal illuminance.

Further, using the same method for correlation between appropriate task horizontal illuminance and appropriate vertical illuminance, similar tread was obtained, but slopes and constants were different. Appropriate task horizontal illuminance and appropriate vertical illuminance for each subject are showed in Fig. 5-13. In appropriate model, the vertical conditions from 5lux to 100lux were adjusted by subjects. Therefore, each line was composed by 5 points. Comparing with slope between minimum and appropriate model, the mean of slope was -0.42 for minimum model and -1.05 was for appropriate model. This performance indicated that subjects were easier to be affected by brightness in appropriate model than minimum model.

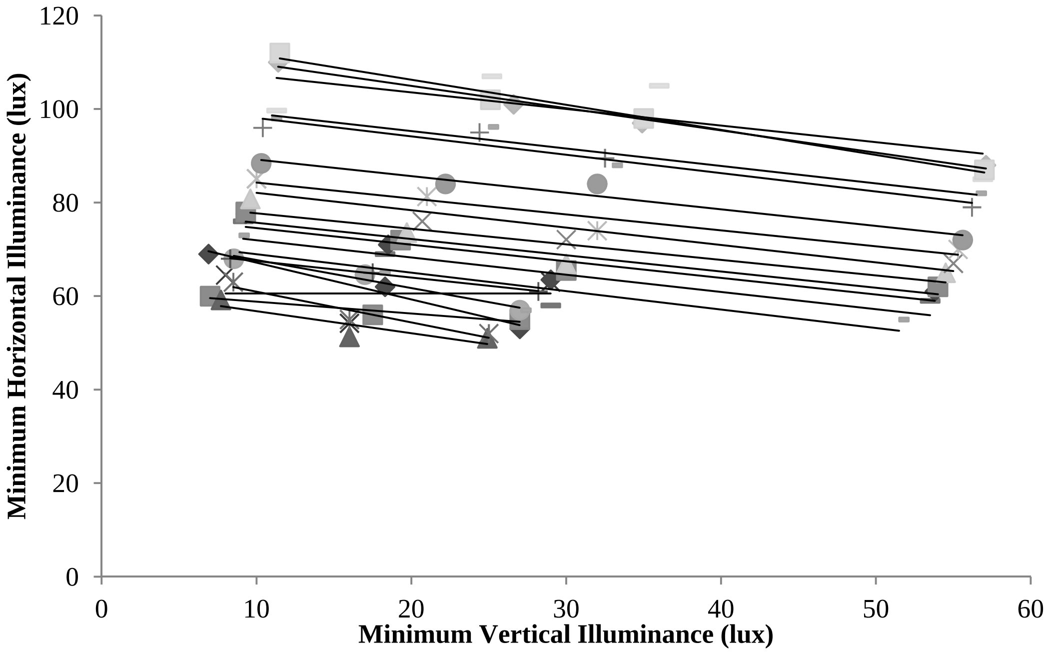


Fig. 5-12 Each subject's minimum allowable task horizontal illuminance and minimum vertical illuminance correlation

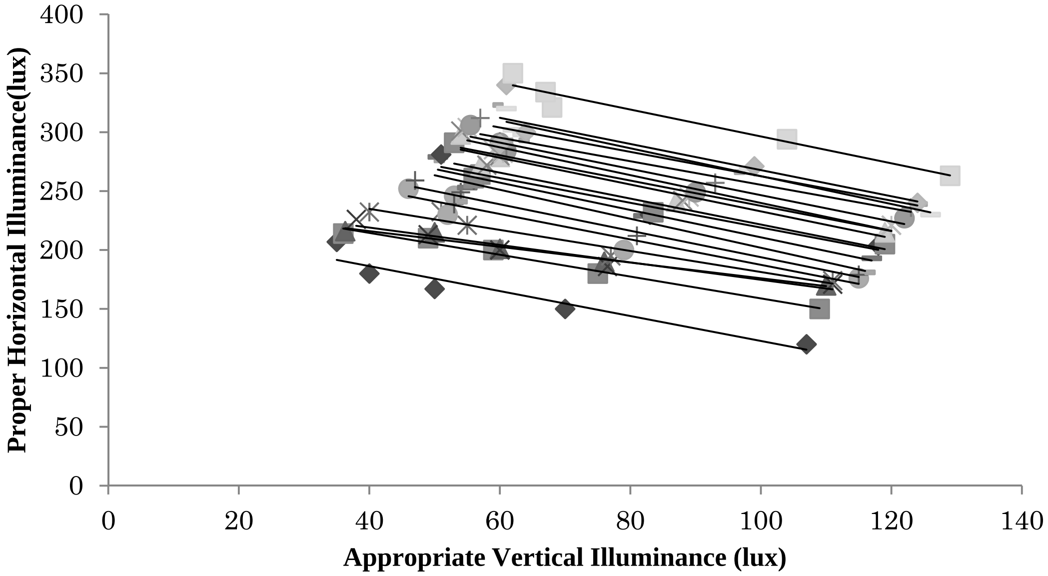


Fig. 5-13 Each subject's appropriate task horizontal illuminance and appropriate vertical illuminance correlation

Table 5-10 Coefficient and constant by each subject

Minimum model				Appropriate model			
	Slope	Constant	R^2		Slope	Constant	R^2
1	-0.787	75.024	0.978	1	-1.0579	228.68	0.907
2	-0.252	61.331	0.910	2	-0.9278	251.66	0.983
3	-0.471	61.47	0.760	3	-0.6661	242.67	0.969
4	-0.001	60.554	0.000002	4	-0.7399	248.7	0.944
5	-0.656	67.485	0.908	5	-0.8925	270.56	0.956
6	-0.601	73.714	0.972	6	-1.0778	295.17	0.925
7	-0.352	71.009	0.9985	7	-1.1233	306.23	0.972
8	-0.394	72.891	0.770	8	-1.2313	325.04	0.902
9	-0.368	75.625	0.676	9	-1.1593	326.71	0.949
10	-0.355	78.093	0.820	10	-1.0507	324.1	0.944
11	-0.347	79.145	0.884	11	-1.102	331.82	0.886
12	-0.333	81.037	0.798	12	-1.1373	346.55	0.921
13	-0.371	85.793	0.870	13	-1.0719	344.66	0.899
14	-0.340	87.669	0.926	14	-1.1803	357.93	0.948
15	-0.355	92.766	0.940	15	-1.1154	358.07	0.945
16	-0.393	102.02	0.938	16	-1.0002	355.41	0.914
17	-0.373	102.76	0.915	17	-1.0338	366.02	0.877
18	-0.355	110.65	0.471	18	-1.1811	380.81	0.952
19	-0.476	114.47	0.989	19	-1.1077	378.58	0.744
20	-0.536	116.99	0.987	20	-1.1424	410.65	0.947
AVG	-0.406	83.523	0.826	AVG	-1.050	322.501	0.924
SD	0.160	17.700	0.233	SD	0.144	51.476	0.051

Table 5-11 Correlation coefficients between illuminance and evaluation

	Correlation coefficient			
	Minimum model		Appropriate model	
	Horizontal illuminance	Vertical illuminance	Horizontal illuminance	Vertical illuminance
Minimum Task-Brightness	0.73	0.368		
Minimum Ambient-Brightness	0.365	0.791		
Appropriate Task-Brightness			0.65	0.459
Appropriate Ambient-Brightness			0.424	0.768

In order to concern human's visual health, one line could include almost people to express correlation between minimum allowable task horizontal illuminance and minimum vertical illuminance, so the constant was equal to average of constant add two times tolerateard deviation. This line could involve 95% in population, the formula is showed below:

- Minimum Horizontal Illuminance= -0.41*Vertical Illuminance +119(2SD)

Equation 5-1

In other hand, to save energy,

- Appropriate Horizontal Illuminance = -1.05*Vertical Illuminance +323

Equation 5-2

Therefore, in order to energy-sappropriate vertical illuminanceng, these two lines could be defined an allowable range from appropriate to minimum of horizontal and vertical illuminance. It is showed on Fig. 5-14

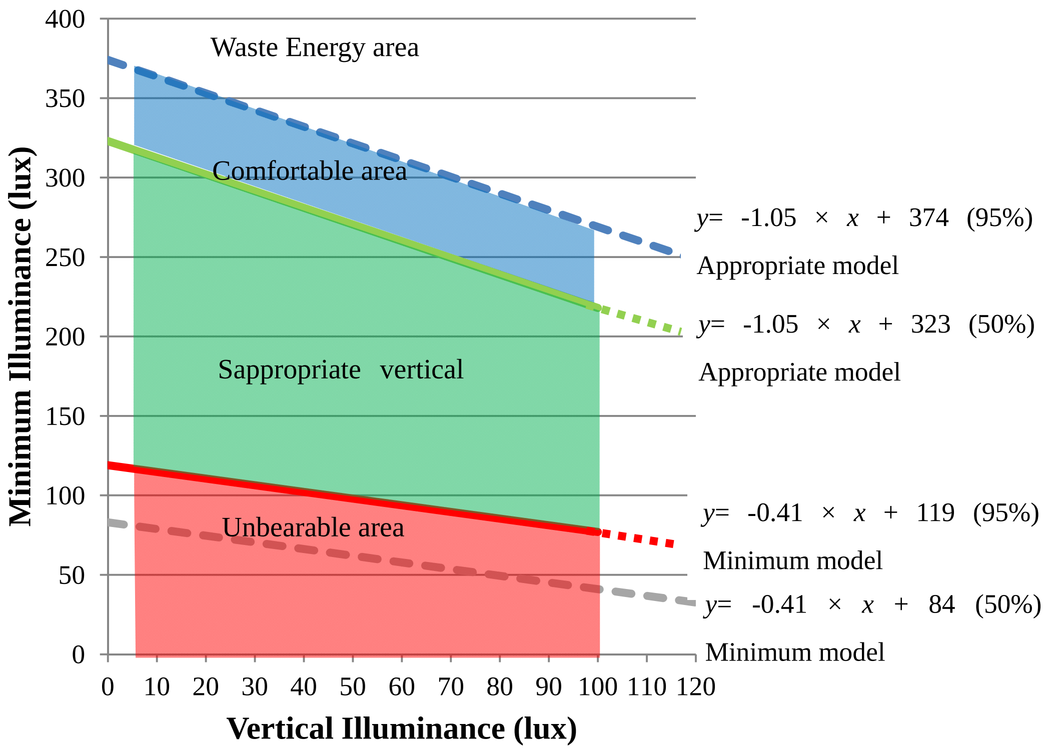


Fig. 5-14 Energy saving range for task illuminance in different brightness space

In order to ensure almost population is bearable minimum allowable horizontal illuminance, the constant of equation is used two times SD for including 95% population. The red line is represented the limit line for minimum allowable horizontal illuminance. Below red line, it may be occurred bad visual health environment. The green line is represented appropriate horizontal illuminance. It is illustrated that 50% population are satisfied with horizontal illuminance on task plane. Therefore, between the red line and green line, “Energy Area” is called. In this area, employees can be bearable for reading and VDT work. The blue line is illustrated 95% population can be satisfied with horizontal illuminance on task plane. Between green line and blue line, “Comfortable Area” is called. Over blue line, “Waste Energy Area” is called, because it is exceeded “Comfortable Area” and will consume more energy. Because this experiment was discussed the vertical illuminance from 5lux to 100lux, below 5lux and over 100lux is not discussed in this study. Although this figure is made by 20 young subjects’ result in this experiment, but according to survey in Japan, the young employees have worse evaluations in power-saving situation than elders. Therefore, this result has possible to apply to each generation, but it still be discussed in the future.

5-3-2 VDT Screen Luminance

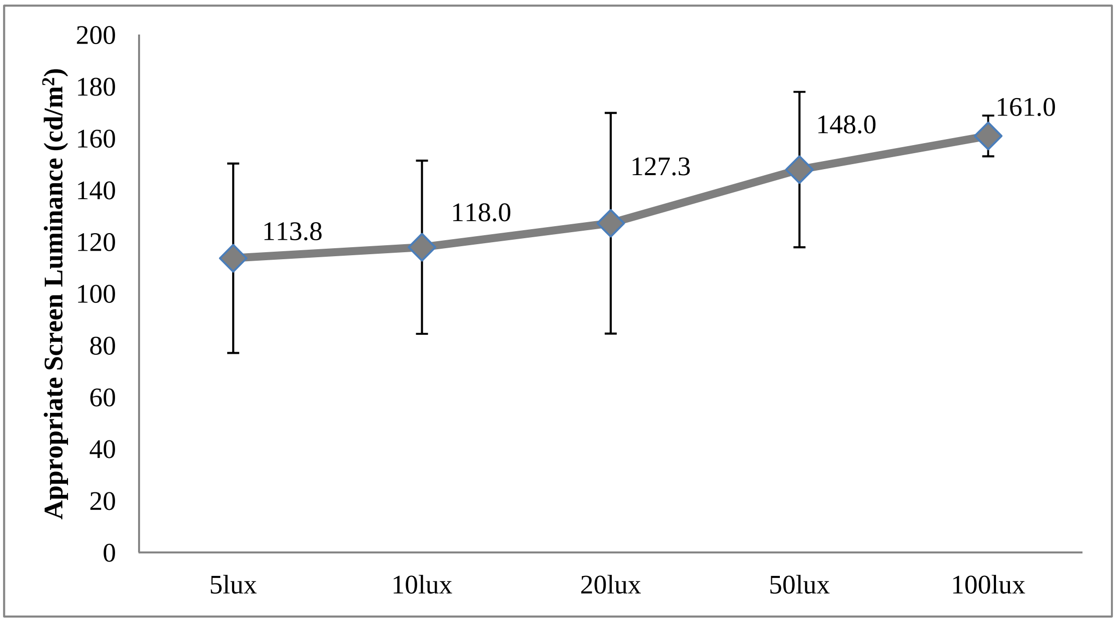


Fig. 5-15 Screen luminance in minimum model

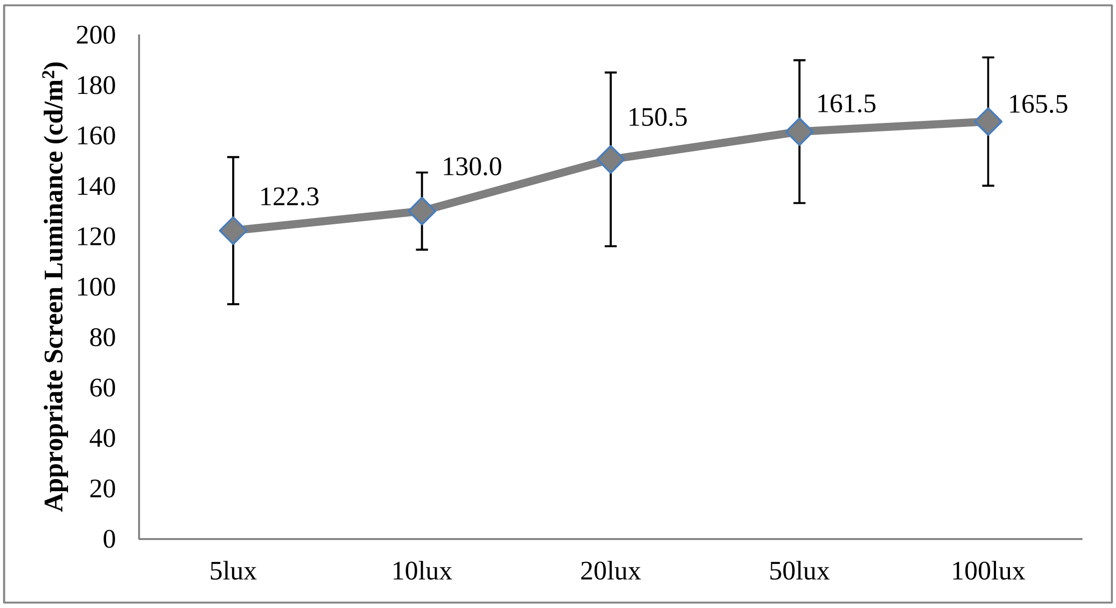


Fig. 5-16 Screen luminance in appropriate model

Screen luminance was another point in this research. The mean screen luminance in each treatment was showed in Fig. 5-15 and Fig. 5-16. When vertical illuminance models became higher, appropriate screen luminance became higher in both minimum and appropriate model. According to correlation analysis, vertical illuminance and appropriate screen luminance had high positive correlation (Correlation Coefficient =0.584), but horizontal illuminance had very few correlation with appropriate screen luminance (Correlation Coefficient =0.388). It is shown in Table 5-11. Therefore, in order to choose an appropriate screen luminance in different brightness space, liner regression analysis was used. Comparing with minimum model and appropriate model, according to paired Samples Test, it shows on Table 5-12 that there two model are significant (p value=0.000<0.05).

Table 5-12 Correlation analysis with Luminance, Vertical illuminance and Horizontal Illuminance

		Luminance	VI	HI
Luminance	Pearson Correlation	1	.584	.388
	Sig. (2 - tailed)		.000	.000
VI	Pearson Correlation	.584	1	.550
	Sig. (2 - tailed)	.000		.000
HI	Pearson Correlation	.388	.550	1
	Sig. (2 - tailed)	.000	.000	

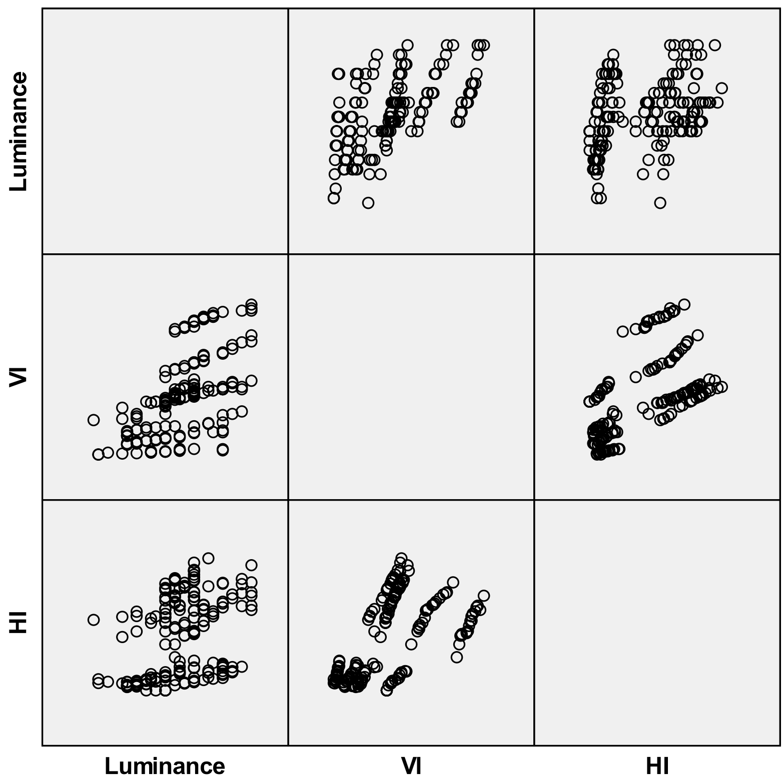


Fig. 5-17 Matrix of VDT screen luminance vertical illuminance and horizontal illuminance

Comparing with each independent variable in minimum model and appropriate model, according to paired samples test, except 5lux – 10lux in minimum model is not significant, the other are all significant (Table 5-13 and Table 5-14).

Table 5-13 Paired samples test of VDT screen luminance in minimum model

Minimum model	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower: Lower	Upper			
5lux – 10lux	-4.25000	20.27930	4.53459	-13.74100	5.24100	-.937	19	.360
5lux – 20lux	-13.50000	24.33862	5.44228	-24.89082	-2.10918	-2.481	19	.023
5lux – 50lux	-34.25000	17.11225	3.82641	-42.25878	-26.24122	-8.951	19	.000
5lux – 100lux	-47.25000	29.62374	6.62407	-61.11434	-33.38566	-7.133	19	.000
10lux – 20lux	-9.25000	12.59438	2.81619	-15.14435	-3.35565	-3.285	19	.004
10lux – 50lux	-30.00000	9.31891	2.08377	-34.36138	-25.63862	-14.397	19	.000
10lux – 100lux	-43.00000	26.72472	5.97583	-55.50755	-30.49245	-7.196	19	.000
20lux- 50lux	-20.75000	14.62469	3.27018	-27.59457	-13.90543	-6.345	19	.000
20lux – 100lux	-33.75000	35.61028	7.96270	-50.41612	-17.08388	-4.239	19	.000
50lux – 100lux	-13.00000	22.96450	5.13502	-23.74772	-2.25228	-2.532	19	.020

Table 5-14 Paired samples test of VDT screen luminance in appropriate model

Appropriate model	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower: Lower	Upper			
5lux – 10lux	-7.75000	14.99781	3.35361	-14.76919	-.73081	-2.311	19	.032
5lux – 20lux	-28.25000	12.06070	2.69685	-33.89458	-22.60542	-10.475	19	.000
5lux – 50lux	-39.25000	13.10635	2.93067	-45.38396	-33.11604	-13.393	19	.000
5lux – 100lux	-43.25000	14.62469	3.27018	-50.09457	-36.40543	-13.226	19	.000
10lux – 20lux	-20.50000	20.31981	4.54365	-30.00996	-10.99004	-4.512	19	.000
10lux – 50lux	-31.50000	15.73631	3.51875	-38.86482	-24.13518	-8.952	19	.000
10lux – 100lux	-35.50000	14.03942	3.13931	-42.07065	-28.92935	-11.308	19	.000
20lux- 50lux	-11.00000	9.81406	2.19449	-15.59312	-6.40688	-5.013	19	.000
20lux – 100lux	-15.00000	13.27840	2.96914	-21.21448	-8.78552	-5.052	19	.000
50lux – 100lux	-4.00000	7.53937	1.68585	-7.52853	-.47147	-2.373	19	.028

The result of liner regression analysis for screen luminance and vertical illuminance was showed in Fig. 5-18 and Fig.5-19. In minimum model and appropriate model, the points of 20 subjects adjusting screen illuminance and corresponding vertical illuminance could obtain 20 regression formulas. Average of coefficients and constants are showed below.

- Appropriate VDT screen luminance in minimum model (cd/m^2) = 0.83* Vertical Illuminance +100 Equation 5-3
- Appropriate VDT screen luminance in appropriate model (cd/m^2) = 0.84* Vertical Illuminance +85 Equation 5-4

Table 5-11 T-test of screen luminance and vertical illuminance

	F test	Sig.	t	p-value
Coefficient	2.004	.165	.113	.910
Constant	.839	.365	-1.585	.122

Comparing with two models via T-test, coefficients and constants were not significant, p=0.122>0.05 for coefficient, p=0.910>0.05 for constant. It is showed on Table 5-14. This indicates that, screen luminance did not differ from minimum or appropriate model.

Table 5-15 Minimum Model- Appropriate Model Paired Samples Test

	Paired Differences							
			Std. Error	95% Confidence Interval Lower				
	Mean	Std. Deviation	Mean	Lower	Upper	t	f	Sig.
Minimum - Appropriate	-12.35	18.48361	1.84836	-16.01755	-8.68245	-6.682	99	.000

Further, because minimum model and appropriate model are not different, Equation 5-3 and Equation 5-4 can be combined to be：

- Appropriate VDT screen luminance (cd/m^2) = 0.833× Vertical Illuminance + 93 Equation 5-5

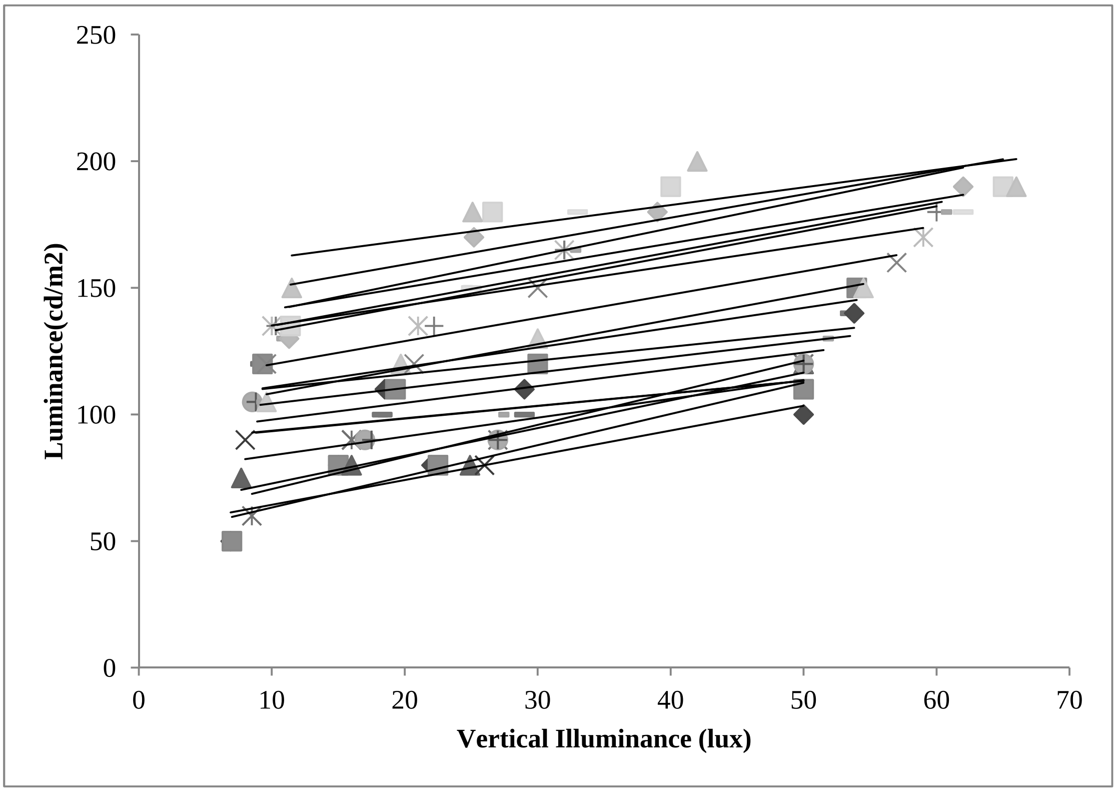


Fig. 5-18 Correlation between screen luminance and vertical illuminance in minimum model

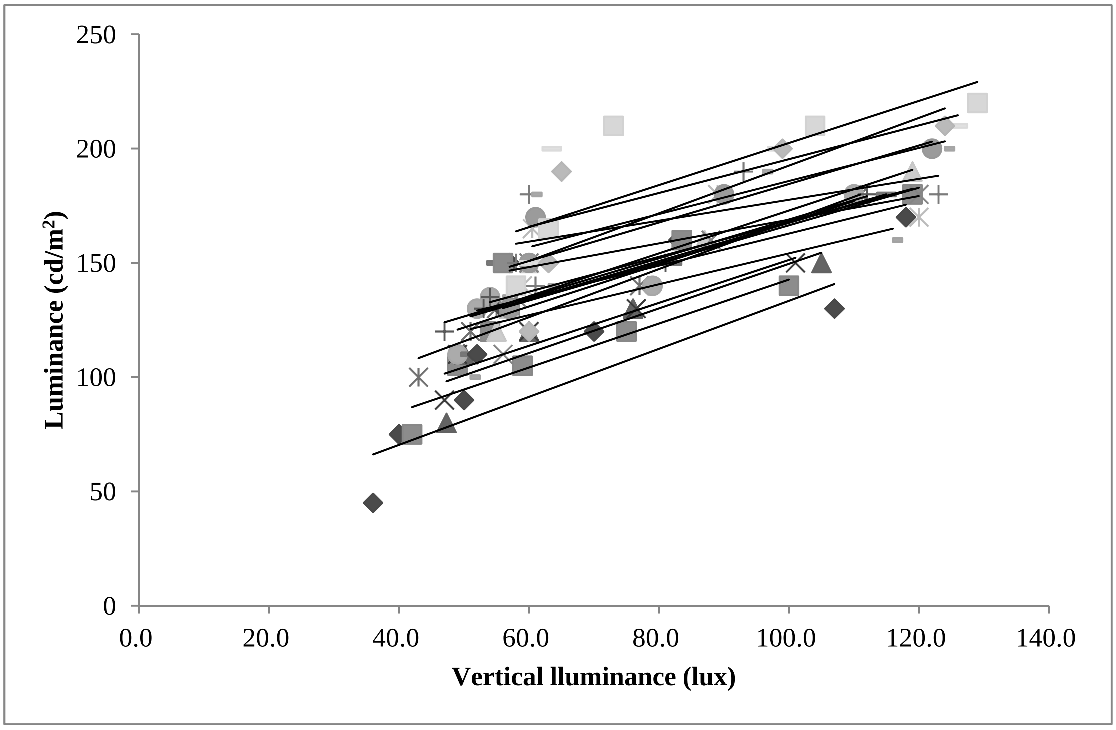


Fig. 5-19 Correlation between screen luminance and vertical illuminance in appropriate model

5-3-3 Questionnaire

The mean evaluation scores without adjusting task-lighting for subjects under each treatment are shown in Fig. 5-20.

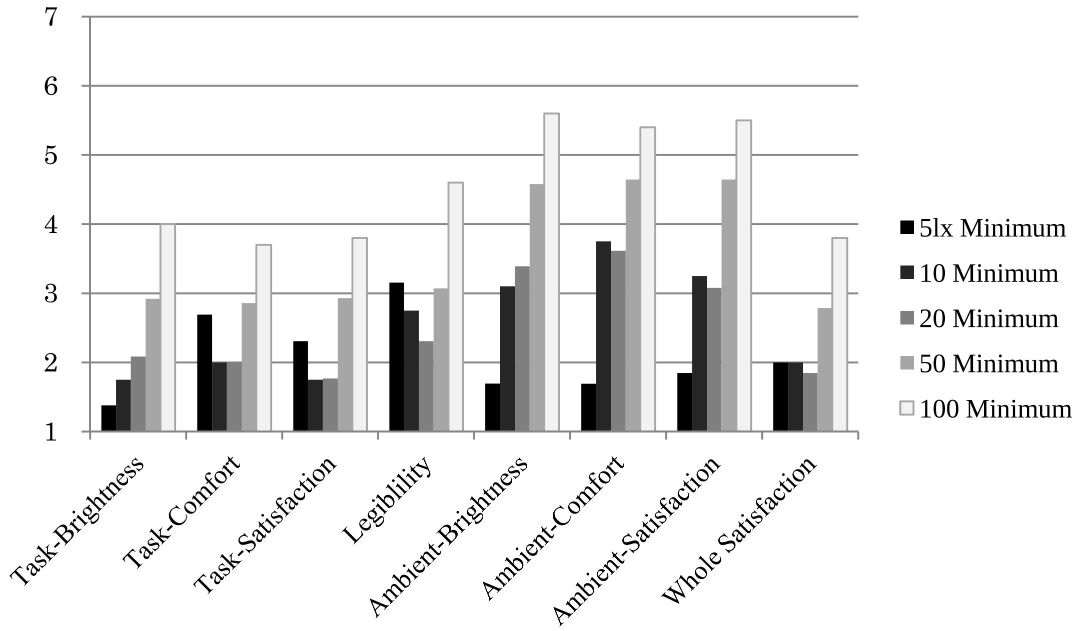


Fig. 5-20 Subject's statement-No task light

Via vertical illuminance from 5lux to 100lux, evaluation of ambient brightness had a strong raise obviously. In vertical 50lux model, mean of space brightness appraisal was above 4. This result indicated that subjects felt no darkness when vertical illuminance was in 50lux, and the same result with S-comfort and S-satisfaction. In the other hand, the performance of task brightness was below 4 except for 100lux condition. The legibility in 100lux model was also obtained over 4.

According to correlation coefficient analysis in all conditions, Task-Brightness, Task-Comfort, Task-Satisfaction and legible were high coefficient, and Ambient-Brightness, Ambient-Comfort and Ambient-Satisfaction had high coefficient. This result indicated that the correlation coefficients were above 0.5 between evaluation of task and legible, but not strong between evaluations of task and ambient. In the working space, task lighting is for operations, like reading, writing and VDT. Even if ambient lighting is very weak, while task plane is bright enough for legibility and employees are able to operate. Further, task and ambient light were independent for task operations. But for productivity, it had over 0.5 in correlation coefficient with each evaluation. That meant that in order to obtain a good productivity, ambient and task light should be concerned. After adjusting lighting, each subject adjusted different horizontal illuminance in minimum and appropriate model. Correlation coefficient analysis is showed in Table 5-16.

Comparing with illuminance and evaluation in minimum and appropriate models in Table 5-16, horizontal illuminance and Task-Brightness had 0.73 (Minimum model) and 0.65 (Appropriate model) positive correlation, and vertical illuminance and Ambient-Brightness obtained 0.791 (Minimum model) and 0.768 (Appropriate model). This result shows that horizontal illuminance has direct correlation with Task-brightness obviously, but it may affect evaluation of Ambient-Brightness very few. Oppositely, vertical illuminance and Ambient-Brightness obtain high positive correlation, but when vertical illuminance becomes higher, it does not mean that Task-Brightness will become higher. Although horizontal illuminance might affect vertical illumiance when subjects adjusted task lighting, but the main effect was from ambient light, not task light actually.

Table 5-16 Correlation coefficient analysis without task-lighting

	Task-Brightness	Task-Comfort	Task-Satisfaction	Legible	Ambient-Brightness	Ambient-Comfort	Ambient-Satisfaction	Productivity
Task-Brightness	1	0.774	0.747	0.698	0.479	0.457	0.392	0.521
Task-Comfort		1	0.832	0.695	0.450	0.550	0.483	0.544
Task-Satisfaction			1	0.775	0.481	0.558	0.482	0.588
Legiblility				1	0.435	0.479	0.431	0.576
Ambient-Brightness					1	0.854	0.814	0.577
Ambient-Comfort						1	0.912	0.703
Ambient-Satisfaction							1	0.697
Productivity								1

5-4 Conclusions

Horizontal illuminance has been the only standard for lighting space for a long time. In order to save energy and respond to new lighting style, lighting recommendations should be reconsidered again. On the other hand, VDT work not only becomes more and more popular, but also might be occupied for a long time in each day. This research aimed to clarify under different ambient lighting space, which was ranged of task horizontal illuminance between necessary minimum to appropriate. However, much research discussed with T/A ratio (task lighting illuminance/ ambient lighting illuminance) in office for a long time, but in this research, vertical illuminance at position of subject's eyes was used to represent ambient lighting illuminance. According to this study, minimum allowable task horizontal illuminance is from 43lux to 112lux, and appropriate task horizontal illuminance is from 120lux to 350lux for reading. Both of them were very different from lighting tolerateard of office in Japan. Further, this results described when vertical illuminance was higher, in other words, when space was brighter, both minimum allowable task horizontal illuminance and appropriate task horizontal illuminance were lower. Therefore, in order to save energy, horizontal illuminance is not the only element in lighting design. Vertical illuminance should be considered as well. Allowable range is a reference in office when manager would like to set a suitable lighting environment including visual brightness and task working.

Regarding screen luminance, the above results indicated that, both in minimum or appropriate model, screen luminance was affected by vertical illuminance obviously and had no correlation with minimum allowable task horizontal illuminance or appropriate task horizontal illuminance. According to result of this study, appropriate screen luminance was adjusted by subjects became higher through brightness of space. One of the reasons is that, in order to avoid background contrast, if brightness from screen and environment could be near, subjects might be able to feel more comfortable.

This study discussed about correlation between vertical and horizontal illuminance, but there are other elements which might affect minimum allowable task horizontal illuminance and appropriate task horizontal illuminance need to be studied in the future, such as uniformity, and luminance distribution in visual. Besides, although minimum allowable task horizontal illuminance and appropriate task horizontal illuminance were adjusted by subjects in experiment for short time, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance might obtain different results in real office or it might be changed when operations take a long time. The impact of these factors needs more follow-up studies to be clarified.

CHAPTER 6 MINIMUM AND APPROPRIATE TASK ILLUMINANCE IN DIFFERENT UNIFORMITY WORKING SPACE

CHAPTER 6 MINIMUM AND APPROPRIATE TASK ILLUMINANCE IN DIFFERENT UNIFORMITY WORKING SPACE

6-1 Introduction

Besides of illuminance standard for lighting environment, the standard of uniformity is recommend for different space. Acorrding to JIEG-008(2002), the uniformity of office should be above 0.6 (average horizontal illuminance/maximum horizontal illuminance)[20]. User can be able to get good visual environment from higher uniformity, and increase their productivity in office. In order to saving energy, task-ambient is adopted in many offices from 1970s, but it might make user to feel gloomy and unsatisfied, because task-ambient is bad for uniformity sometimes. According to chapter 4, the result was indicated that the correlation of brightness, satisfaction and vertical illuminance were high, but there was no correlation with horizontal illuminance. According to Ko et al. research[16], expect average luminance of space, subjects' brightness may be affected by luminance distribution. When luminance of space is uniform, the brightness might increase, however when luminance of space is too dispersive or too concentration, the brightness might decrease. According to result of chapter 5, when ambient lighting became brighter, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance was adjusted to decrease by subjects and appropriate VDT screen luminance was adjusted to increase. This result indicated that horizontal illuminance on task plane may affected by ambient lighting environment under task-ambient lighting style. The different uniformity of luminance was used in the experiment in this chapter. It was discussed correlation with uniformity of luminance in ambient space, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance, and discussed influence of appropriate VDT screen luminance at same time.

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[21] JIEG-008(2002)

6-2 Experiment Plan

6-2-1 Purpose of Experiment

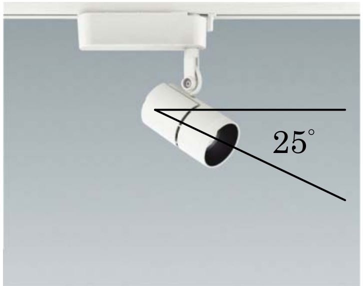
The purpose of this experiment is that the influence of minimum allowable task horizontal illuminance and appropriate task horizontal illuminance under different uniformity of luminance ambient space. Besides of horizontal illuminance, the correlation between uniformity of luminance ambient space and VDT screen luminance was discussed. The hypothesis of this experiment is that the uniformity of luminance in ambient space becomes better, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance should be adjusted decrease by subjects.

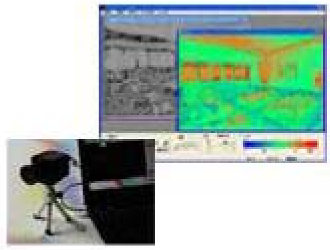
6-2-2 Experiment Equipment

The experiment space, lighting and furniture in of this chapter were the same with chapter 5. In order to change the uniformity of luminance in ambient space, spot lighting was employed. Table 6-1 introduces experiment equipment.

Table 6-1 Experiment Equipment

Equipment	Model	Photo
Illuminance Meter	Konica MinoltaT-10 Illuminance measurement range：0.01 ~ 299,900 lx	
Luminance Meter	BM-910D Measurement angle:1° f = 36mm F2.5 Measurement range :0.1 ～ 1,999,000cd/m^2	

Task Lighting	EndoERK8971W LED 4000K	
Ambient Lighting	Endo ERK8117WC LED 4000K	
Spot Light	Endo ERS3001WA 4000K	
Lighting Modulator	PWM X-239W (Power output 15~100％)	
VDT Working Screen	Acer ASPIRE 4810TG 14”LED LCD Adjustable, 10 luminance steps ($20cd/m^2$~$200\ cd/m^2$)	

Luminance Camera	Luminocam is made by KOZO KEIKAKU ENGINEERING	

The LED lighting in this experiment was made by Endo Lighting Corp, including ambient light and task light. Color temperature was 4000K. Task lighting was able to adjust horizontal illuminance on task plane from 20lux to 750lux. The illuminance meter was made by Konica Mimolta. The model was T-10 which was adopted for measuring horizontal illuminance and vertical illuminance. Luminance picture was taken by Luminocam which is made by KOZO KEIKAKU ENGINEERING(日本構造計劃研究所). The luminocam was set up height 120cm from floor and located in subject’s eye. The distant from screen was 68cm. An lens angle of right and left side was 103.6° and up and down side was 76.5°.

In order to obtain minimum horizontal and appropriate illuminances for reading and VDT, article sample and VDT content should be defined. Letters in the article sample were font size 10 in single space in Times New Roman made by Microsoft Word in A4 paper. The VDT station was 14-in TFT-LCD notebook, and TFT-LCD luminance can be adjusted easily. The TFT-LCD with a 358mm diagonal screen provides an active viewing area of 311mm in horizontal and 175mm in vertical. The pixel resolution was 1366 in horizontal and 768 in vertical. The screen images were refreshed at a rate of 60 Hz. The maximal contrast ratio and maximal luminance of the TFT-LCD have 10 levels between 20 and 220 cd/m^2 and subjects were able to adjust to appropriate luminance which they felt well. The screen surface was coated with a polarizer to reduce glare and reflection. About VDT screen, according to ISO9241, English text 4mm row spacing 2mm was employed by Microsoft PowerPoint, 6.11% of all screen pixels displayed text, 93.89% displayed background, and article content was the same with paper used for reading conditions. According to VESA FPDM (Flat Panel Display Measurements Standard), using luminance-meter (TOPCON BM-9) measured 5~9 points and average them.

Horizontal and vertical illuminance was measured by illuminance-meter (Konica

Minolta T-10). Regarding of measuring position, horizontal illuminance was measured on the center of task plane, and vertical illuminance was measured in subject's eye position (Height =120cm).

Table 6-2 CIE (1931) chromaticity coordinates of the text and background color

CIE(Lux,y)			RGB code value		
$L(cd/m^2)$	x	y	R	G	B
120	0.3166	0.3505	191	188	177
100	0.316	0.3503	176	167	158
75	0.3163	0.3485	158	145	140
50	0.3164	0.3496	144	130	121
25	0.3165	0.3486	117	101	91

6-2-3 Experiment Arrangement

Table 6-3 Experiment summary

Experiment space	No windows, white wall space
Experiment behavior	Reading and VDT
Experiment time	2 hours
Subjects	20 people（student）
Method of lighting	Task-ambient
Average Luminance of Space	$5cd/m^2$
Date	2013.08~2013.09

The experimental space is 410cm in length, 290cm in width, and 270cm in height. Area is $11.9m^2$. The perimeter and ceiling is white and there are no windows. The space contained a desk, a chair, a task-lighting and a frame. The ambient lighting is placed in front wall. There are 4 fluorescent tubes with color temperature of 4000 K installed on top of front wall. The chair in this experiment was able to adjust. Before the experiment starting, experimenter will ask the subject sit and adjust height of chair. The height is fixed to 120cm from floor to subject's eye. The desk of experiment is 180cm in length, 70cm in width. About task lighting, it is the same with ambient lighting as 4000 K and installed on the frame, height is 70cm above the task plane. The task lighting was able to adjust in the range of 0lux to 500lux in this experiment. Avoid to incident light into subject's eye, there were baffles which was 10cm in width in front and behind of task light. The adjusting machine was set in left side from subject, and he or she can adjust task lighting by himself or herself. Spot light was set on the ceiling and 40cm from front wall. The angle of incidence was -25°

Fig. 6-1 and Fig. 6-3 are site plane and section plane for experiment space in next page.

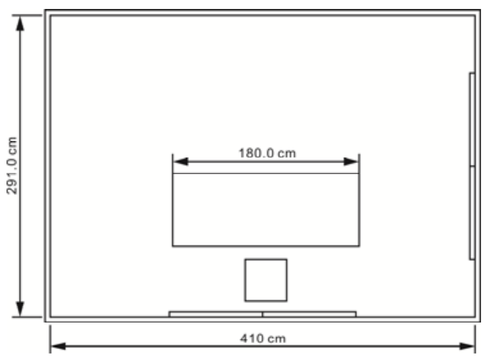


Fig. 6-1 Dimensions of experiment space

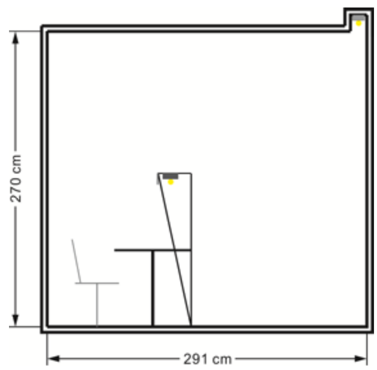


Fig. 6-2 Section of experiment space

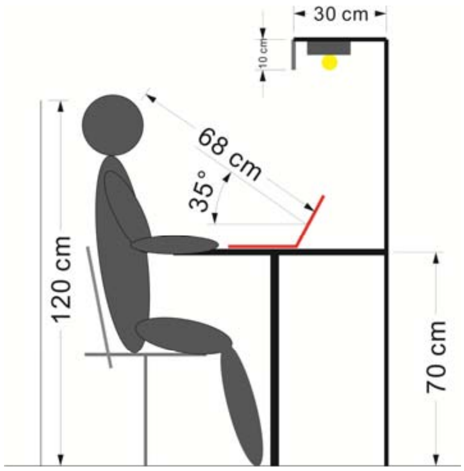


Fig. 6-3 Dimensions of VDT

There are 20 subjects to participate in this experiment. Each subject may spend 120 minutes for whole experiment. In experiment, reading and VDT work was done in turn. Regarding of reading paper, the size of paper was A4. Font and font size was adopted Times New Roma and Microsoft Word 10, single space, which was refer to English newspaper body text or book. Regarding to VDT work, the content on screen was the same with paper. According to ISO-9241, the font for VDT work is recommend to Times New Roma and font size is Microsoft Word 16. The height of letter was 4mm, and line-width is 2mm. ISO-9241 also recommend that distant between screen to user's eye should be 50~70cm. In this experiment, the distant between screen to user's eye was 68cm and a line of vision was kept to 90° on VDT screen[55].

6-2-4 Independent Variables in Experiment

The independent variables in this chapter adopted 5 different luminance distribution of ambient space but the same average luminance of ambient space. According to result of chapter 5, when vertical illuminance was 100lux and horizontal illuminance on task plane was 79lux, no subjects adjusted task lighting in minimum model. When vertical illuminance was 50lux and horizontal illuminance on task plane was 43ux, 13 subjects adjusted task lighting in minimum model. When vertical illuminance was 20lux and horizontal illuminance on task plane was 15lux, all subjects adjusted task lighting in minimum model. At this time, the average luminance was 5cd/m^2. Therefore, the dependent variable of average luminance was set to 5 cd/m^2. Regarding uniformity of luminance in ambient space, this experiment used spot lighting to make the luminance SD of ambient space different and then obtained 5 kinds of different uniformity luminance distribution of ambient space. The summary of independent variables is shown on Table 6-4.

Table 6-4 Independent Variables summary

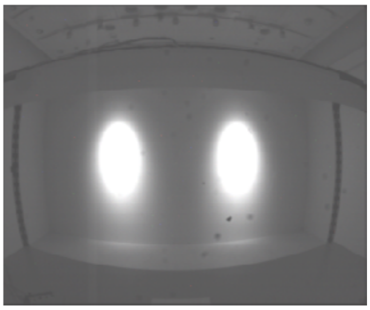
Independent Variables	Average Luminance	SD	MAX Luminance	Horizontal Illuminance	Vertical Illuminance
1	5.09 cd/m^2	10.74	97.32 cd/m^2	17lux	25 lux
2	5.17 cd/m^2	7.48	56.76 cd/m^2	16 lux	23 lux
3	4.90 cd/m^2	5.88	37.37 cd/m^2	15 lux	23 lux
4	5.00 cd/m^2	4.75	30.12 cd/m^2	16 lux	23 lux
5	5.09 cd/m^2	2.42	25.72 cd/m^2	14 lux	21 lux

Variable No. 1~variable No. 4 adopted spot lighting to create higher luminance SD in ambient sace. Variable No. 5 is the same with chapter 5 to adopt uniform light to be the best uniformity variable in this experiment. The luminance SD of ambient space from high to low were 10.74、7.48、5.88、4.75 and 2.42, and the maximum luminance of ambient space were 97.32 cd/m2、56.76 cd/m2、37.37 cd/m2、30.12 cd/m2 and 25.72 cd/m2. The average luminance of ambient space were between 5.09~4.90 cd/m2, it was very close to 5 cd/m2. Because the average luminance of ambient space was almost the same, initial vertical illuminance of subjects eye location was between 25lux~21lux, and initial horizontal illuminance on task plane was between 14~17lux. Table 6-5 is the pictures for each independent variable.

6-2-5 Subjects

The subjects were 20 college students, 10 male and 10 female. Average age is 28. All had at the least 0.8 corrected visual acuity and normal color vision.

Table 6-5 Picture of each independent variable

Independent variable	
1	2
	
3	4
	
5	
	

6-2-6 Experimental Flow

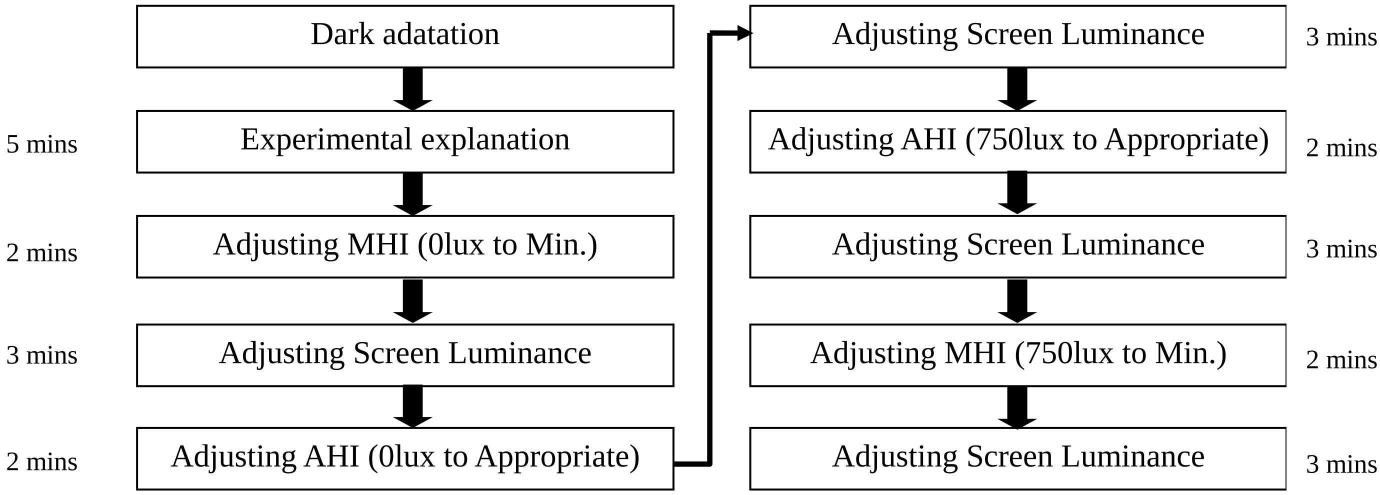


Fig. 6-4 Experimental flow

Subjects were asked to adjust task illuminance in this experiment under 5 different vertical illuminances. At the beginning, each subject was in the dark adaptation in 5mins to adopt. At the same time, experimenter was explaining experiment process and some points for attention to each subject. After dark adaptation, subject were asked to do questionnaire and then experiment was started by adjusting task lighting until subjects can stand it for reading. Each subject was asked to read paper and adjust the task light from 0lux until they can identify each word well using. After adjustment, experimenter recorded illuminance of task lighting by illuminance meter. In this study, it is called minimum allowable task horizontal illuminance (MHI). Next step was adjusted appropriate VDT screen luminance (ASL). Experimenter moved notebook to the center of task desk and requested each subject to adjust screen luminance which they felt the best under minimum horizontal illuminance. Each subject should adjust screen luminance twice. One is ascending from lowest screen luminance (20cd/m^2) to appropriate. Another is descending frominimum allowable task horizontal illuminanceghest screen luminance (220cd/m^2) to appropriate. Experimenter should record them both and average was used to analyze. The third step was adjusting appropriate task lighting illuminance in reading after notebook was removed. Each subject read the paper and adjusted task lighting from 0lux until they felt the best for reading. In this study, it is called appropriate task horizontal illuminance (AHI). After adjusting, experimenter should record illuminance of task lighting by illuminance meter again. The fourth step was the similar to the second step, adjusting appropriate screen luminance under appropriate horizontal illuminance.

The fifth step was also adjusting appropriate task horizontal illuminance, but it adjusted starting from 500lux. The sixth step was adjusting appropriate screen luminance under appropriate task horizontal illuminance in fifth step. The seventh step was adjusting minimum allowable task horizontal illuminance from 500lux. Last step was adjusting appropriate screen luminance under minimum allowable task horizontal illuminance. After the last step, subjects could take a rest and wait for the next pattern. Therefore, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance was adjusted twice, one was ascending to minimum allowable task horizontal illuminance or appropriate task horizontal illuminance. Another was descending to minimum allowable task horizontal illuminance or appropriate task horizontal illuminance. ASL was adjusted four times in minimum allowable task horizontal illuminance and appropriate task horizontal illuminance individually in each vertical illuminance pattern. Doing the whole patterns took 120mins in total.

There are 5 patterns and 20 subjects in this experiment. In order to make random order in this experiment, the Latin Square design is adopted for 5 patterns.

1	2	3	4	5	1= No.1 pattern, 5lux
2	3	4	5	1	2= No.2 pattern, 10lux
5	1	2	3	4	3= No.3 pattern, 20lux
3	4	5	1	2	4= No.4 pattern, 50lux
4	5	1	2	3	5= No.5 pattern, 100lux

Fig. 6-5 Latin Square Design for 5 patterns

6-3 Result of Experiment

The result of this experiment will analyze correlation between luminance uniformity of ambient space, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance. On the other hand, the correlation between appropriate VDT screen luminance and brightness of ambient space was discussed in Chapter 5, and it will be continued to discuss influence of luminance uniformity of ambient space. Fig. 6-6 and Fig. 6-7 show 1^{st} and 2^{nd} adjusting horizontal illuminance in each different uniformity pattern. The same results with Chapter 5: according to T-test (Table 6-6) between 1^{st} and 2^{nd} in each pattern, they are not significant between ascending and descending. The difference is not too large between 1^{st} and 2^{nd} adjusting, neither. Therefore, the final result is adopted 1^{st} and 2^{nd} adjusting average to analyze in Chapter 6.

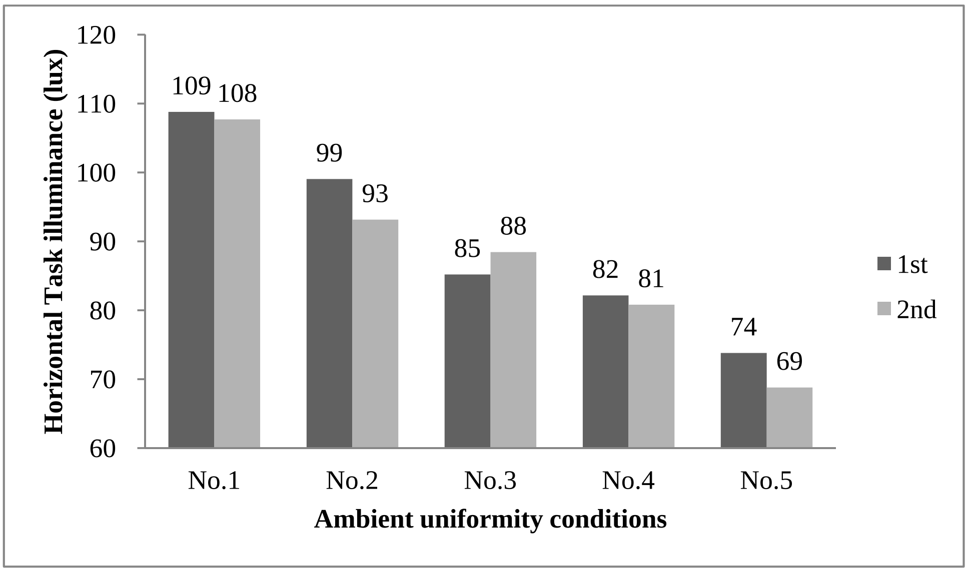


Fig. 6-6 1^{st} and 2^{nd} adjusting horizontal illuminance in minimum model

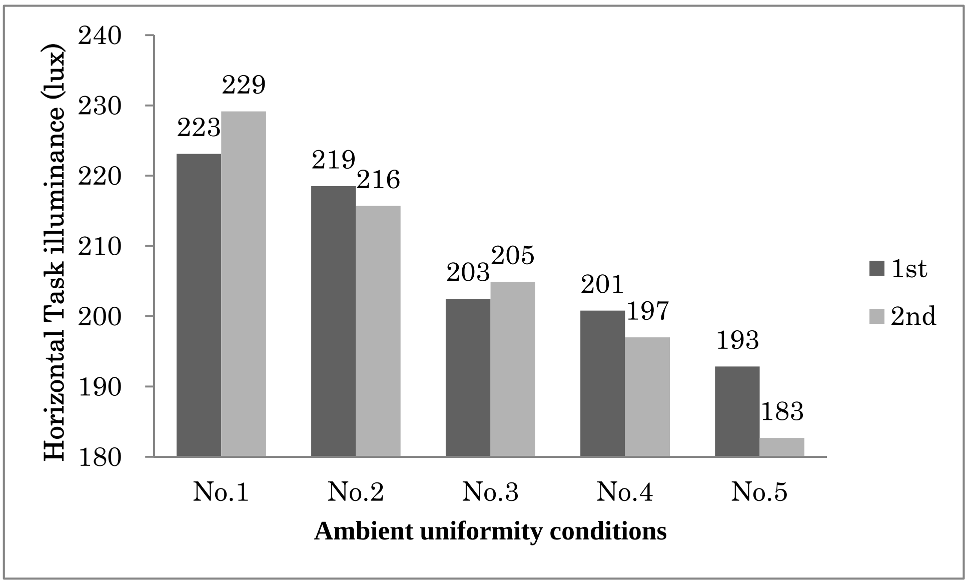


Fig. 6-7 1st and 2nd adjusting horizontal illuminance in minimum model

Table 6-6 Paired samples test of 1st and 2nd adjusting in minimum and appropriate model

Model 1st - 2nd	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower				
				Lower	Upper			
Minimum	-.30685	19.06807	2.23175	-4.75576	4.14206	-.137	72	.891
Appropriate	.78800	34.43182	3.44318	-6.04402	7.62002	.229	99	.819

6-3-1 Illuminance on Task Plane

Fig. 6-10 shows the correlation of average luminance SD of ambient space and average minimum allowable task horizontal illuminance after being adjusted task light by 20 subjects. Fig. 6-11 is the correlation of average luminance SD of ambient space and average appropriate task horizontal illuminance.

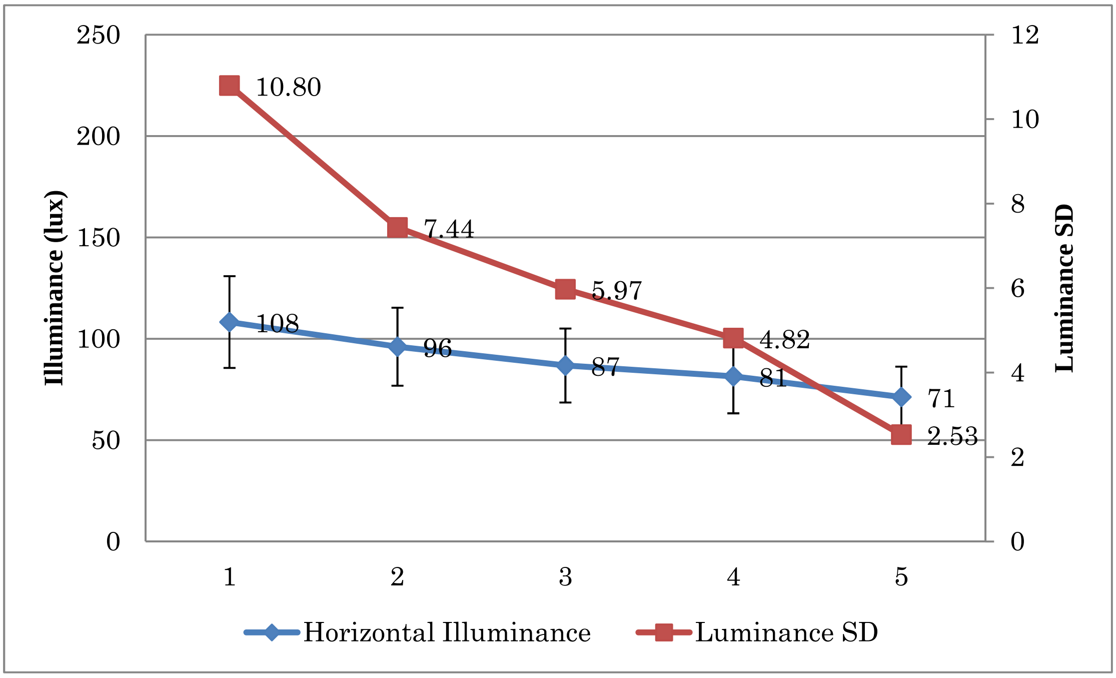


Fig. 6-8 Minimum allowable task horizontal illuminance and ambient luminance SD of space

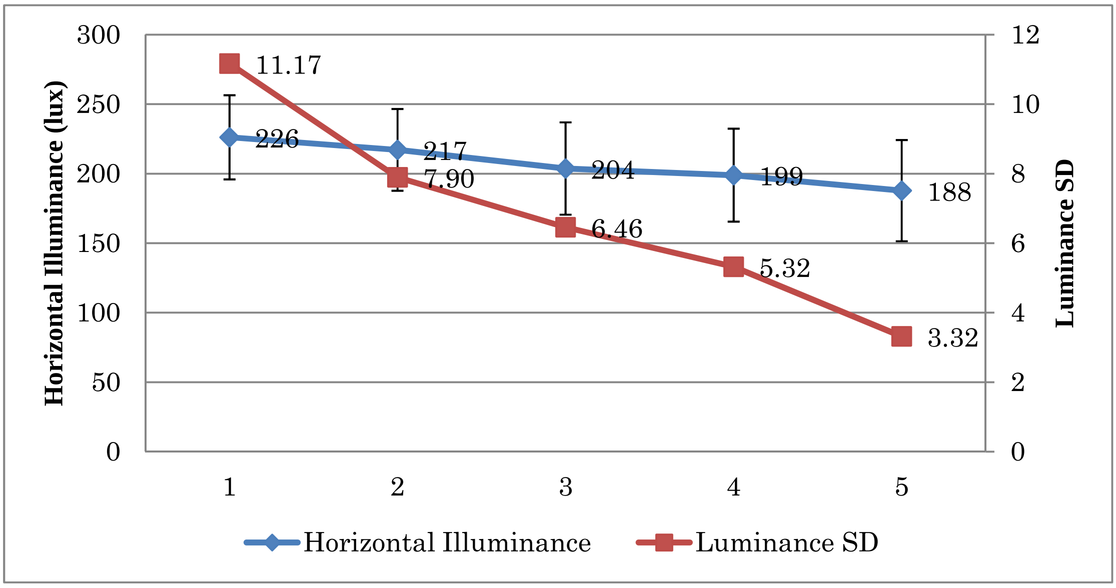


Fig. 6-9 Appropriate task horizontal illuminance and ambient luminance SD of space

In terms of trend, average minimum allowable task horizontal illuminance and average appropriate task horizontal illuminance had the same trend with average luminance SD of ambient space. When average luminance SD of ambient space got higher which represented the uniformity of ambient space worse, and subjects would adjust task light higher. Therefore, the bad uniformity luminance of ambient space indicates that subjects need higher task horizontal illuminance for their work regardless of minimum allowable task horizontal illuminance or appropriate task horizontal illuminance . Oppositely, when average luminance SD of ambient space got lower which represented the uniformity of ambient space better, and subjects would adjust task light lower. Therefore, No. 1 variable obtained the highest minimum allowable task horizontal illuminanceand appropriate task horizontal illuminance. They were 108lux and 226lux. Next was No. 2 (96lux and 217lux), No. 3 (87lux and 204lux), No.4 (81lux and 199lux). Because No. 5 variable was the best uniform of ambient space, the lowest minimum allowable task horizontal illuminance and appropriate task horizontal illuminance was 71lux and 188lux.

Table 6-7 Paired samples test of independent variables in minimum model

	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower: Lower	Upper			
1 - 2	12.15000	10.62903	2.37672	7.17546	17.12454	5.112	19	.000
1 - 3	21.42500	8.56442	1.91506	17.41673	25.43327	11.188	19	.000
1 - 4	26.77500	10.70966	2.39475	21.76273	31.78727	11.181	19	.000
1 - 5	36.95000	13.00799	2.90868	30.86207	43.03793	12.703	19	.000
2 - 3	9.27500	7.06637	1.58009	5.96784	12.58216	5.870	19	.000
2 - 4	14.62500	8.58529	1.91973	10.60696	18.64304	7.618	19	.000
2 - 5	24.80000	9.11679	2.03858	20.53321	29.06679	12.165	19	.000
3 - 4	5.35000	7.61076	1.70182	1.78805	8.91195	3.144	19	.005
3 - 5	15.52500	9.53039	2.13106	11.06464	19.98536	7.285	19	.000
4 - 5	10.17500	8.39999	1.87830	6.24368	14.10632	5.417	19	.000

Table 6-7 and Table 6-8 are paired samples test for each independent variable.

Except No. 3 and No. 4 variables had no significant in appropriate model, they were all significant both in minimum and appropriate models.

Table 6-8 Paired samples test of independent variables in appropriate model

	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower Lower	Upper			
1 - 2	9.05000	16.31104	3.64726	1.41620	16.68380	2.481	19	.023
1 - 3	22.45000	13.89992	3.10812	15.94464	28.95536	7.223	19	.000
1 - 4	27.20000	16.41437	3.67036	19.51784	34.88216	7.411	19	.000
1 - 5	38.35000	18.50825	4.13857	29.68787	47.01213	9.266	19	.000
2 - 3	13.40000	11.57766	2.58884	7.98149	18.81851	5.176	19	.000
2 - 4	18.15000	22.20307	4.96476	7.75864	28.54136	3.656	19	.002
2 - 5	29.30000	22.92803	5.12686	18.56935	40.03065	5.715	19	.000
3 - 4	4.75000	19.41208	4.34067	-4.33513	13.83513	1.094	19	.288
3 - 5	15.90000	22.65740	5.06635	5.29601	26.50399	3.138	19	.005
4 - 5	11.15000	11.47205	2.56523	5.78092	16.51908	4.347	19	.000

Because there were 20 subjects in this experiment, everyone had different demand illuminance in each variable. Average only could show trend for each variable. Therefore, Fig. 6-10 and Fig. 6-11 illustrated correlation between minimum allowable horizontal illuminance, appropriate task horizontal illuminance and 5 different variables for every subject.

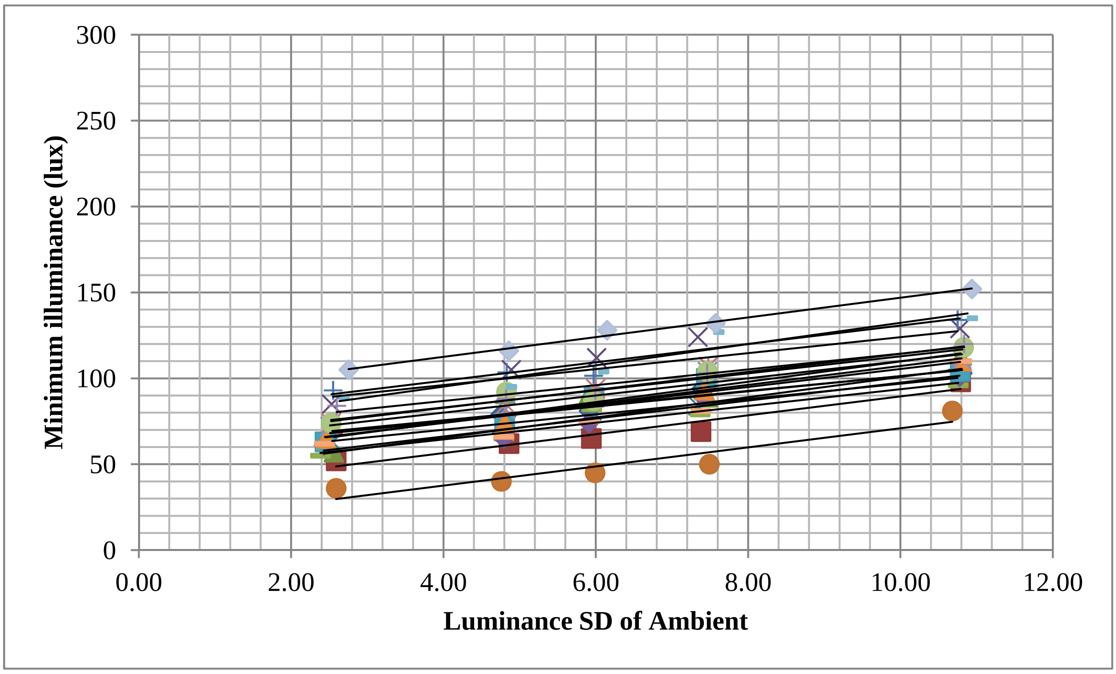


Fig. 6-10 Correlation of Minimum illuminance and ambient luminance SD by each subject

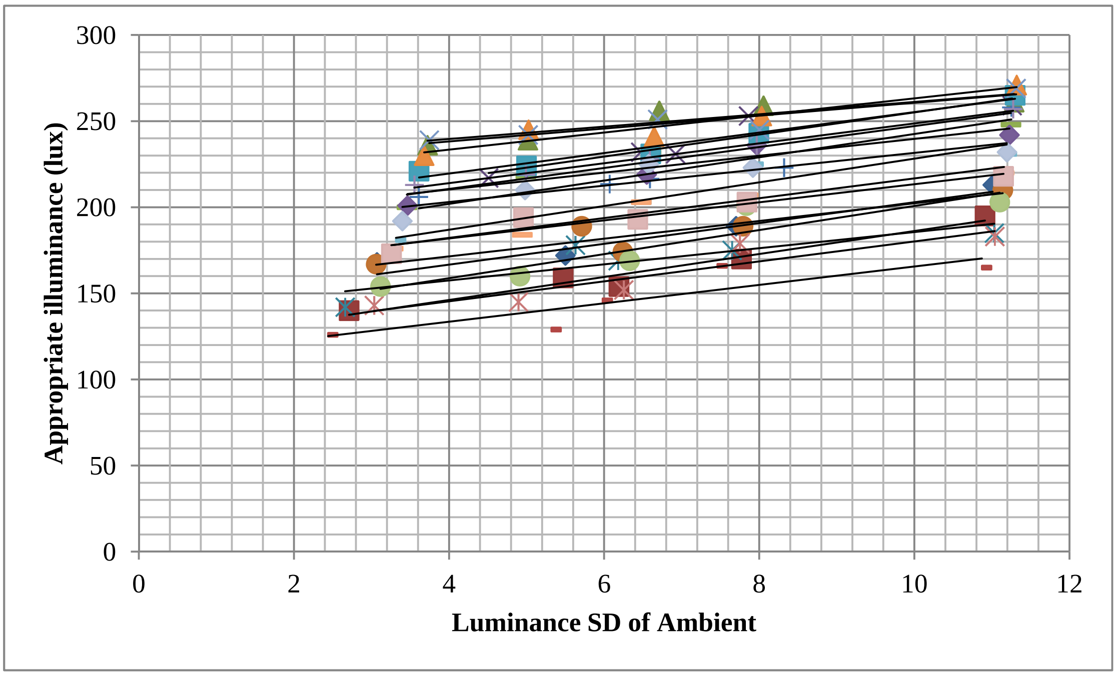


Fig. 6-11 Correlation of appropriate illuminance and ambient luminance SD by each subject

Y axle is represented task horizontal illuminance, and X axle is represent luminance SD of ambient space. In terms of the result of 5 variables for each subject, the same trend with Fig. 6-6 and Fig. 6-7 is obtained. The trend shows that luminance SD of ambient got higher, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance would be increased by subjects adjusting. According to regression analysis for each subject's adjusting illuminance in minimum model and appropriate model, the slope of each formula was positive. In minimum model, the average slope was 5.19, the SD was 0.54, and the average constant was 56.01, the SD was 16.52. In appropriate model, the average slope was 5.57, the SD was 0.97, and the average constant was 170.1, the SD was 37.39. According to figure and SD of constant, the minimum allowable task horizontal illuminance was more concentrative than appropriate task horizontal illuminance. Equation 6-1 and 6-2 are minimum allowable task horizontal illuminance and appropriate task horizontal illuminance of equations from average slope coefficient and average constant in minimum model and appropriate model.

- **Minimum Illuminance = 5.19 × Luminance SD of Space + 56.01** Equation 6-1

- **Appropriate Illuminance = 5.57×Luminance SD of Space + 170.1** Equation 6-2

Table 6-9 Coefficient and constant by each subject

Minimum model				Appropriate model			
	Slope	Constant	R^2		Slope	Constant	R^2
1	4.42	52.20	0.963	1	6.03	142.56	0.907
2	5.49	34.54	0.941	2	6.67	119.48	0.959
3	5.91	50.71	0.828	3	3.58	255.27	0.792
4	5.35	77.23	0.889	4	6.42	190.89	0.849
5	4.47	52.20	0.991	5	4.68	138.80	0.744
6	5.56	15.38	0.888	6	5.14	150.88	0.850
7	4.65	77.48	0.815	7	6.76	174.96	0.893
8	4.28	58.48	0.987	8	5.34	112.14	0.751
9	4.88	44.93	0.917	9	6.07	186.36	0.879
10	5.23	45.27	0.940	10	4.90	190.68	0.831
11	5.24	53.04	0.883	11	5.96	195.70	0.971
12	5.51	52.14	0.943	12	4.97	213.52	0.917
13	4.99	50.11	0.942	13	3.75	223.16	0.843
14	4.96	63.24	0.932	14	5.79	122.20	0.841
15	5.20	60.95	0.987	15	6.99	130.83	0.844
16	5.23	61.91	0.937	16	5.77	190.95	0.995
17	4.59	68.51	0.962	17	6.87	159.45	0.911
18	6.19	70.45	0.906	18	5.75	159.21	0.938
19	5.89	41.89	0.936	19	4.75	184.03	0.804
20	5.74	89.56	0.990	20	5.25	160.87	0.925
AVG	5.19	56.01	0.929	AVG	5.57	170.10	0.872
SD	0.54	16.52	0.05	SD	0.97	37.39	0.070

Table 6-10 T-test of coefficient

	Paired Sample Test				
	Mean	SD	t	df	Sig.
Minimum- Approprate	-.46150	1.30548	-1.581	19	.130

Table 6-10 shows Paired sample test for coefficient in minimum model and appropriate model.

Because T=-1.581, P value=0.13>0.05, the coefficient of two models by each subject were not different. This result represent that the coefficients between minimum model and appropriate model were not significant, so the coefficients in the two models could be averaged to be Equation 6-3.

- **Illuminance=5.38×Luminance SD of Space+C** Equation 6-3

When luminance SD of ambient space decreases 1, horizontal illuminance on task plane will be able to decrease 5.38lux. Therefore, under task-ambient lighting mode, if the uniformity of luminance in visual environment could be improved, the horizontal illuminance on each subject's task plane is decrease and save energy.

Equation 6-1 and 6-2 employed average coefficient and constant in minimum model and appropriate model. Now, regression analysis is adapted to new equations for all data of minimum model and appropriate model to compare with Equation 6-1 and 6-2.

Table 6-11 Summary in minimum model

Minimum model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.574	.330	.323	18.41247

Table 6-12 ANOVA in minimum model

Model		Sum of Square	df	Mean Square	Model	Sum of Square
1	Regression	16330.213	1	16330.213	48.169	.000
	Residual	33223.877	98	339.019		
	Total	49554.090	99			

Table 6-13 Coefficients in minimum model

Minimum model		B	t	Sig.
Min	Constant	59.544	12.948	.000
	SD	5.634	0.668	.000

Table 6-14 Summary in appropriate model

Appropriate Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.457	.209	.201	31.06586

Table 6-15 ANOVA in appropriate model

Model		Sum of Square	df	Mean Square	Model	Sum of Square
1	Regression	24978.620	1	24978.620	25.882	.000
	Residual	94578.620	98	965.088		
	Total	119557.240	99			

Table 6-16 Coefficients in appropriate model

Appropriate model		B	t	Sig.
	Constant	166.090	19.374	.000
	SD	5.950	5.087	.000

According to Table 6-13 and Table 6-16, the equations are obtained:

- **Minimum task horizontal Illuminance = 5.634 × SD + 60** Equation 6-3

- **Appropriate task horizontal Illuminance = 5.95 × SD + 166** Equation 6-4

Comparing with Equation 6-1 and Equation6-3 in minimum model, Equation 6-2 and Equation 6-4 inappropriate model, they are not different significantly. The slopes are shown between 5.19 and 5.95. Constants in equations are almost the same.

- **Minimum horizontal Illuminance = 5.19 × Luminance SD of Ambient Space + 56** Equation 6-1

- **Minimum horizontal Illuminance = 5.63 × Luminance SD of Ambient Space + 60** Equation 6-3

- **Appropriate horizontal Illuminance = 5.57 × Luminance SD of Ambient Space + 170** Equation 6-2

- **Appropriate horizontal Illuminance = 5.95 × Luminance SD of Ambient space +166** Equation 6-4

Although each subject need different horizontal illuminance on task plane in minimum model and appropriate model, according to slope for each subject's formula, it shows that subjects are affected by luminance uniformity of ambient space. Finally, this study adopts Equation 6-3 to be representation to show in Fig. 6-12.

In order to ensure almost population is bearable minimum allowable horizontal illuminance, the constant of equation is used two times SD for including 95% population. The red line is represented the limit line for minimum allowable horizontal illuminance. Below green line, it may be occurred bad visual health environment. The green area is represented saving energy area. It is illustrated that 95% population can bearable in minimum model to be lower limit and 50% population are satisfied with horizontal illuminance on task plane to be upper limit. Therefore, between lower limit line and upper limit line, "Saving Energy Area" is called. In this area, employees can be bearable for reading and VDT work. The blue line is illustrated 95% population can be satisfied with horizontal illuminance on task plane. Between green line and blue line, "Comfortable Area" is called. Over blue line, "Waste Energy Area" is called, because it is exceeded "Comfortable Area" and will consume more energy. Because this experiment is discussed the uniformity from 2.4 to 10.74, at this below 2.4 and over 10.74 is not discussed in this study.

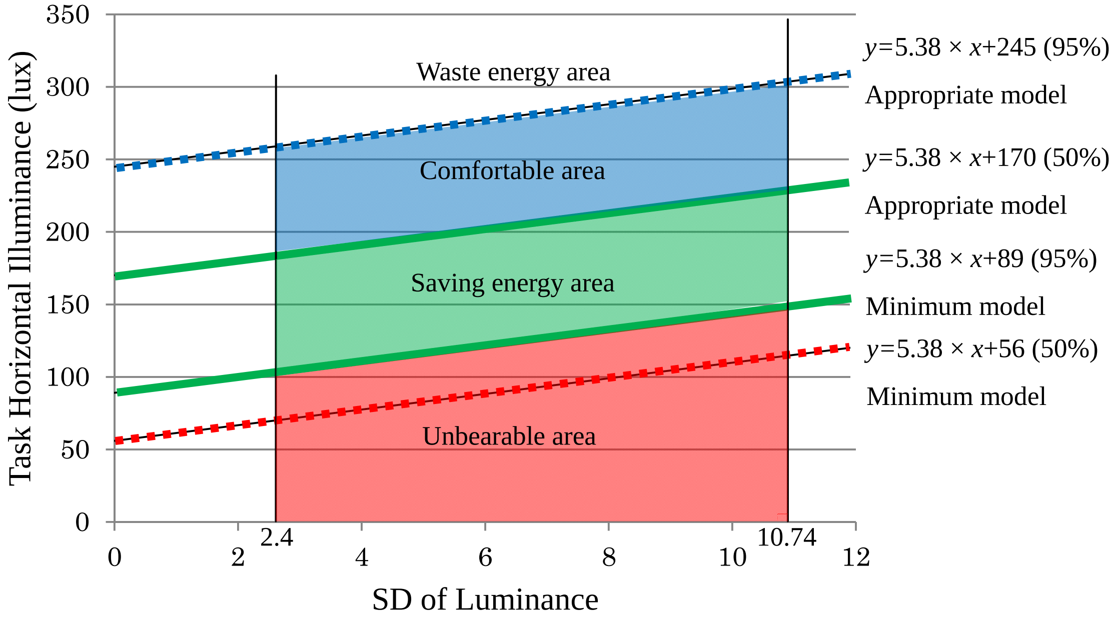


Fig. 6-12 Energy saving range for task illuminance in different uniformity of ambient

6-3-2 Influence of Brightness and Uniformity on Illuminance

According to Chapter 4, when vertical illuminance increase which is represented that luminous flux from ambient lighting increase and raise brightness, the minimum allowable task horizontal illuminanceand appropriate horizontal illuminence on task plane are able to decrease. In Chapter 5, the result shows when luminance uniformity improves, the minimum allowable task horizontal illuminance and appropriate horizontal illuminence are able to decrease. These results indicate that minimum allowable task horizontal illuminance and appropriate task horizontal illuminance are affected by vertical illuminance and luminance SD of ambient space. Therefore, inputting the result of Chapter 5 and this chapter to regression analysis, the correlation of horizontal illuminance, vertical illuminance and luminance SD of ambient space are discussed, except the data of 50lux and 100lux in minimum model in Chapter 5. Because there are 7 subjects who do not adjust task lighting in 50lux pattern and all subjects do not adjust task lighting in 100lux pattern in minimum model in Chapter 5.

Table 6-17 Model summary in minimum model

Minimum model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	.565	.320	.311	16.97526

Table 6-18 ANOVA in minimum model

Minimum model	Sum of Square	df	Mean Square	F	Sig.
Regression	20171.367	2	10085.684	35.000	.000
Residual	42935.765	170	288.159		
Total	63107.132	172			

Table 6-19 Coefficients in minimum model

Minimum model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	63.672	4.989		12.763	.000
Vertical Illuminance	-.114	.137	-.058	-.832	.407
SD	4.618	.560	.578	8.241	.000

Table 6-20 Model summary in appropriate model

Appropriate model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.732	.536	.531	31.10243

Table 6-21 ANOVA in appropriate model

Appropriate model	Sum of Square	df	Mean Square	F	Sig.
Regression	220031.181	2	110015.590	113.728	.000
Residual	190570.158	197	967.361		
Total	410601.339	199			

Table 6-22 Coefficients in appropriate model

Appropriate model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	167.300	7.338		22.799	.000
	Vertical Illuminance	-.372	.106	-.181	-3.520	.001
	SD	7.881	.525	.771	15.008	.000

The equations are divided by minimum model and appropriate model and show in Equation 6-5 and Equation 6-6.

Minimum model

- **Task Horizontal illuminance= -0.114 × Vertical illuminance + 4.618 * SD of luminance+64** Equation 6-5

Appropriate model

- **Task Horizontal illuminance = -0.372 × Vertical illuminance + 7.881 * SD of luminance+167** Equation 6-6

To observe the coefficients of vertical illuminance in Equations 6-5 and Equation 6-6, one is -0.201 in minimum model and another is -0.372 in appropriate model. Through this result, when vertical illuminance is higher, the influence on equations is negative because the brightness is decreased. On the other hand, if vertical illuminance was increased, horizontal illuminance on task lane of demand may raise. To focus on coefficients of luminance SD in Equations 6-5 and Equation 6-6, they are 5.447 and 7.881 in minimum model and appropriate model. This result indicates that the influence on equations is positive. When luminance SD of ambient space is raised, horizontal illuminance on task plane will be needed for higher.

Regarding R square from regression analysis, it is 0.373 in minimum model and 0.536 in appropriate. In minimum model, R square is smaller than 0.5 and also smaller than R square of appropriate model. It may be occurred by two reasons, one is inaccuracy in the experiment, another is that minimum allowable task horizontal illuminance was dispersedness through subjects adjusting. But in appropriate model, the subjects have more concentrative in appropriate task horizontal illuminance. Therefore, the subjects have more common consensuses in appropriate task horizontal illuminance than minimum allowable task horizontal illuminance.

6-3-3 VDT Screen Luminance

Besides discussing the influence of horizontal illuminance on task plane, the influence of appropriate VDT screen luminance is also discussed in this chapter. Fig. 6-13 and Fig. 6-14 are average appropriate VDT screen luminance in minimum model and appropriate model. They are illustrated that there is no trend with appropriate VDT screen luminance and luminance SD of ambient space. The average appropriate VDT screen luminance was between 117cd/m^2 and 134cd/m^2 in minimum model. The average appropriate VDT screen luminance was between 137cd/m^2 and 152cd/m^2 in appropriate model. According to paired samples test analysis, the appropriate VDT screen luminance in minimum model and appropriate model are significant (p value=0.000<0.05).

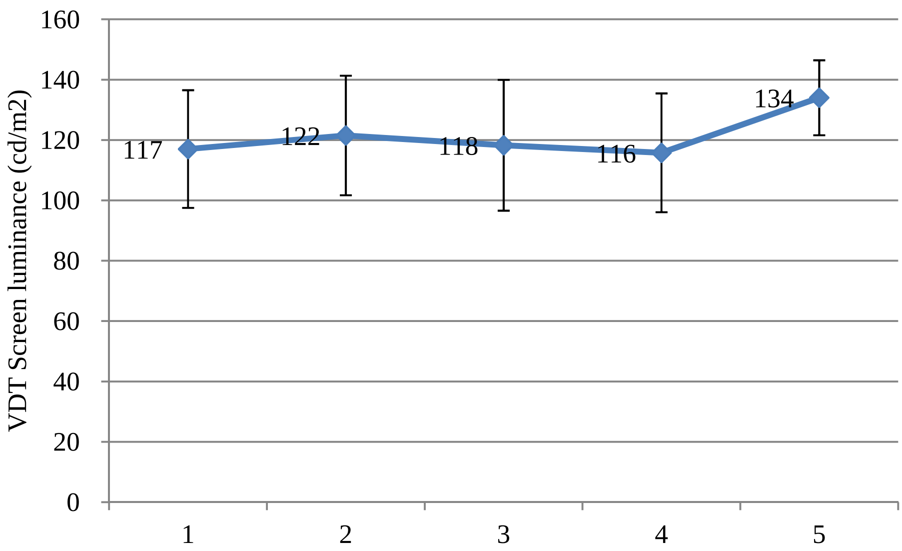


Fig. 6-13 Average VDT screen luminance in minimum model

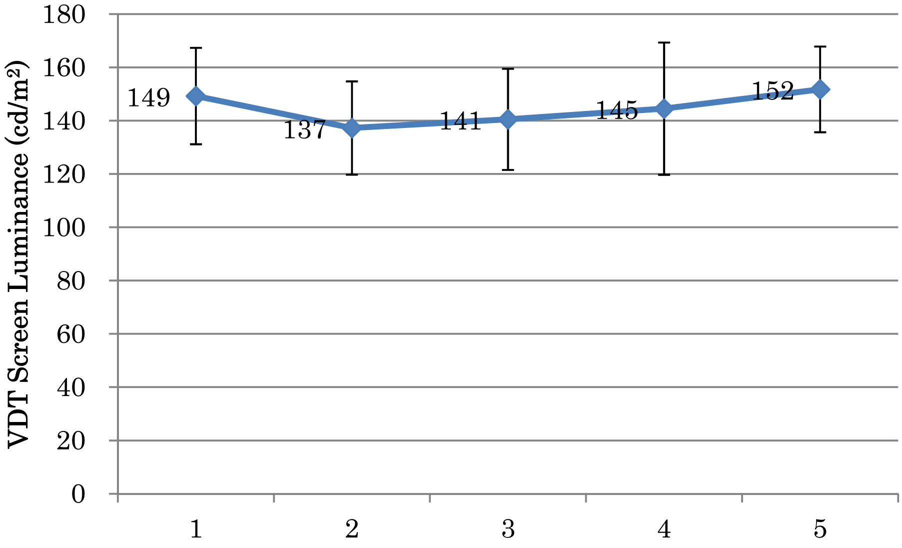


Fig. 6-14 Average VDT screen luminance in appropriate model

Table 6-23 Minimum Model- Appropriate Model Paired Samples Test

	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower				
				Lower	Upper			
Minimum - Appropriate	-23.35000	24.76205	2.47620	-28.26333	-18.43667	-9.430	99	.000

Comparing with each independent variable in minimum model, No.1 and No.5, No.2 and No.4, No.2 and No.5, No.3 and No.5, No.4 and No.5 are significant (Table 6-24). Comparing with each independent variable in appropriate model, No.1 and No.2, No.1 and No.3, No.2 and No.5, No.3 and No.5 are significant (Table 6-25).

Table 6-24 Minimum Model Paired Differences for each Independent Variables

	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower				
				Lower	Upper			
1 - 2	-4.50000	14.68081	3.28273	-11.37083	2.37083	-1.371	19	.186
1 - 3	-1.25000	19.39038	4.33582	-10.32498	7.82498	-.288	19	.776
1 - 4	1.25000	16.21200	3.62511	-6.33745	8.83745	.345	19	.734
1 - 5	-17.00000	18.87633	4.22088	-25.83439	-8.16561	-4.028	19	.001
2 - 3	3.25000	13.30562	2.97523	-2.97722	9.47722	1.092	19	.288
2 - 4	5.75000	12.06070	2.69685	.10542	11.39458	2.132	19	.046
2 - 5	-12.50000	18.53162	4.14380	-21.17307	-3.82693	-3.017	19	.007
3 - 4	2.50000	18.95285	4.23799	-6.37021	11.37021	.590	19	.562
3 - 5	-15.75000	19.28150	4.31147	-24.77402	-6.72598	-3.653	19	.002
4 - 5	-18.25000	20.85508	4.66334	-28.01048	-8.48952	-3.914	19	.001

Subjects were required to adjust task light for minimum allowable task horizontal illuminanceand appropriate task horizontal illuminance in reading. After adjusting task light, the CDT screen luminance was adjusted under the same horizontal illuminance and verital illuminance with reading in minimum model and appropriate model. Table 6-26 is the correlation coefficient analysis between task horizontal illuminance, vertical illuminance and appropriate VDT screen luminance.

Table 6-25 Appropriate Model Paired Differences for each Independent Variables

	Paired Differences					t	f	Sig.
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Lower				
				Lower	Upper			
1 - 2	12.00000	13.80313	3.08647	5.53994	18.46006	3.888	19	.001
1 - 3	8.75000	15.71749	3.51454	1.39399	16.10601	2.490	19	.022
1 - 4	4.75000	18.38728	4.11152	-3.85551	13.35551	1.155	19	.262
1 - 5	-2.50000	16.26265	3.63644	-10.11115	5.11115	-.687	19	.500
2 - 3	-3.25000	13.00557	2.90813	-9.33679	2.83679	-1.118	19	.278
2 - 4	-7.25000	17.73155	3.96490	-15.54862	1.04862	-1.829	19	.083
2 - 5	-14.50000	18.63076	4.16596	-23.21946	-5.78054	-3.481	19	.003
3 - 4	-4.00000	20.62191	4.61120	-13.65135	5.65135	-.867	19	.397
3 - 5	-11.25000	19.25419	4.30537	-20.26124	-2.23876	-2.613	19	.017
4 - 5	-7.25000	23.42260	5.23745	-18.21212	3.71212	-1.384	19	.182

According to correlation coefficient analysis, the coefficient between appropriate VDT screen luminance and luminance SD of ambient space is not high (0.2, p value=0.004<0.05). But the coefficient between appropriate VDT screen luminance and vertical illuminance is 50.576 and significant (p value=0.000<0.05). It has the same result with the correlation coefficient in chapter 5.

Fig. 6-15 is matrix of luminance SD, appropriate VDT screen luminance and vertical illuminance. It is illustrated that the dots of vertical illuminance and appropriate VDT screen luminance is positive, but the points of luminance SD of ambient space and appropriate VDT screen luminance are dispersedness and is represented 5 parallel lines.

Table 6-26 Correlation coefficients with VDT screen luminance, luminance SD of space and vertical illuminance

		SD	Screen	Vertical
VDT screen Luminance	Correlation	1	-.037	.576
	Sig.		.601	.000
	N	200	200	200
Luminance SD of space	Correlation		1	.200
	Sig.			.004
	N		200	200
Vertical illuminance	Correlation			1
	Sig.			
	N			200

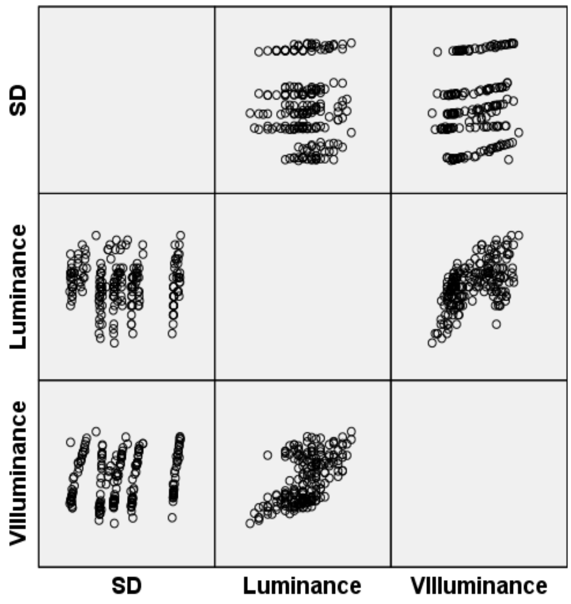


Fig. 6-15 Matrix of luminance SD, appropriate VDT screen luminance and vertical illuminance

P.S: SD= luminance SD, Luminance= appropriate VDT screen luminance, VIlluminance= vertical illuminance

Besides correlation coefficient analysis, the luminance SD, appropriate VDT screen luminance and vertical illuminance should be discussed more to identify as their correlations. Table 6-27 is One-way ANOVA test between appropriate VDT screen luminance and luminance SD, appropriate VDT screen luminance and vertical illuminance. This analysis combines with the data in minimum model and appropriate model.

According to One-way ANOVA, the appropriate VDT screen luminance and vertical illuminance are high significant (F=4.938, p value=0.000<0.05), but the appropriate VDT screen luminance and luminance SD of ambient space are not significant (F=0.781, p value=0.752>0.05). Therefore, the appropriate VDT screen luminance was affected by vertical illuminance significantly. However it would not be affected by luminance uniformity of ambient space. In other words, when vertical illuminance rises, the appropriate VDT screen luminance is needed to increase.

Table 6-27 One-way ANOVA test of VDT screen luminance

Dependent variable: vertical illuminance and luminance SD of space

VDT screen luminance		Sum of Squares	df	Mean Square	F	Sig.
	Between Groups	6300.140	23	273.919	4.938	.000
VI	Within Groups	9763.838	176	55.476		
	Total	16063.978	199			
	Between Groups	137.060	23	5.959	.781	.752
SD	Within Groups	1342.627	176	7.629		
	Total	1479.687	199			

Fig. 6-16 shows distribution of vertical illuminance and appropriate VDT screen luminance. Each dot is represented appropriate VDT screen luminance which was adjusted by subjects. It is discussed by Equation 5-5:

- **Appropriate VDT screen luminance (cd/m^2) = 0.833×Vertical Illuminance +93**

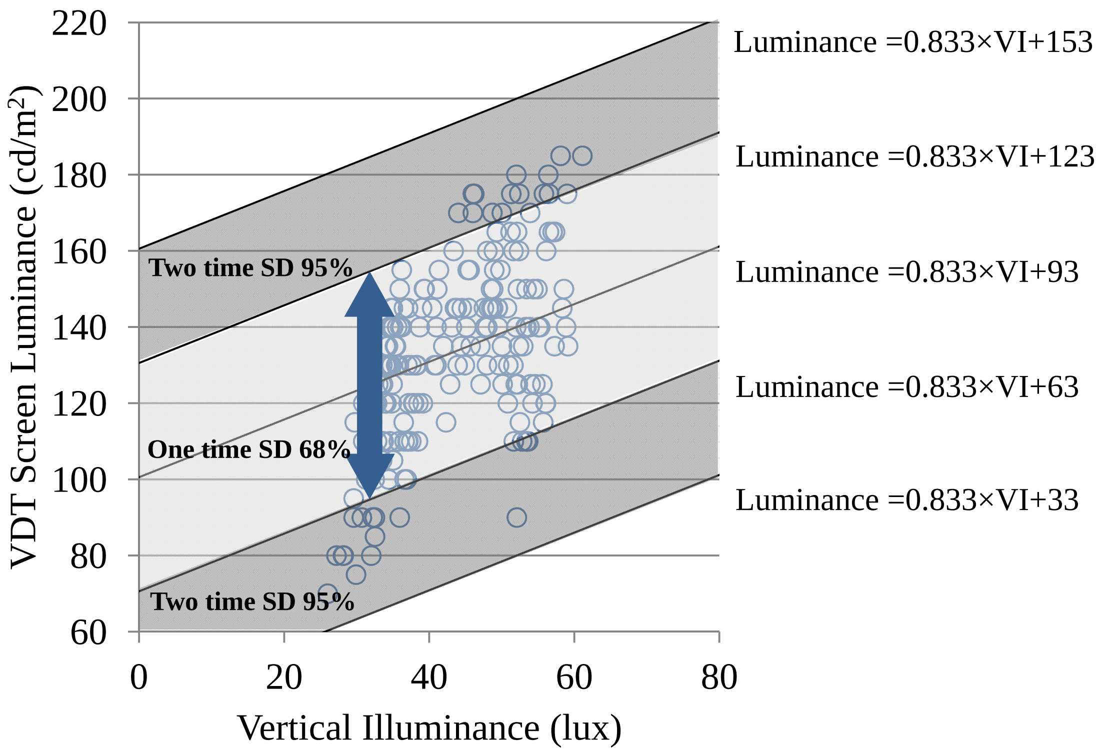


Fig. 6-16 Suitable range test of appropriate VDT screen equation

Equation 5-5 was made by regression analysis of appropriate VDT screen luminance which was adjusted by each subject in different vertical illuminance variables in chapter 5. The average constant was 93 and SD was 30. Therefore, in the normal distribution, between one time SD, 68% samples are able to include. Between two times SD, 95% samples are able to include.

In blue area which is one time SD area from Equation 5-5, almost dots are in this area (constant is between 63 and 123). In red area which is two times SD area from Equation 5-5, all dots are included (constant is between 33 and 153).

6-4 Conclusion

The experiment of this chapter is discussed that the influence of minimum allowable task horizontal illuminanceand appropriate task horizontal illuminance on task plane which 20 subjects adjusted it in different uniformity luminance of ambient space. Besides horizontal illuminance, this experiment was also discussed the influence of appropriate VDT screen luminance which 20 subjects adjusted it in different uniformity luminance of ambient space. The independent variables were luminance SD of ambient space which was taken by luminance camera (Luminocam). There were 5 luminance SD variables in this experiment. They were 10.74, 7.48, 5.88, 4.75, and 2.42 and the average luminance was fixed in 5cd/m^2.

Through 20 subjects adjusted minimum allowable task horizontal illuminance and appropriate task horizontal illuminance, the main conclusions of this chapter are pointed out that:

1. When luminance SD of ambient space get higher, it is indicated that luminance distribution is not uniform, and the contrast is serious. Regardless of minimum allowable task horizontal illuminance and appropriate task horizontal illuminance will be adjusted higher by subjects. Oppositely when luminance SD of ambient space gets lower, subjects will demand minimum allowable task horizontal illuminance and appropriate task horizontal illuminance lower.

2. Inputting each subject’s data in regression analysis (dependent variable is task horizontal illuminance, and independent variable is vertical illuminance), and then average coefficients and constants, the equations are obtained:

- **Minimum illuminance = 5.19 × luminance SD of ambient space + 56.01**
- **Appropriate illuminance = 5.57 × luminance SD of ambient space+ 170.1**

3. When luminance SD of ambient space decreases 1, task horizontal illuminance will be able to decrease 5.38lux.

4. Combining the results of chapter 5 and chapter 6 and input them to regression

analysis (dependent variable is horizontal illuminance, and independent variable are vertical illuminance and luminance SD of ambient space), the equations are obtained:

- **Minimum Allowable Task Horizontal Illuminance = -0.114 × Vertical illuminance + 4.618 × SD of luminance + 64**
- **Appropriate Task Horizontal Illuminance = -0.372 × Vertical illuminance + 7.881 × SD of luminance + 167**

When vertical illuminance increase or luminance SD of ambient space is good, minimum allowable task horizontal illuminance and appropriate task horizontal illuminance will be decreased by subjects adjusting

5. According to correlation coefficient analysis and One-way ANOVA, appropriate VDT screen luminance is not affected by luminance SD of ambient space significantly. However it is affected by vertical illuminance significantly. Therefore, appropriate VDT screen luminance is able to refer to Equation 5-5 and all data were included in two times SD:

- **Appropriate VDT screen luminance=0.833×Vertical illuminance+93**

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CHAPTER 7 CONCLUSIONS

CHAPTER 7 CONCLUSIONS

7-1 Conclusions

After East Japan Earthquake, the nuclear power plant in Fukushima was destroyed by tsunami caused by earthquake, the effectively way to solve the problem of nuclear accident still not been found and caused considerable ecological exhaustion, the influence is not only a local environment disaster, but also an unrecoverable global issues. Currently the world, including Japan, Germany closed some or all of the nuclear reactor and re-examine the nuclear safety issues. At present, Japan replaced nuclear power plant with thermal power and development of renewable energy, but the policy caused sharp rise in electrical bill and the possibility of power shortage in summer power-use peak, as the result, the government appealed to the messes and business save electricity on their own to reduce the electricity load. Lighting account 30% in commercial and office electricity consumption approximately, if the lighting could be controlled efficiently, it is a great help for electricity saving. This study based on the office lighting, explored several ways of lighting in task-ambient, the minimum tolerance and the optimum task plane illuminance in personal space were investigated based on different bright environment and office space with different uniformity, and besides, the relation between luminance in office VDT work and eyes postion vertical illuminance was examined. The following lists the conclusions of the study in each chapter:

7-1-1 Chapter 2: Lower Task Horizontal Illuminance Is Not Bad for Visual Fatigue and Productivity for Taiwanese

When comparing subjective feelings in the 200lux and 500lux conditions, the visual fatigue of the 200lux environment is more serious than that of the 500lux environment in the experiment. However, when working on a VDT for an hour with low luminance (30cd/m^2), the level of visual fatigue in the 200lux lighting environment was not as serious as that in the 500lux environment, according to the CFF measurement. The results mentioned above highlight the conflict between subjective feeling and objective experiment, which is exactly the contribution made by this study regarding the influence on the productivity of VDT interaction from visual fatigue in the different artificial lighting environments. Therefore, better working performance occurs in the lower illumination environment of 200lux in this study, which means that the contrast of luminance between the surrounding environment and the low-luminance monitors for VDT use is suggested to be smaller in order to minimize the sources of reflected luminance, thus influencing visual fatigue. On the contrary, a lighter environment creates higher luminance, and an increase in visual fatigue might occur as a result. This research also discovered that subjective visual fatigue does not directly result in visual fatigue; hence, other measurements of visual fatigue are suggested for verification in the future. As for the choice of lamps and light bulbs, LED lighting causes less subjective visual fatigue than T5, and results in better productivity in a VDT working environment. In this experiment, all subjects are Taiwanese.

7-1-2 Chapter 3: Taiwanese and Japanese Employees Are Not Different For Brightness and Psychology Evaluations Is Not Bad in Lower Task Horizontal Illuminance.

This chapter includes actual investigation and survey about office lighting environment in Tokyo (after earthquake) and Taiwan. Due to the electronic saving policy, according to the result of questionnaires from 13 offices in Tokyo, majority of them select to decrease light or to use the natural light as the way to save electronic cost on lighting. The task plane illuminance is affected directly by lighting reducing. The almost horizontal average central task plane illuminance in 13 offices is between 400lux and 600lux in Japanese office. The result shows, although the task plane illuminance reduces, or even far below 750lux in JIS standard, workers can still work and did not feel dissatisfied. The same result appears on the survey of Taiwan. The measurement operated in 5 offices in Taiwan. The almost horizontal average central task plane illuminance is between 400lux and 600lux in Taiwanese office, and some of them less than 500lux in CNS standard, there is no significant dissatisfaction was found in the satisfaction and brightness of lighting environment. The result shows it is possible for present lighting standard to be reduced, or other factors also should be evaluated to construct better or more energy save office lighting environment expect task horizontal illuminance.

7-1-3 Chapter 4: Task Horizontal Illuminance Is Affected by Brightness of Ambient Space and Allowable Task Horizontal Illuminance Is Able To Decrease below Recommended Levels of Illuminance (推奨照度) in Reading or VDT

Through the technology is gotten better and better now, the luminance camera is able to describe the luminance distribution of space. This experiment shows a main point which is the task horizontal illuminance may affected by luminance of ambient space (brightness). When luminance of ambient space was higher, the subjects will bearable lower horizontal illuminance on task plane because ambient space is brighter. Another new point is that in order to saving energy, it is possible for task horizontal illuminance can be decreased. In this study, natural skylight (no direct sunlight) was used as lighting resource, and task horizontal illuminance decreases with sunset. The minimum task horizontal illuminance and vertical illuminance under the premise of the subjects can see clear when they deal with reading and VDT work was measured.

Based on the result of the experiment, the average minimum allowable task horizontal illuminance is 67lux in reading work; the average minimum allowable task horizontal illuminance is 57lux in VDT work. Reading needs higher task horizontal illuminance than VDT work. The subjects turn on the artificial lighting earlier on reading than VDT work and the task horizontal task illuminance is also higher than VDT. The minimum allowable task horizontal illuminance in reading and VDT work does not exceed 300lux and large different with present JIS recommended levels of illuminance. When deal with general task work, the present task horizontal standard can be reduce possibly.

7-1-4 Chapter 5: Task Horizontal Illuminance Is Able to Decrease When Brightness of Ambient Space Is Increased.

The chapter 5 was discussed correlation between task horizontal illuminance and brightness of ambient space under ambient-task lighting in office.

The value of the vertical illuminance at the position of eyes shows office lighting tends to bright, as the result, the vertical illuminance at the position of eyes goes higher, the lighting is brighter. Minimum allowable task horizontal and appropriate illuminance vary from personal conditions and preferences, but when the ambient lighting get brighter, subjects adjust the minimum allowable and appropriate task illuminance horizontal lower than when the ambient lighting get darker. In other words, minimum allowable task horizontal and appropriate illuminance are reverse proportional to ambient lighting. The formulae of minimum allowable task horizontal and appropriate task horizontal illuminance and vertical illuminance at the position of eyes show as follow:

Minimum Allowable Task Horizontal Illuminance = -0.41 × Vertical Illuminance + 119(2SD) Equation 7-1

Appropriate Task Horizontal Illuminance = -1.05 × Vertical Illuminance + 323 Equation 7-2

In order to saving energy, according to this experiment result, the ambient luminance is recommended as 20cd/m^2.

On the other hand, during VDT work, the most appropriate display luminance will be affected by brightness. When the brightness in space goes up, the vertical illuminance at the position of eyes goes up. To avoid the unwell feel exerted by contrast of display luminance and space, the appropriate display luminance of VDT work need improve, to make contrast of display luminance and space get balance. The relationship of appropriate display luminance and vertical illuminance shows as follows:

Appropriate Screen Luminance = 0.833 × Vertical Illuminance + 93 Equation 7-3

7-1-5 Chapter 6: Task Horizontal Illuminance Is Able to decrease When Luminance Uniformity of Ambient Space is increased

The minimum allowable and appropriate task horizontal illuminance is not only affected by that brightness in space, the uniformity of space lighting is also one of affecting factors. When the space average luminance is 20cd/m^2, the uniformity is satisfied, the minimum allowable and appropriate task horizontal illuminance is lower than when the uniformity is unwell, so that under the same average luminance, the uniformity improved can help reduce the task horizontal illuminance to achieve energy save. On the aspect of VDT work, the uniformity doesn't make remarkable affect on appropriate display luminance, and the degree of the space brightness is still main factor which affects the appropriate display luminance. Summarize the task horizontal illuminance and the affect from the space brightness and uniformity, the formula of minimum and appropriate task illuminance shows as follows:

Minimum Allowable Horizontal Illuminance = -0.114 × Vertical Illuminance + 4.618*SD of Luminance + 64 Equation 7-4

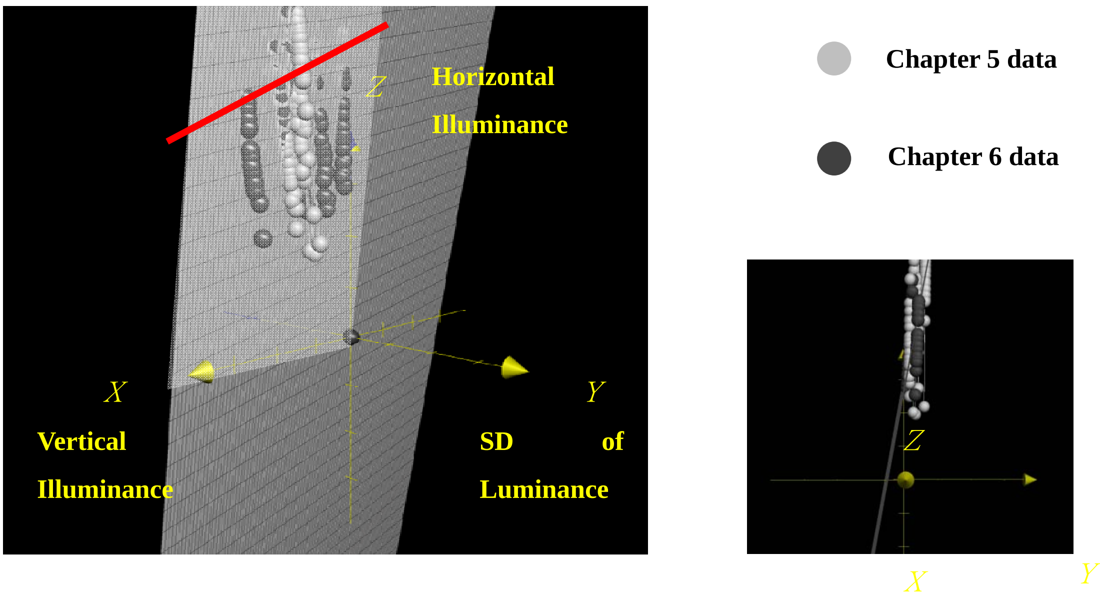

Fig. 7-1 Minimum Allowable Horizontal Illuminance equation in three dimensional axes

Fig. 7-1 is combined the minimum model of chapter 5 and 6 with minimum allowable horizontal illuminance, vertical illuminance and SD of luminance in three dimensional axes. The gray plane in Fig. 7-1 indicates Equation 7-4. (*X*=Vertical Illuminance >0, *Y*=SD of Luminance >0, *Z*= Minimum Allowable Horizontal Illuminance >0) Light gray ball is indicated Chapter 5 data and dark gray ball is Chapter 6 data. They are almost in this plane. Red line is Equation 7-1 in three dimensional axes.

Appropriate Horizontal Illuminance = -0.372 × Vertical Illuminance + 7.881 × SD of Luminance + 167 Equation 7-5

Fig. 7-2 is combined the minimum model of chapter 5 and 6 with appropriate horizontal illuminance, vertical illuminance and SD of luminance in three dimensional axes. The gray plane in Fig. 7-2 indicates Equation 7-5. (*X*=Vertical Illuminance >0, *Y*=SD of Luminance >0, *Z*= Appropriate Horizontal Illuminance >0) Light gray ball is indicated Chapter 5 data and dark gray ball is Chapter 6 data. They are almost in this plane. Red line is Equation 7-2 in three dimensional axes.

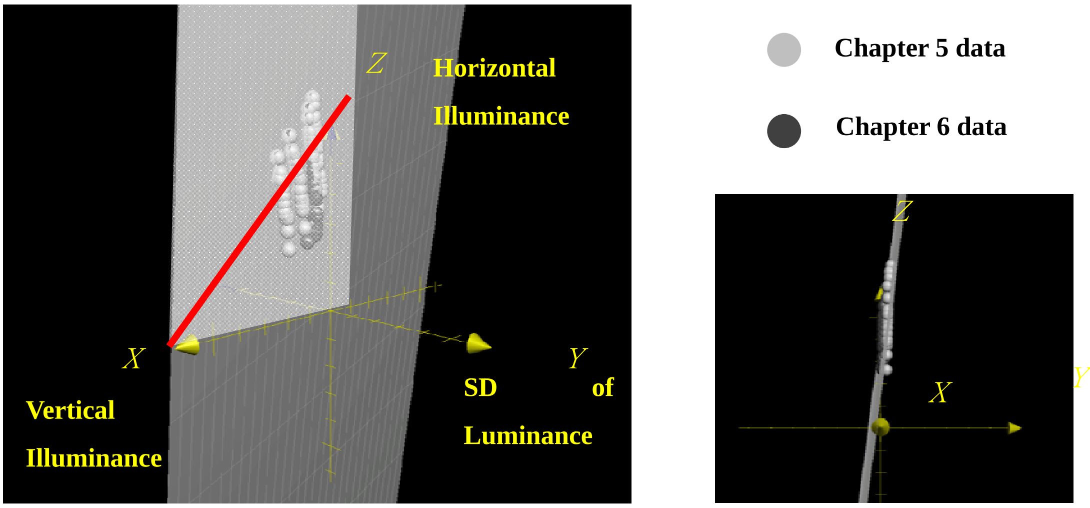

Fig. 7-2 Appropriate Horizontal Illuminance equation in three dimensional axes

7-1-6 Relation Between Ambient Space and Task Plane in Lighting Space

Fig. 7-3 and Fig.7-4 are the simple pictures to explain the main conclusion in this study. In Fig. 7-3, the left picture is shown that when ambient space is bright, the task horizontal illuminance can be reduced in working space, but screen luminance should be brighter. The right picture is reverse. When ambient space is dark, the task horizontal illuminance shall be added but screen luminance should be darker.

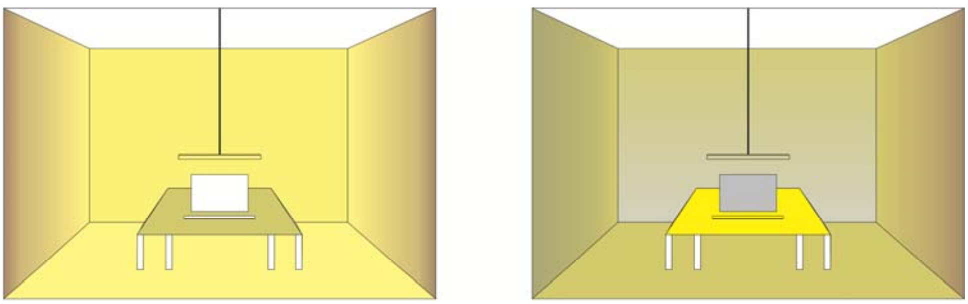

Fig. 7-3 Relation between ambient brightness and task horizontal illuminance

In Fig. 7-4, the left picture is shown that when ambient space is uniform, the task horizontal illuminance can be reduced in working space, but the screen luminance should be increased. The right picture is different. When the uniformity of ambient space is not good, the task horizontal illuminance shall be added, but the screen luminance should be decreased.

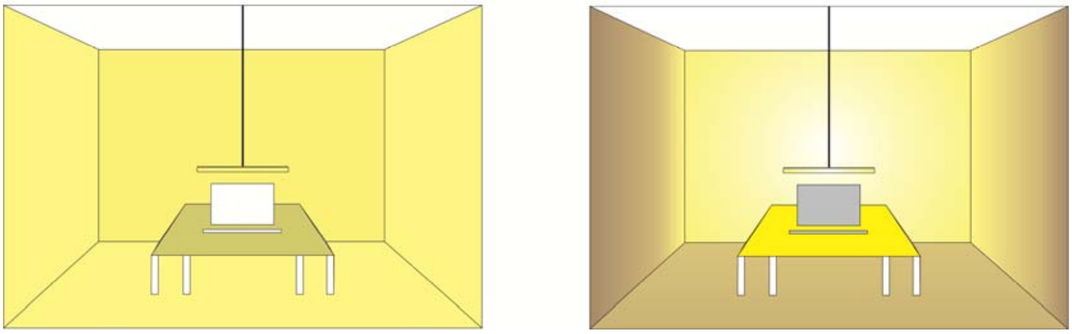

Fig. 7-4 Relation between ambient uniformity and task horizontal illuminance

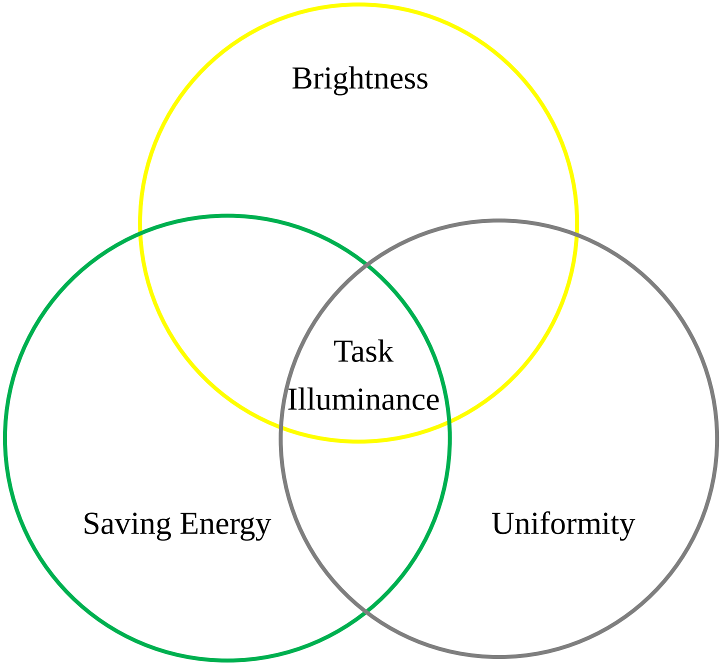

Fig. 7-5 Research composing

7-1-7 Summary of Conclusions

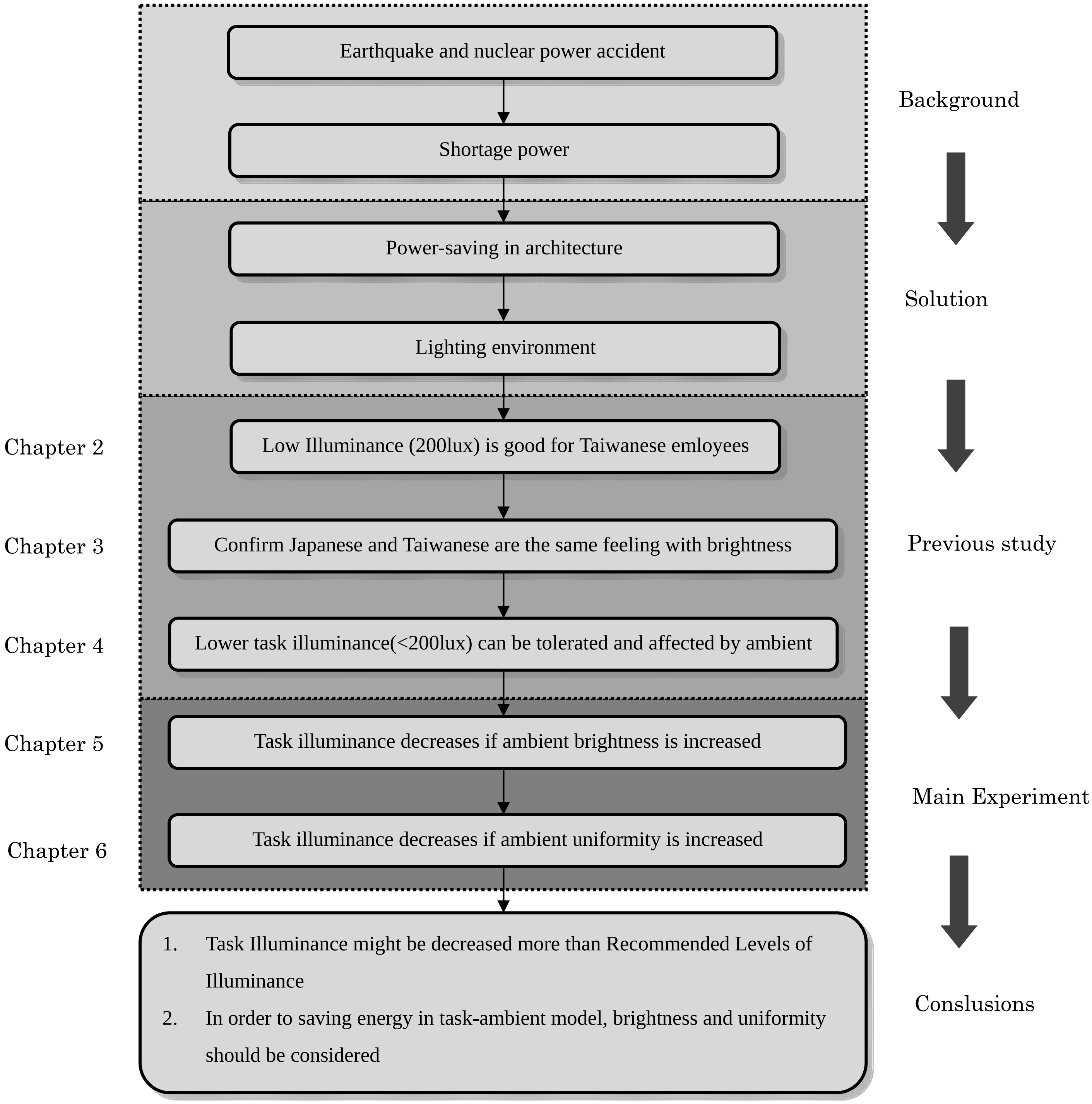

Fig. 7-6 Simmary of Conclusions

7-2 Application and Shortage of Study

7-2-1 Application of Results

The results in the final formulas and saving energy range diagram are composed by horizontal illuminance, vertical illuminance and luminance uniformity of space and only for task-ambient style of working space. In order to save energy, the artificial lighting is reduced to make ambient space dark. Because luminance uniformity of space should be measured by luminance camera, but the luminance camera is a little expensive. Therefore, if there is no luminance camera, the results of Chapter 5 could be employed. In Chapter 5, the experiment conditions are divided 5 patterns, from 5lux to 100lux for vertical illuminance. In normal working space, the office manager can use illuminance meter to measure vertical illuminance at each seat and adopts formula or saving energy range diagram of this study to determine minimum or appropriate horizontal illuminance. If the vertical illuminance of working space is below 5lux or over 100lux, the results should be reconsidered. Because of below 5lux, it is almost no ambient lighting and do not involved in this study; over 100lux, it is not saving power in working space and is not purpose for this study.

If there is the luminance camera to be used, the results and formulas can be used in Chapter 6. According to vertical illuminance and luminance uniformity of space, the minimum or appropriate horizontal illuminance can be obtained by formulas in working space.

The final results are from experiment and without windows and day lighting. Besides at night or in no windows room, if the brightness change effect from day lighting and glare are ignored, the results maybe are useful. But it should be consider more in the future.

7-2-2 Subjects' Background Was Too Concentrative

The subjects in this study were all college student. The average age was between 25 in chapter 4 to 28 in chapter 5, 6. These subjects were in young generation. The elder generation or children were not included in this study. According to chapter 4, elder generation and young generation are not too different both in Japan and Taiwan. Even elder generation does not feel visual fatigue and tired easier than young generation.

7-2-3 Influence of Long Time Work under Minimum Allowable Task Horizontal Illuminance

The minimum allowable task horizontal illuminance is a concept from experiment space. During the Great East Japan Earthquake, the employees faced power shortage and power-saving policy immediately. The minimum allowable task horizontal illuminance is for this severely situation. Although the minimum allowable task horizontal illuminance is created by subjects adjusting in experiment space, the influence of adopting the minimum allowable task horizontal illuminance for a long time have to do more research and discuss to ensure that the minimum allowable task horizontal illuminance is good for visual environment.

7-2-4 Limitation of Result in the Research

The formulas in the research are in no daylight, no windows and in white wall experiment environment. The behaviors are reading and VDT in this research, but meeting, communication, design, writing and walking are not involved.

7-3 Recommendations for Future Research

Energy save and carbon reduction has become a global issues, well architecture lighting design can achieve the prupose. In this study, the relationship of brightness degree and task illuminance was mainly explored. For brightness, the vertical illuminance and space luminance was treated as factors, through task artificial lighting resource adjustment to find minimum and appropriate horizontal illuminance. However, there are still many factors in physical and psychological amount which affects the human perception of architecture lighting. In the technical and economical side, there are many ways to save energy, still a considerable number of studies need to be accumulated and continued.

7-3-1 Influence of Different Spaces, Generations, Careers and Time under Minimum Allowable Task Horizontal Illuminance

This study is discussed the minimum allowable task horizontal illuminance in lighting environment in office. The minimum allowable task horizontal illuminance may be changed in other space, like school, house and library. On the other hand, for different generations or careers also need different minimum allowable task horizontal illuminance. Finally, when the minimum allowable task horizontal illuminance was adopted in office for a long time, the employees' visual healthy, psychology evaluation and productivity should be discussed more in the future.

7-3-2 Establish multivariate lighting environment recommendation indicator.

Present lighting environment always uses illuminance as evaluate indicator, however, some problems maybe produced if use illuminance as evaluate indicator, for instant likes the left picture shows: compare with the right picture, 4 FHT fluorescent lamps used and the average illuminance is 290lux, due to the lighting way is different and uniform, overall space brightness feels higher and energy consumption is relatively low[22].

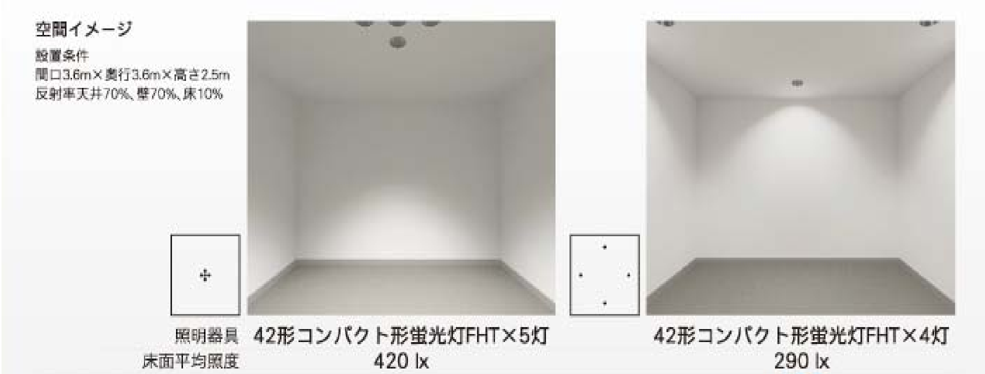

Fig. 7-7 Higher floor horizontal illuminance differ from higher brightness

From it we can know illuminance as the only one indicator is not enough to evaluate present lighting space, well designed lighting, improves illuminate and other physical factors can be measured, optimize human psychological sense such as brightness, openness, and it will help the lighting meet with user's need.

7-3-3 Brightness and Task Illuminance in Different Spaces

With the lighting diversification and LED light resource popularization, brightness researches have been gradually expanded and increasingly in-depth, such as Feu.　But for the different space types or the space need energy save, should build corresponds criteria of brightness and task illuminance, for example, conference room and working zoom in office should have different recommendation range; the brightness and illuminance recommendation range should be different in living room, bedroom and hall.　The kind of research has not had a more thorough discussion.　Besides, the present brightness evaluation equation always used in artificial light as light resource, with the architecture space gets diversity, outside space or semi-outside space are influenced by natural lighting resource easily, when deal with brightness evaluation, whether it is same with when the light resource is artificial light still need to more confirm by research.

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22 Panasonic homepage:
http://www2.panasonic.biz/es/lighting/plam/knowledge/feu/feu-1.html

7-3-4 Influence on Brightness from Light Color, Color Temperature, Space Material

Some researches state the brightness is different in different light color and color temperature. In light adaption, the sense for green light is higher than red and blue, thus, different light color and color temperature have significant impact on brightness. Present brightness evaluation formula is based on white light, light color and color temperature can be add to revise the formula to satisfy the trend of architecture diversification. Besides, space material is another factor which impacts brightness, like high reflection ceiling, wall and floor. Because the subjects did not see the ceiling directly, the reflection from ceiling is not discussed in this research. Using high reflection ceiling or iron reflector can increase brightness of space and make the uniformity good. When different architectural material used, the difference reflection ratio and color of material reflects into eyes should be different with influence on brightness from light color. The mentioned factors can be research theme in the future.

7-3-5 Influence of Fatigue and Work Efficiency from Brightness

Brightness is a sense which people evaluate lighting environment directly, some researches state color temperature, light color, energy and others influence melatonin significantly. High color temperature, blue and green light influence melatonin secrete and then influence rest and sleep. Besides, light on human’s sympathetic has a significant impact. One-third of human life cost indoor space, especially in modern society. Time cost in office environment increase gradually, the research relate worker’s fatigue and efficiency always be discussed. Face with energy save, less research relate the performance on users’ fatigue and efficiency influenced by low illuminance, low brightness. Besides, the ways of work develop from paper work to self-luminous display, such as telephone, tablet and display for VDT work. When reading or VDT work in environment with different brightness, works’ fatigue and productivity should be discussed in future.

APPENDIX

APPENDIX

Experiment Statement

説　明　書

承認日：　　　　年　　月　　日

研究代表者（所属・職名・氏名）：東京大学 大学院工学系研究科建築学専攻・教授・平手小太郎

研究課題名：　1.異なる明るさ空間における最低許容照度と最適照度の研究
　　　　　　　2..執務空間における違う均一性による許容照度と最適照度の影響

研究の概要

研究の目的
■　異なる明るさと異なる均一性空間における許容照度を落ちることを**目的とします**。 ■　異なる明るさと異なる均一性空間における VDT 輝度に与える影響を調べます
実験の方法
1. 読書と VDT で実験参加者が task-lighting を調整する。（１パターンで最低照度と最適照度２回を調整する 2. VDT 時、screen の輝度を調整いたします。(調整する時、上げると下がること２回を調整する） 3. ご了解いただいた場合に、実験状況の写真を撮ることがあります。 4. 毎回 task-lighting と screen の輝度を調整したとアンケートに評価してください。 5. 手順を繰り返し、約５パターンについて評価してください。 6. 光が直接入射しないと視線の角度を保持するように、姿勢を固定してください。 所要時間：実験参加者一人つき約 2 時間、１パターン終わった、５分間の休憩時間があります。
研究を実施する研究者
東京大学 大学院工学系研究科建築学専攻・教授・平手小太郎 東京大学 大学院工学系研究科建築学専攻・助教・古賀　誉章 東京大学 大学院工学系研究科建築学専攻・博士課程・林裕森
研究のための費用
大学運営費交付金および委任経理金によるものです。

実験への参加について

対象とする研究参加者と研究参加者としてお願いした理由
視覚能力に関わる疾病や傷害を持たない一般の健常者を対象とします。 このような条件に適合する研究参加者として貴方にお願いいたしました。
実験への参加の任意性について
参加者は、この実験に参加しない自由があります。 実験の中でなんらかの不具合などにより途中でもいつでも実験を止めることができます。 なお、途中で実験を止めても参加者には不利益を受けることはありません。
実験への参加に伴う危害の可能性と、それに対する配慮について
1．暗室における印象評価実験では、暗い環境で映像と写真を観察することによる疲労や視力低下がわずかに発生する可能性があります。ただし,本研究では、疲労や視力低下を起こさない範囲で輝度と実験時間を制御するように設定しています。 2．本研究では、万一の危険に備え、実験の参加者がいつでも装置から離れられるようにして実験を行います。
傷害保険等への加入について
大学として、国立大学法人総合損害保険特約に加入しており、教職員に損害賠償の責任が生じた場合に補償に対応できるようになっております。研究を実施する学生は、学生教育研究災害傷害保険付帯賠償責任保険に加入しており、第三者に怪我をさせたり、財物を損壊した場合の法律上の損害賠償を補償できるようになっております。
実験の参加に伴う謝金
本実験への参加に伴う謝金は、1 回（約 1 時間程度）あたり 1000 円です。

成果の公表等について

研究成果の公表について
本研究で得られたデータは、様々な学術的な場において公表します。
個人情報の取り扱いについて
研究参加者の個人情報は、個人が特定されない形で記録します。研究成果の公表に際しては、研究参加者全体としての統計的な情報に加え、個々の研究参加者から得られた情報についても言及する場合がありますが、その際は、具体的に人物を特定できない形で行います。
知的財産権の帰属
本研究で得られたデータ等の知的財産については、研究代表者もしくは研究実施機関である東京大学に帰属します。

問い合わせ先、苦情等の連絡先
〒113-8656　東京都文京区本郷 7-3-1 工学部 1 号館 建築学専攻　教授　平手小太郎 E-mail: hirate@arch.t.u-tokyo.ac.jp 大学院工学系研究科 建築専攻　博士課程・林裕森 TEL: 080-4385-5589、E-mail: linyusen.mail@gmail.com

同　意　書

研究代表者：東京大学 大学院工学系研究科・教授・平手小太郎　殿
研究課題名：1. 異なる明るさ空間における最低許容照度と最適照度の研究
2. 執務空間における違う均一性による許容照度と最適照度の影響

私は，上記研究課題に関する以下の事項について文書による説明を受けました．理解した項目について，自分で□の中にレ印を入れて示しました．

□ 説明書を受領しました。
□ 研究の目的
□ 実験の方法
□ 研究を実施する研究者
□ 研究のための費用
□ 対象とする研究参加者
□ 実験への参加が任意であること（実験への参加は任意であり，参加しないことで不利益な対応を受けないこと．また，いつでも同意を撤回でき，撤回しても何ら不利益を受けないこと）
□ この実験への参加に伴う危害の可能性について
□ 傷害保険等への加入について
□ 実験への参加に伴う謝金
□ 研究成果の公表について
□ 個人情報の取り扱いについて
□ 知的財産権の帰属
□ 問い合わせ先，苦情等の連絡先

なお，この実験において撮影・記録された私の映像（静止画）の公開につきましては，以下の□の中にレ印を入れて示しました．

□ 公開に同意しない
□ 下記条件のもと，公開に同意する．
　□ 顔部分など個人の同定可能な画像も含んで良い
　□ 顔部分や眼部などを消去・ぼかすなど個人の同定不可能な状態に限る
　□ その他（特別な希望があれば，以下にご記入ください）

これらの事項について確認したうえで，研究参加者として実験に参加することに同意します．

平成____年____月____日

研究参加者署名，または，記名・押印　________________________________印

本研究に関する説明を行い，自由意志による同意が得られたことを確認します．

説明担当者（所属・職名・氏名）　________________________________印

（署名，または，記名・押印）

同意撤回書

研究代表者：東京大学 大学院工学系研究科・教授・平手小太郎　殿

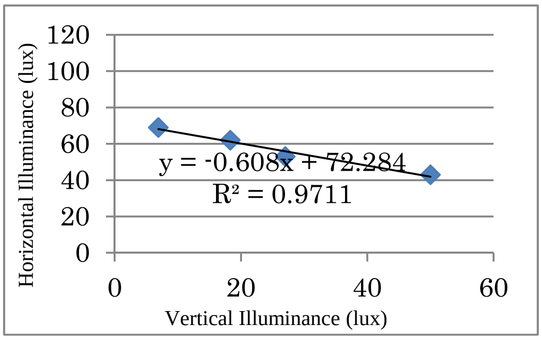
研究課題名：1. 異なる明るさ空間における最低許容照度と最適照度の研究
2. 執務空間における違う均一性による許容照度と最適照度の影響

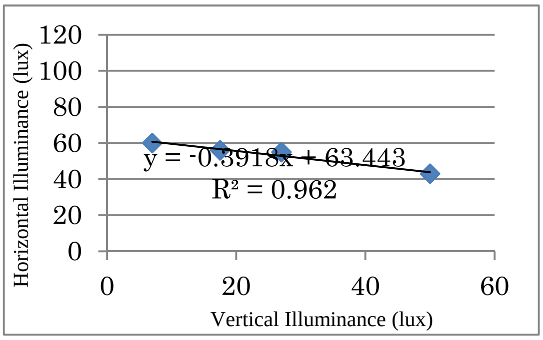
このたび私は上記研究課題に参加するにあたり，説明担当者より別紙文書に書かれた内容について詳細な説明を受け同意しましたが，同意の是非について再度検討した結果，同意を撤回します.

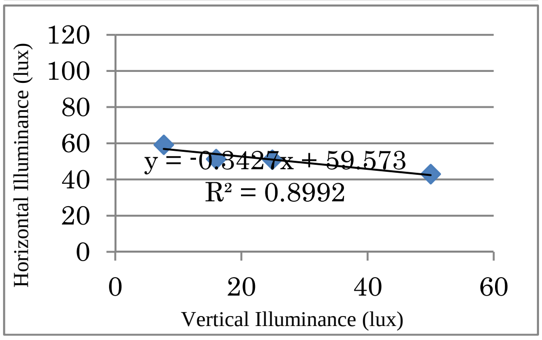
平成____年____月____日

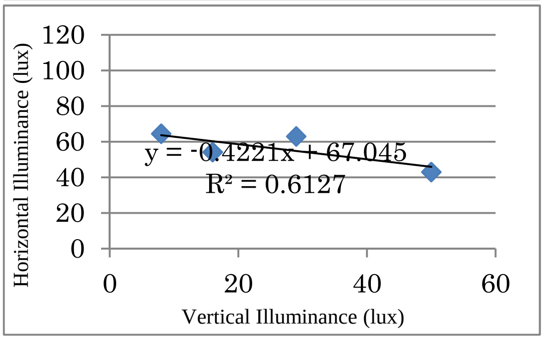
研究参加者署名，または，記名・押印　______________________________印

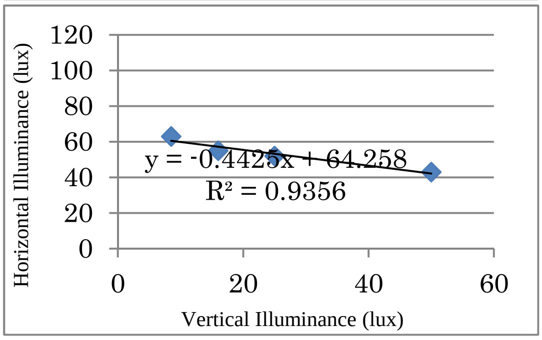
Regression Analysis in Minimum model for Each Subject in Chapter 5

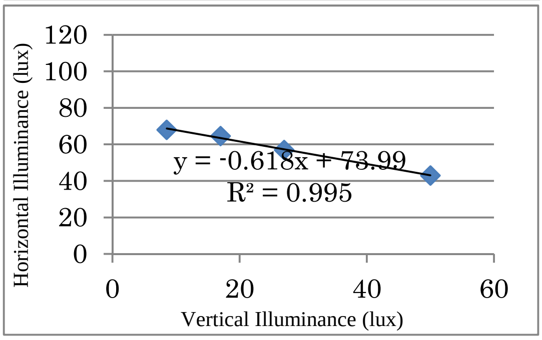


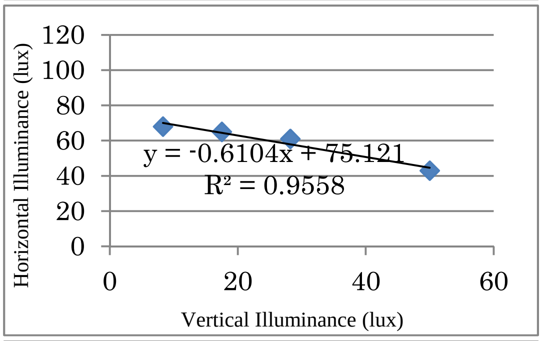


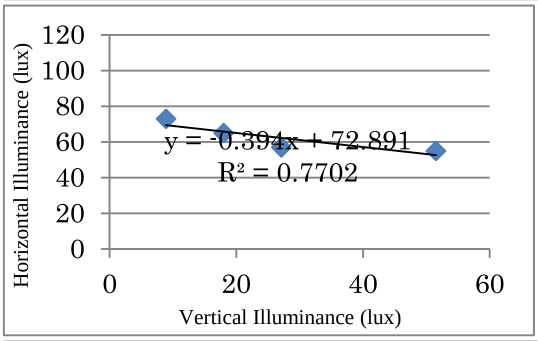


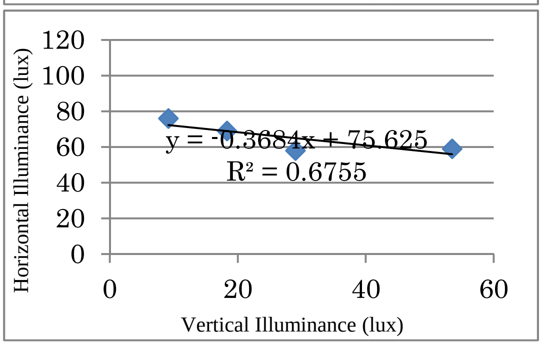


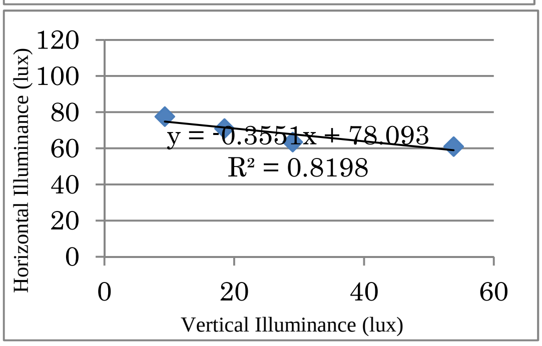


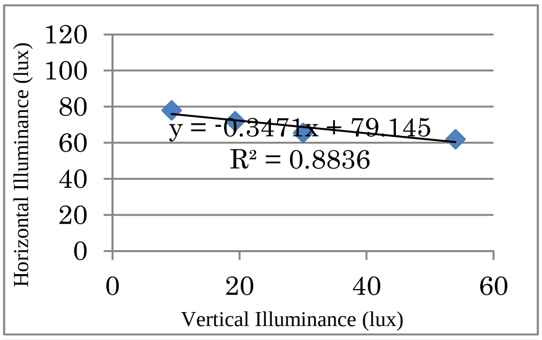


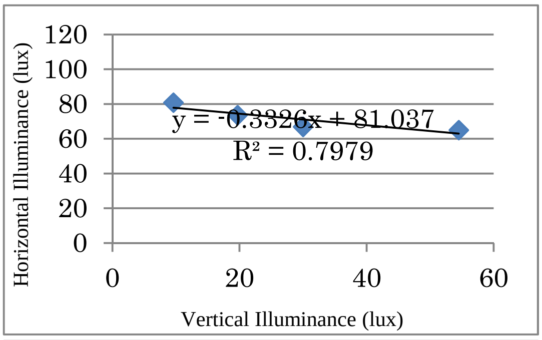


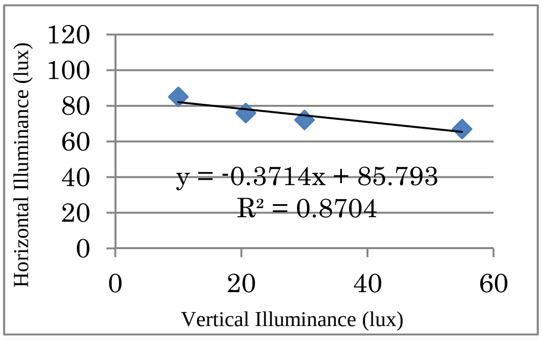


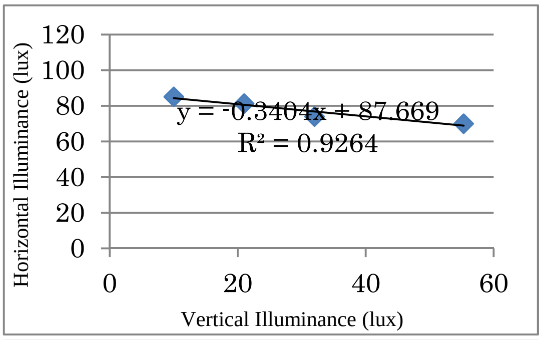


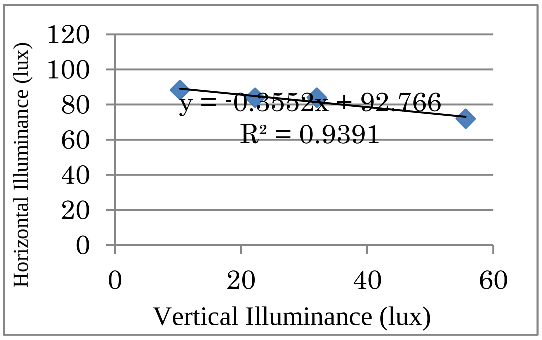


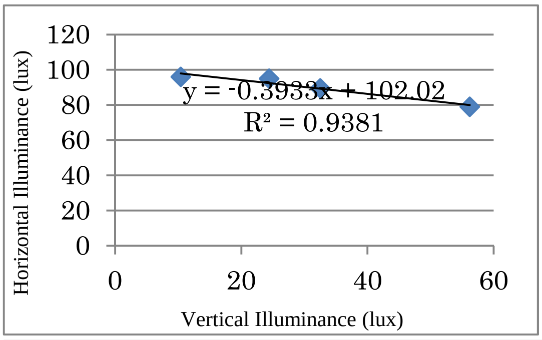

y = -0.3471x + 79.145
R^2 = 0.8836
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

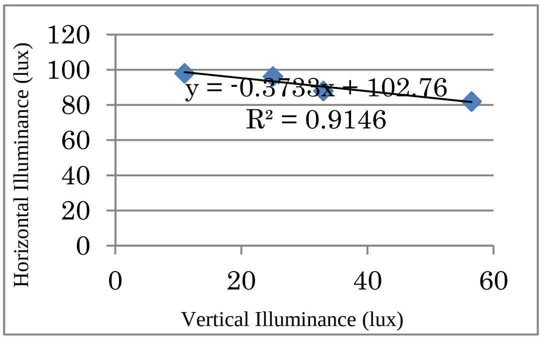

y = -0.3326x + 81.037
R^2 = 0.7979
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

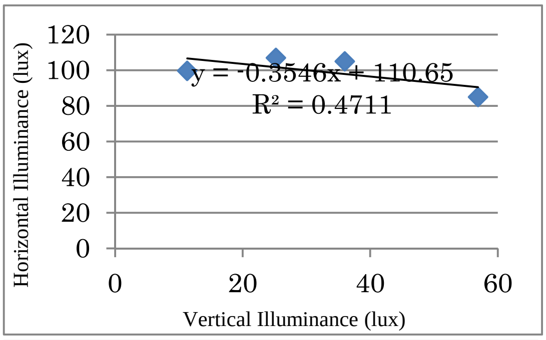

y = -0.3714x + 85.793
R^2 = 0.8704
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

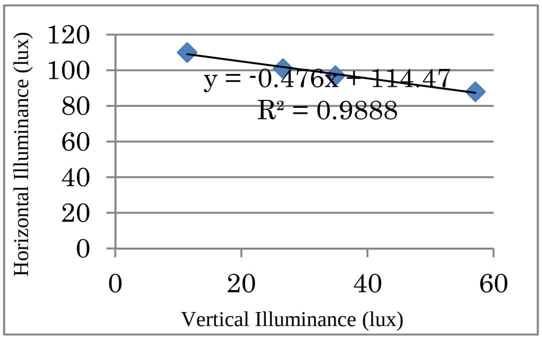

y = -0.3404x + 87.669
R^2 = 0.9264
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

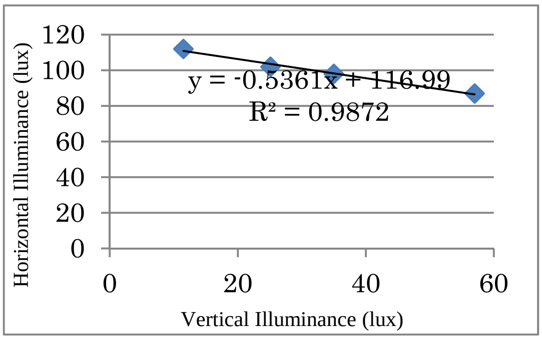

y = -0.3552x + 92.766
R^2 = 0.9391
Horizontal Illuminance (lux)
Vertical Illuminance (lux)


y = -0.3933x + 102.02
R^2 = 0.9381
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

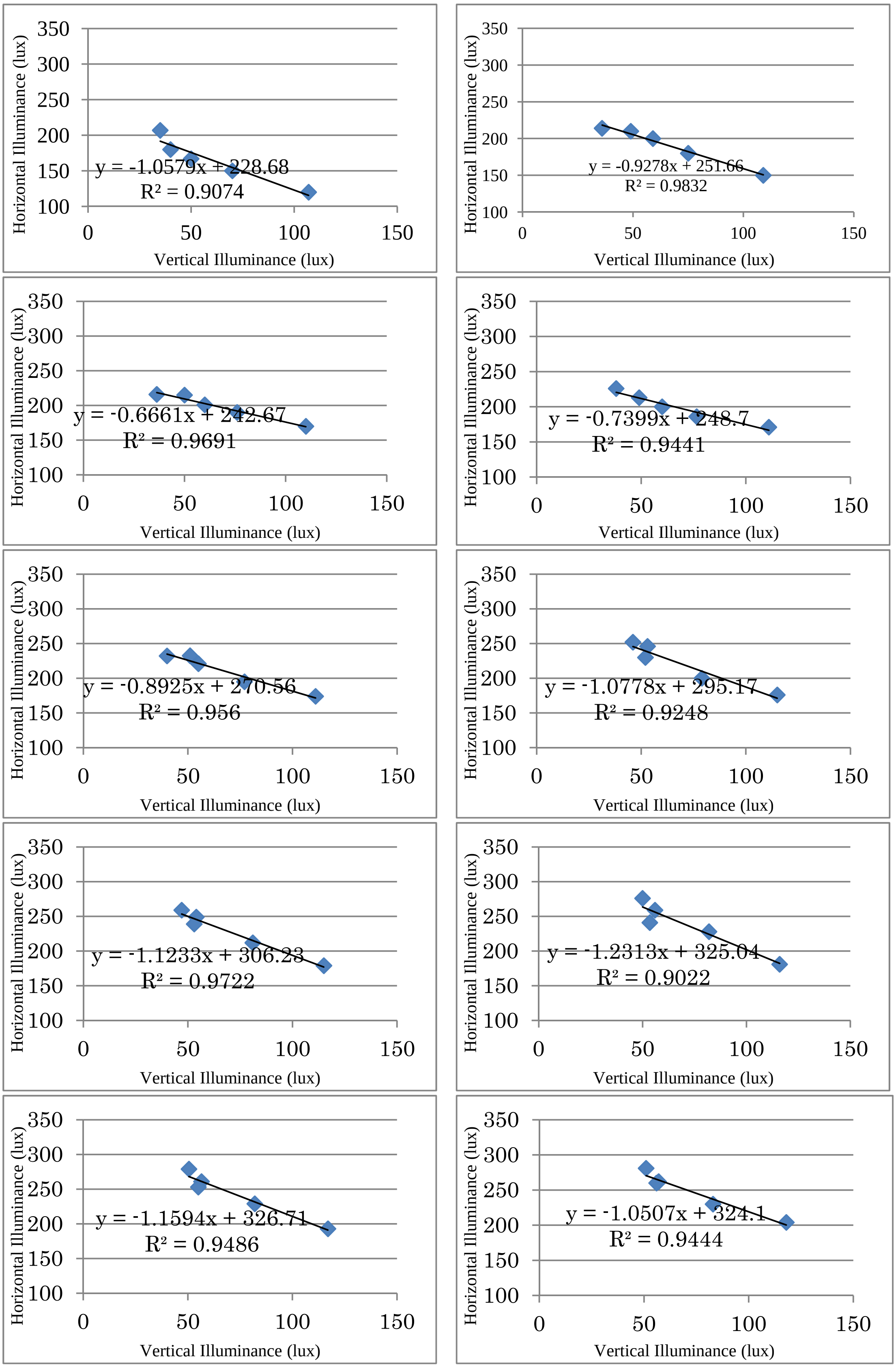

y = -0.3733x + 102.76
R^2 = 0.9146
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

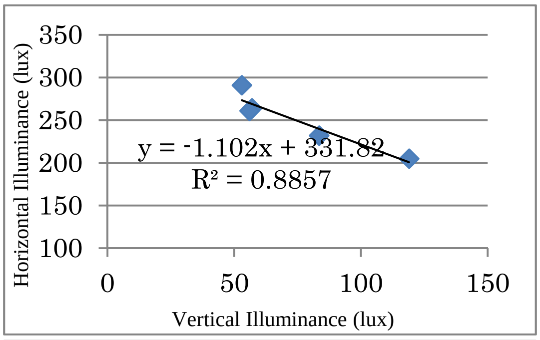

y = -0.3546x + 110.65
R^2 = 0.4711
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

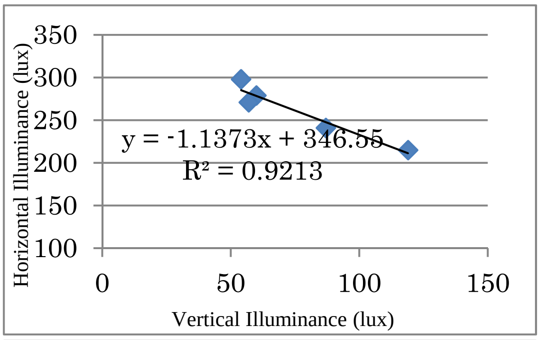

y = -0.476x + 114.47
R^2 = 0.9888
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

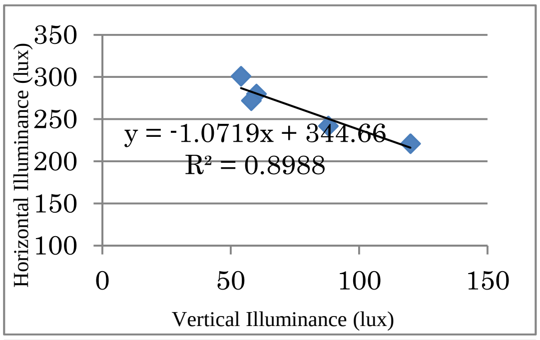

y = -0.5361x + 116.99
R^2 = 0.9872
Horizontal Illuminance (lux)
Vertical Illuminance (lux)

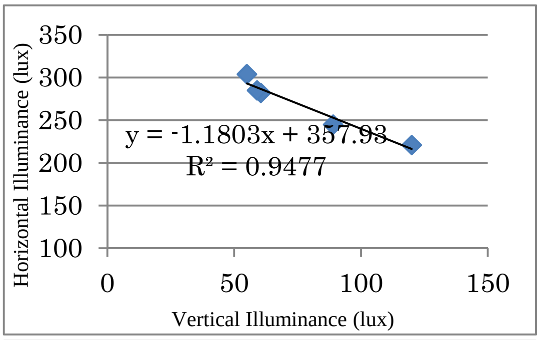
Regression Analysis in Appropriate model for Each Subject in Chapter 5

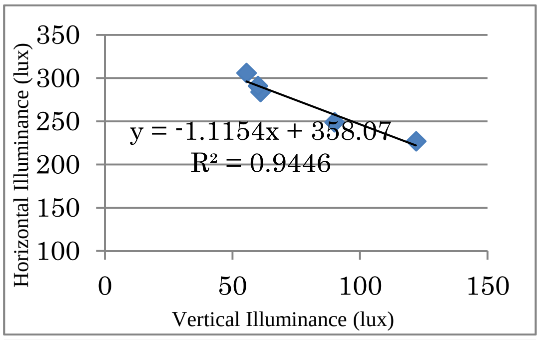


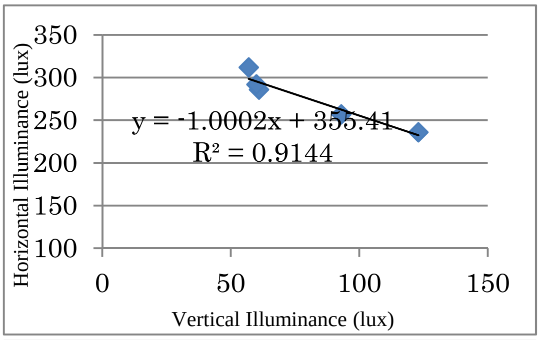

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.102x + 331.82
R² = 0.8857
Vertical Illuminance (lux)

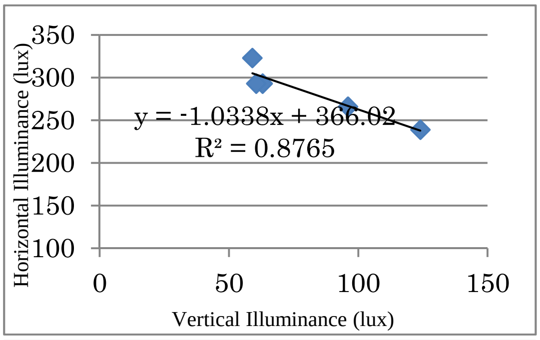

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.1373x + 346.55
R² = 0.9213
Vertical Illuminance (lux)

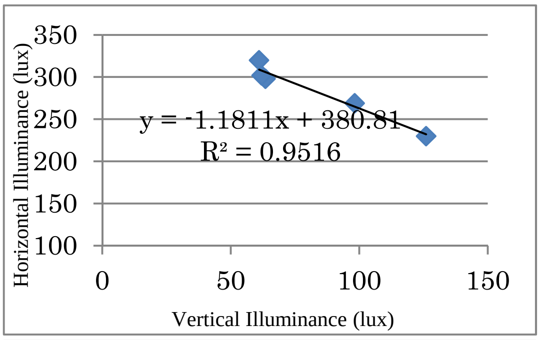

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.0719x + 344.66
R² = 0.8988
Vertical Illuminance (lux)

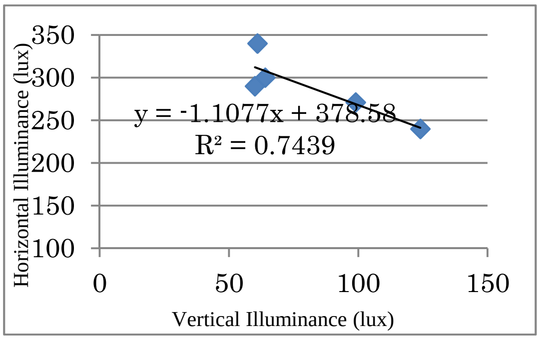

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.1803x + 357.93
R² = 0.9477
Vertical Illuminance (lux)

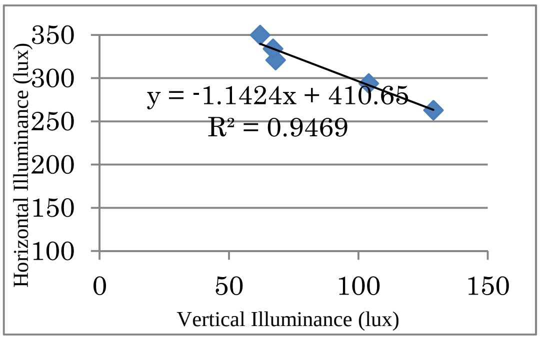

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.1154x + 358.07
R² = 0.9446
Vertical Illuminance (lux)


Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.0002x + 355.41
R² = 0.9144
Vertical Illuminance (lux)

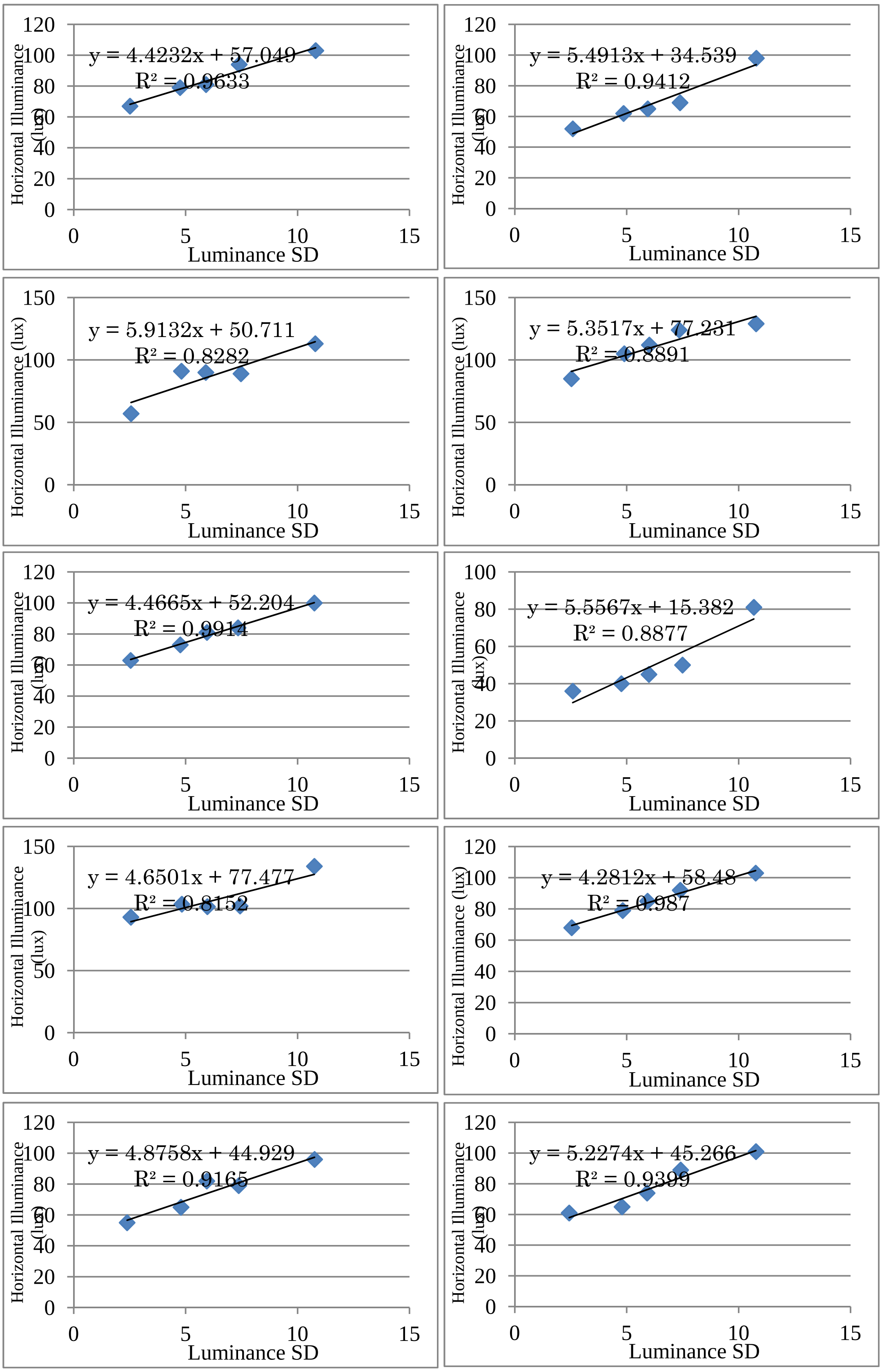

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.0338x + 366.02
R² = 0.8765
Vertical Illuminance (lux)

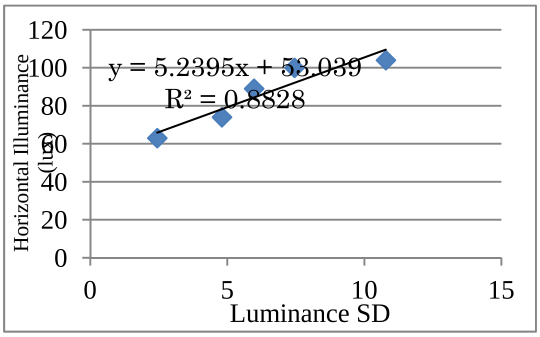

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.1811x + 380.81
R² = 0.9516
Vertical Illuminance (lux)

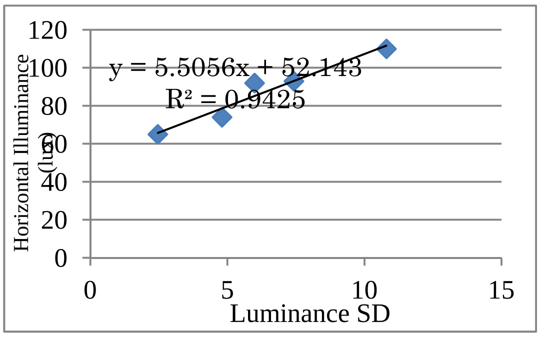

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.1077x + 378.58
R² = 0.7439
Vertical Illuminance (lux)

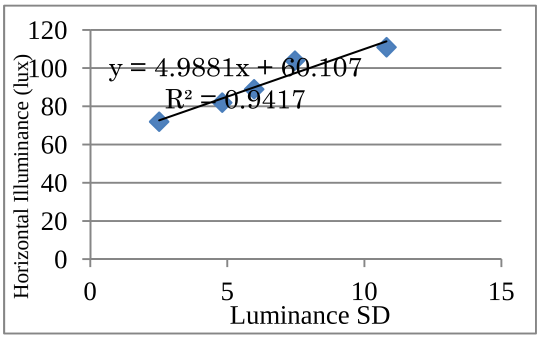

Horizontal Illuminance (lux)
350
300
250
200
150
100
0
50
100
150
y = -1.1424x + 410.65
R² = 0.9469
Vertical Illuminance (lux)

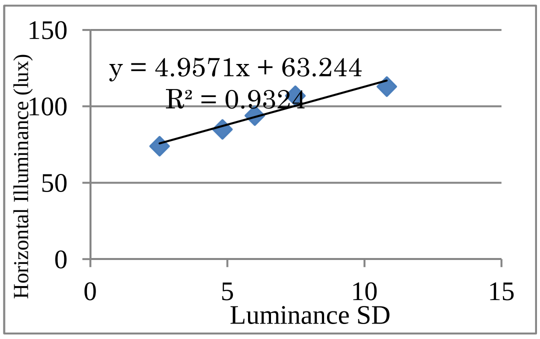
Regression Analysis in Minimum model for Each Subject in Chapter 6

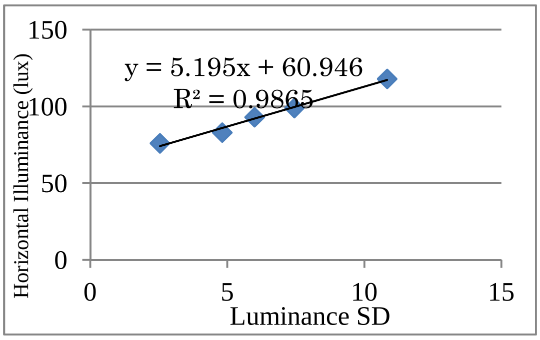


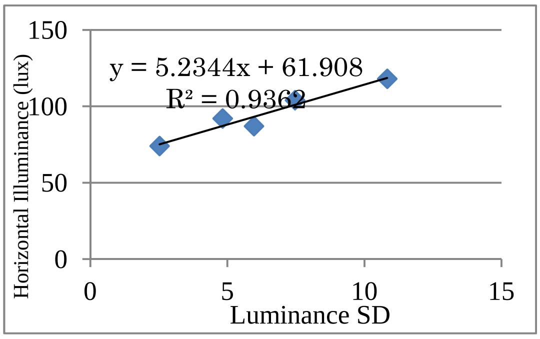

y = 5.2395x + 53.039
R² = 0.8828
Horizontal Illuminance (lux)
Luminance SD

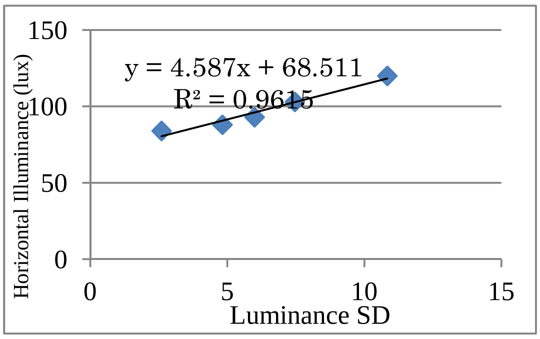

y = 5.5056x + 52.143
R² = 0.9425
Horizontal Illuminance (lux)
Luminance SD

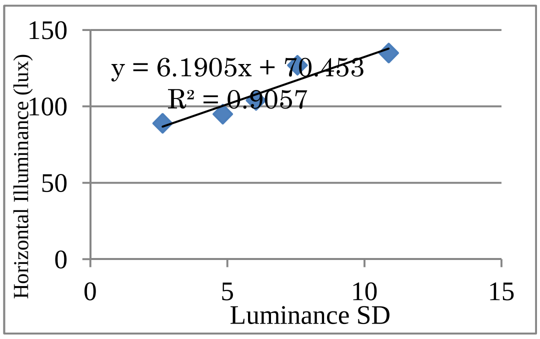

y = 4.9881x + 60.107
R² = 0.9417
Horizontal Illuminance (lux)
Luminance SD

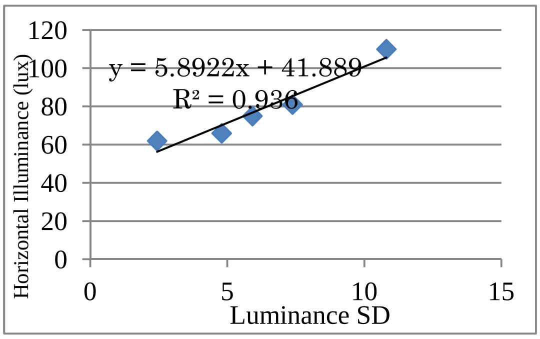

y = 4.9571x + 63.244
R² = 0.9324
Horizontal Illuminance (lux)
Luminance SD

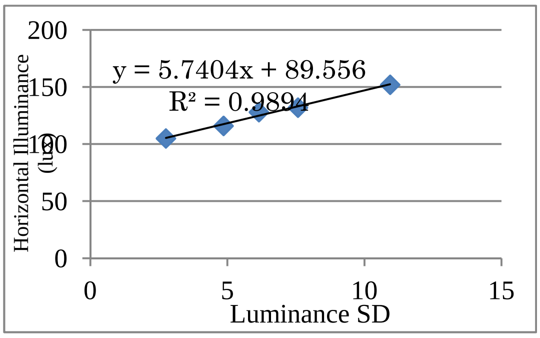

y = 5.195x + 60.946
R² = 0.9865
Horizontal Illuminance (lux)
Luminance SD


y = 5.2344x + 61.908
R² = 0.9362
Horizontal Illuminance (lux)
Luminance SD

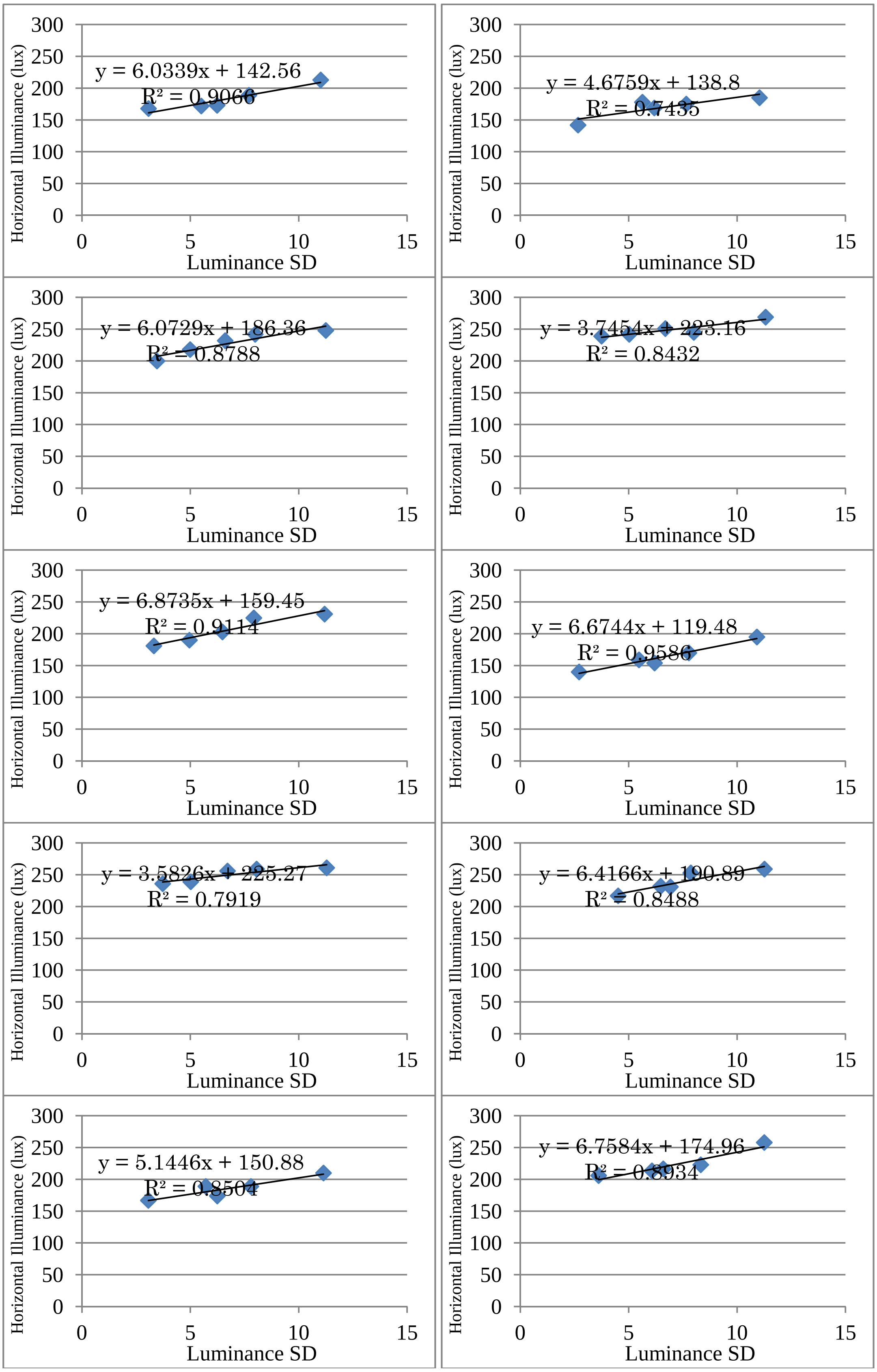

y = 4.587x + 68.511
R² = 0.9615
Horizontal Illuminance (lux)
Luminance SD

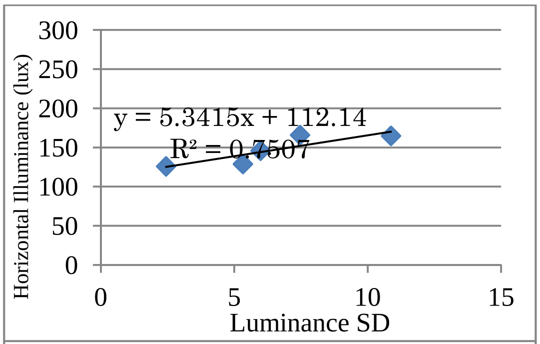

y = 6.1905x + 70.453
R² = 0.9057
Horizontal Illuminance (lux)
Luminance SD

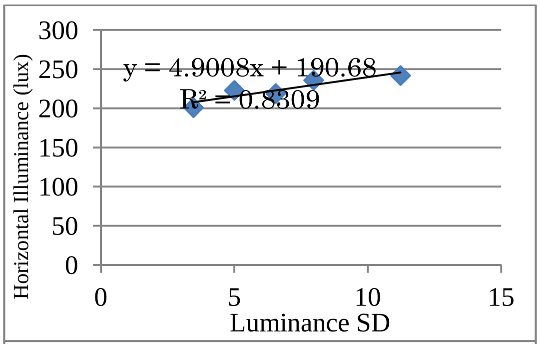

y = 5.8922x + 41.889
R² = 0.936
Horizontal Illuminance (lux)
Luminance SD

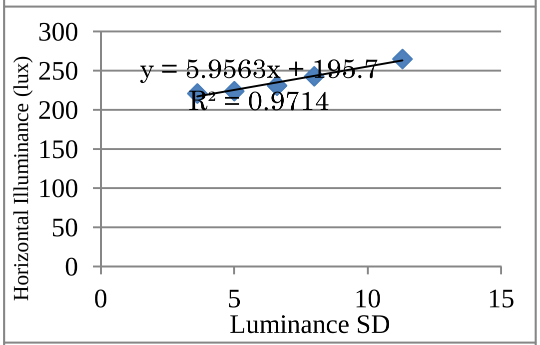

y = 5.7404x + 89.556
R² = 0.9894
Horizontal Illuminance (lux)
Luminance SD

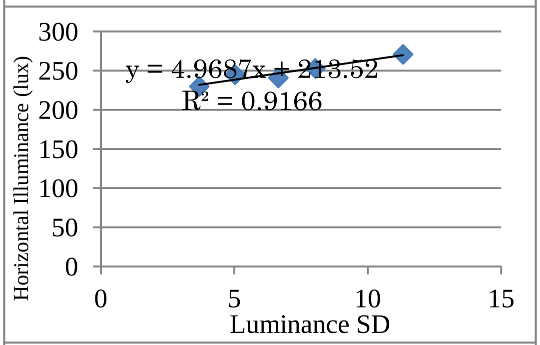
Regression Analysis in Appropriate model for Each Subject in Chapter 6

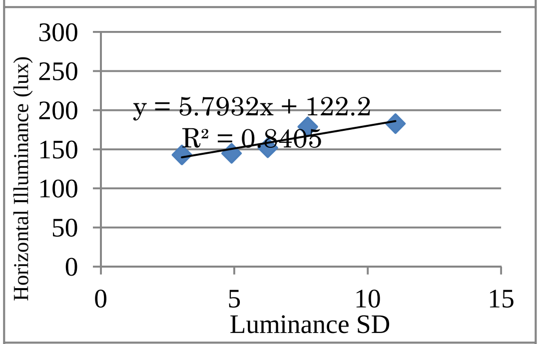


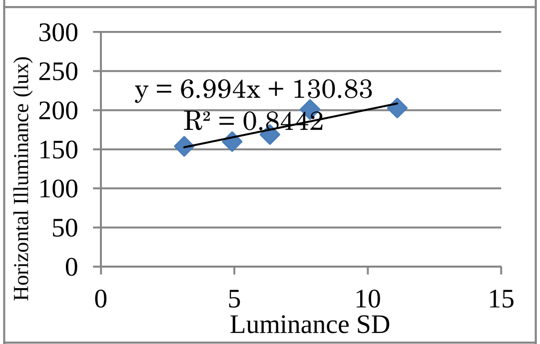

y = 5.3415x + 112.14
R² = 0.7507
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15

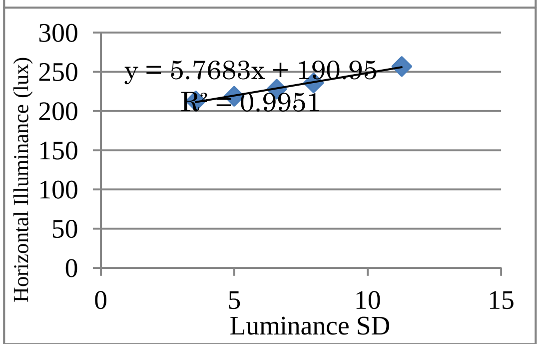

y = 4.9008x + 190.68
R² = 0.8309
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15

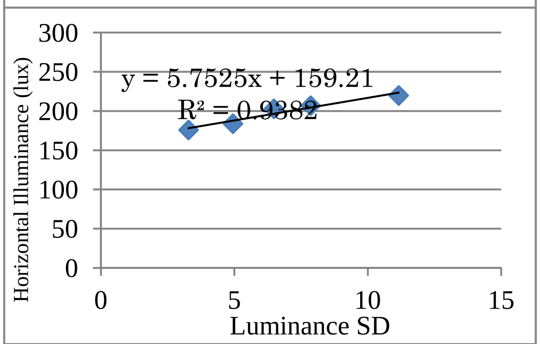

y = 5.9563x + 195.7
R² = 0.9714
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15

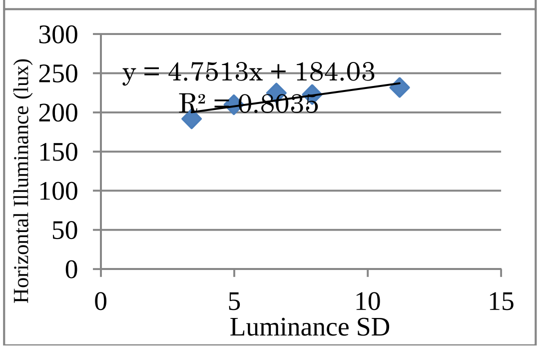

y = 4.9687x + 213.52
R² = 0.9166
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15

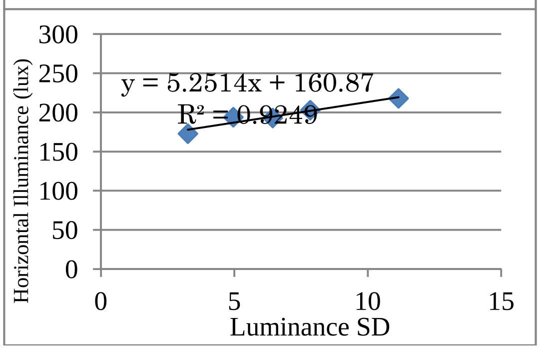

y = 5.7932x + 122.2
R² = 0.8405
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15


y = 6.994x + 130.83
R² = 0.8442
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15


y = 5.7683x + 190.95
R² = 0.9951
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15


y = 5.7525x + 159.21
R² = 0.9382
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15


y = 4.7513x + 184.03
R² = 0.8035
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15


y = 5.2514x + 160.87
R² = 0.9249
Horizontal Illuminance (lux)
Luminance SD
0
50
100
150
200
250
300
0
5
10
15

The Questionnaire for Taiwanese Survey

台灣辦公室照明環境調查之研究

親愛的辦公室工作者，您好！

首先感謝您撥冗協助填答本問卷！這是一份探討「台日辦公室照明環境」的評價問卷。本實測為晴天、陰天與夜間三類型，實測所需時間為一個完整工作天(AM 8:00~PM6:00)。實測項目包括實地照度輝度等物理量量測與辦公者心理評價問卷兩個項目。照度、輝度物理量等需要在辦公室裝設無線照度計，並且為了減少對工作者的影響，設備均會安置在不影響正常辦公作業區域，以不影響辦公為原則，各位工作者可以正常辦公，除了於下午四點半填寫本問卷外，其他時間不會打擾各位進行工作。

東日本大震災後，面臨巨大的天然災害以及產生各種複合式的災變，讓人類不得不重新檢視自我的生存環境有什麼問題。由於地震導致核能電廠的輻射外洩，嚴重危害生物基本生存環境，日本許多核電廠相繼關閉導致電力供給緊縮，日本政府相繼呼籲社會大眾自主節電，以維持基本國家運作電力。然而在如此嚴苛的節電環境以及全球氣候劇烈改變的情況下，發生許多因為過度節電導致影響人類健康的問題。台灣也位處於地震帶上，核電廠靠近都市只有短短二、三十公里，未來避免發生複合式災變，台灣對於能源的使用規畫必須要慎重考慮，然而日本進行的節電措施，尤其在照明環境方面亦可為台灣借鏡。因此本研究為比較「台、日辦公室照明環境」之工作者心理評價狀況，藉此了解目前台灣辦公室對照明環境的滿意度以及其他各項評價，以利後續進行相關辦公室照明研究。

順頌

時祈

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壹、填表人資料

編　　號：

服務編號：

年齡：□20~29 □30~39 □40~49 □50~59 □60~69　　性別：□男 □女

填表日期：　　年　　月　　日　　時　　分

貳、填寫說明

本研究採「語意分析法」針對「辦公室照明各項環境心理因子」及「工作型態」、「工作習慣」項目進行，以了解工作者對該辦公室環境的評價尺度。

首先先針對工作型態與工作習慣進行勾選；再依評估項目因子影響程度分為1至7七個等級，數字為越小者，表項目較傾向「不滿意」、「不明亮」等意思；數字為越大者，表項目較傾向「很滿意」、「很明亮」影響程度越大。

請依您個人當下之感受，評定每個因子之範圍，並在空格內圈選。

肆、問卷開始

請您分別依以下所列之評估項目，進行填寫與勾選。

一、 請問您的作業內容 □電腦作業 □桌面文書作業 □兩者皆是 □兩者皆非

二、 請問您使用檯燈的頻率 □很常使用 □有時使用 □不使用

三、

<table>
<tr><th>評估因子項目</th><th colspan="7">評估尺度</th></tr>
<tr><td rowspan="3">1 作業面明亮感
內容：您作在您工作的位置上讓您感受明亮的程度為何？</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="7">非常暗＜----------------------＞非常亮</td></tr>
<tr><td colspan="7">意見：</td></tr>
<tr><td rowspan="3">2 文書作業能見度
內容：您觀看文書紙面作業是否感覺容易</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="7">非常困難＜------------------＞非常容易</td></tr>
<tr><td colspan="7">意見：</td></tr>
<tr><td rowspan="3">3 電腦螢幕能見度
內容：您觀看電腦螢幕是否感覺容易</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="7">非常困難＜------------------＞非常容易</td></tr>
<tr><td colspan="7">意見：</td></tr>
<tr><td rowspan="3">4 作業容易度
內容：您進行總體一般辦公作業是否容易</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="7">非常困難＜------------------＞非常容易</td></tr>
<tr><td colspan="7">意見：</td></tr>
</table>

5 作業面滿意度 內容：您進行辦公作業時，桌面照明是否感覺滿意	1	2	3	4	5	6	7
	非常不滿＜-------------------＞非常滿足						
	意見：						

6 辦公空間明亮感 內容：您覺得整體辦公空間讓您感受明亮的程度為何？	1	2	3	4	5	6	7
	非常暗＜----------------------＞非常亮						
	意見：						

8 辦公空間照明滿意度 內容：您覺得辦公室的照明環境是否滿意	1	2	3	4	5	6	7
	非常不滿＜-------------------＞非常滿足						
	意見：						

7 作業效率 內容：您覺得因為辦公室的照明環境使您的辦公作業效率高低程度	1	2	3	4	5	6	7
	非常惡劣＜-------------------＞非常良好						
	意見：						

9 改善前作業效率比較(曾進行節能改善才作答) 內容：您覺得您現在的工作效率與改善前相比是否有上升或惡化	1	2	3	4	5	6	7
	更為惡化＜-------------------＞更為上升						
	意見： 改善前照度值(如知道請回答)：						

四、請問您受到窗面眩光的影響頻率　很常受到影響　偶爾受到影響　毫無影響

五、請問您受到照明眩光的影響頻率　很常受到影響　偶爾受到影響　毫無影響

六、請問您工作時眼睛感受到疲勞的頻率　很常疲勞　偶爾疲勞　毫無影響

七、請問您工作時感受到疲勞的頻率　很常疲勞　偶爾疲勞　毫無影響

八、請問您如果貴辦公室有採取照明節能方案，此方案為何

分區照明　降低照明數量　使用檯燈　更換節能燈管　使用日光　其他：

本問卷到此為止，非常感謝您的填寫，謝謝！

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REFERENCE

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