Interdisciplinary Approach for Design of the Lighting Environment in Art Museum by Focusing on Emotional Evaluation

WANG ZHISHENG

Japan Advanced Institute of Science and Technology

Doctoral Dissertation

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WANG ZHISHENG

Supervisor: Professor Yukari Nagai

Graduate School of Advanced Science and Technology

Japan Advanced Institute of Science and Technology

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ABSTRACT

This research shows the influence of artificial lighting in the museums on the viewers' emotion through an innovation thinking method and puts forward a new lighting evaluation standard. Through evaluating the visitors' response index, the process of lighting design can be more humanized and induce more desirable emotional feedback. This study is an interdisciplinary research on basic theories and methods involving several subject areas. It covers the fields of architecture, design, optical engineering and psychology, which put forward the relationship among museums, people and the illuminated environment. Through theoretical derivations and experiment evaluations, it aims to create a comfortable lighting environment in museums.

Through the investigation on art museums, this study finds out their characteristics and the existing problems. On this basis, it proposes a lighting design evaluation model of SVOE, which includes four parts, i.e. Spatial, Visual, Optical and Emotional. It also optimizes the evaluation index of environment lighting. Combining the SVOE model, it uses computer software to conduct simulation experiments, and evaluates the subjects via eye movement tracking indicators.

This study uses three methods, which are computer simulation, laboratory simulation and museum field research. Firstly, it simulates the lighting of an art museum and studies the subjective emotions of the visitors while they appreciating the paintings. Two lighting parameters of color temperature and illuminance are compared and analyzed. Secondly, based on the study of visitors' emotion under the lighting of Japanese art museums, it analyzes the emotional response of the visitors in three different illuminated environments. Thirdly, it combines subjective questionnaires with objective evaluation methodology, and the actual evaluation is carried out with the aid of eye movement tracking equipment to study which illuminated environment parameters get the most visitors' attention.

Based on the lighting quality and comfort model established in this thesis, the experiment of emotional response and thinking comprehension under artificial lighting are designed and verified respectively. In the experiment, the parameters of visual comfort and quality of the lighting are obtained through the psychological evaluation of the visitors' appreciation of artworks in the museum. The relationship between the validity and applicability of the evaluation model is demonstrated. In the experiments of understanding and thinking, the visual comfort under various lighting conditions in different scenarios is evaluated and used for the verification of two evaluation models of visual comfort respectively. The parameters are obtained via eye movement tracking equipment. Through comparing theses subjective and physiological indexes, an emotional response index is confirmed. Finally, this study establishes the evaluation methodology of the influence of artificial lighting on visitors' emotion in the museums.

Keywords: Evaluation methodology; Psychophysical experiments; Emotional response; Lighting design; Lighting environment.

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CHAPTER 1
Introduction

1.1 Research Background

As a new field, lighting design only began to develop independently in the 1950s and attracted scholars from various disciplines to study it as a subsidiary specialty. At present, the evaluation standard of environment lighting based on individual emotional response lacks a corresponding theoretical system. In the field of architectural design, it is only regarded as an auxiliary discipline, having a certain impact on the theoretical construction of lighting design evaluation. It belongs to an interdisciplinary specialty, which requires innovation thinking. This study uses an innovation thinking method of knowledge to carry out a systematic theoretical research on the environment lighting evaluation model.

Museum design as a topic of great interest for interior designers, architects, lighting designers and museum staff is also attracting more and more public attention. At the time when building the major art galleries and museums, artificial lighting design was still in its infancy [1]. The art museums aim to exhibit, preserve and educate. However, exhibiting and preserving purposes are usually conflicting [2]. For example, to achieve higher exhibition quality, higher visual sensitivity is often required, which may damage the exhibits, especially with the two spectral components of ultraviolet and infrared in light [3].

Despite the fact that for museums, spending a large amount of money on the collection, and designing buildings to house, display and protect them are no more important than favorable lighting to a successful design, rigorous analyses of museum lighting design are extremely limited [4]. The lighting design of exhibition space has a great impact on people's visual and color perception, and the differentiated lighting arrangements can create quite different visual impressions on artworks. If not exquisitely designed, it will affect the visual perception of the observers [5].

Architecture is a container of space, the most important element of the exhibition space, and it also affects people's visual perception of light. Architectural space designed with different functions pays more attention to people's emotional responses in space. Different from optical engineering, it pays more attention to the accuracy of optical parameters. In this study, lighting design evaluations are mainly based on people's subjective answers from questionnaires and emotional response data. The interdisciplinary standards and laws of lighting evaluation are sorted based on innovation thinking methods. Through the changes of optical parameters and emotional data in different architectural spaces, it constructs a theoretical framework and evaluation model. Concepts of psychology is used to improve the lighting design evaluation content. Theories in architecture space and optical engineering can provide a suitable lighting for museum visitors.

In this study, the architectural space has an effect on the lighting. People observe an environment through their eyes and generate certain emotional response due to the lighting. Optical engineering parameter index is key for evaluating the lighting quality. In optical engineering, illuminance is one of the earliest and most frequently used objective index to evaluate lighting quality. The research of illuminance on visual evaluation, especially the visual comfort evaluation, has a long history. From the perspective of visual physiology, Spencer from the United States in 1947 thought that the higher the altitude of illuminance, the better in effect. But in those days, due to the limitation of the economic condition, they did not stipulate the upper limit of illuminance. They recommended the most appropriate illumination determined by the economic level [6]. In 1963, Japan researcher Matsui et al. showed through the visual fatigue experiment that the space illuminance should be higher than 500 lx to avoid the rapid growth of visual fatigue [7].

1.2 International and Industry Research Status

1.2.1 Research Status

As a specialized discipline, the research of lighting design has a general tendency to emphasize practice rather than theory. As a result, there is no formed design theory to apply the practice in the field of lighting design. Evaluation methodology is the most important link in the theory. It is also the premise to constructing a satisfying lighting design evaluation. Therefore, there is a need to know more about the status of evaluation methodology.

Current academic research has found that illuminance acts as the most critical evaluation index. Therefore, the illuminance level in various countries has developed from academic research standards to national ones. Illumination is also a very important index in lighting design evaluation. The CIE and most countries in the world have calibrated the illuminance value of working activities with high visual requirements. In CIE and the United States, it is 500 lx. In comparison, it is 500-750 lx in China. While the standard illuminance value of CIE is 400-500 lx, it is 300 lx in China [8, 9]. High illuminance is not equivalent to high lighting quality. But it is found that high illuminance levels may affect visual perception. For example, it may cause unnecessary glare [10, 11]. At the same time, Fotios' research shows that a environment with high brightness can achieve the best visual clarity [12]. In the designing process, the level of illumination need to be evaluated and systematically arranged. In 2014, Van Den compared several existing evaluation indexes of uncomfortable glare and carried out experiments. Scholars researched on the strength of the current indexes of uncomfortable glare, and proposed that the subjective evaluation indexes of awkward glare were caused by high illuminance or unreasonable light distribution [13]. But the scholars paid more attention to the lighting itself. There is not much research on the combination of environment lighting, architectural space, visual perception and emotional response index.

Illuminance is the most important index that affects people's visual perception. However, in the lighting design for art museums, we should pay attention to people's visual perception in the space and the quality of lighting instead of the mere factor of illuminance. In the past years, exhibition space lighting, which evolved upon this theory, was widely concerned,. In the lighting design of art museums, many exhibition space lighting design methods should be applied. Taking both the characteristics of space and the exhibits into consideration, a new lighting environment should be constructed with light source parameters and lighting style. It has been agreed in many space lighting design processes that different exhibition spaces need different lighting. But some scholars proposed that lighting comfort and preference should be pursuant to specific application scenarios. When evaluating the warmth of the lighting in catering and party activities, the conclusion was that Kruithof's research principle can be applied [14]. However, for pre-sleep lighting, people prefer darker color temperature. While in the learning environment, people prefer high illuminance [15]. Meanwhile, many scholars also evaluated the preference of lighting background for some exclusive indoor space, such as in museums and bedrooms[16].

Tanner's research showed that the space lighting can affect students' learning efficiency, and determined the relationship between the classroom physical lighting and students' performances with the regression model [17]. In 2004, Van Bohme studied healthy lighting, non-visual biological effects, and productivity improvement, and pointed out that the standard for high-quality artificial lighting has changed. The illumination level was no longer the only necessary standard to evaluate lighting quality, and dynamic lighting with variable color temperature would become the new design model of lighting in the future [18]. This research will obtain the lighting design evaluation standard for art museums to improve the lighting quality of space, achieve high-quality presentation of exhibits, and help the audience obtain more visual details and knowledge.

Difference in lighting environments affect the audience's emotional response in art museums. It is shown that different lighting can affect the observers' emotions, and thus affect their demand for information in art museums. But it also depends on how much influence different light sources have on people's emotional response. Emotion is a necessary component of human's cognitive activities. And vision is the most important pathway for human beings to obtain emotion. Good emotional responses can significantly improve the experience of information acquisition in the art museum environments. A favorable lighting can improve the viewing quality and also improves a person's emotional response in the art museum space, which can be categorized into subjective response and objective response.

This study aims to interpret the observers' psychological data and the changes in optical parameters. A person's emotional response in the lighting environment of an architecture is the most important part of lighting evaluation standard, and is also the innovative point of this study. Emotion is a complex physiological and psychological phenomenon, which plays a crucial role in creating social activities. Emotional ability plays an indispensable role in lots of smart activities, such as perception, reasoning, planning and creation [19]. American psychologist Neisse Ulrich and psychologist Herbert Simon think that one of the signs of a person's thinking is that rational thinking starts from emotions [20]. The lighting of an art museum is an important means to simulate and reproduce different scenarios that can improve the efficiency of people's perception of information. It is very important to research about how to establish and make the environment lighting meet people's emotional response. This research sets out to explore how visitors perceive different types of exhibition environment and determines how such perceptions may influence the overall visiting experience [22]. The style of lighting design can affect the lighting environment. The way the ambiance is shaped by light and shadow is a matter of fundamental importance [21]. The decision of whether to plan direct or indirect lighting significantly affects the proportion of directional or diffused lighting in a space. This result shows the lighting design concept in the case of indirect lighting to produce general lighting. In contrast, a direct lighting concept comprises both direct and diffused light, both general and accent lighting [23], and lighting in various ways. This is a unique art creation and culture connotation [24].

In 1941, Kruithof first studied people's subjective feelings under environment lighting in different combinations of color temperature and illuminance, from which he came up with the famous Kruithof's Curve [25]. As shown in Figure 1-1, this curve is the most classical theoretical model for the subjective evaluation of environment lighting [25]. The research theory obtained under the lighting conditions at that time was of great help to later research. This theory was also a very important reference to the emotional response of art museum lighting evaluation. Through years of technological innovation and academic development, the evaluation has been improved and verified from different angles. The results showed that under the condition of high color temperature and low illuminance, people feel depressed and cold. In contrast, in the environment of low color temperature and high illuminance, a high color temperature area makes people think that the surrounding objects lose their naturalness. However, with the development of new light source technology, one can't merely reply on color temperature and illuminance to evaluate people's emotional response. This theoretical model can't accurately reflect the relationship between lighting environment and emotions anymore, and needs to be studied further.

Many scholars studied the theory deeply and combined the research results on illumination and color temperature. Neither of these two lighting environments can bring people comfort. Only when the color temperature and illuminance in certain environment increase synchronously or decrease correspondingly can a person feel comfortable. In 1990, Boyce and Cuttle conducted color discrimination experiments. They found that the participants felt more relaxed and liked it when the illumination increased. However, there were no significant changes in comfort and expectations within the color temperature range of 2,700K to 6,300K [26].

The research showed that exhibition lighting and emotional response are important indicators for environment lighting evaluation of art museums. Researchers Oi and Takahashi tested the application of 20 lighting environments, with illuminance from 50 lx to 800 lx, and color temperature from 3,000K to 6,500 K in daily life. Through more accurate evaluation of color temperature and illumination, they obtained the emotional response of the lighting environments. The results showed that the preference in different color temperature and illuminance mainly depended on specific application scenarios [27]. Scholar Fotios' research found that the difference in color temperature and spectral composition would have an impact on the brightness of the environment. The results showed that the visual intensity of the colored light with vibrant blue and purple are significantly higher than that of red and yellow [28].

In 1941, Crusoe proposed a method, which then was called Crusoe's Law. It showed that high (low) illuminance in a specific area of high (low) CCT makes the observer feel happy [32]. The Kruithof's curve is the earliest rule that was sorted out in the light environment evaluation, and it is hoped that the applicability will be verified in this study.

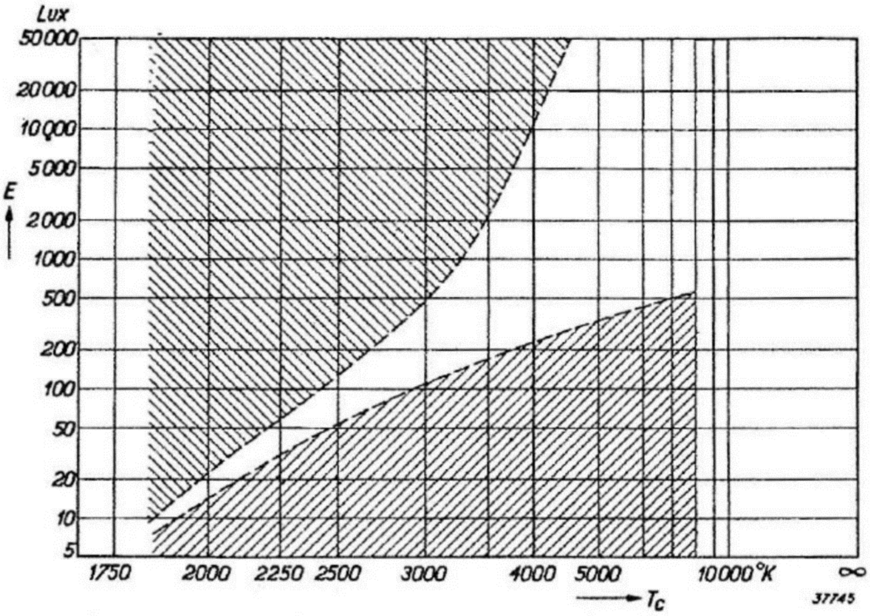


Figure 1-1. The Kruithof's curve.

(Source: Kruithof. A. A. (1941). Tubular Luminescence Lamps for General Illumination. Philips Tech Review, 6, 65-96)

Researchers Park et al. studied the preference of indoor color temperature. They proposed that people's choice for color temperature was significantly different in different scenarios. And they suggested that the color-adjustable temperature lighting system could improve people's indoor comfort than fixed color temperature lighting [29]. Researchers Bullough et al. studied the influence of flickering light sources on indoor lighting comfort. In this study, the two-color temperature conditions 4,000 K and 6,000 K were different. They found that although there are difference between the color temperature of LED and flickering light sources on comfort, the difference was not statistically significant [30]. At the same time, researchers Luo Ming et al. studied the LED lighting conditions suitable for viewing artworks in the museum and tested the Kruithof Rule, which defined pleasant lighting according to the proper color temperature (CCT) and illuminance. Also they proposed a Chinese vocabulary to express the scale of light's psychological evaluation [31]. Researcher Crusoe's statement verified that a high CCT at low illuminance was unpleasant. Based on principal component analysis, the results of all average scores, small-scale space, and large-scale space were synthesized. Regarding Crusoe's concept of a pleasure area and perception area map, museum interior lighting has been established [15]. Researchers Pardo et al. studied the influence of color temperature on the color discrimination ability of human eyes. They found that color temperature has a significant impact on the color discrimination ability of different color samples [33].

Researchers Royer et al. have checked color discrimination between tungsten halogen, two fluorescence and one RGB LED, with peak wavelength of 452 nm, 527 nm and 644 nm respectively in method tone test [34]. It was found that RGB LED system showed significantly poor color discrimination ability. The study focused on white LED and conducted two independent psychophysical experiments in the art museum by varying lighting CCT, CRI with illuminance value of 400 lx [35]. Their results showed that these factors determined the visual perception and visibility of the texture of oil paintings. Scholars from Taiwan University of Science and Technology also conducted two groups of similar experiments in special light boxes and real art museums respectively and reached the conclusion of similar clarity and warmth [36].

Based on the comfort evaluation response model of the museum lighting, this research is critical to the establishment of lighting environment evaluation theory. Lighting evaluation has transformed from the starting point of serving the building to a focus of serving people's emotional and cognitive responses, which is of great significance. This study has extensive and profound academic and practical value.

1.2.2 Evaluation of Lighting in the Art Museums

This research focuses both on the real art museum environment and simulated art museum environment. The former mainly adopts the subjective evaluation methodology, and the latter adopts the combination of subjective evaluation and objective data analysis. For different scenarios and methods, scholars have different research results and progress. Illuminance, color temperature and color rendering index are important indexes for lighting design evaluation. The lighting effect on observers was varied in different architectural spaces. But the assumption that light affects people's emotional responses in art museums has not been proved. There is still a lack of standards and specific methods in the lighting design evaluation of art museums, which requires the support from more research. The results indicate that the choice of lighting, color and illuminance should be based on the effects of lighting on the human body's physiological rhythm and visual efficiency in real-life situation. Research methods of other architectural space can be applied to test and analyze the lighting design evaluation theory of art museums.

The quality of the lighting in real art museums is the foundation for the application of light source in each space. Only when the quality of lights is guaranteed, can we get better feedback from the observers. Huang and colleagues published a series of thesis on illumination whiteness and color preference. They described the relationship between perceived whiteness and color preference of lighting [37,38]. Their studies proved that people do prefer the color rendition of white lighting at multiple correlated color temperatures ranging from 2,500 K to 5,500 K, while they dislike color temperature by higher than 5,500 K. For art preservation purpose, total darkness would be the best. But for the observers to fully appreciate the minute color and detail differences, an illumination of at least 1,000 lx would be required. This is also related to the time when the art works were painted. If a painting was prepared under natural daylight, the correlated color temperature would be correspondingly high [39].

The experiments used empty light box to evaluate color preferences for lighting, studying color preferences for several LED white lights with different CCTs [40]. The other experiments tested on the dominance of color preference when the CCTs weree different [41]. Lighting color preference is usually influenced by three environmental factors, i.e. the lighting, the object and the observer. Psychophysical experiments were carried out to investigate and compare the effects of certain factors on color preference, including spectral power distribution of lighting, individual color preference of observers, cultural and gender differences.

Luo et al. studied LED lighting conditions suitable for viewing art in a museum environment, testing Kruithof's Rule that defines pleasant lighting in terms of CCT and illuminance. Experimental results revealed that illuminance has a greater effect on the works than CCT. The results displayed that the visibility model is only related to illuminance, and the warmth model is only related to CCT [42]. Scuello et al. studied the effects of light source CCT in museums. Experiments were conducted in different rooms, each of which was independently illuminated by a color-corrected tungsten light source and equipped with a neutral density filter to control the lighting. Among the 11 colors with temperatures ranging from 2,500 K to 7,000 K, the illuminance of a painting was 200 lx–250 lx. It showed that the observer was satisfied with the CCT at 3,600 K [43].

Researchers Davis and Ginthner disagreed with the Kruithof's Rule. In a color-balanced environment with a color rendering index of approximately 90, the subjective preference score was only affected by the illuminance level of 270 lx to 1,345 lx, while not affected within the CCT range of 2,750 K to 5,000 K [44]. Yoshizawa and Luo et al. made visual evaluation experiments on paintings under LED lighting [45,46]. It is concluded that visual perception is subject to visibility and warmth when viewing museum paintings. In the experiment room and real exhibition room of the Morohashi Museum of Modern Art in Japan, two independent experiments were conducted to prove it. Yoshizawa et al. researched the changes of CCT from 2,700 K to 5,000 K, CRI from 55 to 100 and illuminance up to 400 lx respectively on LED illuminance. TQ Khanh et al. researched the observer's preference model for interior lighting. By assessing their visual impressions about scene brightness (SB), visual clarity (VC), color preference (CP) and scene preference (SP), they tried to find "good" levels of the visual attributes. The results showed that criterion illuminance for "good" levels of the visual attributes were determined by CCT [47,48]. These scholars obtained different result from Kruithof's Rule.

Many scholars conducted experiments that simulated the brightness and contrast of art museums in their researches. Yoshizawa and Luo [49] conducted visual evaluation experiments on paintings under LED lighting. They all concluded that when viewing museum paintings, two factors affect visual perception, namely visibility and warmth. Yoshizawa et al. conducted two independent experiments in a model room and an exhibition room at the Morohashi Museum of Modern Art in Japan. They studied the changes of CCT parameters at 2,700-5,000 K, CRI parameters at 55-100, and lighting parameters at 400 lx. The light source was LED lighting. Each painting was evaluated with 11 pairs of words, including colorful/monotone, simple/details, distinct/vague, exciting/depressive, warm/cold, wet/dry, desirable/undesirable, contrast/blurry, gloss/matte, deep/flat, and rich/humble. Luo Ming et al. studied LED lighting conditions that are suitable for viewing paintings in art museum environment. They examined Kruithof's Rule, which defines pleasant lighting based on consistent CCT and illuminance [50]. Increase in illuminance would increase the score on experiments. Experimental results showed that illuminance has a more significant influence on the illuminated environments than the color temperature.

Therefore, in order to create a comfortable lighting environment for art museums with proper visibility, warmth and comfort, brightness and contrast of the lighting environment play a very important role [51]. The concept of lighting comfort also represents that people's requirements for the environment have transformed from the most basic illumination functions to more comfort.

Many scholars simulated lighting environments using eye movement trackers. Masuda and Nascimento [52] conducted psychophysical experiments at commercial food counters to optimize the lighting environment. The result showed that the more suitable the light source is for the environment, the larger color gamut it has. And the most suitable the light source is, the more symmetrical the color gamut is. Also, they extended their method to determine the best light source for artistic painting in art museums. They found that the average color temperature of real viewing conditions was respectively similar at 5,500 K and 5,700 K [53].

Eye movement tracker is also a way to collect emotional data from the observers. In other studies, pictures were shown to subjects to monitor their eye movements. The average fixation time in picture viewing and pattern recognition was longer than reading, which was 300-350 ms [54, 55]. Others have shown that the complexity of stimuli also affects gaze retention time [56]. A study found when observers viewed line drawings, the range of gaze duration is 125-1,000 milliseconds. The distribution of gaze duration is not normal but skewed. Most gazing time was less than 333 milliseconds. The first fixation was significantly longer than the subsequent fixation [57]. The fixation time data was used to monitor the observers' attention focus.

Research on saccade distance shows that the average saccade distance and saccade time when viewing pictures are more significant than when reading. Some people found that the saccade distance when viewing pictures is 3.5 degrees, and the saccade distance when reading is 2 degrees [58]. Some people believe that there is a big difference in saccade distance. Moreover, the size of the pictures also affects the average saccade distance. Some studies showed that 85% of the time is spent on watching pictures and pattern recognition. Longer saccade distance helps the observers understand the information of the picture.

There is sufficient evidence to support the hypothesis that the lighting environment affects people's emotional response. The facial expression, voice tone, posture action, and physiological signals can be used as data sources of emotion recognition, since physiological signals are difficult to camouflage and usually contain more information [59]. The lighting environment can affect emotional and visual tasks.

The discovery of light on non-visual research in human body puts forward new standards for the study of emotional response and evaluation. The evaluation of lighting quality has gradually shifted from the original single visual effect evaluation to the double evaluation of visual effect and emotional response. The first focuses on visual functionality, and the other relates to people's emotional response [60, 61]. There are two main categories for the evaluation method of physiological response to illumination. The first is based on the inhibitory effect of melatonin [62-64].

The problem with the method is that it requires long duration and high levels of lighting to be effective. The spectral response curves is based on changes in pupil size. The visual channel and non-visual channel of lighting cannot be completely separated effectively [65, 66]. This study was based on the immediate changes of subjective questionnaire parameters and physiological parameters caused by visual tasks to the lighting. It aims to establish an evaluation model of emotional response to lighting with improved evaluation index in the illuminated environment.

1.3 Thesis Structure

This research mainly studies people's emotional response in the illuminated environment, and tries to understand human's visual perception. Vision is the most important sensory organ of human beings. According to scholars' research, at least 80% of the data in the environment is obtained by vision. Through vision, humans and animals perceive the size, brightness, color, and movement of objects and obtain various kinds of information critical to their survival. The rod cells and cone cells of human's vision can sense the light. The ray of light reflects the information of the object through photometry and chrome. And then people discovered that compatible lighting is more conducive to the acquisition of knowledge. A good lighting can improve visual perception as well as the emotion response level. In this study, we will explain the lighting design and evaluation model from a multidisciplinary perspective. It is believed that a suitable lighting can meet people's needs to obtain information in a space and that comfortable lighting is conducive to perceive visual image. Comfort is a very important evaluation index. However, to improve people's emotional response level, index of comfort is not enough.

This study was segmented into six chapters as shown in Figure 1-2. The first chapter is an introduction of the research. It described the construction of the illuminated environment evaluation model, introduced foreign research and development of art museum lighting design, as well as the research content and framework.

The second chapter is preliminary investigation and discovery of art museum lighting evaluation. Based on the investigation on difference types of art museums, it put forward some problems in the current evaluation of museum lighting. At the investigation stage, the purpose was mainly to obtain the museums' architectural environment, lighting design method and people's visual tasks, so as to better integrate the actual environment and raise the current design-related problems. This chapter focused on the environmental analysis, lighting parameters and classification of space and exhibits. It described the deficiencies in environment lighting evaluation of art museums and the problems to be solved.

The third chapter is the lighting design evaluation model of SVOE. This segment focused on innovation theoretical research related to museum lighting design, including four elements, namely spatialization, visualization, optical engineering and emotional response. This research established an SVOE evaluation model based on these four factors and explained the model. This part provided a more detailed division to the architectural space, the study method in the architectural space, classifies the observer's visual factors and set up a connection between it and the observer's purpose.

Through innovation thinking, the third chapter created an evaluation model and a method to study the lighting of art museums. It described the SVOE evaluation model in details and broke down the interdisciplinary research elements in the evaluation model. Through reasoning the main contents logically of the research, it decomposed the evaluation indexes of spatialization, visualization, optical engineering, and emotional response. It improved the system and method of lighting evaluation of art museums. This part digitized the parameters in the illuminated environment. It obtained observers' emotional responses during their visits in the museum environment by subjective questionnaires and testing, and processed it in combination with data analysis. Thus, it provided a complete SVOE of evaluation theory model and method.

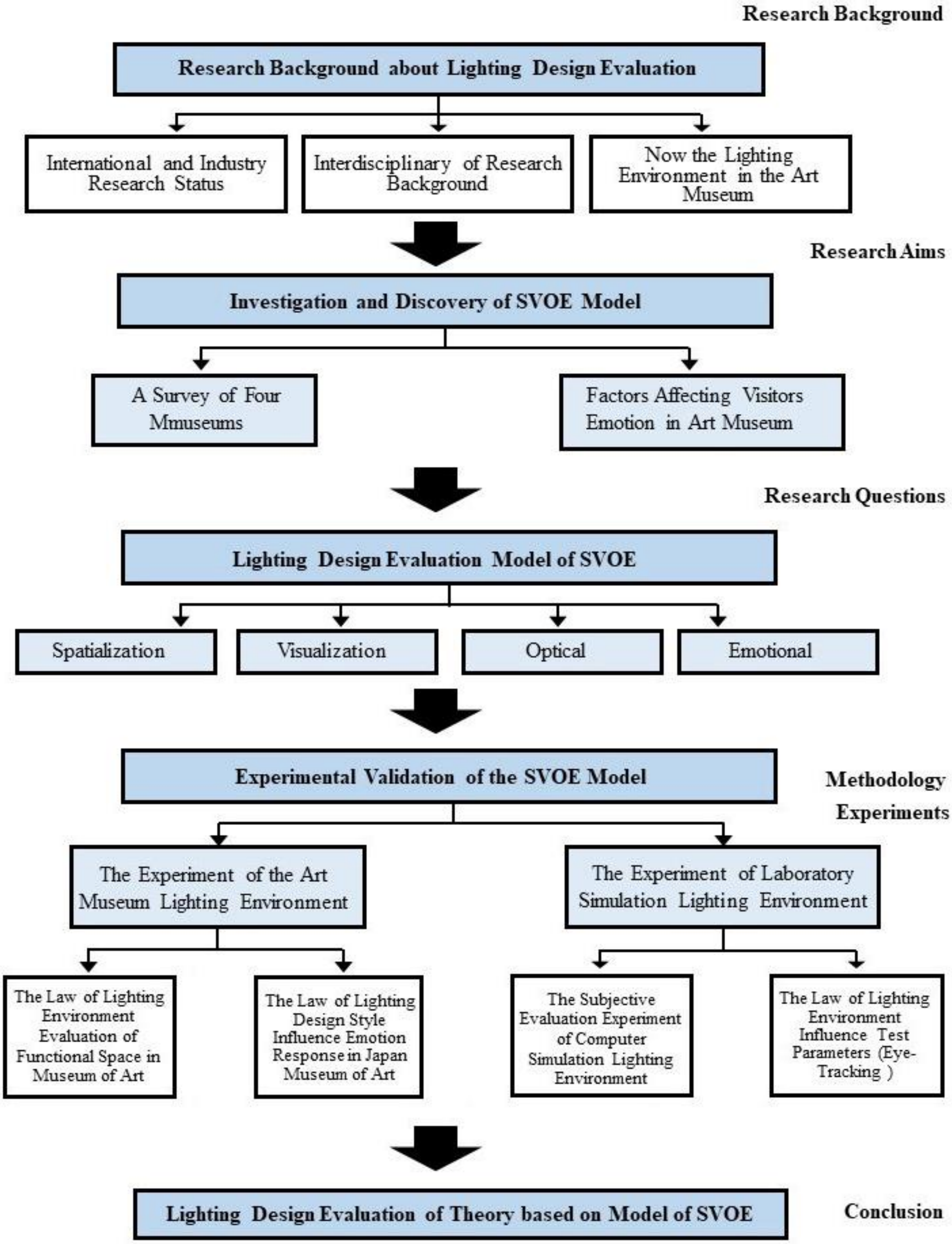


Figure 1-2. The main content structure of the thesis.

The fourth chapter described the real art museum lighting evaluation experiment, mainly involving the Liaoning Provincial Museum in China and three art museums in Japan. In the museum, the illuminated environment brought by artificial lighting design was used to test the emotional response level of visitors, including comfort, texture clarity and color authenticity. And the distribution of light sources, lamps types and optical parameters were analyzed and evaluated. In the Japanese art museums, the relationship between the observer's reaction and artificial lighting conditions in real museum space was revealed. The experiments classified the emotional response indexes in three Japanese art museums.

The fifth chapter was based on the subjective questionnaire evaluation and eye movement tracking data analysis of visitors' emotions in the simulated museums. This chapter was mainly divided into two experimental studies, including computer-simulated art museums and data acquisition experiments of eye movement tracking. Through the experiments, it collected the visitors' psychological emotions, and used a small amount of data to prove the science and accuracy of subjective questionnaire evaluation data. The experimental results provided support for the conclusion of the research.

The sixth chapter is the conclusion. Through theoretical research and experimental demonstration, the result of visual emotion evaluation index was proposed, which showed the emotional response in different illuminated environments. It proposed a visual psychological evaluation methodology based on data of experiments response. Through the evaluation analysis, it confirmed the result of emotional response, and created the evaluation method of emotional response index in art museums. The results will contribute to future evaluation of lighting design in art museums.

CHAPTER 2

Preliminary Investigation and Discovery of Art Museum Lighting Evaluation

2.1 Introduction

The lighting design of art museum plays an important role in the exhibition effect. It has gradually become an element that observers attach importance to while visiting the museum. Good lighting design of an art museum not only meets the basic purpose of cultural relics preservation and visual clarity, but also improves the artistic style and creates an atmosphere [66, 67]. Recently, many visual researches on art museums have studied and discussed this topic from knowledge of different fields. The lighting evaluation model of art museums has been paid more and more attention, but there has not been a unified standard. Therefore, the lighting of art museums is not only a research hotspot in the field of lighting design, but also widely concerned by the practitioners of art museum. Field investigation is an important means to evaluate the lighting of art museums. The measurement of illumination, brightness and spectrum on the spot can evaluate the quality of the illuminated environment from radiation, luminosity, chromaticity and other dimensions. Subjective questionnaires can evaluate the lighting effect from the perspective of the observers [68, 69].

Investigations are conducted to build a unified evaluation model of lighting for various art museums. Therefore, at the investigation stage, information such as the museum's architectural space, lighting parameter and visual information should be obtained through field research. So that design evaluation index related problems can be discovered to improve the lighting of the art museum. Through innovative thinking, this study will come up with relevant evaluation theories. The study will improve the evaluation model of art museums, and provide a theoretical basis and evaluation methodology for the illuminated environment.

This chapter focuses on the lighting environmental analysis, classification of space and exhibits in the art museums. It will expand and perfect the evaluation methodology of art museum lighting. This chapter investigates the lighting design in art museums using traditional evaluation methods, with only a brief introduction to the spatial and optical parameters, and without categorizing the spatial. There is no response to the visual tasks and emotions of the people in the space. This chapter focuses on the lighting evaluation of art museums with innovative theoretical research that usually concerns four areas, i.e. spatialization, visualization, optical engineering and emotional response. Traditional lighting evaluations are too formalized, lack of surveys and statistics on visual tasks and emotional responses. This chapter will focus on these aspects to analyze the existing problems of lighting evaluation in art museums.

2.2 Lighting Investigation Report of Dalian Zhongshan Art Museum

2.2.1 Investigation Overview

Dalian Zhongshan Art Museum was located on the Yingbin Road, covering an area of 5,600 square meters, and a building area of 11,000 square meters. This art museum building has two floors, there are two exhibition halls with a total area of 2,500 square meters. It has six exhibitions of all sizes, among them are two regular exhibitions, four temporary exhibitions. The largest exhibition hall is 1,300 square meters, and the smallest one is 200 square meters. It is an ideal place for contemporary artists and scholars to display their works. The functional lighting in the art museum meets the requirements of use, but the lighting conditions are not ideal for visitors. Through this investigation, the lighting of the museum is analyzed. And the lighting was tested to find out why the visitors had poor emotional reactions.

The space of the museum is divided into two categories, i.e. the regular exhibition hall and the central hall. The light source of the exhibition halls is LED lighting. The regular exhibition hall mainly uses LED track lights. The central hall uses natural light and the ceiling is equipped with downlights as auxiliary lighting for night visits. The environment lighting of the central hall mainly relies on the luminous ceiling.

2.2.2 Lighting of the Calligraphy Exhibition Hall

Dalian Zhongshan Art Museum calligraphy exhibition hall is a regular exhibition hall. The exhibits and lighting basically are located at the same place. We measured a calligraphy work in the exhibition hall. In the uniformity and illumination distribution test, we used the central distribution method to take the average value of 3 points. As shown in Figure 2-1. The artwork's vertical illumination is 933.33 lx, and uniformity is 0.86. The optical engineering parameters of the calligraphy exhibition hall were also measured.

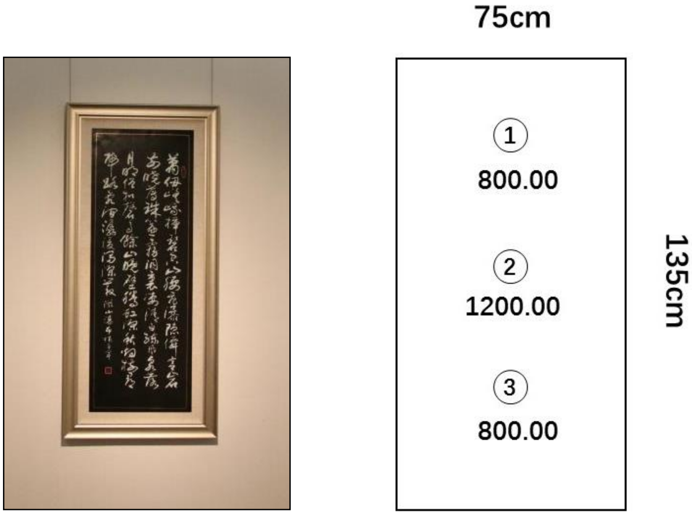


Figure 2-1. The actual view and illumination distribution of calligraphy. (Unit: lx, AVG 933.33 lx, Uniformity 0.86)

As shown in Table 2-1. The calligraphy work's brightness parameter is 27.34 cd/m^2, Reflection coefficient is 34.14. The test showed that there are difference in the uniformity data in terms of the brightness and the illumination The illumination distribution and brightness distribution are relatively similar in the exhibition space of calligraphy works shown in the photos. When the background is dark, the data obtained by illumination is more accurate, but the method of brightness test and evaluation is more intuitive. The difference is due to the background reflectivity and calligraphy background color.

Table 2-1. The brightness distribution and average of calligraphy.

No.	The brightness distribution (cd/m^2)	Average brightness (cd/m^2)	Brightness uniformity
1	28.00		
2	34.00	27.34	0.73
3	20.00		

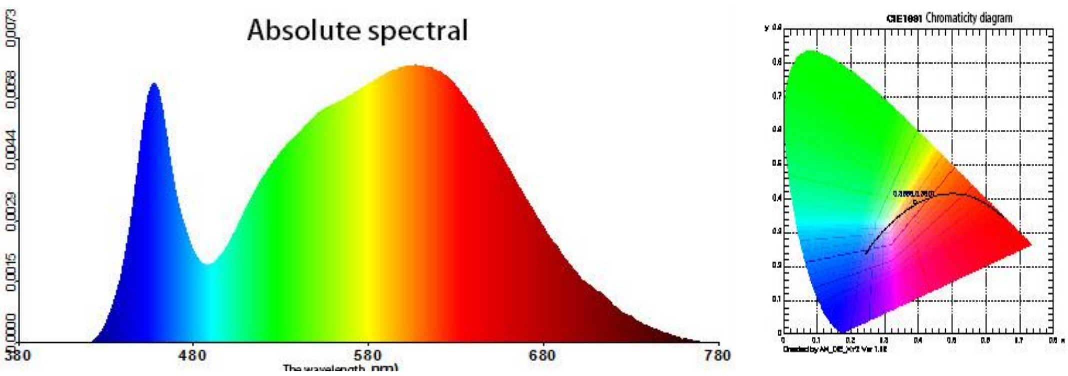


Figure 2-2. The illumination spectrum of calligraphy exhibition.

As shown in Figure 2-2. The color temperature of the lighting environment in the calligraphy exhibition hall is 3,862 K, with CIE color coordinate X at 0.3895, and coordinate Y at 0.3901. The peak wavelength is 596nm. It can be seen from the spectral parameters that the lamp used in the environment is LED light source. As shown in Figure 2-3, the color rendering index of lighting environment in the calligraphy exhibition hall is 82.7, and the R9 is 85. The color rendering index in the light source has good color reduction.

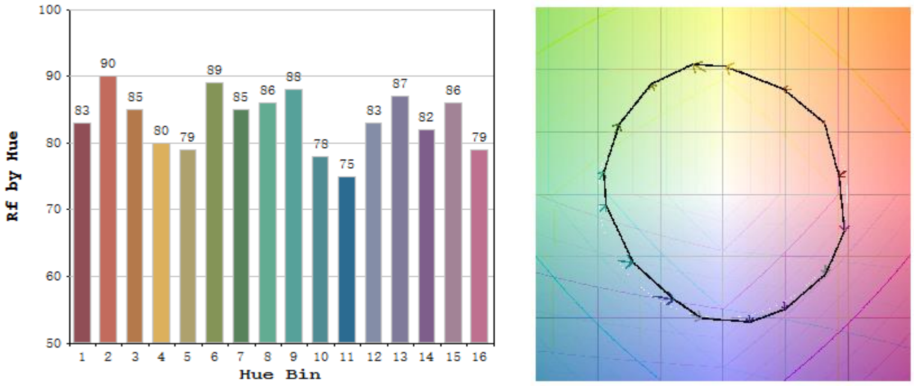


Figure 2-3. The color rendering index and illuminance spectrum of calligraphy exhibition.

As shown in Table 2-2, the data was obtained through the scintillation test of the light source in the calligraphy exhibition hall. The comprehensive evaluation of the scintillation index is more severe 8.1. The flicker frequency is 100 Hz. The scintillation index is 0.085. The average illumination of the horizontal plane is 5,533 lx The maximum illumination is 7,237 lx, and the minimum illumination is 3,727 lx. The data shows that the lamps have high luminous efficiency. The functional lighting in the space also meets the lighting requirements, among which the illumination value of the horizontal plane and the vertical illumination value of the exhibits also exceed the average parameter. However, the flicker of lamps and lanterns is more serious, which is easy to affect the visual tasks of the viewers. So the viewers' emotional evaluation in the art museum is not good.

Table 2-2. The test data of calligraphy exhibition.

Flashing frequency	100 Hz	**Time axis**	Milliseconds
Percentage (Depth of fluctuation)	28.2 %	**Scan**	5.0 KHz
Flicker index	0.085	**Access**	C3
Maximum	7,237 lx	**Minimum**	3,727 lx
Average illumination	5,533 lx	**Evaluation (Visual flicker)**	More severe 8.1

2.2.3 Lighting of the Painting Exhibition Hall

Dalian Zhongshan Art Museum painting exhibition hall is a temporary exhibition hall, we conducted an objective measurement of a painting in the exhibition hall. The uniformity and light color test used the central distribution method to take the average value of point 2 x 3. As shown in Figure 2-4, the vertical illumination of the artwork is 536.30 lx, and the evenness is 0.84. In this test of the art museum, the brightness of the temporary exhibition hall was also measured.

Figure 2-4. The actual view and illuminance distribution of paintings. (Unit: lx, AVG 536.30 lx, Uniformity 0.84)

Table 2-3. The brightness distribution and average of paintings.

The brightness distribution (cd/m^2)						Average brightness (cd/m^2)	Brightness uniformity
1	40.00	**2**	28.00	**3**	37.00	36.50	0.77
4	40.00	**5**	37.00	**6**	37.00		

As shown in Table 2-3, the brightness parameter of the Chinese painting of landscape is 36.50 cd/m^2, and the reflection coefficient is 14.69. The test showed that the brightness parameter is different from the illumination parameter in the uniformity data. The illumination distribution and brightness distribution shown by photos in the exhibition space of calligraphy works are relatively similar, and the background color is relatively moderate, lighter than the color in calligraphy works. So the value of reflection coefficient is smaller than the calligraphy works.

As shown in Figure 2-5 and Table 2-3, the color temperature of the illuminated environment in the temporary exhibition hall is 5,366K. The CIE color coordinate X is 0.3369, and coordinate Y is 0.3639. The peak wavelength is 546nm. It can be seen from the spectral parameters that the lamp used in the environment is the fluorescent lamp. As shown in Figure 2-3, the color rendering index of the illuminated environment in the temporary exhibition hall is 76.2, and the value of R9 is 80. The color rendering index in the light source has a general color reduction.

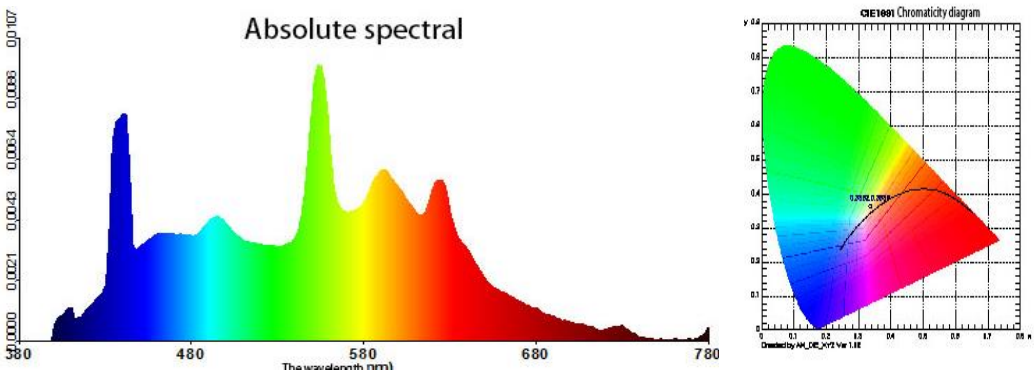


Figure 2-5. The illumination spectra of exhibition.

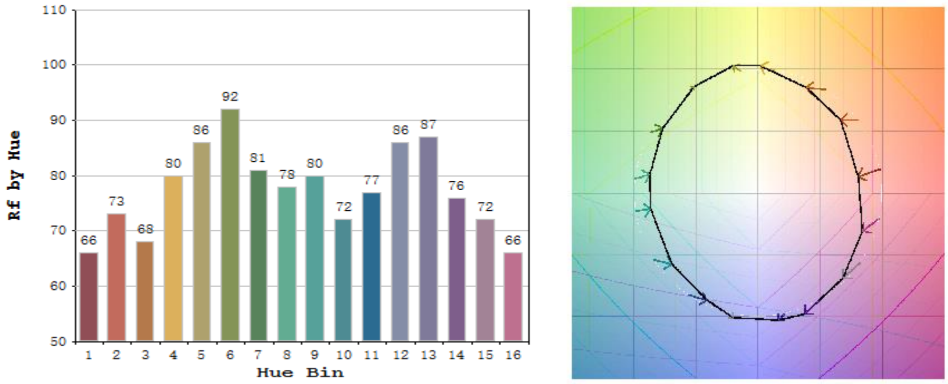


Figure 2-6. The color rendering index of illuminance spectrum data of exhibition hall 8.

Table 2-3. The test data of exhibition.

Illuminance E=395.31 lx	**E(fc)=36.7392fc**	**Irradiance E=1.19263W/m²**	
CIE x=0.3362	CIE y=0.3639	CIE u'=0.2009	CIE v'=0.4892
Relative color temperature=5,366 K	Peak wavelength=546.0nm	Half wave width=19.2nm	Dominant wavelength=558.4nm
Color purity=10.1%	Red ratio=13.9%	Green ratio=80.7%	Blue ratio=5.5%
Duv=0.00969		S/P=1.98	
Color rendering index Ra=76.2	R1=66	R2=72	R3=68
R4=80	R5=86	R6=92	R7=81
R8=78	R9=80	R10=72	R11=77
R12=86	R13=87	R14=72	R15=66
SDCM=9.1（F5000）		White light grading: Out	

As shown in Table 2-4, the data was obtained by scintillation tests on the light source in the temporary exhibition hall. The comprehensive evaluation of the scintillation index is more severe 8.1. The flicker frequency is 100Hz, and the scintillation index is 0.066. The average illumination of the horizontal plane is 318 lx. The maximum illumination is 388 lx, and the minimum illumination is 241 lx. According to the data, the luminous efficiency of lamps is relatively ordinary, and the lighting in the space meets the requirements of functional lighting. Among which the illumination of the horizontal plane and the vertical illumination of exhibits meet the requirements. However, the flicker of lamps and lanterns is more serious, which is easy to affect the visual tasks of the viewers. So the viewers' emotional evaluation in the art museum was not good.

Table 2-4. The test data of exhibition hall 8.

Flashing frequency	100 Hz	**Time axis**	Milliseconds
Percentage (Depth of fluctuation)	21.5%	**Scan**	5.0 KHz
Flicker index	0.066	**Access**	C3
Maximum:	388 lx	**Minimum**	241 lx
Average illumination	318 lx	**Evaluation (Visual flicker)**	Apparent 8.1

The test of the lighting of art museums found that the overall color temperature in some areas is too high that it can't well display art works and is inconsistent with the style of the art works. The lighting of public areas is affected by natural light, and the color rendering index parameter in the illuminated environment is not satisfying, which affects the visual perception of visitors.

The art museum has typical features in its space. The whole building includes small spaces and large spaces, temporary exhibition halls and regular exhibition halls, and a rich collection of art works. The environment in the art museum is in line with the functional lighting of the building. The illumination distribution value of some exhibition halls and art works is very high, even higher than that of ordinary art museum exhibition halls. The lighting parameters were measured by equipment, i.e. illumination distribution, color temperature and color rendering index. However, it can't reflect the spatial characteristics of the building. Illuminance and color temperature index are in line with the parameter range of current lighting evaluation research. But observers have poor visual perception in space, resulting in less favorable viewing experience and lack of emotional response data in the environment.

Similar to the investigation results of the Dalian Zhongshan Art Museum. At present, most art museums only measure the lighting environment of the exhibits in their evaluation methods. Only the lamp and lighting parameters are recorded, but lack of evaluation on space and the overall lighting. Therefore, it is necessary to evaluate the lighting in a more reasonable way. There is a need for better definition of space and more accurate recording of optical parameters and lighting methods. Since accurate evaluation methodology of the environment lighting is missing, it is necessary to adopt a scientific way to obtain the emotional response parameters of visitors through data collation and analysis in order to establish a reasonable environment lighting evaluation model.

2.3 Lighting Investigation Report of Ningbo Art Museum

2.3.1 Investigation Overview

The Ningbo art museum was completed and officially opened in October 2005. The museum is in excellent condition. It covers an area of 15,800 square meters and a building area of more than 23,100 square meters. The large and small exhibition halls have an area of 5,300 square meters. It can hold different types and different themes of exhibitions at the same time or separately. Though the lighting environment of the museum was designed to meet an ideal standard. The lighting environment was problematic. It is not easy to evaluate it with current evaluation model.

The lighting environment of Ningbo Art Museum is representative, which is a different mode from that of Dalian Zhongshan Art Museum's general lighting. There is no higher illumination in the environment, but a more suitable lighting distribution. The lights are arranged based on different exhibition works to create a different uniformity of illuminated environment. This survey tested the vertical brightness of art works through the display exhibition hall, defined the category of lighting environment through the data, and found the emotional response index of visitors after meeting the visual task in different lighting environments. There is no natural light in Ningbo Art museum exhibition halls. Only artificial light source is used for illumination, which is easier to define and classify. Under the premise of meeting the lighting environment standards, it tries to reduce the illumination at the same time to improve the brightness, and creates a illuminated space that corresponds to the visual task.

2.3.2 Lighting of the Display Screen Exhibition Hall

The Ningbo Art Museum display screen exhibition hall is very special. There is no functional lighting in the environment, but only light source from the display screens. The illumination in the overall environment is low. There is no independent light source in the display screen exhibition hall. The backlight of the LED display is mainly used to statically display the photos, combined with the environment light of other exhibition areas to ensure the illumination on the ground. Figure 2-7 shows an illuminance distribution of the display area. 7 x 3 points were taken for measurement according to the center distribution method.

Since the electronic display screens belong to a new type of exhibition, there is no detailed definition and requirements in the art museum lighting standards. So the illumination of the lighting environment in the exhibition hall is low. But the brightness of the electronic screen meets the requirements of the exhibition, and at the same time, it also creates a better lighting effect and visual contrast.

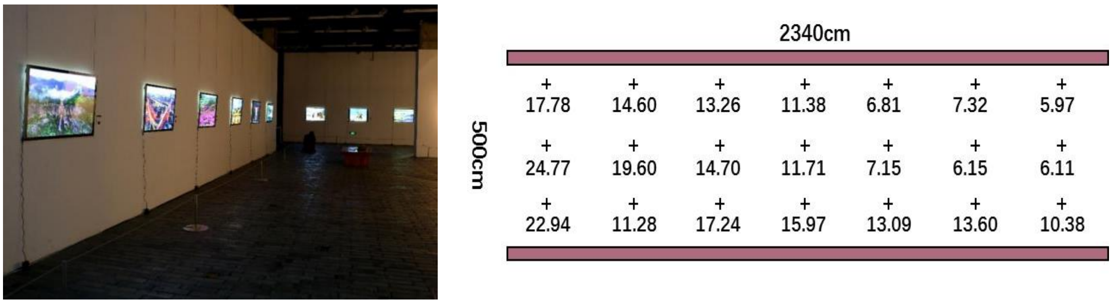


Figure 2-7. The actual view and illumination distribution of display screen exhibition (Unit: lx, AVG 12.94 lx, Uniformity 0.47).

Table 2-5. The test data of display screen exhibition hall.

Exhibition hall scale		Area 117 m^2, Height 5m					
Type of light source		Non illuminating light source + LED backlight display					
Wall reflectance		0.61		**Ground reflectance**		0.27	
Temperature rise		0.20		**Glare evaluation**		Slightly uncomfortable glare	
Maximum illumination	24.77 lx	**Minimum illumination**	5.97 lx	**Average illumination**	12.94 lx	**Illumination uniformity**	0.47

Figures in Table 2-5 shows that non-illuminating light source and LED backlight display are used in the electronic screen exhibition hall of the museum. The wall reflectivity of the exhibition hall is 0.61, and the floor reflectivity of the exhibition hall is 0.267. Temperature Rise index of the exhibition hall is 0.20, and the glare evaluation shows slightly uncomfortable glare of the exhibition hall.

The photography work "Buddhism" in the display area of exhibition hall 1 was tested. The photo is exhibited in a display screen. The display pattern can be changed and the brightness of the screen can be adjusted. Figure 2-8 shows the illuminance distribution of the test area of the work, and Table 2-6 shows the test data.

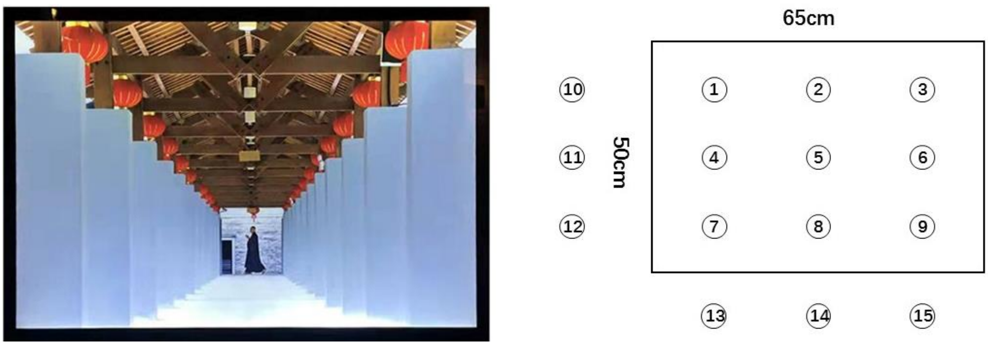


Figure 2-8. The actual view and illuminance distribution of "Buddhism".

As shown in Table 2-6, the photography work "Buddhism" has a brightness parameter of 8.72 cd/m^2. The uniformity is 0.28. The background brightness of the artwork is 3.72 cd/m^2, and the brightness contrast is 7:1. There is no other light source used for illumination in the exhibition space. The background's brightness comes from the display, depending on ambient light for auxiliary lighting, a typical modern art museum form of expression. Although the illumination is low, it can also satisfy the visitors to do the visual task. Through this study we want to create a new evaluation response index to evaluate the comfort and clarity of electronic screen display in the environment.

Table 2-6. The test data of "Buddhism".

Types of exhibits	**Electronic screen and wall data collection**				
No.	**1**	**2**	**3**	**4**	**5**
Brightness (cd/m²)	10.67	4.60	5.00	2.80	11.93
No.	**6**	**7**	**8**	**9**	**10**
Brightness (cd/m²)	3.98	2.42	25.40	11.67	4.36
No.	**11**	**12**	**13**	**14**	**15**
Brightness (cd/m²)	4.20	3.78	3.40	3.42	3.19
Brightness contrast	7:1				

2.3.3 Lighting of the Seal Script Exhibition Hall

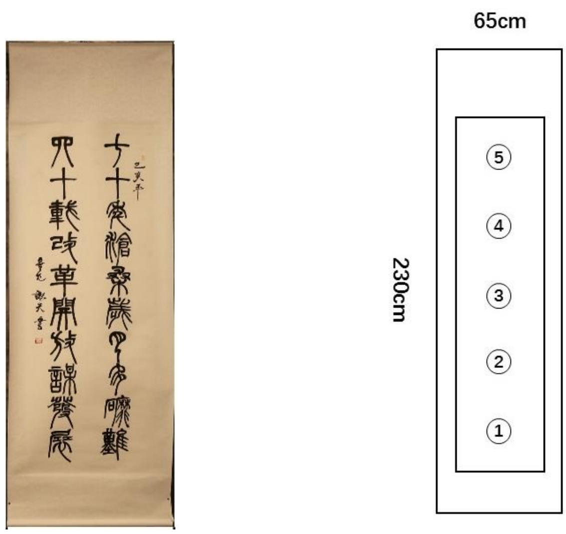


Figure 2-9. The actual view and illuminance distribution of seal script (Unit: lx, AVG 139.52 lx, Uniformity 0.80).

The seal script works in the exhibition hall were tested. This type of exhibits were frameless. The lamps were installed at a distance of 1 meter from the wall. Figure 2-9 shows the layout of the test area of the work, and Tables 2-7 shows the test data for this work. In this survey, the brightness of the calligraphy was also tested, which is 32.80 cd/m^2 and the reflection coefficient is 4.25.

Table 2-7. The test data of seal script.

Sampling number	**1**	**2**	**3**	**4**	**5**	**6**
Illumination (lx)	112.30	137.40	143.60	154.10	150.20	129.00
Brightness （cd/m^2）	28.83	29.01	34.89	38.4	32.88	50.03
Average (lx)	**Maximum (lx)**	**Minimum (lx)**	**Uniformity (lx)**	**Average （cd/m^2）**	**Maximum （cd/m^2）**	**Minimum （cd/m^2）**
139.52	154.10	112.30	0.80	32.80	38.40	28.83

Different from the conversion coefficient of the calligraphy works of the Zhongshan Art Museum, the reflection coefficient varies significantly with the background color of the works. Studying the data collection and analysis, when defining the lighting environment and the art works, we should not simply consider the brightness parameter, but also the reflection coefficient of color, so as to define the illuminated environment in a more scientific way and make a more scientific evaluation. The investigation of Ningbo Art Museum showed that it is inaccurate to only consider the brightness in the illuminated environment. Illuminance is more accurate in describing the environment, but brightness is more easily noticed in an art museum.

Although the evaluation of the environment lighting in the Ningbo Art Museum. has added the evaluation index for some of the spaces, the definition space lighting mode and lighting environment evaluation are still missing as the style of the exhibits in the art museum would also have an impact on the choice of lighting parameters. The color temperature of lighting for calligraphy is not as high as that of paintings. Visitors' subjective reactions mainly focus on sensorial comfort and preference as the illuminance, brightness and contrast within the lighting environment determine the visual pleasure, and the color rendering index of color temperature in the environment determines the visual preference. We need to further research on how to measure and analyze the evaluation index of comfort and preference of the viewers. The evaluation of the illuminated environment must measure the emotional response of the observers. More accurate data can be obtained from further research.

2.4 Investigation Report on the Art Museum of Lu Xun Academy of Fine Arts

2.4.1 Investigation Overview

The Art museum of Lu Xun Academy of Fine Arts is located in the Jinshitan National Seashore Tourist Resort, Jinzhou District, with a total construction area of 24,000 square meters, a building height of 20 meters, and a public space of 7,000 square meters. It has 20 exhibition halls of various specifications, including 12 fixed exhibition halls and 8 temporary exhibition halls, with the largest exhibition hall space of 2,000 square meters and the smallest exhibition hall space of 500 square meters.

The Art Museum of Lu Xun Academy of Fine Arts has good architectural space conditions. The original drawings are well preserved, suitable for the study. The museum uses both natural light and artificial light for illumination, and some parts of the exhibition hall mainly uses artificial light sources. The major form for exhibition is temporary exhibition.

2.4.2 Lighting of the Lobby Exhibition Hall

The lobby is lit mainly by natural light, with glass walls designed to allow daylight to enter the pavilion. The lobby uniformity and light color test used the center distribution method to take an average of 5 x 6 points. The average reflectivity of the lobby and the surrounding walls is 0.24. The daylight color temperature in the lobby is 4,583 K, and the average illumination is 235.0 lx. The illumination uniformity is 0.64.

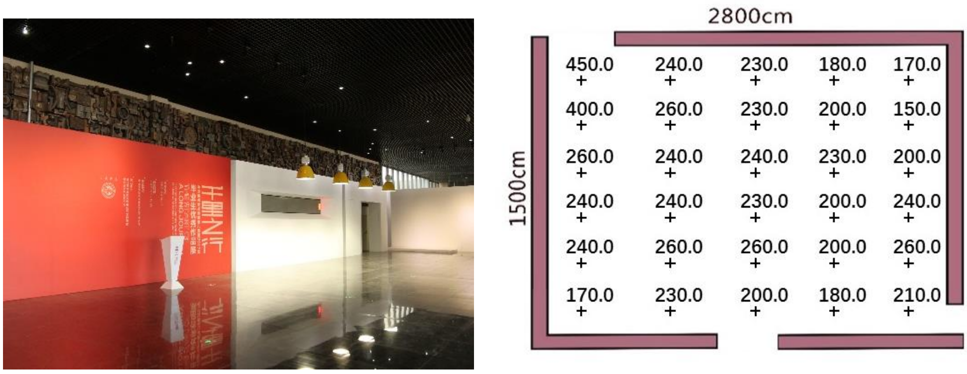


Figure 2-10. The actual view and illuminance distribution of lobby (Unit: lx, AVG 235.0 lx, Uniformity 0.64).

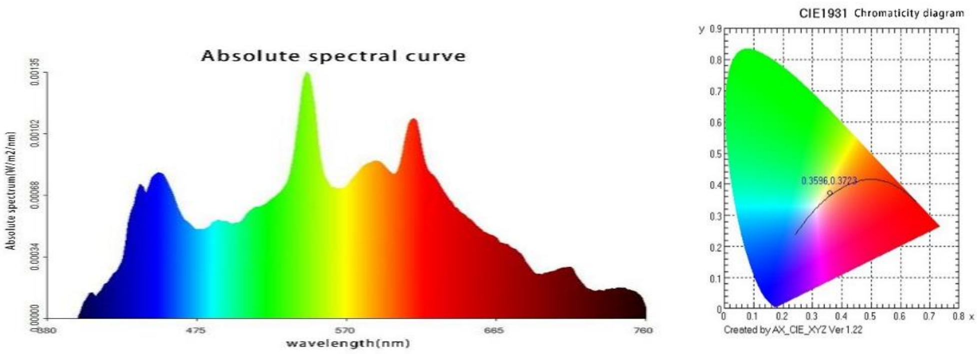


Figure 2-11. The illumination spectrum of lobby.

The space displayed in the lobby through photographs has a smaller luminance distribution, a darker background color and a lower luminance to create a more moderate visual contrast. The lighting environment in the lobby feels more open, and the strong color contrast and visual contrast of the lighting environment can enhance the visitors' sense and awareness of obtaining information.

As shown in Figure 2-5 and Table 2-3, the lighting environment color temperature in the lobby is 4,583 K. The CIE color coordinate X value is 0.3596 and the coordinate Y value is 0.3723. The peak wavelength is 545nm. It can be seen from the spectral parameters that there is an influence of natural light in the environment, and the lamp used is LED light source. As shown in Figure 2-12, the lighting environment color rendering index in the lobby is 87.4, among which R9 value is 90, and the color rendering index in the light source has a better color reduction.

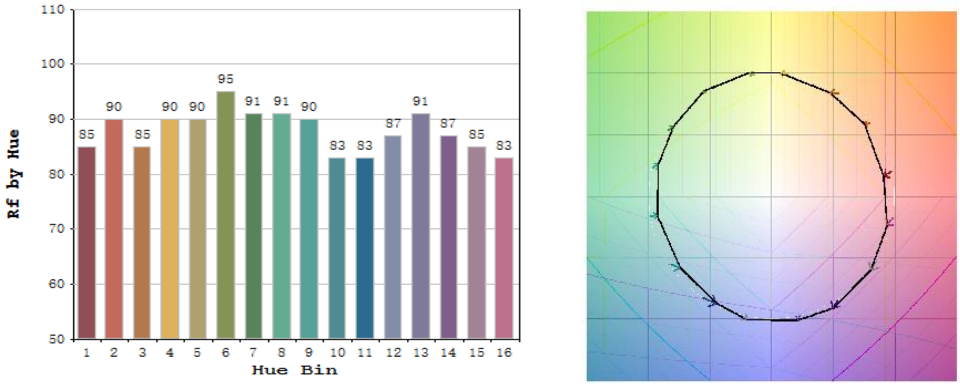


Figure 2-12. The color rendering index data of lobby.

2.4.3 Lighting of the Oil Painting Exhibition Hall

The oil painting exhibition hall of the Art Museum of Lu Xun academy is a permanent exhibition hall. We have made an objective measurement of one oil painting in the exhibition hall. For the ground uniformity and light color test of the exhibition hall, the center distribution method was used to take the average value of point 3 x 3. The average illumination of the horizontal surface of the exhibition hall is 602.0 lx, and the uniformity is 0.83, as shown in Figure 2-13.

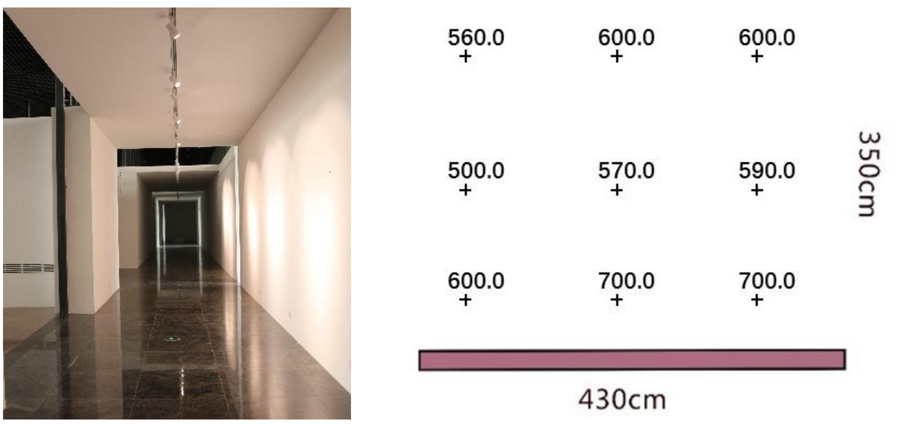


Figure 2-13. The actual view and illuminance distribution of oil painting exhibition hall (Unit: lx, AVG 602 lx, Uniformity 0.83).

Figure 2-14. The illuminance distribution of oil paintings (Unit: lx, AVG 68.11 lx, Uniformity 0.38).

As shows in Figure 2-14., the average illumination of the painting is 68.11lx, and the uniformity is 0.38. As shown in Figure 2-15, the color temperature of the lighting environment in the painting is 4,344 K, of which the CIE color coordinate X is 0.3657, and the coordinate Y is 0.3641. The peak wavelength is 449nm. It can be seen from the spectral parameters that the lamp used in the lighting environment is LED light source. As shown in Figure 2-16, the oil painting ‘s color rendering index in lighting environment is 85.0, and R9 value is 88, indicating that the color rendering index in light source has a favorable color restoration. Several indicators and parameters of the light source are suitable, among which the parameter of R9 is very important for the art museum, and the restoration degree of red is the best.

Table 2-8. The illuminance distribution and uniformity of oil paintings.

The illuminance distribution(lx)						**Average illuminance (lx)**	**Illuminance uniformity**
1	80.00	**2**	32.00	**3**	60.00	68.11	0.38
4	26.00	**5**	40.00	**6**	45.00		
7	90.00	**8**	110.00	**9**	130.00		

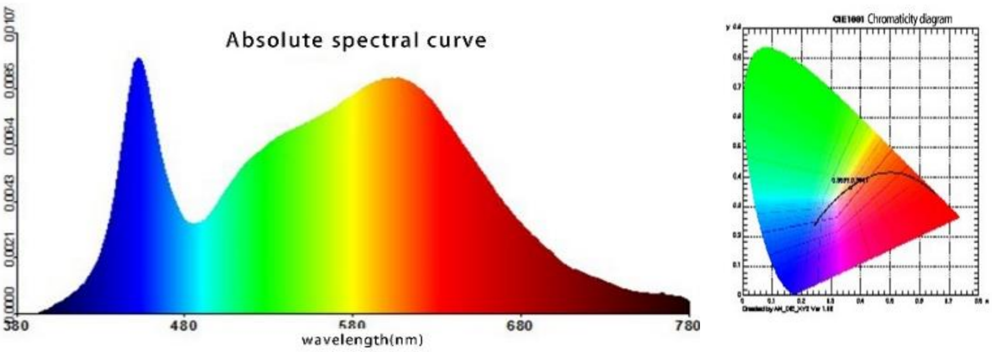


Figure 2-15. The illuminance spectrum of oil painting exhibition hall.

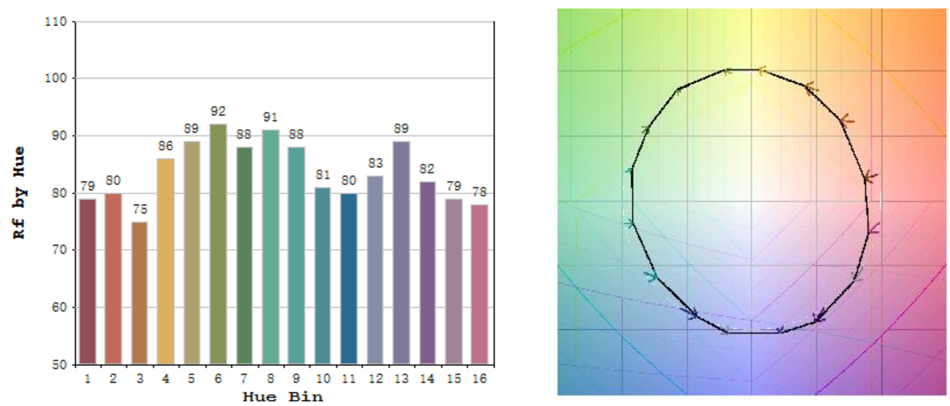


Figure 2-16. The color rendering index of illuminance spectral in the exhibition hall of oil.

As shown in Table 2-9, data was obtained from scintillation test of the light source in the oil painting exhibition hall. The comprehensive evaluation of scintillation index was almost none. The scintillation frequency is 0.0Hz. The scintillation index is 0.000, and the average illuminance of the horizontal plane is 4,021 lx. The maximum illuminance is 10,165 lx, and the minimum illuminance is 1,059 lx. The data shows that the luminous efficiency of the lamps is relatively ordinary, and the lighting in the space meets the requirements of functional lighting. The illumination of the horizontal plane exceeds the average index, and the vertical illumination of the exhibits meets the requirements. The lamps and lanterns do not flicker, but the horizontal illumination is strong and easy to cause glare, which has an adverse impact. When doing the visual tasks, the viewers' emotional evaluation in the art museum was not good.

Table 2-9. The test data of oil painting exhibition hall.

Flashing frequency	0.0 Hz	**Time axis**	Milliseconds
Percentage (Depth of fluctuation)	0.6 %	**Scan**	100.0 KHz
Flicker index	0.000	**Access**	C4
Maximum	10,165 lx	**Minimum**	1,059 lx
Average illumination	4,021 lx	**Evaluation (Visual flicker)**	Almost none

The results of the lighting environment survey on Art Museum of Lu Xun Academy of Fine Arts shows that although the building has a large space and an open visual perception, there are problems in the creation of the environment lighting It is not that the stronger the illumination distribution is, the better in the effect. The improvement of illumination is helpful to improve the clarity of viewing, but when it reaches a certain parameter index, this kind of improvement becomes very small. It needs to improve the lighting environment through more detailed design and lighting styles for different artworks to improve the evaluation of emotional response.

We have found the problems in art museums, and need to resolve the issue between emotional response and evaluation indicators. These factors constitute a comprehensive subjective evaluation index, such as information content, the distinction between design and art style, visual adaptation, the quality of the environment lighting such as geometric relations, the diffusion characteristics, directivity, spectral composition and quantity etc.

The Art Museum of Lu Xun Academy of Fine Arts took the effect of natural illumination in the measurement. Because of this, the data for the environment has been significantly improved. But the subjective feeling in the space is not as obvious as the indicators. So the establishment of lighting evaluation model should avoid natural lighting as much as possible. In this study, only artificial lighting was used for evaluation in the experiment and evaluation.

2.5 Investigation Report of Liaohe Art Museum

2.5.1 Investigation Overview

The museum has a building area of 11,331 square meters, two floors above ground, at a height of 12.8 meters. The exhibition hall covers an area of about 6,000 square meters and is divided into 9 exhibition areas. We mainly tested three exhibition spaces, namely the permanent exhibition hall 1 and hall 3, as well as the temporary exhibition hall 4, and three non-display spaces, namely the central hall, hall countertops and warehouses.

The lighting scenes included exhibition lighting and work lighting. The light source is mainly LED lighting. The lamp are mainly direct lights. Lighting control included independent control of each exhibition hall and manual switch. The investigation shows that the light sources used in the environment of Liaohe Art Museum included artificial light source and natural light, and all the lighting environments were affected by natural light. It has certain influence on the creation and evaluation of the illuminated environment.

2.5.2 Lighting of the Exhibition Hall

The permanent exhibition hall for this investigation is Hall 4 located on the north side of the first floor of the art museum. The exhibited works from the collections of Liaohe Art Museum is on display and is open for a long time. The distribution of lighting collection points is shown in Figure 2-17, and the specific lighting conditions are shown in Table 2-11.

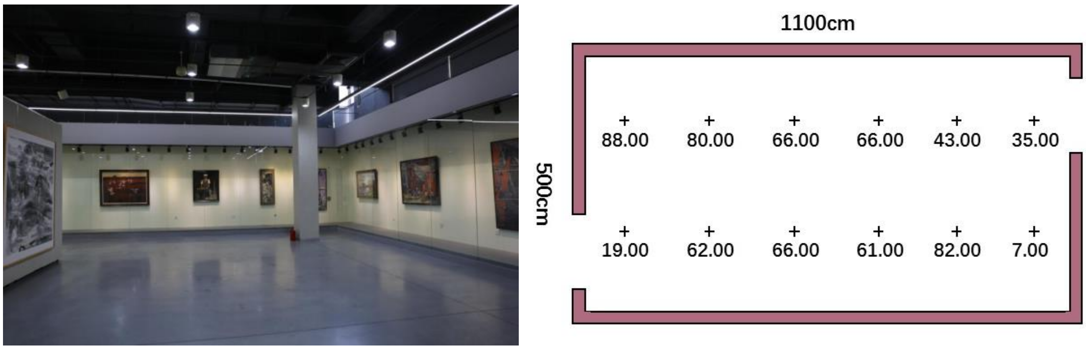


Figure 2-17. The actual view and illumination distribution of exhibition hall 4 (Unit: lx, AVG 56.25 lx, Uniformity 0.13).

The illumination distribution value in the space of exhibition hall 4 is small and the background color is dark. Lower brightness creates a more moderate visual contrast. In exhibition hall 4, the environment makes people feel dim. There is a strong color contrast in the environment, but the lighting has a low illuminance contrast, and the visual perception of visitors was not good.

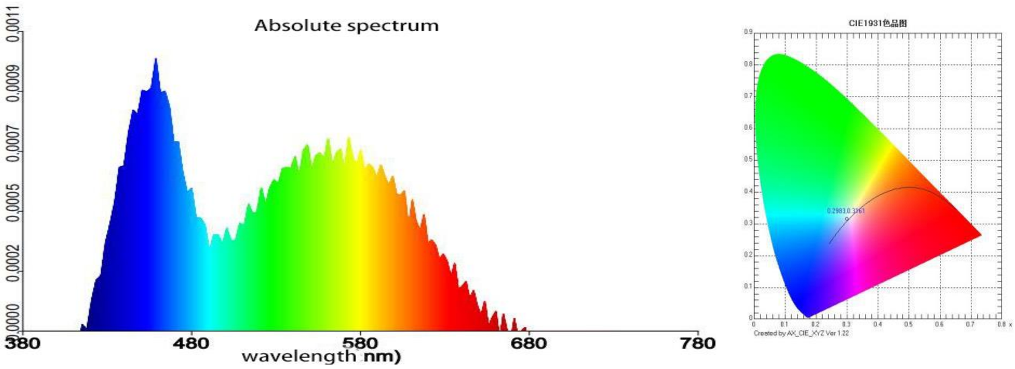


Figure 2-18. The illumination spectrum of exhibition hall 4.

As shown in Figure 2-18, color temperature of the lighting environment is 8,550 K. As shown in Table 2-11, the color rendering index of the exhibition hall 4 is 62.8, and the value of R9 is -124, indicating that the color rendering index in the light source has a poor color reduction.

Table 2-10. The test data of exhibition hall 4.

Space type	**Illuminance**	**Color temperature**	**S Mean DCM**	**Ra mean**	**R9 mean**
Hall 4	56.25 lx	8,550 K	22.3	62.8	-124
	Illumination uniformity	**Ground reflectivity**	**Wall reflectivity**	**Temperature rise**	
	0.13	0.36	0.69	1.90	

2.5.3 Lighting of the Painting Exhibition Hall

The art painting of "Field of Hope" is located in Hall 4, the size of the work is 1.93m x 1.94m, without spotlights for accent lighting, and the exhibit is uncoated and exposed under the light source. The lighting condition is shown in Figure 2-19, and the relevant data is shown in Table 2-12 and Figure 2-21.

Figure 2-19. The actual view and illumination distribution of "Field of hope".

Table 2-11. The test data of "Field of hope".

No.	1	2	3	4	5	6
Illumination (lx)	56.60	67.90	58.90	71.40	48.10	67.30
Brightness (cd/m²)	8.10	9.40	8.10	10.20	3.29	4.71
No.	**7**	**8**	**9**	**10**	**11**	
Brightness (cd/m²)	6.10	7.80	7.70	8.90	10.30	
Average (lx)	**Maximum (lx)**	**Minimum (lx)**	**Uniformity (lx)**	**Average (cd/m²)**	**Maximum (cd/m²)**	**Minimum (cd/m²)**
61.70	71.40	48.10	0.78	7.69	10.30	3.29

Exhibition hall 4 was tested. The exhibits were uncoated and frameless. Figure 2-19 shows the layout of the test area of the work, and Tables 2-11 shows the test data for this work. In this survey, the brightness of the art works is 7.69 cd/m^2 and the reflection coefficient is 8.02.

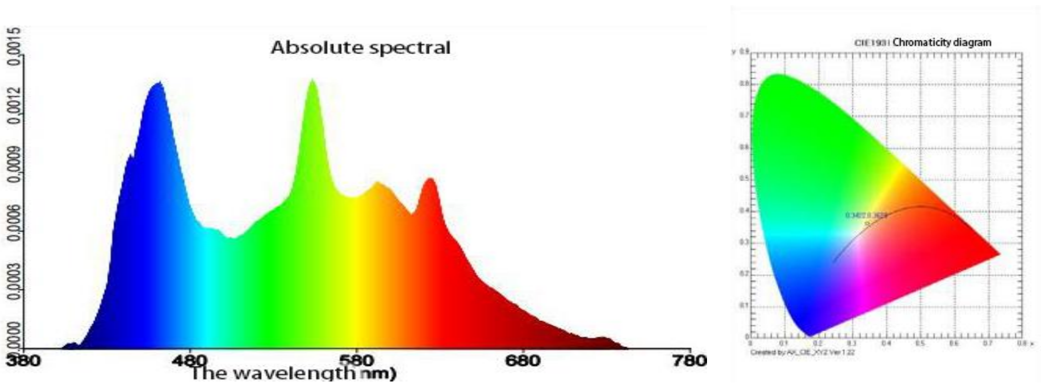


Figure 2-20. The illumination spectrum of exhibition.

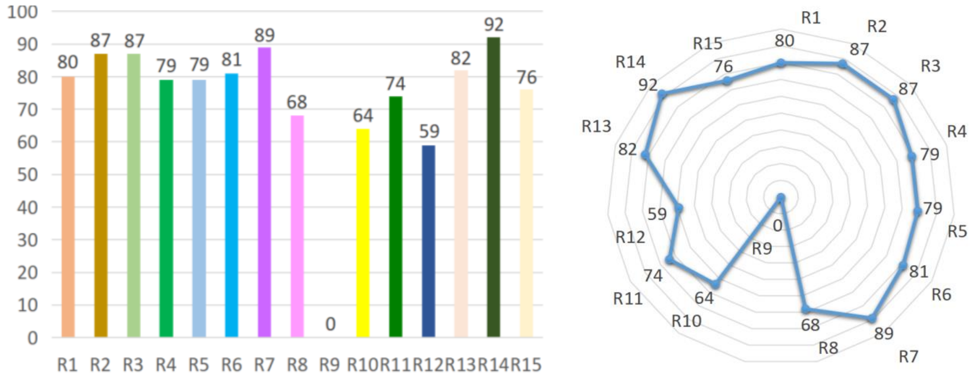


Figure 2-21. The color rendering index of illuminance spectral data in the exhibition hall.

As shown in Figure 2-20, the color temperature of the lighting of exhibition hall 4 is 5,438K, in which the CIE color coordinate X is 0.3422, and the coordinate Y is 0.3820. The peak wavelength of the CIE is 549nm. It can be seen from the spectral parameters that the lamps and lanterns used in the environment are LED light source, and the lighting of the exhibition hall space is affected by natural light. The viewing comfort is compromised. As shown in Figure 2-21, the color rendering index of the lighting in exhibition hall 4 is 73.1, and the value of R9 is -12. The color reduction of the color rendering index in the light source is general.

Through the investigation of the Liaohe Art Museum, we found that the color temperature in the illuminated environment has a great influence on the space and the feeling towards the exhibits. This effect was not measured and quantified in this survey. So the visual tasks and evaluation indexes should be determined in the evaluation of the lighting of an art museum. Only then can we set up more comprehensive evaluation index options for the lighting of the art museums through research.

The lighting of Liaohe Art Museum is ordinary in quality. The spatial system is good, but the lighting environment and space parameter can’t be well described in the evaluation process. The evaluation response index of lighting environmental is not perfect. The inaccurate evaluation method affects people’s observation of the artworks in the exhibition hall, and also affects the emotional response of the observers. Through the investigation of the art museums, we obtained the problems existing in the current lighting environment evaluation, such as that the classification of evaluation indicators is not clear and the indicators in the specific classification is not detailed. The lack of a way to evaluate the emotional feedback of the observers will be solved in the research.

2.6 Research Questions

Through many investigations in real art museums, we found that the evaluation of their lighting environment cannot be limited to the objective data of the light source itself. Factors such as space, mood, and vision all have an impact on visitors’ evaluation of the art museum. We hope to find out the law between the environment lighting and people’s emotional response index. The main problems of the research are put forward. The study applied the most advanced technology in this field to interdisciplinary research by scholars in the areas of architecture, optical engineering and psychology. The research hypothesis of environment lighting affecting emotional response was raised. Interdisciplinary research also has made excellent progress in the study of emotional response which is based on a physiological test. Through the introduction of innovative ideas, this study found the existing problems in current research. It tested the relationship between environment lighting and emotional response, and discussed the relationship between them. Therefore, the following research questions are raised.

- **A study on the important factors influencing visitors' evaluation index in art museum**

The purpose of this study is to investigate the visitors of different ages and different majors when they visit the art museums, analyze the data through subjective questionnaires, eye movement tracking, and find out what kind of lighting environment and visual perception the visitors need. To test and analyze the lighting mode, lighting quality, illumination, color temperature and environmental color of art museums are also the purposes of this study.

Illumination and uniformity of the space are the only requirements for the traditional lighting design. Situations such as poor quality of light, lack of research on a specific area, streamlined application for different spaces, lighting design methods, and types of lighting environment should also be changed. In this study, the effects of different lighting methods on emotional response were studied with different methods in fixed space. There are many kinds of exhibits in the museum. Different exhibition halls have different requirements for lighting. Through investigating various museums and exhibitions, the study set the physical conditions of the space as the primary quantitative, and summarized the data and parameters of the lighting environment. It also proposed the leading evaluation indicators, and obtained the main factors of its impact based on the analysis of variables.

- **A study on the regular relationship between the characteristics of the lighting environment and people's emotional response**

It is very important to find out the main indexes and parameters that affect people's emotional response through established research and theoretical models in optics and architecture. From the perspective of sociology, this thesis found the key points from interdisciplinary research method. It is necessary to establish a theoretical model on people's emotional response and environmental data. Based on the theoretical background of multiple disciplines, we have carried out several experiments on environment lighting and emotional response, and found the connections behind the experimental data.

Scholars from different disciplines have a certain research foundation for optical engineering. Through the optimization of the existing theoretical formula, the evaluation model of lighting was established combined with the research results from psychology and other disciplines, .This study used the inter-disciplinary direct cognitive law as the guidance of emotional response method, and used the model to verify the visual response to help with the recognition of emotional response.

- **A study on the characteristic factors of data changes between physiology and psychology in emotional response**

The traditional emotional response analysis adopts subjective questionnaires and statistical method to analyze the data. There was no description of the eye movement tracking data of the subjects. There are some shortcomings in the data from subjective questionnaires that needs to be supplemented by eye movement tracking analysis. It is impossible to genuinely reflect the characteristics of the visual signal that affects the physiological indicators merely through the subjective data. There is a lack of evaluation model applicable to the visual and emotional response. People’s questionnaires tend to have high subjectivity. The eye movement tracking test was a real emotional response parameter with proved objectivity. Therefore, it was added to verify the results of subjective questionnaire evaluation in art museums.

CHAPTER 3
Lighting Design Evaluation of SVOE

3.1 Introduction

The illuminance in the space of the museums is the most important index for evaluating the lighting environment as the intensity index it expresses is the most accurate. It is not affected by the colorimetric level or the reflectance of the surrounding materials, and it has an impact on emotional responses. We established evaluation indexes and model in the study. This model should have a logical system of evaluation. This evaluation index should also be subdivided when applying the model and it is the most basic index to evaluate the lighting environment. Illumination and color temperature are the most apparent expressions in museum lighting.

The changes in the indexes can be directly recognized by the human eyes, and at the same time they are the biggest factors to affect the visitor's perception. The space of the exhibition hall is mainly illuminated by artificial light sources. The LED light source has been widely applied in museum lighting as a result of its excellent characteristics, such as energy efficiency and the controllable spectrum. And LED light technology can accurately define the color temperature and illuminance of an environment. These are the characteristics that traditional halogen lamps and fluorescent lamps do not possess [70].

The studies have shown that there are some key points in each area, which act as hubs during the visit and that have a power of attraction entirely independent of the content and the objects on display [71]. Possible criteria for selecting the type of illumination for paintings is the lighting intended by the artist or the subjective effects intended by the curators [72]. Until the beginning of the 20th-century, the only illuminance high enough for good color vision was daylight. Daylight would be the optimum illuminant [73]. Curators and exhibit designers must take many factors into account as to how artworks are displayed, among which one aspect is how the displays are lit, which is the focus of our research [74]. Museums must choose the illumination that can optimize the aesthetic experience without compromising the preservation of the artworks. It should not not daylight as it does not correspond with the conditions under which the paintings were created, and it does not match the adaptation state of our visual system. This study might also speculate that our lifelong experience with artificial lighting in interior settings has somehow dragged our preference away from natural daylight towards somewhat lower color temperatures [75].

There are many factors that affect the visitors' emotions in an art museum, but traditional lighting design only took the basic function of illumination for spaces and exhibits into account and has not considered the influence of spatial visualization conditions and emotions or feelings. This research focuses on innovative theoretical research related to museum lighting design, which generally concerns four closely connected elements in the study. They are spatialization, visualization, optical engineering and emotional factors.

Through innovative thinking, we can create a new theoretical model for lighting design. Meanwhile, we can use the hypothesis on the relationship between lighting and emotional response to improve the efficiency of information acquisition for visitors. It is an excellent way to optimize the lighting design evaluation model to solve the differences among disciplines. Therefore, the research supported a model based on SOVE theory, which straightened out the interdisciplinary problem of lighting design by logical thinking and proposed an innovative way to solve the problem. The key of this chapter was the theoretical framework of SOVE, and theory of knowledge science was applied to improve and optimize the model. Subjective questionnaires and eye movement tracking were also applied in the experiments to verify the theories, as well as the theories of explicit knowledge and tacit knowledge.

The basic framework of lighting evaluation model based on emotional response in art museums was established to encourage the observers to find a better lighting environment. In the research, the theories in the knowledge science system were verified by experiments, subjective questionnaires and eye movement tracking experiments. Physiological index parameters were used for verification. Meanwhile, this study used interdisciplinary innovative experimental methods, as well as questionnaires, field measurements and eye movement tracking. It introduced new computer simulation technology to carry out the experiment, and used the new experiment method to verify the theory. This part of the experiments broadened the knowledge science domain and innovation thinking.

This study used innovation thinking to conduct interdisciplinary research of lighting design processes and related disciplines. The lighting design theory and the SVOE model were adopted to influence the visitors' emotional response when they were visually perceiving a space. A theoretical model concerning the relationship between human, space, and lighting was proposed. The new lighting design evaluation model would improve the existing evaluation model by quantifying people's emotions, so as to find the indicators that affect emotional response towards the lighting environment.

3.2 Part of Spatialization

The definition of space is the first step in the evaluation model. It is necessary to accurately describe the space, turn the architectural space into data, and express the space with parameters. The spatialization is the digitization of design and the classification of architectural spaces and exhibits through analyzing the physical space of museums. By studying of the principles and methods of architecture, the space of the museum can be clearly defined, and the physical properties and functional scales of the space can be sorted and classified. For example, the length, width, and height of the space can be digitalized, and the orientation and size of the windows can be simulated. A function-oriented art museum determines the form of the space by the function, which is to satisfy the visitors' viewing purpose. In this study, the lighting of the environment was evaluated through the evaluation model, and the key evaluation indexes that affect the lighting was analyzed and obtained.

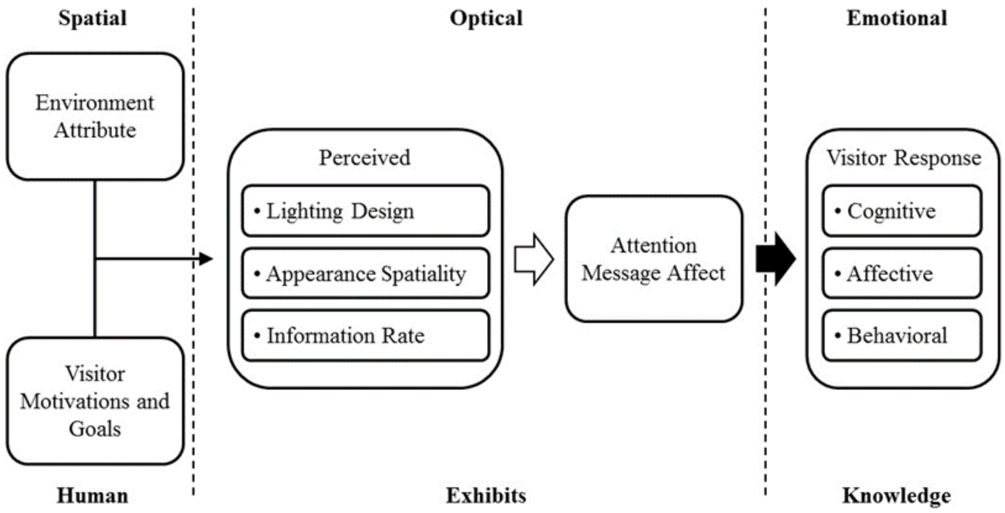


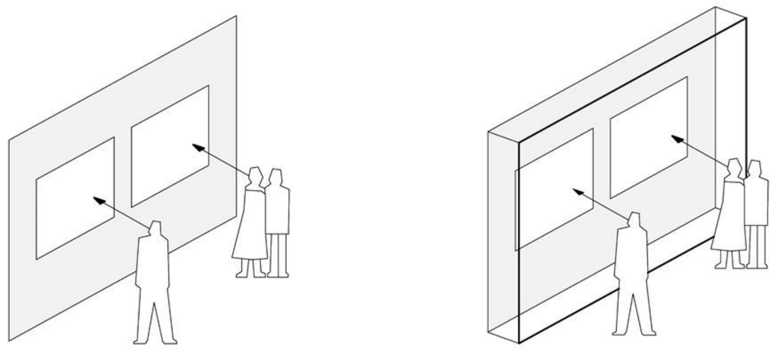
Figure 3-1. Consolidated museum atmospherics model.

This part focuses on the space layout and lighting of the art museum. It classified the architectural space types, and provided an accurate definition of academic research scope and concept for the research. The function of the building plays an essential role in this holistically-defined exhibition environment. The proposed program explored the relationship between the perceived atmosphere and visitor emotional responses. This chapter took the observers' response into account with cognitive, affective and behavioral aspects. This part was guided by the theoretical framework shown in Figure 3-1. We got emotional response of the visitors by connecting the architectural space with their visual perception, so that the architectural space can meet the functional requirements.

3.2.1 Spatialization Types and Functions

Firstly, the spatial classification and main functions of art museums should be determined. Art museums can be classified into open and private types from the perspective of architectural attribution. An open art museum is a type of museum that openly displays works of art to the general public. Private art museums often refer to those built by individuals instead of official organization. Both types of art museums offer public art exhibitions. The most important event of an art museum is the art exhibition. Exhibitions can usually be categorized into regular and temporary exhibitions. The regular exhibition is an exhibition of the museum's own collections. In temporary exhibitions the artworks are usually displayed in turns in difference art museums. So the regular and temporary exhibitions have difference styles of lighting design.

A temporary exhibition in an art museum is an exhibition of works of art related to a particular theme, which usually have something in common. In addition to the collections belonged to the art museum on display, art works may be borrowed from other museums or private collectors. Temporary exhibitions are usually held during a specific period, and may be funded or sponsored by the media, planning companies or commercial corporations etc. Such non-artistic exhibitions may rotate in many different museums, in a way called tour shows. The main displaying methods in the art museum are direct display and cabinet display. As shown in Figure 3-2, the different ways of art display demand different lighting.



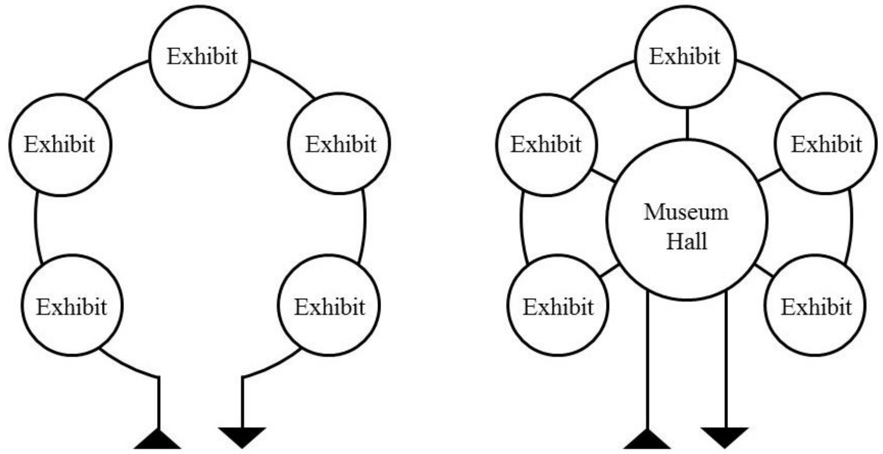
(a) Directly display. (b) Showcase display.

Figure 3-2. Display the space type of painting works.

The museum building is divided into the display and auxiliary spaces in terms of functions. The exhibition space can be divided into a permanent exhibition space and temporary exhibition space. Each museum has a permanent exhibition that conforms to the local culture, as well as temporary exhibitions that are regularly changed. The basic layouts of the permanent and temporary exhibition halls are similar. While the permanent exhibition hall will not change its layout, the temporary exhibition hall can have adaptations for different types of exhibitions.

The auxiliary space is the area that connects the display spaces, and generally includes the entrance hall, the preface hall, and the corridors. The auxiliary space does not include the exhibit warehouse or office space. The lighting design of these auxiliary spaces has a close correlation with the lighting arrangements of the exhibition space. The visual lighting design of the auxiliary space can affect the lighting of the exhibition space. Faced with such diversity within the building, the requirements for lighting design of the building are also high, and each space must be provided with a lighting mode that meets the specific requirements of that space.

Every display space in the museum tells a story to its visitors. As there are different types of exhibits and display conditions in the exhibition space, each story requires a different lighting to allow for the creation of a particular atmosphere. Moreover, the lighting environment also needs to allow for changes in strength and rhythm, reflecting different feelings through changes in illuminated environments. The main functional spaces of the building in the art museum are in the hall and the exhibition hall. The ways to divide and design these two zones will produce different spatial effects. As shown in Figure 3-3, there is a great difference between the series space and the parallel exhibition hall space, and to achieve different effects there should be different lightings, giving the observers different feelings. Tandem space arrangement needs a balanced lighting, with parameters that don’t vary too much, so that the visitors feel like staying focused in a consistent atmosphere. For radiation and tandem space arrangement, what we need is an open feeling in the museum hall. The exhibition halls should have a lower illuminance than the hallway so that the visitors can have a change of visual rhythm. The contrast can be realized through the illumination distribution of the lighting environment and the change of color temperature.



(a) Tandem space arrangement. (b) Radiation and tandem space arrangement.

Figure 3-3. The effect of different streamlines on space.

The standard exhibition hall space is divided into three areas according to their functions, the viewing area, traffic area and resting area, as shown in Figure 3-4. The resting area in the exhibition hall is a space where the observers stay to take a break. Usually, the resting area is designed at the center of the exhibition space, where visitors could feel the atmosphere of the environment while others can still appreciate the artworks. The difference is that the resting area is for visitors to feel the environment of the whole space, while the viewing space is mainly designed to feel the lighting of the artworks. The requirements and quality of the lighting environment in different functional areas are also different.

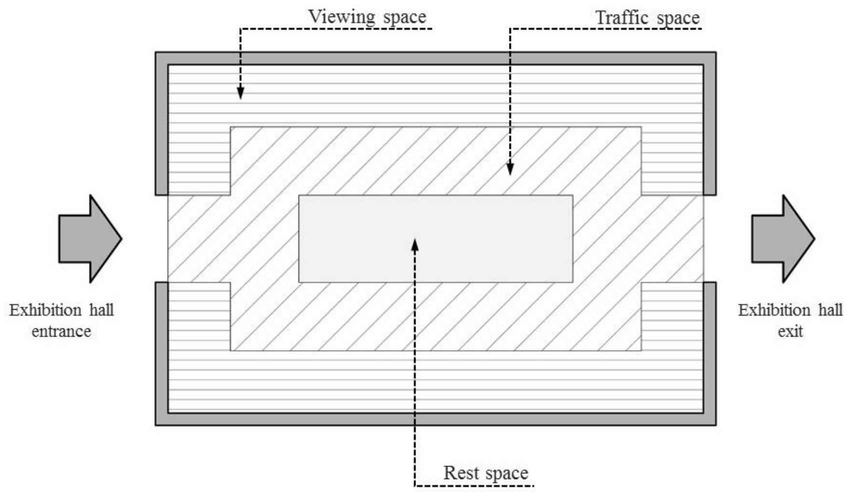


Figure 3-4. The spatial function of the standard exhibition

In the SVOE evaluation model, the space of different functional areas need different lighting parameters while the visiting area needs more clear illumination. The walk of traffic need to have security lights. And the rest of the spaces need more comfortable lighting. This will influence the visitors' feelings while they pass or stay in these areas, and further influence their emotional response.

3.2.2 Spatialization in SVOE Applications

The spatiality factor is the basic element of the objective world in the SVOE evaluation model. It includes materials, colors, and function types in the space. These elements are influenced by the lighting environment and are closely related to each other. The space let the observers have different psychological feelings by different lighting environment changes that produce different atmosphere. Researcher Kaplan's find the factors for complexity in the spatial environments through observers interviews and model of spatial environments, which was an understanding and exploration way of human feelings [97]. As shown in Table 3-1, the evaluation of environment vibrancy related to the overall feeling of the participants towards the art museum, this change is achieved by changing the lighting environment of the space through lighting design, which covers the observers' influence on the elements and indicators in the museum environment. Researcher Osgood first identified the activities of key elements in the space environment and found the relationship that was directly related [76]. This relationship explains one's progressive spatial perception of the environment through changing the lighting environment. The space gives the observers different perceptions through two-dimensional images and three-dimensional images. This study requires more experiments to verify this theoretical relationship.

Table 3-1. Relationship between factors of environmental preference.

Condition	Understanding	Exploration
Two-dimensional The plane images are displayed directly.	**Consistent** The visual perception to the observer is consistent with the spatial imagination.	**Complexity** Suitable for displaying complex information on the plane in the space.
Three-dimensional Rich expressions, visual perception has changed.	**Integrity** Give the observers an interest in exploration and a complete performance.	**Mystery** Suitable for displaying diversified spatial information.

Note: Adapted from Forrest R. Design Factors in the Museum Visitor Experience. The University of Queensland. 2014. P48, Table 2-2.

The art museum environments are categorized according to the type, lighting mode and size of the space. The type of space can be classified into display space and non-display space. Display space includes regular exhibition and temporary exhibition space. The lighting environment of the ordinary exhibition hall does not change easily, while the that of the temporary exhibition halls may change according to different art exhibitions. Therefore, it's very important to evaluate the architectural space. The lighting design of architectural space can be divided into general lighting, accent lighting and mixed lighting. The different spaces require different lighting methods. These three lighting methods are the most basic methods, which are refined in different environments to meet the visitors' requirements of usage of the space as well as conform to the functions of the building. The scale of the space can be divided into large, medium and small space as shown in

Table 3-2.

The scale indexes in the space can well explain the size of the space. And the recorded parameters are used to classify the space. Different spaces give people different visual perceptions, and different visual perceptions affect the emotional response of visitors. Therefore, parameterized building evaluation indexes are used to improve the evaluation model of SVOE.

Table 3-2. Spatial objective assessment indicator system

Architectural space	**Level**	**Indicators**
	Space type	Display space Non-displayable space
	Lighting mode	General illumination Accent lighting Mixed lighting
	Space scale	Large space Medium space Small space

Artificial lighting is more common in museums, mainly for better control of the lighting effect. There are three main lighting modes, i.e. general lighting, accent lighting and mixed lighting. General lighting is a uniform lighting for illuminating the whole place. Accent lighting aims to improve the illuminance of the designated area or target. As a result, the target would be more prominent than the surrounding area. Mixed lighting is composed of general lighting and accent lighting. Different lighting modes create distinct lighting environments, contributing to distinct emotional response of the observers.

In the process of emotional response analysis of the observers to establish the evaluation model, the building parameters were analyzed, and the lighting of the space was classified. The final result was the application of the SVOE evaluation model in the lighting design of art museums.

3.3 The Part of Visualization

In the SVOE model of environment lighting assessment, the visual part is the most basic condition to connect visitors with the space, since environmental information is mostly transmitted through vision. In an architecture, the environmental space in line with the function creates the lighting in line with the visual purpose of the visitors, and thus affects the audience's viewing emotion through the visual transmission to the audience's consciousness. Visualization means the analysis of the visual factors and sensory factors of the human experience. The visual factors in the human senses determine how much information is received by humans in the world. The quantity of images perceived by each people is different. Furthermore, there are some other differences among individuals, such as different age groups and academic levels or artistic experience, which adds even more uncertainty to the definitive characterization of visitors’ visual factors. Thus, visualization in the museum is segmented into tacit knowledge and factors of visual influence, which are set as variables in the lighting design model.

Human's eyes are the main organ to receive external signals. They can clearly feel the lighting and space of an environment. And in the overall lighting environment assessment of people's emotional response, it's also most easily overlooked. The lighting environment through visual perception is not only about optical parameters. It needs to be in the space environment, reflecting the sense of space of the architecture, then communicates this sense of space to people's emotional organs. People then give feedback in the form of emotional response indexes. For example, the same illumination in different architecture spaces triggers different emotional response indexes. The visual system and non-visual system are formed by the brain and eyes working closely together. The visual system of the human eyes is similar to an image processing system mainly comprised of three parts. They are the eyeball muscles, the optical system of the eyes, and the optic nerve system. The illuminated environment is an essential part of the physical environment.

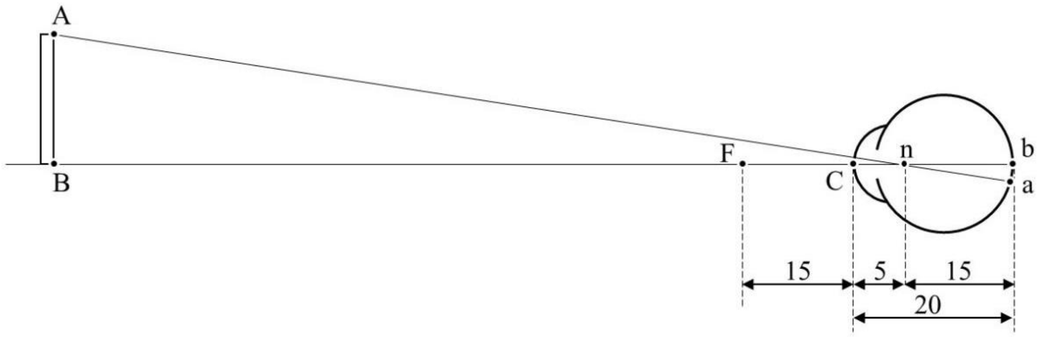


Figure 3-5. The theory of optical system imaging for vision.

The imaging principle of vision is an essential part of optics. The optical system of the eyes is shown in Figure 3-5. The geometrical optics of the eyes is very complicated, because it has to go through many optical media with different refractive indexes. And these media are often inhomogeneous structures with different refractive indexes and separated by different curved surfaces, such as the cornea and lens. We can understand its main principle through a simplified method, which is the reduced eye. The light path through the eyes can be obtained with sufficient accuracy. In this study, after understanding how visual imaging works, we can subdivide the lighting environment evaluation index of the visualization part.

Assuming that all the refraction of a simple eye is a simple interface between air and the contents of the eye. It is assumed here that the content in the human eyes is uniformed, with the refractive index as 1.333 like water. And the radius of curvature of the "corneal" surface of the simple eye is 5 mm, and the center of curvature is the node n of this optical system. ab is the image formed by AB on the retina, which is located 15mm behind the node and 20mm from the cornea, and its size Equation 3-1 is as follows:

$$\mathrm{ad} = \mathrm{bn} \times \mathrm{AB}/\mathrm{Bn} \qquad (3-1)$$

For example, there is a work of art with a height of 1m at a distance of 10m from the exhibition hall of a museum. Then its human retina image size is 0.015x1 / 10 = 0.0015m, and its size on the viewing network is 1.5mm.

The light sensor in this angle pays more attention to the quality and clarity of light, while a larger viewing angle requires the environment to maintain better comfort. Therefore, the illuminated environment in the museum space should not only focus on the quality of its local lighting but also plan and design the overall visually precepted field.

3.3.1 Visualization Influencing Factors

The exhibition hall of the museum is the necessary condition for learning culture. People watch artworks in the area so the lighting environment is the key in the space. Through analysis and calculation of the visual imaging principle and the angle of view of the human plane and elevation, the best viewing distance can be obtained. As shown in Figure 3-6, the human's plane viewing angle includes the optimal viewing angle, color viewing angle, and eye viewing range.

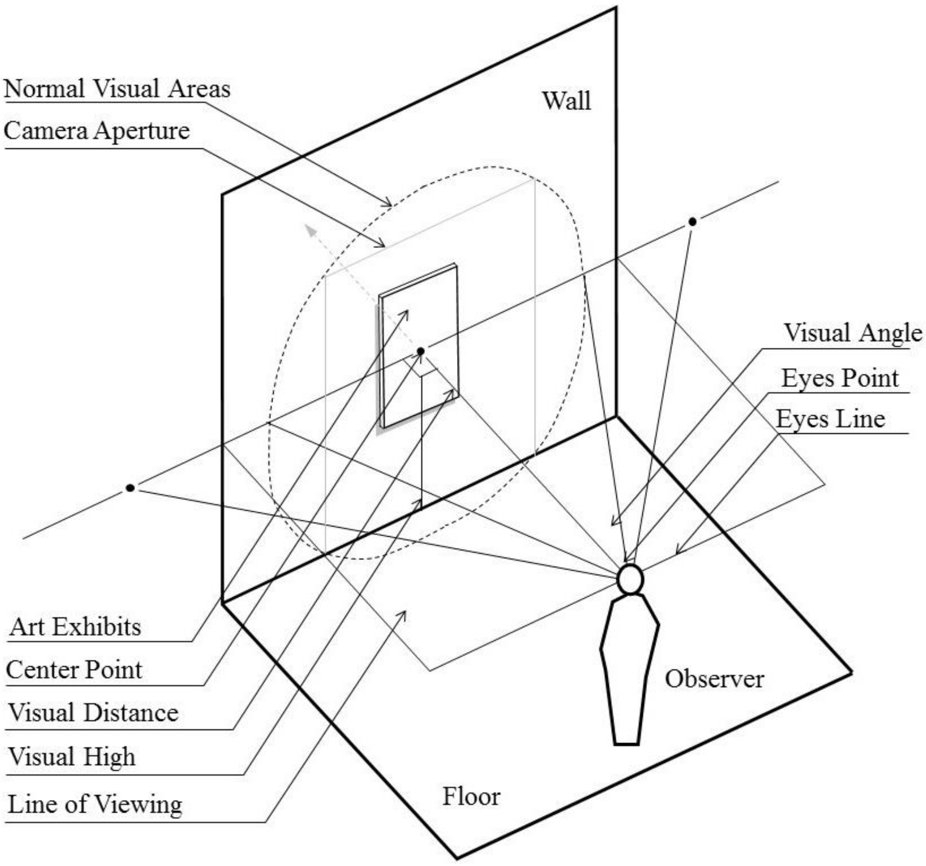


Figure 3-6. The visual imaging principle and perspective of the observer in the museum of art.

The analysis of visual factors in the environment can clearly reflect the factors affecting the observer. The architectural space elements include the basic conditions of the space, the works of art and the background of the environment. The visual distance of the observer, eye level height and visual angle affect the position of the artwork in the environment. Observer's visual point and the center of the artwork should stay in the same position. The artworks can be in different sizes. For different artworks, the lighting design methods should be different. Through the lighting environment evaluation of different art museums, the evaluation indicators of lighting design, factors affecting visual conditions can be improved. Clarity and comfort are the most basic visual indicators, but the evaluation of lighting environment can't be carried out merely by these two indicators. In this study, 25 pairs of evaluation keywords were used to conduct emotional evaluation of different art museums, and statistical methods were used to analyze the obtained data.

Through the visual factors in the SVOE evaluation model, this thesis found out the factors that affect the emotions of visitors and the changing rules of different evaluation keyword pairs. In the evaluation model, there is a close relationship between architectural space, visual factors and lighting environment. Both lighting environment and viewing distance affect the visitors' response to the clarity of artistic works in the space environment. According to the investigations and analysis on the four art museums mentioned in the previous chapter, the change of the visitors' comfort level in the space does not affect their emotional response because of the higher illumination, and the change between the two needs to be recorded and verified in a more scientific way. The core of the visual factors is the artworks. A good background contrast is very important to highlighting artworks on the walls in the space. Lighting design should determine the lighting method according to the style and type of artworks, and this parameter needs to be recorded in the evaluation model.

The human visual perception is a dynamic optical activity. The main business in the museum is to feel the environment and appreciate the artwork. This is the activity of two groups of people with different goals in the museum. The main visual movements of people who go to the museum to obtain information will be focused on the artworks. The primary visual goals and scope are in the area of the artwork. The height and width of the artwork form the most concentrated visible area. This visual area needs the best quality of light. In contrast, other areas need a more comfortable illumination. 20° in the human visual plane is the critical area for appreciation, and the visible range of both eyes is in the field of 124 °.

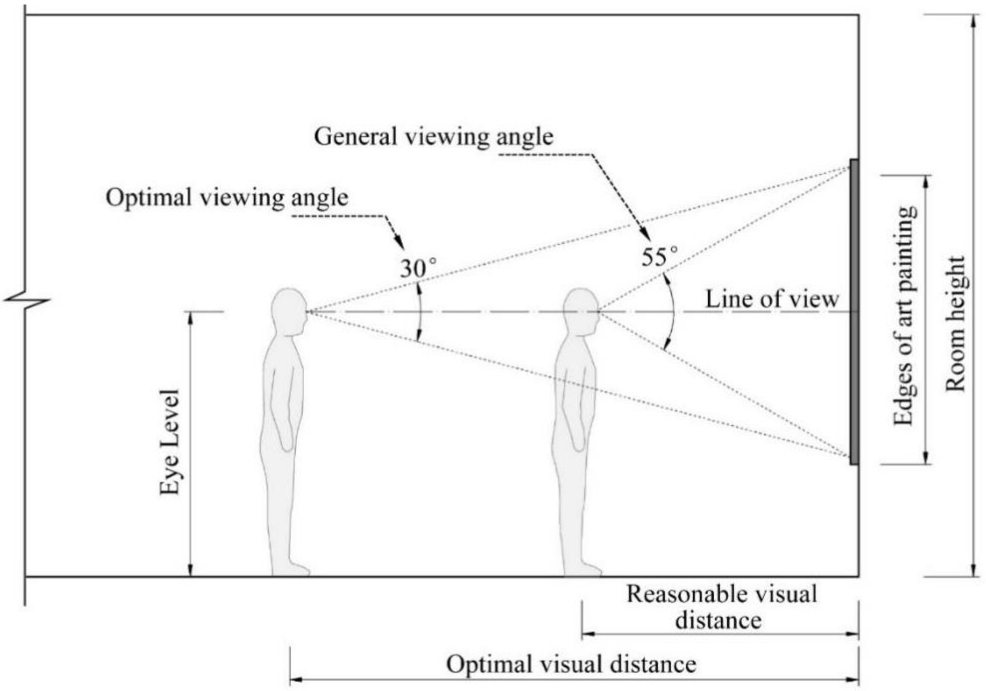


Figure 3-7. The best vertical angle for viewing art painting.

The artworks in the museums are excellent learning materials and documented the history of human beings. It is possible to obtain information and train people's imagination through images. A suitable visual viewing distance is essential. The visual presentation of the illuminated environment of the artworks should be harmonized with the overall space of the exhibition hall, focusing on the illuminance and uniformity of the plane and facade. Environment lighting will directly affect the artworks displayed. Artworks from different times and of different types have different themes to express, so the content and emotions to be displayed by the author should be different, which can be reflected in the lighting style. Different styles of lighting designs should be used to show corresponding ambience of the space, so that visitors can better feel the artworks in the environment, understand the feelings that the author wanted to convey. To feel the emotions of the artworks, improving the quality of the environment lighting is very important.

The visual analysis chart shows that the viewing distance is determined by the visual angle and the restricted area set in front of the artwork, which not only protects the works but also defines a suitable viewing distance. The distance is a regular instead of optimal viewing distance. The viewer in the space need to adjust position from now and then to see the works of art. The analysis diagram shows that in the evaluation model of SVOE, viewing distance and viewing angle have a certain influence on the parameters of glare and background uniformity, and are the main influencing parameters of visitors and lighting environment parameters in the illuminated environment. These factors are sorted out in the evaluation index of SVOE.

The angle pays more attention to the quality and clarity of light, and a larger viewing angle requires the lighting environment to provide certain level of comfort. Therefore, the lighting environment in the museum should not only focus on the quality of its local lighting but also need to plan and design the overall visual perception field.

3.3.2 Visualization in SVOE Applications

The research focuses on the interior space of the museum. Human being's visual range changes with the viewing angle. The center of the image is usually the most informative part, and the area outside the image is where environmental information can be received. That is, the area where feelings and emotions are felt.

Visualization is classified according to the table, and the visual design distance width of the light source is examined with light source placement width through understanding of the spatial condition. The visual design distance height of the light source includes the use of lighting design to arrange the light source height through the understanding of space. Based on ergonomic theory, score items suitable for light source installation can be observed by design vision.

The core role of the visual part in the evaluation index is to link the relationship between the architectural space and the visitors in the form of visual influence indexes. The test data is substituted into the calculation formula to calculate the distance between the visitors and the environment, and the distance between vision and light source lamps, so as to perfect the SVOE lighting design evaluation model.

Based on ergonomic theory, score items suitable for light source installation can be observed by design vision. The key for examining the clarity of the artwork for observation include determining the distance of the artwork according to its type and size. The range of the best clarity of the artwork for observation is determined according to the determined post-observation distance. The key for examining the comfort level of the artwork for observation include determining the distance of the artwork according to its type and size. The distance range of the best comfort level for observation of the artwork is determined according to the set post-observation distance.

Table 3-3. Visual objective evaluation index system.

Classification	Level	Indicators
Visualization	Distance and range of vision and light	Visual design distance (width)
		Visual design distance of light source (height)
	Distance between vision and observation	The clarity of visual observation works
		The comfort of visual observation works
		Spatial scale observed by vision
		Visual glare index

The key to examine the spatial scale of visual observation includes evaluating the architectural space and environment lighting, and scoring items for visual access to the spatial scale. Whether the visual perception in China at this spatial scale is consistent with the actual spatial scale widely accepted. The key to examine the visually observed glare index includes a scoring item that evaluates whether the space and environment lighting of the building are evenly distributed, evaluating whether there is a source distribution condition for uncomfortable glare and disabled glare in vision. The added evaluation indexes have improved the evaluation model of the environment lighting.

3.4 Part of Optical

Optical engineering belongs to the category of natural science. In SVOE's evaluation model, the optics is a basic condition in physical space. And architectural space also belongs to the category of explicit knowledge, which can be quantified and digitized. Therefore, quantified data and visitors' emotional response are used for analysis. The evaluative indicators of visible light in optics mainly include illumination, color temperature, color rendering, and environmental contrast. Through simulating and changing the lighting parameters in space, an analysis of the illumination environment in the exhibits in different spaces becomes possible. By means of analysis of the factors of visual influence for different groups of people, the optical parameters in the museum turn into the most important factor affecting visitors' viewing mood. Indicator parameters govern the way emotions are affected. They have a clear definition, and supply a stable condition for the final emotional response map. The techniques and principles of optical engineering are common explicit knowledge, which set optics as invariants in the lighting design model.

The LED light source has been popularized in museum lighting as a result of its excellent characteristics, such as energy efficiency, environmental protection, and the controllable spectrum. These are characteristics that the traditional halogen lamps and fluorescent lamps do not possess [70]. There have recently been great efforts to improve the color rendering and performance of LED lighting [77,78,79,80]. This study has become a potential lighting source for a new generation of museums. Experiments and discussions on the color quality of LED lighting applications in museums have been taken frequently in the international academic arena. The feasibility of museum LED lighting has been verified. Objectives have been set, such as building a lighting environment that observers can appreciate and introducing feelings and emotions into a method of lighting design evaluation, which places higher requirements on the method of lighting design itself.

3.4.1 Concept of Optical Parameters

The most basic conceptual index in lighting is illuminance. The commonly used indicators in the evaluation of environment lighting are illuminance, brightness and uniformity, different in unit of measurement. The optical engineering can provide valid data for the evaluation model and has been defining the lighting in the space. However, a common feature is that they are obtained by calculating and converting the total luminous flux of the light source. As shown in Figure 3-8, the method of exhibit display in the figure is a standard display method in an art museum. Illuminance is the most important optical condition for the environment.

Figure 3-8. The use of artificial lighting in the environment of an art museum.

The photometric is derived from the effect of radiation on the standard photometric observer. The unit is Lumens (lm). $1\mathrm{lm} = 1\mathrm{cd} \cdot 1\mathrm{sr}$。The Equation of the luminous flux of bright vision is as follows：

$$\Phi = K_m \int_0^{\infty} \frac{d\Phi_e(\lambda)}{d\lambda} V(\lambda) d\lambda \qquad (3-2)$$

In Equation 3-2, $d\Phi_e(\lambda)/d\lambda$ is the spectral distribution of radiant flux, $V(\lambda)$ is the spectral light (apparent) efficiency, and K_m was the maximum value of radiation spectral. This unit is

Lumen / Watt (lm / W). The value of K_m under bright visual conditions is 683 lm/W（λ=555nm）for monochromatic radiation. By analyzing human visual principles, a more reasonable light source is created, which includes more reasonable light distribution and spectral settings. In the space of the museum, it provides visitors with a favorable lighting environment and optimizes the lighting of the area while also saves energy.

Through understanding and mastering the optical concept, this study can define the uniformity and luminance index of the art museum. In this study we could find that a higher-quality lighting environment can better help the visitors to observe the illuminated object. For example, bright lights were a mark of wealth through much of Chinese history as they can show more details in the environment [81]. While this study might understand more details and connotations of the bright object, which is especially important in the lighting environment of the art museum. This concept is the complete calculation process of luminous flux. This part uses the interpretation of formulas to show the explicit knowledge and tacit knowledge to provide evaluation indexes for SVOE lighting environment evaluation model. In the lighting design process of the space in a museum, the designer usually determines the luminous flux through the bright efficiency parameters of the luminaries provided by the manufacturer, and designs the lighting according to the functional requirements of the situation. That's also the evaluate method of the lighting environment in art museum.

The human eyes cannot tell the difference when the color temperature only changes within a minimal range. The CIE 1931 x, y chromaticity space, also shows the chromaticity of black-body light sources of various temperatures and lines of constant correlated color temperature.

The color coordinate diagram can show the position of the artificial light source in the color coordinate, as shown in Figure 3-9. When the chromaticity of the light source is the same as the chromaticity of the black body at a specific temperature, the absolute temperature of the black body is the color temperature of the light source, also known as Chroma. The unit is K. When the chromaticity point of the light source is not on the trajectory of the black body, the trajectory of the black body refers to the trajectory that represents the color temperature in the coordinate. The illuminated environments of art museum typically have a color temperature value between 2,700 K to 4,500 K. The chromaticity of the light source is the closest to the chromaticity of the black body at a specific temperature. The absolute temperature of the black body is the correlated color temperature of the light source, referred to as CCT. The color temperature is a condition that can be directly felt in the spatial lighting environment, and it is easy to cause emotional changes in the space.

Both color temperature and color coordinates are indicators for describing light color, and they can be described either separately or in combination. We can estimate the approximate position of the excellent coordinates through the color temperature. In a similar way, we can get the approximate color temperature by using the color coordinates。

Through the application of color contrast, visual comfort can be improved, especially when the brightness contrast is poor. However, the color contrast not only depends on the color rendering performance of the light but also the environment and people’s preference for color. Light with different wavelength can induce mixed feelings in visual psychology. The view with low color temperature (< 3,300 K) indoors gives the visitor a warm feeling close to the mood in dusk, and forms a relaxing atmosphere. The light with high color temperature (> 5,300 K) is close to the natural light, giving people a cold feeling, and makes them more energetic. Visitors prefer high color temperature in the warm climate and low color temperature in cold weather. Generally, in art museum a color temperature of middle value is used.

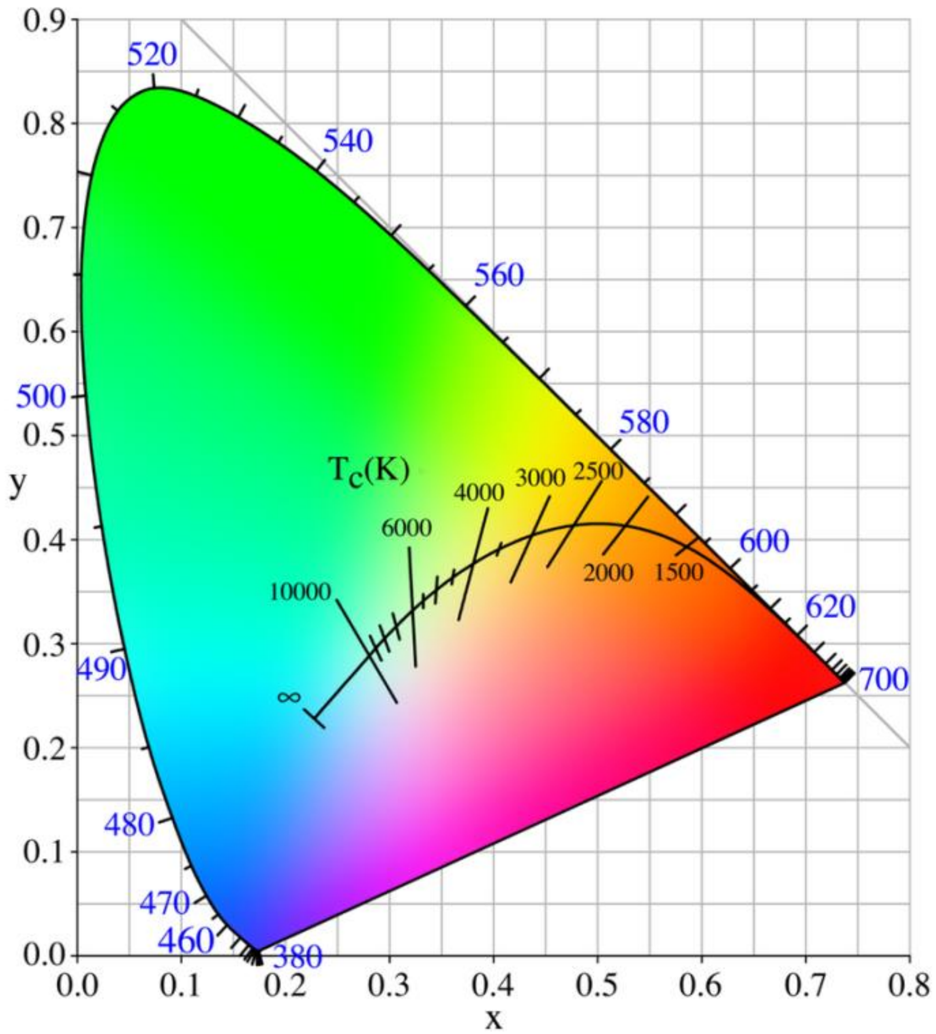


Figure 3-9. CIE chromaticity diagram with black-body curve.

(Source: Public Domain, https://commons.wikimedia.org/w/index.php?curid=107655)

The quality of the lights in the museum is the key index that determines the display quality of artworks. In the visual concept, the effect of the illumination on the color appearance of the object is called coloration, which is associated with color temperature. And the inherent color rendering characteristics of the light source are called color rendering, which are associated with color rendering index. The higher the color rendering index of the light source, the better the color rendering. The CIE stipulates that the color rendering index Ra of the reference standard light source is 100. General artificial lighting sources use Ra as an index to evaluate color rendering index. When assessing the color rendering of a light source to a specific color, one or several individual color rendering indexes from 7 additional color samples must be used as indicators. The seven-color samples including R9 is red quality. R10 is yellow quality. R11 is green quality. R12 is blue quality.

R13 is white skin color quality. R14 is green leaf quality. R15 is the quality of Asian skin tones. When the measured object has the same color rendering as the reference light source, its color rendering index is 100. It is generally believed that when the range of Ra reaches 80 to 100, the color rendering is excellent. When the scope of Ra is 50 to 79, the color rendering is general. When the value of Ra is less than 50, the color rendering is poor. The color rendering index in the lighting of the art museum is generally above 90 (Ra >90).

The main factor determining the color rendering of the light source is the spectrum of the light source. The light source has a high color rendering in general if the spectrum is continuous. When the light source lacks a certain spectrum, its color rendering is relatively low. Generally, there is no necessary connection between the color rendering and the color temperature of the light source. The lights in art museums typically have a color rendering index higher than 85.

According to the illumination distribution, the illumination generated by a point light source at a certain spot on the horizontal plane can be classified into horizontal illumination, vertical illumination and illumination in any direction. The direction of horizontal illumination is perpendicular to the horizontal plane, and the direction of vertical illumination is parallel to the horizontal plane. Illumination in any direction is related to the included angle of the illumination of the electric light source. In order conduct field measurement, the horizontal illumination and vertical illumination are selected as the research points of the illumination distribution of the light source at the spot.

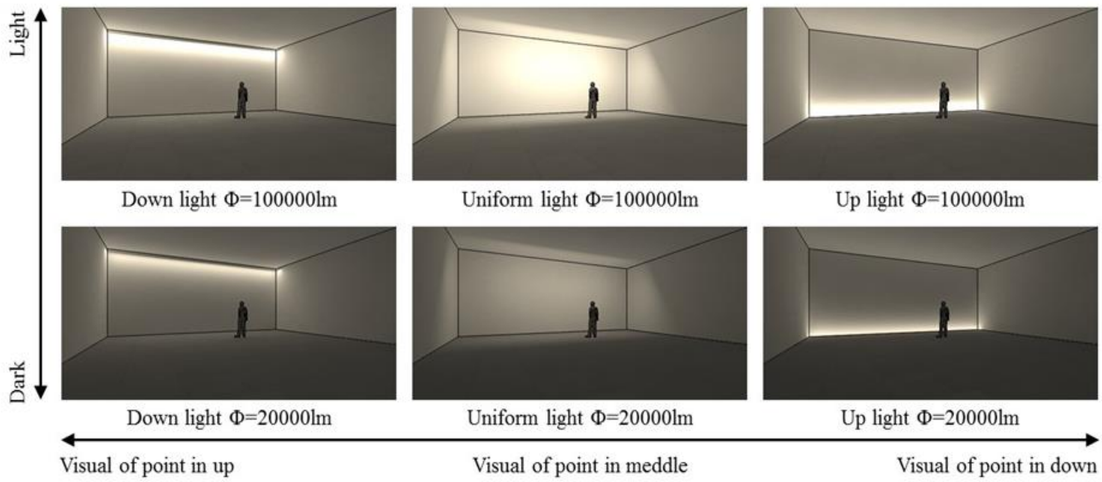


Figure 3-10. Visual effects and optical parameters of three different lighting styles.

There are three forms of lights in front of the wall of a museum, as shown in Figure 3-10. The computer simulation used different lighting arrangements to achieve the performance of the environment lighting. The three lighting modes used the same light flux to display different effects in the space. Different lighting effects give people different sensations as well. It is not accurate to define the spatial lighting environment only by the spatial illumination index without using the lighting mode.

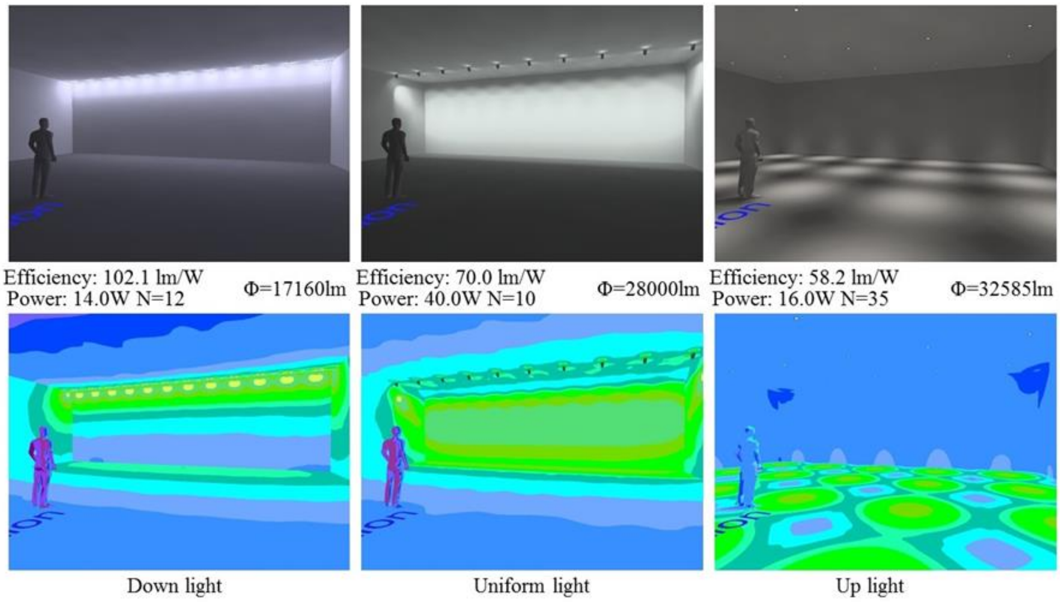


Figure 3-11. Visual effects and optical parameters of three different lighting design styles.

As shown in Figure 3-11, the lighting style was down light. Uniform light and up light were used to perform the simulation of the environment lighting. The lighting style of the environment in the art museum can trigger different emotional reactions of the visitors.

Through the application of color contrast, visual comfort can be improved, especially when the brightness contrast is poor. However, the color contrast not only depends on the color rendering performance of the illumination but also the environment and people's preference for color. Different wavelengths of light will have mixed feelings in visual psychology.

3.4.2 Optical in SVOE Applications

Through field investigations and the refinement of relevant theoretical concepts, we classified the optical aspects into specific categories, as shown in Table 3-4.

In order to improve the application of SVOE in real-life venues, this study set up inspection sites for the 10 secondary indicators in the table.

Annual exposure mainly investigate whether the exhibits in the evaluated space meet the illumination and annual exposure requirements of relevant lighting specifications.

Spectral distribution of light sources of typical exhibit SPD mainly evaluates whether the exhibits can be protected from mid-infrared and ultraviolet in the lighting specifications, as well as the spectral distribution form of the main light sources in the evaluated space.

Exhibit surface temperature mainly evaluates the surface temperature of the exhibits to see if the preservation requirements are met.

Glare control investigates whether the light source causes uncomfortable feelings during the observation or reduces the ability to observe details or objects or extreme brightness contrast due to inappropriate brightness distribution in the visual field. In addition, whether the exhibits have additional thermal radiation needs to be taken into account.

Table 3-4. Optical objective evaluation index system.

Classification	Level	Indicators
Optical	Safety of Lighting	Illumination and annual exposure
		Spectral distribution of light sources exposed to typical exhibits SPD (IR, UV)
		Surface Temperature
	Quality of Lighting	Surface Temperature
		Color rendering index
		Flash control
		Color temperature
	Light distribution	Horizontal distribution of illumination
		Vertical distribution of illumination
		Contrast between exhibits and background illumination

The color rendering index rates the color reduction ability of the characterized light source, and evaluates the ability of artistic processing of a certain color on the special artistic performance effect.

Stroboscopic control evaluates unstable visual phenomena caused by fluctuations in brightness or color distribution over time.

Color temperature assesses the color temperature of the light source.

Horizontal spatial distribution of illumination evaluates the rationality of horizontal spatial distribution of illumination of the evaluated space and whether there are interfering factors in the horizontal spatial distribution of the evaluated illumination.

Vertical spatial distribution of illumination evaluates the rationality of vertical spatial distribution of illumination in the evaluated space and whether there are interference factors in the vertical spatial distribution of the evaluated illumination.

Contrast of illumination between exhibits and background assesses whether the display of typical exhibits in the evaluated space meets the contrast requirements of lighting specifications and whether the contrast between the evaluated exhibits and the background meets the psychological expectations of the testers.

Through the study of the definition and parameters of the environment lighting, this study can find the changing laws that affect people’s emotions. Through the indicators in the evaluation model, the evaluation indexes can be selected in different spaces in the art museum to assess the lighting in the space.

3.5 Part of Emotional

The processing of visitor's thoughts and emotional reactions in the environment determines their behavior in the background. This research defines the observation reaction and behavior of the visitors to the artworks in the museum environment. It evaluates them through subjective evaluation and physiological test. With subjective and objective data of emotional reactions, this part introduces the theory of optical engineering to define the environment lighting, as well as the lighting environment and the emotional response to establish the response of the operational model.

3.5.1 Observer's Emotional Response

Emotional factor is the ultimate indicator of the lighting design model. The first three indicators in the model were to create an illuminated environment suitable for the observers' emotions. The traditional lighting design does not take human emotions into consideration, and only considers the illuminative function of lighting in space. The lighting design based on the SVOE evaluation model integrates spatial, visual and optical considerations and enables the realization of emotional evaluation maps for different groups of people in different types of lighting environments.

The degree of visitors' adaptation to the environment lighting determines their behavior in the space, and the degree of visitors' interest in the exhibits determines their visual movements in front of the artwork. Phototropism effect refers to a phenomenon that bright light can attract people's attention towards an object even under the influence of its adjacent things. Different lighting environments have significant differed influence on the viewing behavior and access to information quality. The space and the interest in artworks determine people's emotion and action. Bright lights only enable the eyes to adapt to a higher level of brightness, so as to reduce the requirement for signal quality and sensation intensity. Therefore, it is necessary to provide an appropriate illumination in the environment of the art museums so that the artworks remain the focus of visual pursuit against the background.

The appropriate lighting environment is set in the art museum to turn the visual factors around the art exhibits into auxiliary elements. The observer would pay attention to the signals that obtained by the displays that make the strong points of the artworks more visible and prominent. Therefore, the primary ornamental purpose of the visitors in the environment can determine the main factors of attention and emotional response. As shown in Table 2-5, the more intense the focus of attention, the less effort it takes to maintain it. The first factor that affects how well an observer looks at a work of art in its environment is the degree to which the object stands out as a natural focus of attention in the visual environment. Finding the right environment lighting to provide critical evaluation conditions is the focus of the research. The brightness, uniformity and contrast of the light source in the environment provide a strong visual signal for the vision and attract the behavior of the observers.

Through the lighting in the environment, visitor can notice the characteristics of the art exhibits, including the significant degree of shape, surface texture, color and inherent contrast, etc., which has a substantial influence on the quality of visitor's viewing at all levels of lighting. Different types of objects require different types of lighting. The quality of the illumination necessary to maximize the visibility of the data shows the surface features of the object. The size of the contrast produced by an object is determined by its shape and surface features. The quality and quantity of lights used also affect the perception of the difference on the object surface. Color perception depends on the spectral composition of the light. The knowledge of texture and form is related to the direction and concentration of the illumination.

The general rule of the art museum environment is to provide high-quality lighting in the exhibition space. If the experiences of visual perception in the illuminated environment are the same as the feelings in the memory task, visitors with liberal arts and science education background have different visual memory experience. With a better visual perception, visitors only need less visible information to form sufficient perception.

3.5.2 Emotional in SVOE Applications

To understand emotions of the visitors, this study made an overall evaluation of four first-level indicators, including the brightness of the exhibits, the clarity of the details of the exhibits, the comfort of the lighting environment, and the illumination sensitivity of the architectural space. From the four first-level indicators, we divided 13 second-level indicators into corresponding scores for detailed description.

Color authenticity of exhibits includes whether it conforms to the judgment of daily testers on the authenticity of color of exhibits, and color preference of the light source. The tester can approve the cold - warm color selection effect of the light source. The color of the light source has a high correspondence with the psychological expectation of the evaluator. The lighting can clearly bring out the details of exhibits and the environment has a fine and accurate performance on exhibits, which is satisfactory.

Stereo performance including the three-dimensional effect of exhibits is excellent. The contrast of light and the color is comfortable. The three-dimensional effect of the exhibits is rich, which can improve the aesthetic effect of art pieces. Clarity of the exhibits texture including the details of materials are clearly displayed. The exhibits are rich in texture and performance. Clarity of the outer contour of the exhibits involves whether the overall contour of the exhibits can be clearly seen, and whether the performance of the outline of the exhibits is easy to identify.

Illuminance acceptance of exhibits includes the psychological and visual acceptance of the subjects, as whether it can remain high after the illumination of the calligraphy and painting exhibits is reduced. The environment lighting not only meets the requirements of preservation for exhibits, but also has rich artistic appeal.

Visual adaptability includes the subjects' adaptability to light and shade changes in the environment and their adaptability in visual perception score items. The subjects' scoring items have psychological impact upon the change of light and shade in the lighting environment. Visual comfort includes the degree of psychological feeling to the coordination of the overall space lighting and shadow and the space color collocation of the exhibition site of the art museum. Psychological pleasure includes whether there is discomfort in the evaluated space due to the inappropriate brightness distribution in the visual field or the extreme brightness contrast. The scoring items for the uncomfortable shadows on the floor and walls of the space, as well as the feeling of too strong a contrast of shadows that reduces people's ability to observe details of the targets.

Table 3-5. Evaluation index system of emotional response.

Classification	Level	Indicators
Emotional	Perception of colorful	Color authenticity of exhibits
	Details of exhibits	Exhibits details expressive
		Stereo expressiveness
		Texture clarity
		Outline clarity
	Perception of comfort	Bright acceptance of exhibits
		Visual adaptability
		Visual comfort
		Psychological pleasure
	Architectural space lighting perception	Use this artistic preferences
		Affective preferences
		Spatial scale perception

Liking degree of lighting art reflects the overall excellence of artistic effect of the lighting when test subjects have high visual comfort. A wonderful lighting performance makes people linger and form a deep impression. The design of lighting adds lustre to the entire environment, which can become a classic case.

Affectionate degree includes whether the lighting is in line with the museum's own positioning and collection characteristics. The light form of the exhibition is closely related to the theme and forms a unified and coordinated style with the exhibition content. The light form can convey a good effect to express, foil and deduce the exhibition site in a profound level. Sensitivity of spatial scale includes the sensitivity of the environment lighting that can be felt in space, the atmosphere formed by lights and the degree of openness created for vision, so that one can feel the lighting atmosphere and exhibits well.

This table can be applied to different types of art museums to evaluate the visitors' emotional response in a more visualized way, while also convenient for designers in the lighting design in different art museums to figure out a unified emotional evaluation standard. It can not only ensure an optimized effect of display, but also to create a people-oriented lighting design with visual comfort in account.

The psychological test of visitors in the lighting environment of the art museum included subjective evaluation and physiological reaction. Among them, a personal assessment is studied by combining the methods of psychology and statistics. The main visual factors and conditions of visitors are classified. The questionnaire is designed through the subjective evaluation model as the visitors in the space were tested.

The evaluation data of the conditions that look good are analyzed. The higher the intensity of the visual stimulus, the higher the level of quality and the content of the information. That is, the higher the signal ratio in the visual environment, the better the visual effect, which means that the perception that visitors need in terms of visual information can be formed. All of these factors are related to the surface characteristics of the object of attention, the condition of the visitor as well as the features of the light source, and the quality of illumination.

The main evaluation indexes in the lighting environment determine the essential quality of the light source and the artistic rendition of the space. The clarity of the area, comfortable degree, color preference degree and artistic quality constitute a level index. In different experiments of this study, different evaluation indexes were set up, namely the evaluation index of less for four parts, number of evaluation index for twenty-three, number of evaluation index with factor analysis method, the primary factors and subjective factors in the evaluation model, so this study also verified the experiment and researched the scientific nature of the subjective evaluation index.

The first-level index and second-level index of the subjective evaluation of the lighting environment in the art museums constitute a perfect evaluation model, in which different weights and scores can obtain the specific evaluation scores of different spatial lightings. The subjective psychological response are acquired through physiological indicators. So this study also carried out further research on the evaluation of the psychological intervention, using the current representative physiological test to obtain data. Through analysis and data processing, the difference between the analysis of physiological indicators and subjective evaluation was revealed.

3.6 Summary

Traditional lighting evaluation only takes the basic lighting requirements of spaces and exhibits into account and has not considered the influence of spatial visualization conditions and emotions. As shown in Figure 3-12, this study uses innovation thinking to conduct interdisciplinary research on lighting design process. By adopting the lighting evaluation theory, this study adopted SVOE model to influence the visitors' emotional response when they were visually perceiving a space.

Explicit knowledge, also known as direct knowledge, refers to knowledge that can be clearly expressed, such as in written words, diagrams, and mathematical formulas. In SVOE mode, space and optics are part of the explicit knowledge. The knowledge that one cannot clearly express is called tacit knowledge. Visual perception and subjective experience are part of tacit knowledge.

Spatialization is digitization and classification of architectural spaces and exhibit types through analyzing the physical space of museums. Principles and methods for studying architecture clearly defined the space of museum and classified the physical properties and functional scales of the space. For example, by digitizing the length, width, and height of the space, the orientation and size of the exhibition hall can be simulated.

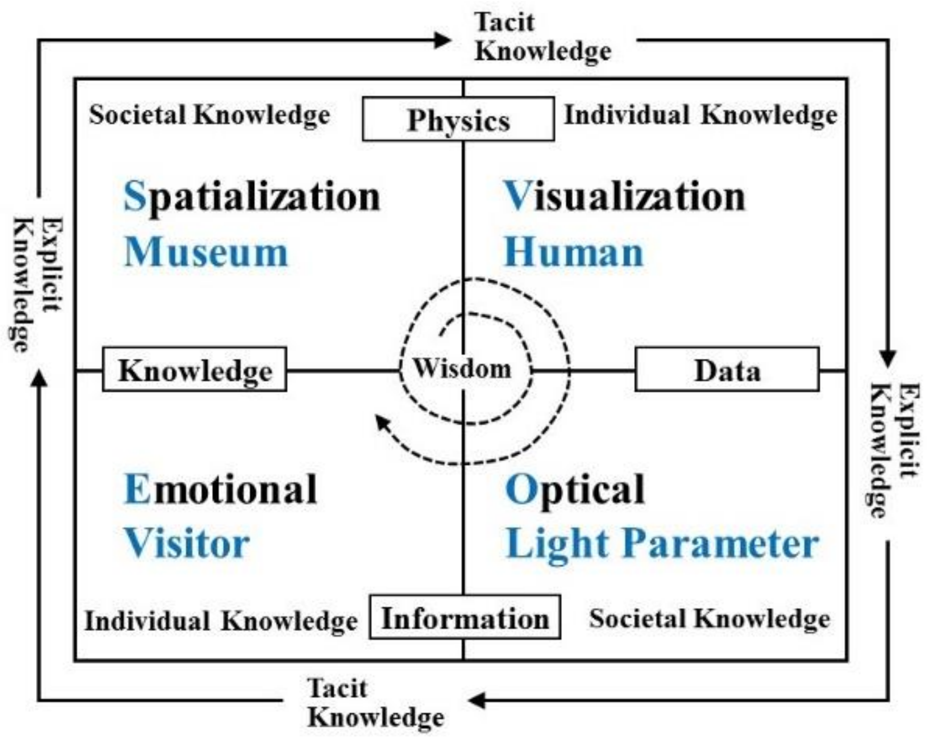


Figure 3-12. The SVOE model of lighting evaluation conversion process.

This part shows the classification of spatial properties and exhibit types. For example, the paintings in museums are classified based on art style (such as ink painting, oil painting, gouache, printmaking, printing and dyeing). The architectural spaces are classified based on certain criteria, so the architectural spaces and exhibits in the museum can be put forward as explicit knowledge. The spatial data parameters that are measured are set as invariants in the lighting evaluation model.

Visualization means the analysis of the visual factors and sensory factors of the human experience. The visual factors in the human senses determine how much information is received by humans from the world around them. The quantity of images perceived by each people is different. Furthermore, there are some other differences among people, such as different age groups and academic levels or artistic experience, which adds even more uncertainties to the definitive characterization of visual factors. Thus, visualization in the museums can be seen as tacit knowledge, which are set as variables in the lighting evaluation model.

Optical engineering belongs to a category of natural science. The evaluative indicators of visible light in optics chiefly include illumination, color temperature, color rendering index and environmental contrast. Through simulating and changing the lighting parameters in architectural spaces, an analysis of the illuminated environment of the exhibits in different spaces becomes possible. Through analysis of the factors of visual influence for different types of people, the optical parameters in the museum turn into the most important factor affecting visitors' emotional response. Indicator parameters are the parameters which govern the way emotions are affected. They have a clear definition, and supply a stable condition for the final emotional response map. Optical engineering can be categorized as explicit knowledge, and optics can be set as invariants in the lighting evaluation model.

The emotional factor is the ultimate indicator of the lighting evaluation model. The previous three indicators in the model are set to create a lighting environment suitable for the observers' emotions. The traditional lighting evaluation did not take human emotional factors into account, and only considered the functional side of lighting in space. It only addressed functional problems and did not consider people's emotional requirements for different spaces. As the lighting evaluation results from the SVOE evaluation model including spatial, visual and optical considerations are comprehensively taken, the emotional evaluation maps for different groups of people can be rendered, making it possible to build different types of lighting environment spaces.

At present, most scholars in the optical part only analyze and experiment on the quality of light. This study is different from theirs. The scholars in architectural field also plan and design the illuminance layout of the overall space. Contrast and uniformity were required, but not too much on color temperature and color rendering. Museum lighting needs further research with the help of interdisciplinary study. To plan the lighting environment and provide a more proper lighting environment, classifying the observers and exhibits in the exhibitions is necessary. In this way, people can feel more cultural information of exhibits in the spaces.

In the area of the knowledge science, the scientific thinking of SVOE evaluation model has a particularly important role, drawing on logical thinking method to transformed the explicit knowledge and tacit knowledge.

The explicit knowledge and tacit knowledge was used to conduct this research. In SVOE lighting evaluation model, space and optics belong to the category of explicit knowledge, while visual perception and subjective experience are part of tacit knowledge. Through the lighting evaluation which results from the "SVOE" model, spatial, visual and optical considerations are comprehensively taken, which enables the realization of emotional evaluation response for different groups of people, thereby making different types of illuminated spaces for art museums.

CHAPTER 4

Subjective Evaluation Experiment of Environment Lighting of Real Art Museums

4.1 Introduction

This chapter explored and experimented on the lighting environment of the Liaoning Provincial Museum and three art museums in Japan, including the National Museum of Western Art, the Aichi Prefectural Museum of Art and the Yamazaki Mazak Museum of Art. The museums were investigated and tested, and the lighting environments of the museums were optimized. Lighting design was combined with interdisciplinary theory to improve the emotional response level of museum visitors. This study adopted subjective experiments to evaluate the real art museum lighting environment. These experiments results were quantified, and the relationship between the observers' emotional response levels and the lighting conditions was analyzed. The evaluation methodology of SVOE was used to test and evaluate these experiments.

4.2 Visitors' Emotional Response of Liaoning Province Museum

4.2.1. Experiment Introduction

Based on an investigation by Liaoning Provincial Museum, the lighting environment brought by artificial light source was used to test visitors' emotive response levels. The investigation focused on visitors' emotive experience. Each group with more than twenty visitors were invited to participate in the evaluation of the exhibits through simulative experiments. The keywords were recorded throughout the exhibition in order to assess the subjective factors that have the greatest impact on the emotive experience, including comfort, texture clarity and color authenticity. The color rendering index in the optical correlation properties was discussed in detail, and the color temperature was briefly described. The corresponding color table data was obtained through the use of the theoretical formula of R, G and B color signals and the color tone formula in experiment 1 building color vision model. Taking 2,950 K tricolor florescent lamps in Liaoning Provincial Art Museum as an example, the corresponding Kendall level correlation coefficients Ra, Qa, FCI were obtained via CIE color rendering sample measurement method and also 2,950 K florescent lamp spectral energy data as the research object in experiment 2. The weight was discussed in combination with the visitors' questionnaires to characterize the color fidelity evaluation of the light source. Finally, the lighting environment characteristics were analyzed, so as to come up with suggestions for improving the emotive response level to museum lighting. This research has far-reaching significance regarding the design of artificial lighting in art museums.

4.2.2 Experiment Design based on Evaluation Model

The illuminance test uses the central distribution method in which the illuminance measurement area is divided into grids. The grids must be square and the illuminance must be measured at the center of each grid. This method is suitable for measuring horizontal illuminance, vertical illuminance or vertical illuminance in the camera direction. The vertical illuminance should indicate the normal direction of the measuring surface of illuminance.

Some areas of the lobby rely on natural light for illumination, and the design of the glass ceiling allows for the penetration of sunlight into the stadium. Other areas are illuminated by energy-saving lamps. The lobby uniformity and light color test selects the lighting area of the energy-saving lamps and uses the central distribution method to take the average of 7 x 2 points. The reflectivity of the lobby and its surrounding walls averages 24.2% of the sampling points, and the color temperature of the artificial light illumination in the lobby is 3,094 K.

Figure 4-1. Illuminance distribution and real scene of lobby illuminance test.

The horizontal average illuminance is 139.30 lx and illuminance uniformity is 0.93. The lobby illuminance of 101.89 lx and illuminance uniformity of 0.49, the corridor illuminance of 121.21 lx and illuminance uniformity of 0.87. As shown in Figure 4-1.

The lobby space was classified of architectural space type in art Museum, it belongs to the public space. In the lighting environment design of public space, the first step is to complete basic illuminance rules. Secondly, these observers to art museums have different purposes, these spaces require different types of lighting environments, these lighting environments can be improved. The lobby space is directly illuminated, the LED lamps were used to illuminate the space.

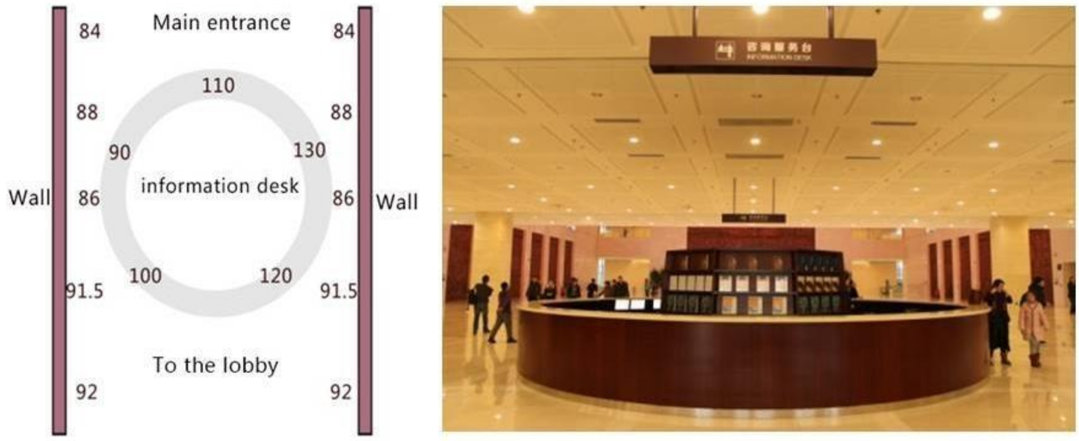


Figure 4-2. Illuminance distribution and real scene of lobby service desk.

The lobby service desk has an average illuminance of 95.53 lx and illuminance uniformity of 0.88, as shown in Figure 4-2. The lighting environment of the lobby has a low color temperature, it has the same color temperature as public and exhibition spaces. This space gives these observers the same visual experience, it did not create a better visual feel.

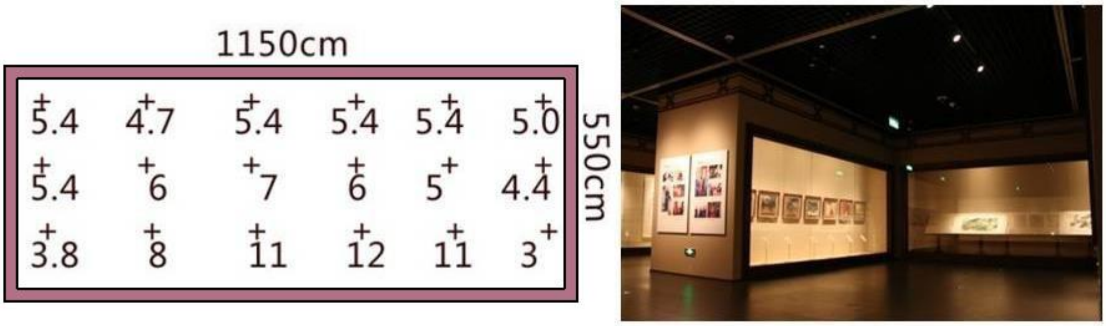


Figure 4-3. Local ground illuminance distribution and real scene of exhibition hall 2.

The exhibition hall 2 was classified in the architectural space type of the art museum, It is a functional exhibition space. In the lighting environment design of the exhibition space, the first step is to complete the functional illumination of the exhibits. Secondly, the display methods in the exhibition space are divided into conventional display and showcase display. The different display methods require different types of lighting environments. The exhibition space was illuminated in both general and key ways, the LED lamps were used to illuminate the space.

The average illuminance on the ground of exhibition hall 2 is 6.31 lx and illuminance uniformity of 0.48, as shown in Figure 4-3.

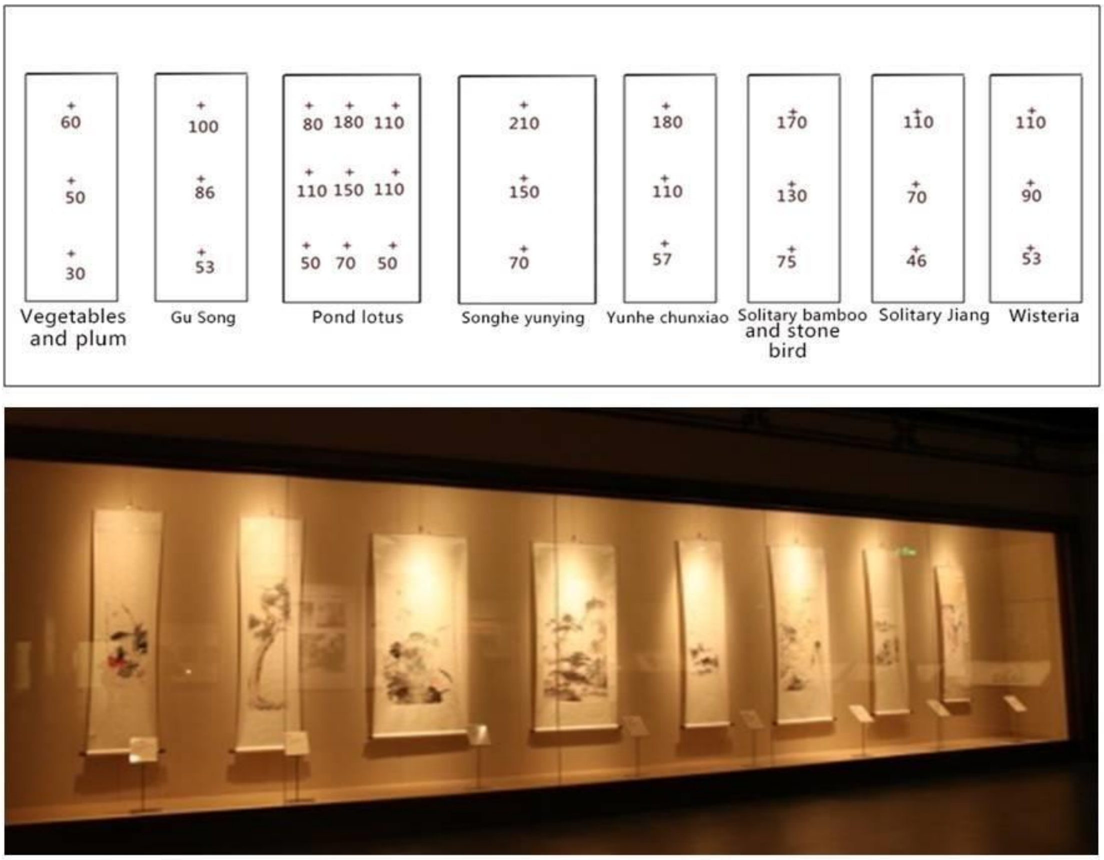


Figure 4-4. Illuminance and real scene of eight paintings in exhibition hall 2**.**

Illuminance distribution of 8 paintings in the exhibition cabinet mean 92.90 lx, and illuminance uniformity 0.32, as shown in Figure 4-4. Hall 4 illuminance of 56.42 lx and illuminance uniformity of 0.89, as shown in Figure 4-5.

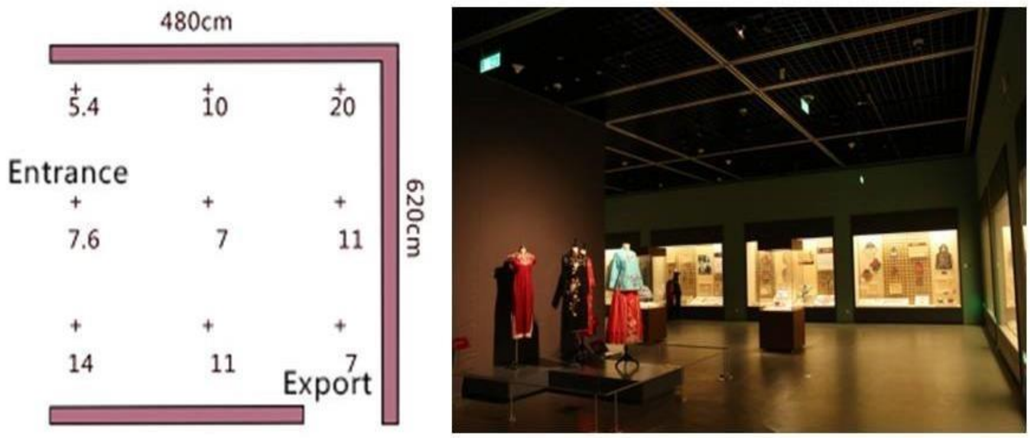


Figure 4-5. Illumination distribution and real scene of exhibition hall 4.

From the perspective of the museum’s simple and omitted function, there are three basic functions with higher requirements for the quality of light and color of lighting. First, the exhibition function, which requires lighting to achieve a higher definition of exhibits. This requirement is related to illumination, fidelity and color gamut of lighting. Second, the preservation and maintenance function of cultural relics or artwork, which requires the lowest light-induced damage of illumination to the target object, while traditional light sources, such as halogen lamps and fluorescent lamps, have the most harmful ultraviolet and infrared spectral components. In contrast, LED light sources can easily adjust and control the spectrum to reduce harmful bands. Third, the lighting environment has studies educational function. For example, lighting requirements of the cultural relic researcher in the workbench environment require lighting to reach maximum fidelity. Besides the fidelity index, color gamut, and relevant index mentioned above, the spectral characteristic parameters that affect the apparent color quality of LED lighting in the museum mainly include illuminance and color temperature.

Table 4-1. The testing results of the Liaoning provincial museum.

	Exhibition hall 2	**Exhibition hall 4**	**Lobby**	**Corridor**
Ra	96.6	99.6	87.0	80.3
R9	89.0	99.0	23.0	7.0
Rf	98.0	100	83.0	79.0
Rg	97.0	100	100	97.0
The flicker index of the lamps	0.009	0	0.011	0
Percentage	4.0 %	0.6 %	5.2 %	0.6 %
The color tolerance	4.4	4.5	6.2	5.1

A spectral radiometer was used to measure the color temperature and color rendering index of the site. The number of measuring points in each environment space does not fall below 9, and the arithmetic average value was used for the color temperature and color rendering index of the tested lighting environment. As shown in Table 4-1.

There were more than 3 measuring points per functional area. The color rendering index and color temperature of each light source were measured respectively when different light sources were used for mixed illumination, and the color rendering index and color temperature after mixing were also measured.

The corresponding data of the lobby, the ground of exhibition hall 2, the eight paintings, and exhibition hall 4, are substituted into the formula to obtain reflection ratios of 0.46, 0.5, 0.72, and 0.54, respectively. The brightness of exhibition hall 2 tested for a lighting environment was 2.83 cd/m^2 and that of exhibition hall 4 was 2.85 cd/m^2.

4.2.3 Experimental and Data Analysis

A subjective evaluation was carried out by inviting an audience to scan the QR code onsite and to complete a questionnaire, convenient and efficient for statistics. A total of 106 sets of data were collected for more than 20 observers. The display areas used were the painting area of hall 2, the embroidery bare display area of hall 4, the epitaph display area of hall 8, and the stereo display area of hall 17.

The non-display areas used were the lobby and corridor. Regarding the exhibition space at the art museum, the setup was measured with the following grades, including a + is 10 points, a - is 8 points, b + is 7 points, b - is 6 points, c + is 5 points, c - is 4 points, d + is 3 points, and d - is 0 points. Indicators included the color performance of the exhibits, the clarity of the detail of the exhibits, the comfort of the lighting environment, and the artistic performance of the overall space of the lighting. The testers marked 1, 2 or 3 according to each score, the average value x 10 x weight value was converted into a score.

Table 4-2. The subjective evaluation results of a basic display.

	Satisfied	**Normal**	**Very satisfied**	**Poor**	**Better**	**Worse**	**Bad**
Realistic degree of color	16	6	0	0	0	0	0
Light source color preference	19	3	0	0	0	0	0
Details of the exhibit	18	4	0	0	0	0	0
The three-dimensional sense	18	4	0	0	0	0	0
The clarity of the outline	13	4	5	0	0	0	0
The brightness acceptance	18	3	0	1	0	0	0
Visual adaptability	16	0	0	0	5	1	0
The pleasure in their hearts	0	0	0	0	3	2	17
The artistic preference of using light	17	0	0	0	3	2	0
Appeal preferences	17	0	0	0	2	3	0

The total subjective evaluation score is equal to the subjective evaluation score x weight; the safety score of the temporary exhibition evaluation for the non-display space is the actual score x 0.4, the actual score x 0.3 for the distribution of light in the environment. The classification of statistical indicators and objective data in the procedure were divided into three levels of indicator systems including a first level indicator, a second level indicator, and a total score. When scoring, the scores of the main points of the investigation were first calculated, then, comprehensively, the scores and total scores of the secondary index and the primary index were calculated. To calculate a first-level index score of each investigation point including the actual score of the first-level index = point score x weight value.

To calculate the secondary index score (where a full score is 100 points) including the actual score of the secondary index = the average value of the investigation and evaluation x 10 x weight. The subjective evaluation total score was equal to 100 points; the total score of objective evaluation was equal to 100 points, the total light maintenance score was equal to 100 points. According to each evaluation, the corresponding scores are above 80 points, above 70 points, above 60 points, and below 60 points, respectively. The evaluations were divided into four grades including excellent, good, average, and poor.

The subjective evaluation results of a basic display were analyzed. As shown in Table 4-2. There were 16 persons who felt satisfied with a realistic degree of color of the exhibits in the museum and 6 persons who felt normal. 19 persons were satisfied with the light source color preference and 3 person felt normal. 18 persons were satisfied with the details of the exhibit, while 4 felt normal. 18 persons were satisfied with the expressive force of the three-dimensional sense, while 4 person felt normal. 5 persons were more than satisfied with the clarity of the outline of the exhibit, 13 were satisfied with it, and 4 felt normal. 18 persons were satisfied with the brightness acceptance of the exhibit, 3 felt normal and 1 felt poor. For visual adaptability including 16 person felt satisfied, 5 felt better, and 1 felt worse. In the heart, 17 felt happy, 3 felt better, and 2 felt worse. 17 persons were satisfied with the taste of using light art, 3 felt better, and 2 felt worse. 17 person felt satisfied with their appeal preferences, 2 felt better, and 3 felt worse.

The highest mean value was 8.4 for the evaluation of artistic preference for light use, while the lowest mean value was 7.6 for the evaluation of visual adaptability and appeal preference. 17 persons were satisfied with the degree of realism of the exhibits in the museum, 2 felt better, 1 felt worse, and 1 felt very bad. For the degree of light source color preference including 15 person felt more than satisfied, 4 person felt satisfied, and 2 person felt poor; 14 persons were satisfied with the details of the exhibit, 6 felt normal, and 1 felt poor. 15 person felt satisfied with the three-dimensional representation, 4 felt normal, and 2 felt poor. 14 persons were satisfied with the clarity of the exhibits, 5 felt better, and 2 felt worse.14 persons were satisfied with the clarity of the outline of the exhibit, 6 felt normal, and 1 felt poor. 14 persons were satisfied with the brightness of the exhibit, 6 felt better, and 1 felt worse. 14 persons were satisfied with the visual adaptability, 6 felt better, and 1 felt worse. 14 persons were very satisfied with the pleasure in their hearts, 6 felt better, and 1 felt worse. 8 person felt very satisfied with the artistic preference of using light, 12 felt better, and 1 felt worse. For the appeal preferences including 5 persons were very satisfied, 15 person felt better, and 1 person felt worse. The highest mean value was 8.5 for subjective visual comfort, and the lowest mean value was 7.6 for light source color preference. As shown in Table 4-3.

Table 4-3. The number of person who were tested on how they felt about different indicators.

	Satisfied	Normal	Very satisfied	Poor	Better	Worse	Bad
Realistic degree of color	17	0	0	0	2	1	1
Light source color preference	4	0	15	2	0	0	0
The details of the exhibit	14	6	0	1	0	0	0
The three-dimensional representation	15	4	0	2	0	0	0
The clarity of the exhibits	14	0	0	0	5	2	0
The clarity of the outline	14	6	0	1	0	0	0
The brightness acceptance	14	0	0	0	6	1	0
Visual adaptability	14	0	0	0	6	1	0
The pleasure in their hearts	14	0	0	0	6	1	0
The artistic preference of using light	8	0	0	0	12	1	0
Appeal preferences	5	0	0	0	15	1	0

Using the entropy weight method to weigh the influencing factors in the questionnaire; if the amount of data information of a certain factor is larger, the entropy value will be smaller, and instead, it should be given greater weight. After screening, the factors affecting the lighting of the museum's environment, such as the degree of realism of display color, the degree of light source color preference, the display detail expression, the three-dimensional expression, the display texture definition, the display outer outline definition, the display brightness acceptance, the visual adaptability, the psychological pleasure, and the degree of light artistic preference, were selected, and the test questionnaire data were processed to form a matrix. In order to ensure that the data will not be affected by dimensions during use, it is convenient to establish a comprehensive index and standardize the data to obtain a normalized matrix nm.

Table 4-4. The weight value of subjective evaluation of temporary exhibitions.

	The secondary weight	**The weight x 10**
Realistic degree of color	20 %	16.2%
Light source color preference	5%	3.8%
The detail of the exhibits	10%	8.3%
The expressive force of stereoscopic impression	5%	4.1%
The texture definition of the exhibits	5%	4.1%
The outline definition of the exhibits	5%	4.0%
The brightness acceptance of the exhibits	5%	4.1%
The visual adaptability	5%	4.0%
The subjective visual adaptability	5%	4.3%
The happiness in the heart	5%	4.0%
The artistic preference of light usage	20%	16.4%
The appeal preferences	10%	7.7%
the brightness acceptance of the exhibits	10%	8.1%
The visual adaptability	10%	7.7%
The subjective visual adaptability	10%	8.0%
Feelings of happiness	10%	7.9%
The artistic preference of light usage	40%	34.4%
The appeal preferences	20%	15.2%
The sum of the attack		81.3%

In the subjective evaluation of temporary exhibitions, the secondary weight of the degree of realism of the exhibits was 20 %, the weight x 10 was 16.2 %, and the degree of light source color preference corresponded to 5 % and 3.8 %. The detail of the exhibits corresponded to 10 % and 8.3 %, respectively. The expressive force of stereoscopic impression corresponded to 5 % and 4.1 %. The texture definition of the exhibits corresponded to 5 % and 4.1 %. The outline definition of the exhibits corresponded to 5 % and 4.0 %. The brightness acceptance of the exhibits was 5 % and 4.1 %. The visual adaptability corresponded to 5 % and 4.0%. The subjective visual adaptability corresponded to 5 % and 4.3 %. The happiness in the heart corresponded to 5 % and 4.0 %. The artistic preference of light usage corresponded to 20 % and 16.4 %. The appeal preferences corresponded to 10 % and 7.7 %. In the subjective evaluation of the hall, the brightness acceptance of the exhibits was 10 % and 8.1%. The visual adaptability corresponded to 10 % and 7.7 %. The subjective visual adaptability corresponded to 10 % and 8.0 %. Feelings of happiness corresponded to 10 % and 7.9 % respectively. The artistic preference of light usage corresponded to 40 % and 34.4 %. The appeal preferences corresponded to 20 % and 15.2 %. The sum of the attack weights x 10 was 81.3.%. As shown in Table 4-4.

Table 4-5. The weight value of the corridor subjective evaluation.

	The secondary weight	**The weight x 10**
The brightness acceptance of the exhibits	10%	7.4%
The visual adaptability	10%	6.9%
The subjective visual adaptability	10%	7.5%
Feelings of happiness	10%	7.0%
The artistic preference of light usage	40%	29.2%
The appeal preferences	20%	12.8%
The attack weighted value x 10 totaled		70.8%

In the corridor subjective evaluation, the brightness acceptance of the exhibits was 10% and 7.4%, the visual adaptability corresponded to 10% and 6.9%, the subjective visual adaptability corresponded to 10% and 7.0%, feelings of happiness corresponded to 10% and 7.0%, respectively. The artistic preference of light usage corresponded to 40% and 29.2%. The appeal preferences corresponded to 20% and 12.8%, the attack weighted value x 10 totaled 70.8. As shown in Table 4-5.

Table 4-6. Subjective evaluation of the satisfaction of the museum hall results.

	Satisfied	**Very satisfied**	**Better**	**Worse**
Brightness Acceptance	5	0	14	1
Visual adaptability	5	0	14	1
Subjective visual comfort	7	0	12	1
Feelings of happiness	0	4	15	1
Using light art	0	0	0	0
The appeal preferences	0	10	9	1

Analysis of the subjective evaluation results of the museum hall showed 5 persons were satisfied with the brightness acceptance of the museum exhibits, 14 felt better, and 1 felt worse. 5

persons were satisfied with the visual adaptability, 14 felt better, and 1 felt worse. 7 persons were satisfied with the subjective visual comfort, 12 felt better, and 1 felt worse. 4 persons were very satisfied with their happiness, 15 felt better, and 1 felt worse. 10 persons fond of using light art felt very satisfied, 9 felt better, and 1 felt worse. For the appeal preferences, 5 person felt very satisfied, 13 person felt better, and 2 person felt worse. The highest average was 8.6 for the artistic taste of light consumption, while the lowest average was 7.6 for appeal. As shown in Table 4-6.

Table 4-7. The subjective evaluation results of the museum corridor.

	Satisfied	**Very satisfied**	**More satisfied**	**Better**	**Worse**	**Bad**	**Very bad**	**Poor**	**Very poor**
Brightness acceptance	3	0	0	19	0	0	0	0	0
Visual adaptability	0	2	20	0	0	0	0	0	0
Subjective visual comfort	5	0	0	17	0	0	0	0	0
Psychological pleasure	3	0	0	17	1	0	1	0	0
An artistic preference degree of light	3	0	0	18	1	0	0	0	0
The appeal preferences	15	2	0	0	0	0	0	3	2

Analysis of the subjective evaluation results of the museum corridor showed 3 persons were satisfied with the brightness of the museum's exhibits and 19 felt better. For visual adaptability, 2 person felt very satisfied, 20 persons were more satisfied. 5 persons were satisfied with the subjective visual comfort and 17 felt better. 3 persons were satisfied with their psychological pleasure, 17 felt better, 1 felt worse, and 1 felt very bad. 3 persons with an artistic preference degree of light felt very satisfied, 18 felt better, and 1 felt worse. For the appeal preferences, 2 persons were very satisfied, 15 persons were satisfied, 3 persons felt poor, and 2 persons felt very poor. The highest mean value was 7.5 for the subjective visual comfort, and the lowest mean value was 6.4 for appeal. As shown in Table 4-7.

Emotional quantitative evaluation and analysis

Through the variability within and between observers, the root mean square value (RMS) on the emotional scale was used to test the uncertainty of the experimental evaluation data. Variability within the observer indicated how well the observer's response was when repeated under the same evaluation conditions. The difference between the observers indicates the degree to which the responses of the observers are consistent with the average values within the group. In addition, the

RMS value can determine the consistency of the two data sets.

The smaller the RMS value, the greater the consistency between the two data sets. The higher the RMS value, the worse the consistency within or between observers. The change of the root mean square value depends on the scale range of the dataset. For variability within that observer, Xi (X1、X2、X3...) and Yi (Y1、Y2、Y3...) represent the first score and the second score of the individual observer of the number i stimulus, respectively. For variability among observers, yi is the score of the individual observer for the i stimulus. Xi is the average value of all observers for the i stimulus. N is the total number of stimuli. As shown in Table 4-8.

Table 4-8. Root-mean-square (RMS) values of inter- observer variability and intra-observer variability.

No.	Emotional scale	Inter-observer variability	Intra-observer variability
1	Colorful / Monotone	0.89	0.37
2	Bright / Dark	0.84	0.35
3	Warm / Cold	0.90	0.36
4	Relaxed / Tense	0.83	0.39
5	Soft / Hard	0.96	0.44
6	Natural / Unnatural	0.92	0.46
7	Negative / Positive	0.96	0.35
8	Comfortable / Uncomfortable	0.92	0.43
9	Visibly / Fuzzy	0.92	0.35
10	Interesting / Boring	0.88	0.38
11	Classical / Modern	0.92	0.37
12	Clarity / Messy	0.85	0.35
Mean Value		0.89	0.36

Consistency Verification of Emotional Response Model

This study was applied ERMS（Electronic Response Management System）for indoor lighting to watch the paintings in art museum. Based on linear regression analysis, it is possible to accurately predict component museum lighting with CCT and illuminance. Therefore, the RMS for installing small-scale and large-scale spaces is expressed as a visibility model (VM) and a warm model (WM).

Based on the brightness, the VM fitting input of the small-scale and large-scale spaces was derived. The WM fitting for small-scale and large-scale spaces was derived using CCT as the input. The model with TC ranging from 2,700 K to 6,500 K. Substituting the measured data from the museum into the correlation analysis of the available scores and predicted dates. As shows in Figure 5-6, including (a) the visibility model (VM) in a small-scale space, (b) the warm model (WM) in a small-scale space, (c) the visibility model (VM) in a large-scale space, and (d) the warm model (WM) in a large-scale space.

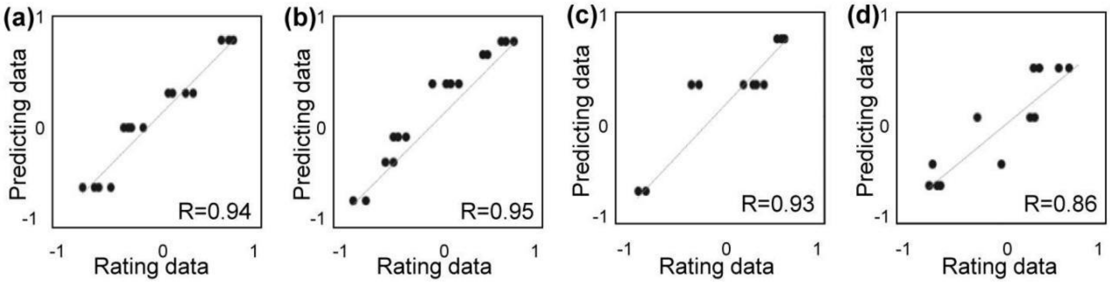


Figure 4-6. Correlation analysis between rating scores and predicted date.

According to the measured score, the predicted score, and the correlation report coefficient (R), it can be seen that all models predict the visual results well and have higher values of R between the predicted score and the rating score. The small-scale space predicted scores were 0.94 (VM) and 0.95(WM), and the rating scores were 0.93 (VM) and 0.86 (WM). This experiment of the score refers to the average evaluation score collected from all subjects, and the predicted score is calculated based on the recommended. The WM r value (0.86) in a large-scale space is slightly lower than that in a small-scale space (0.95), as shown in Figure 4-6.

4.2.4 Discussion

This part adopts the spatial principle and method of SVOE to collect experimental data. These space types include halls, lobby, temporary exhibitions, and general exhibitions. The preference for basic display lights was relatively high, and the visual adaptability and appeal preferences needed to be improved. The subjective visual comfort of a temporary display was relatively high, and the degree of light source color preference needed to be improved. The artistic taste of the hall lighting was high, and the appeal taste needed to be improved. The corridor lighting offered good subjective visual comfort but still had room for improvement, while the appeal preference could generally be improved.

The distribution of light sources, the types of light source, and the optical parameters of the light sources in the Liaoning Provincial Art Museum were analyzed. In terms of the light effect alone, the traditional halogen lamps have been used as the main lighting of the exhibition for a long time due to its good color rendering, light distribution, and easy adjustment of brightness. The color temperature of the halogen lamps was as low as 2,700 K, resulting in poor brightness and vision, hence a greater illumination was required which could virtually increase the exposure of the exhibits. According to the optical parameters of each exhibit, halogen lamps have strong infrared radiation, so the amount of infrared radiation on exhibits would increase, especially for display cabinet lighting. The space lighting environment conforms to the requirements of lamp selection.

Factors such as the display's color reduction degree, light source color preference degree, detail ability of the display, three-dimensional display ability, texture definition of the display, outline definition, light brightness acceptance degree, visual adaptability, and happiness in the heart are all important factors for evaluating museum lighting. It is necessary to conform to the real judgment of daily testers on the color of the exhibits. The light source color was in good accordance with the expectation of appraisal. The stereoscopic effect and light color comparison of the exhibits were exactly the same. Regarding the artificial nature of the museum, attention should also be given to the artistic expression of lights. The overall artistic effect, the import theme in line with the museum's own positioning and collection characteristics, and the exhibition content should form a unified and coordinated whole. The lighting environment of Liaoning Provincial Art Museum used the indicators in the evaluation model to assess the space in the environment. Once an objective evaluation score for the museum was obtained, it analyzed the data to get the results of the evaluation response, which verified the influence of main parameters in lighting environment on visitors' emotional response. The experimental results show that the lighting environment of the general exhibition is the most important in the spatial classification.

4.3 Environment Lighting Evaluation of the Japanese Art Museums

4.3.1 Experimental Introduction

This experiment mainly studied the effect of artificial lighting environmental factors on the psychological emotions of observers in the large and practical space of the museums. The purpose was to reveal the relationship between the observers' response and the artificial lighting condition in the actual art museum space. Field research regarding three art museums in Japan was carried out and the optical environment parameters applied in those museums were quantified. The innovational method was to define the artificial lighting environment space in the way of classified lighting design. Each art museum collected feedback on its lighting from 31 observers. In addition, this thesis analyzed and discussed the influence of the actual spatial lighting parameters of museum buildings on observers' psychological emotions (comfort, clarity, preference and warmth) under three modes of illuminance and color temperature (CCT) combination. One-way ANOVA and correlation analysis got the correlation of the four evaluation and three lighting environments indexes, which were less than 0.05. The observer in an environment with high illuminance and a high CCT gave higher psychological evaluation of the art museum.

4.3.2 Experiment Design based on Space Models

Museum Lighting Environment

The first museum is the national museum of western art Figure 4-7a. The second museum is the Aichi Prefectural museum of art Figure 4-7b. The third museum is Yamazaki Mazak museum of art Figure 4-7c. The measuring is the painting exhibition room of the 19th–20th century. The parameters of CCTs and illuminance in the three lighting environment experimental spaces is within Kruithof's rule [25].

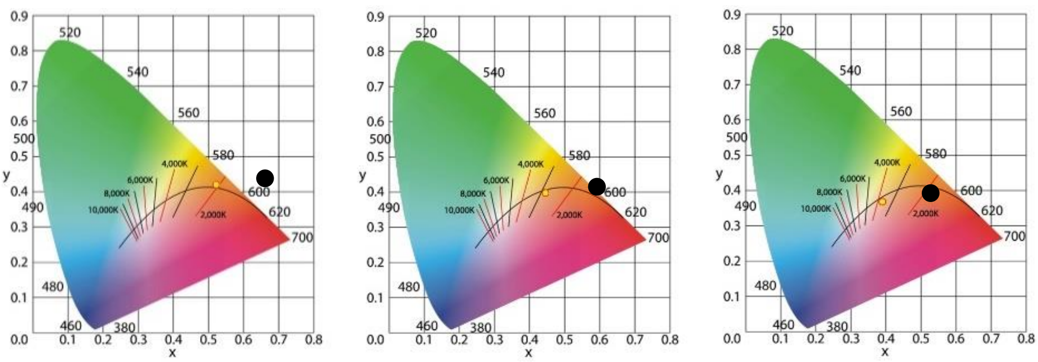
This experiment adopts lighting environment parameters of three museums to study the factors affecting psychological perception via different lighting methods (Only the lighting environment and typical paintings and background were evaluated). Dang R et al. studied the effects of illumination on inorganic pigments used in traditional paintings, they think that high illuminance could be a problem for some museum objects including textiles, tempera paints, etc. [82].

(**a**) (**b**) (**c**)

Figure 4-7. Three museum lighting environments. (a) The national museum of western art. (**b**) The Aichi Prefectural museum of art. (**c**) The Yamazaki Mazak museum of art.

CCTs analysis of the three lighting environments is shown in Figure 4-8. The first and second lighting environments CCT light color slant yellow, giving us a warm feeling. The CCT of the third lighting environment is white, which is a warm white light.

CRI analysis of the three lighting environments is shown in Figure 4-9. The R9 of the three art museums is 46, 92 and 88. CCTs, x and y are used to describe the CIE1931 chromaticity. The three spaces use different light sources and spectra, this method is used to define and quantify the parameters of the art museum lighting environment. And the CCTs in art museum lighting is different, which brings different visual perception and feeling to the observer. The lower the CCT, the warmer the hue of the art museum space; the higher the CCT, the cooler the hue of the art museum space and different CCTs give different subjective feelings. In order to accurately represent the color of the lighting environment. The study uses the x and y values to give the position of the Correlated color temperatures (CCTs) in CIE1931 accurately and provide more detailed optical data.

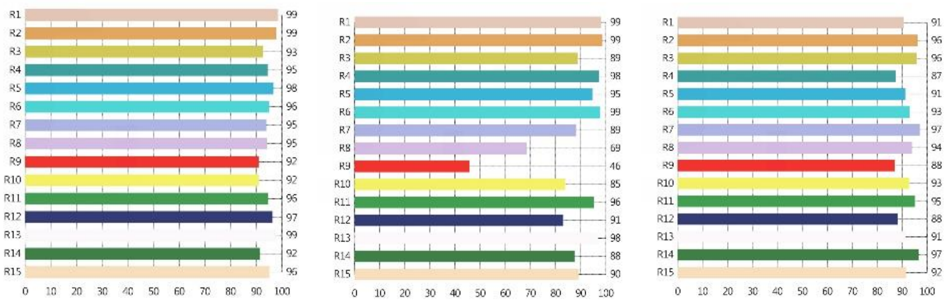


(**a**) (**b**) (**c**)

Figure 4-8. Color coordinate diagram of three lighting environments. (**a**) Direct lighting CCT = 2,079 K. The national museum of western art. (**b**) Indirect lighting CCT = 2,960 K. The Aichi Prefectural museum of art. (**c**) Mixed lighting CCT = 3,568 K. The Yamazaki Mazak museum of art.

Shown in Figure 4-8, illuminance is direct illuminance, CCT = 2,079 K, x = 0.5239, y = 0.4208, color rendering index Ra = 96, R9 = 92, average illuminance Eav = 84 lx. The second museum is the Aichi art museum Figure 4-7b. The measuring is the permanent exhibition room. The illuminance method is indirect illuminance, CCT = 2,960 K, x = 0.4409, y = 0.4073, color rendering index Ra = 90, R9 = 46, average illuminance Eav = 115 lx. The third museum is the Yamazaki Mazak art museum Figure 4-7c. The measuring is the painting exhibition room on the fifth floor. The lighting method is mixed lighting, CCT = 3,568 K, x = 0.4130, y = 0.4196, color rendering index Ra = 93, R9 = 88, average illuminance Eav = 538 lx.

The R9 is a very important evaluation index for museum lighting. R9 is saturated red, it is an indicator of the ability of the light source to restore the redness of the object. The larger the value of R9, the higher the ability of the light source to reduce the redness of the object. The LED light source used in most museums is blue light to excite yellow phosphors to emit light. The value of the red light spectrum in the spectrum of this light source is relatively low, but the red spectrum is important in the lighting of art museums, the R9 value was used as an important indicator of evaluating the quality of the lighting environment.

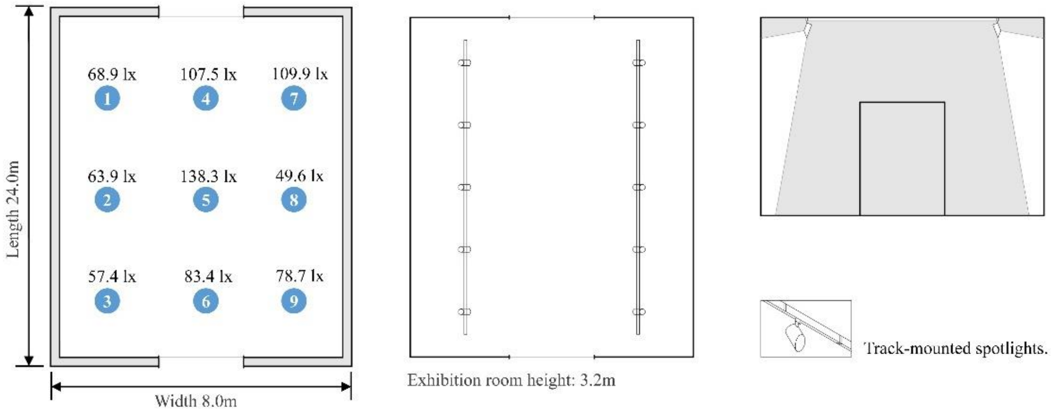


(**a**) (**b**) (**c**)

Figure 4-9. Color rendering index(CRI) of three lighting environments. (**a**) Direct lighting Ra = 96, R9 = 92. The national museum of western art. (**b**) Indirect lighting Ra = 90, R9 = 46. The Aichi Prefectural museum of art. (**c**) Mixed lighting Ra = 93, R9 = 88. The Yamazaki Mazak museum of art.

People have maintained close ties with architecture. The size of the space inside a building also determines whether the lighting environment is comfortable for us. Good lighting design is inseparable from understood its architectural and space environment. The research classified the types of space, lighting and exhibits of three art museums. This type of research approach can be better defining the lighting environments of the space and exhibits.

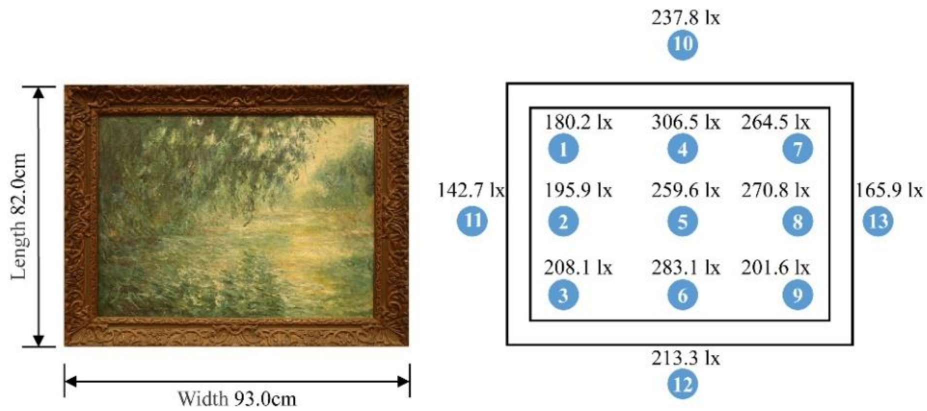
The illuminance distribution in the national museum of western art lighting environment is shown in Figure 4-10a, the arrangement and elevation of the direct lighting display source is shown in Figure 4-10b. Direct lighting is adopted in the lighting environment. The lights shine directly into the middle of the paintings in the museum, highlighting the position of the paintings. The national museum of western art is installed with track on one side of the roof area by use of spotlights for direct lighting is shown in Figure 4-10.



(**a**) (**b**)

Figure 4-10. The national museum of western art building interior. (**a**) Illuminance plane spot test. (**b**) The arrangement and elevation of the direct lighting display source.

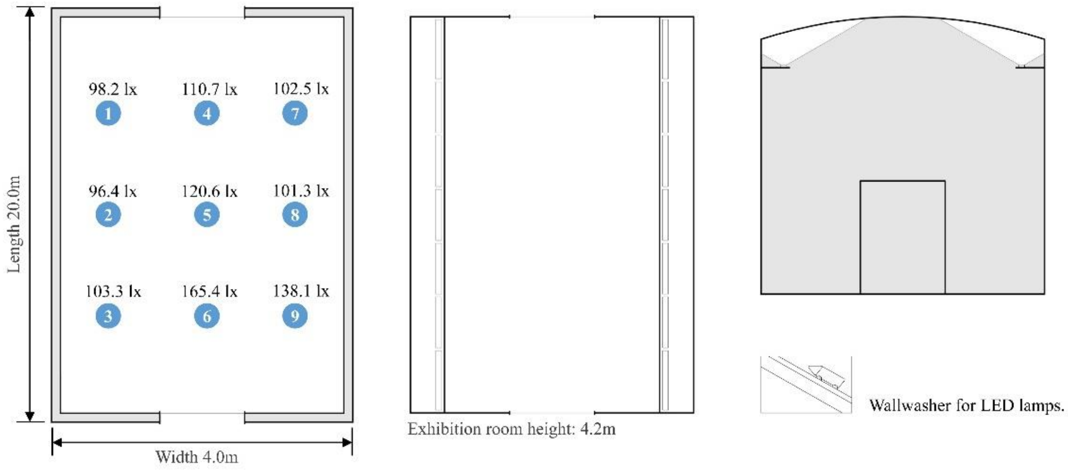
Figure 4-11 shows the paintings used in the national museum of western art lighting experiment, shows the 13 illumination distribution test points include typical oil painting and background wall. It was drawn by Claude Monet from French, an impressionist painter. The oil painting title is morning on the seine. The oil painting size is 82.0 × 93.0 cm, painting date in 1898. The average illumination of the oil painting and background wall is 225.4 lx, the minimum illumination is 180.2 lx, and the uniform of illumination is 0.80.



No.	1	2	3	4	5	6	7	8	9	10	11	12	13
lx	180.2	195.9	208.1	306.5	259.6	283.1	264.5	270.8	201.6	237.8	142.7	213.3	165.9
AVG	225.4	Max		306.5		Min		180.2		Uniform		0.80	

Figure 4-11. Illumination distribution test of oil painting in indirect lighting environment.

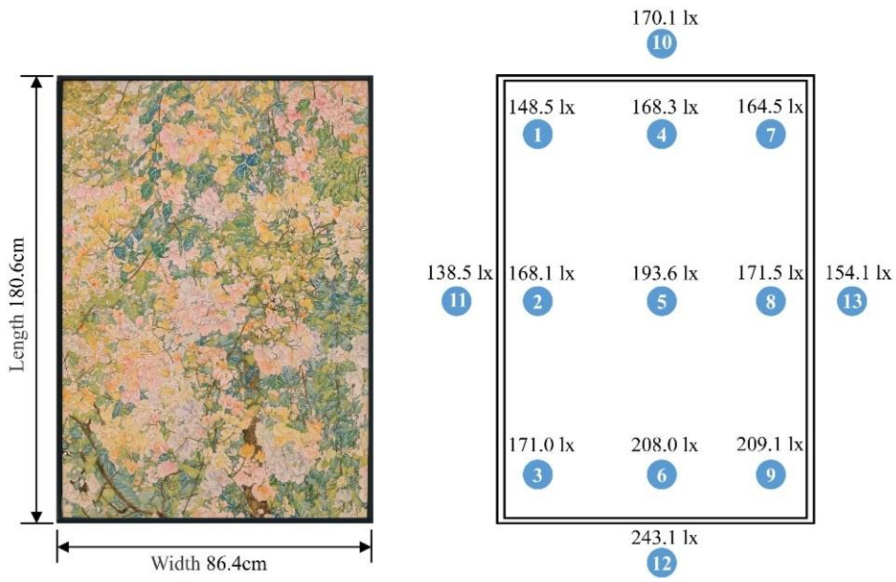
The illuminance distribution in the Aichi Prefectural museum of art lighting environment is shown in Figure 4-12a, the arrangement and elevation of the indirect lighting display source is shown in Figure 4-12b. Indirect lighting is adopted in the lighting environment. The light source shines on the ceiling, illuminating the entire lighting environment with reflected light. The Aichi Prefectural museum of art has LED lamps arranged roof with indirect lighting is shown in Figure 4-12.



(**a**) (**b**)

Figure 4-12. The Aichi Prefectural museum of art building interior. (**a**) Illuminance plane spot test. (**b**) The arrangement and elevation of the indirect lighting display source.

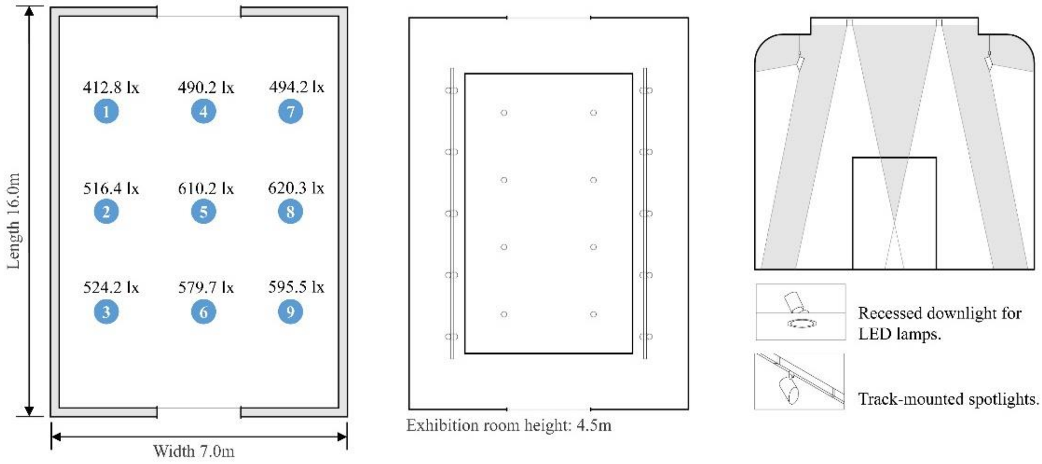
Figure 4-13 shows the paintings used in the Aichi Prefectural museum of art lighting experiment, shows the 13 illumination distribution test points include typical oil painting and background wall. It was drawn by Rinen Hoshi from Japan, a contemporary painter. The oil painting title is spring colorful flowers. The oil painting size is 180.6 × 86.4 cm, painting date in 2016. The average illumination of the oil painting and background wall is 117.6 lx, the minimum illumination is 148.5 lx, and the uniform of illumination is 0.84.



No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
lx	148.5	168.1	171.0	168.3	193.6	208.0	164.5	171.5	209.1	170.1	138.5	243.1	154.1
AVG	177.6	Max		209.1		Min		148.5		Uniform		0.84	

Figure 4-13. Illumination distribution test of oil painting in indirect lighting environment.

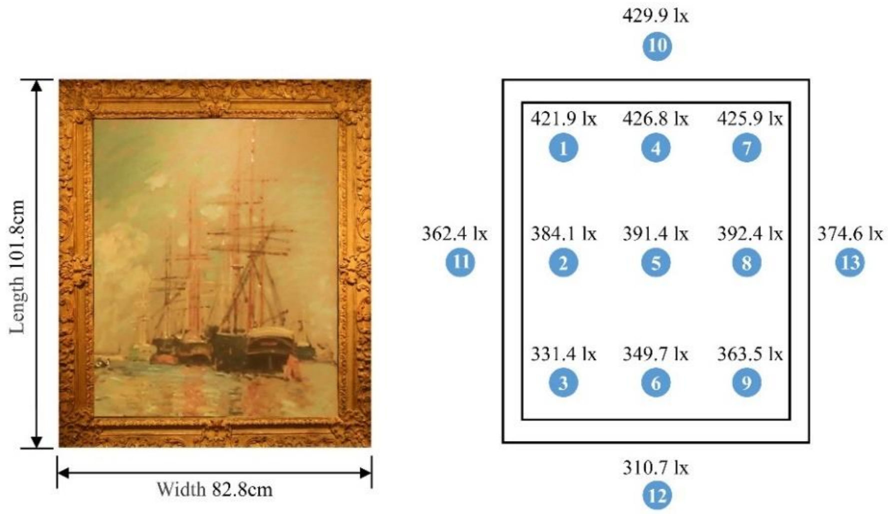
The illuminance distribution in the Yamazaki Mazak museum of art lighting environment is shown in Figure 4-14a, the arrangement and elevation of the mixed lighting display source is shown in Figure 4-14b. Mixed lighting is used in the lighting environment. Both the light source directly illuminating the painting and the light source illuminating the ground are combined. The Yamazaki Mazak museum of art is equipped with an average arrangement for LED recessed downlights. A series of singlets allow additional accent lighting using spotlights is shown in Figure 4-14.



(**a**) (**b**)

Figure 4-14. The Yamazaki Mazak museum of art building interior. (**a**) Illuminance plane spot test. (**b**) The arrangement and elevation of the mixed lighting display source.

Figure 4-15 shows the paintings used in the Yamazaki Mazak museum of art lighting experiment, shows the 13 illumination distribution test points include typical oil painting and background wall. It was drawn by Jean-Marc Nattier from Paris, a rococo painter. The oil painting title is sailboat in the morning. The oil painting size is 101.8 × 82.8 cm, painting date in 1739. The average illumination of the oil painting and background wall is 381.9 lx, the minimum illumination is 331.4 lx, and the uniform of illumination is 0.87.



No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
lx	421.9	384.1	331.4	426.8	391.4	349.7	425.9	392.4	363.5	429.9	362.4	310.7	374.6
AVG	381.9	Max		426.8		Min		331.4		Uniform		0.87	

Figure 4-15. Illumination distribution test of oil painting in mixed lighting environment.

Psychophysical Experiment

This experiment applies the method of categorical judgment in the psychophysical experiment method. The observer performs subjective scoring of comfort, clarity, preference and warmth in three different lighting environments.

A minimum of 1 point means completely not comfort/ clarity/ preference/ warmth, a score of 2 means not comfort/clarity/preference/warmth, a score of 3 means less comfort/ clarity/ preference/ warmth, a score of means relatively comfort/clarity/preference/warmth, score of 5 for comfort/ clarity/ preference/ warmth, and up to a score of 6 for very comfort/ clarity/ preference/ warmth.

The experimental process is as below:

1. Introduction. Introduce the content and process of the art museum lighting experiment to the observer.

2. Visual testing. Test the observer for visual defects or color blindness.

3. Environmental adaptation. The observer first adapts to the museum lighting environment under a typical space for about 2 min. The experiment should allow the observers to whole experience the art museum lighting environment of the exhibition space and evaluate and feel the lighting environment of the viewing space, traffic space and rest space through observers' vision.

4. Main experiment. Through the moving, viewing and staying of the observer in the exhibition space visual task is completed, the process takes about 5 min. Next, observers viewing the typical painting lighting environment in the viewing space, observe the oil paintings and feel the lighting environment in the viewing space, the process takes about 3 min.

5. Subjective evaluation. The observer makes a subjective evaluation of the current lighting environment in the art museum, the observer fills in the corresponding score according to the questionnaire. The experimental process obtained subjective response data through four evaluation dimensions (comfort, clarity, preference and warmth) from observers. And analyzes the influence of the actual spatial lighting parameters of art museum buildings on observers' psychological emotions.

6. Museum lighting environmental changes.

7. Repeat steps 3–5 until the experimental data are collected.

Observer Difference Analysis

The same 31 observers selected went to three museums for field research and data evaluation. Each was evaluated for comfort, clarity, preference and warmth in three lighting environments, and 93 groups of subjective evaluation data were obtained. In this experiment, the coefficient of variation (CV) is adopted to compare the data stability among observers [83].

Table 4-9. CV for evaluating scores in different lighting environments.

CV	Comfort	Clarity	Preference	Warmth
Environment 1	19.86	17.87	16.58	17.23
Environment 2	18.92	14.05	14.96	13.81
Environment 3	13.39	13.54	12.41	20.16

Table 4-9 indicates the CV for the evaluation scores in different lighting environments. Environment 1 is the national museum of western art. Environment 2 is the Aichi Prefectural museum of art. Environment 3 is the Yamazaki Mazak museum of art. It's verified that the data in Table 2 are within the normal limits of the psychophysical experiment CV, the data obtained from the psychophysical experiments in this study are all reliable.

4.3.3 Experimental Data Analysis

Through analyzing the spectral power distribution of the actual lighting environment of the three art museums and considering illuminance and CCT, the ΔC* is obtained by calculation (measured in terms of the quantity ΔC*, an object saturation measure computed in CIELAB color space that corresponds to the mean value of the individual ΔC* values of the 15 CQS test color samples VS1–VS15) [84]. It is observed in Table 4-10, three nominal illuminance levels (84 lx, 115 lx, 538 lx) and three nominal CCT levels (2,188 K, 2,903 K, 3,671 K) were used. All of them were at the same high CRI ($90 \leq Ra \leq 96$) level corresponding to a low oversaturation level ($-0.08 \leq \Delta C^* \leq 1.08$).

By assessing their visual impressions about CP and SP, try to find "good" levels of the visual attributes. Under the actual horizontal illuminance of the light source, their visual impression on the scene brightness was evaluated, including CP and SP. The data in Table 4-10 indicates SP and CP. Distinctly, samples 3 > 2 > 1 demonstrate that the values of CP and SP of environment 3 are good.

Table 4-10. Three museums of 3 spectral properties. (No.1 is the national museum of western art. No.2 is the Aichi Prefectural museum of art. No.3 is the Yamazaki Mazak museum of art).

No.	CCT (K)	ΔC*	Illuminance (lx)	CP	SP	Ra
1	2,188	−0.08	84	7.82	8.96	96
2	2,903	1.08	115	29.89	30.11	90
3	3,671	0.41	538	61.17	63.98	93

From the perspective of correlation, the Pearson correlation coefficient between subjective preference score and the calculated results of the index (CP, SP) was calculated. The p-value was adopted to indicate whether the correlation was significant.

As shown in Table 4-11, the p-value of CP and SP was less than 0.05, indicating a high significance level. SP < 0.01 shows that it was more significant, and SP accounted for more of the preference score. The Pearson correlation coefficients of CP and SP were both higher than 0.99, indicating that their preference scores were significantly correlated with CP and SP.

Table 4-11. Pearson correlation coefficient between preference rating and index (CP, SP).

Name	r	P-Value
CP	0.9996	0.0172
SP	1.0000	0.0040

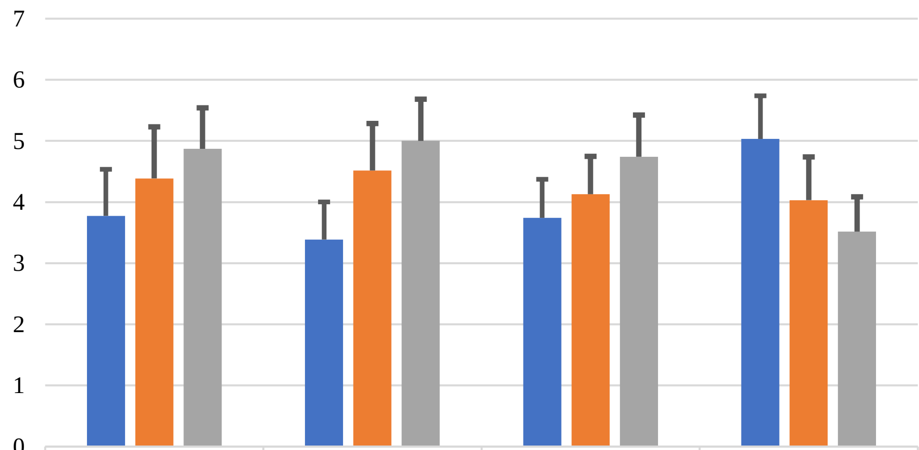
One-way ANOVA was carried out on the observer's evaluation in the three lighting environments. The results are demonstrated in Table 4-12. The results in Table 4-12 indicate that the significance is less than 0.01 under the four indicators of comfort, clarity, preference and warmth, which demonstrates a significant difference in the observer's evaluation of comfort, clarity, preference and warmth in three lighting environments. The analysis of variance (ANOVA) used to test the significance of difference between two or more samples.

Table 4-12. Results of one-way ANOVA of different psychological perceptions in three lighting environments.

Evaluation Items	**F Value**	**Significant**
Comfort	16.130	0.000
Clarity	44.349	0.000
Preference	18.990	0.000
Warmth	41.780	0.000

In three different lighting environments, the four psychological factors (comfort, clarity, preference, warmth) are processed in relation to the data. Figure 4-16 shows the mean of the psychological perception of the 31 observers in these three lighting environments.

It can be observed from Figure 4-16 that all the four psychological perception degrees are above 3, showing that the three environments are more or less suitable for person's psychological feelings. In the three environments, person hold the same views on comfort, clarity and preference. They all think that the lighting environment in the third environment is the most suitable, while the special condition of warmth is on the contrary. Environment 1 has the highest data feedback value for warmth, caused by the low CCT environment.



	Comfort	Clarity	Preference	Warmth
Environment1	3.774193548	3.387096774	3.741935484	5.032258065
Environment2	4.387096774	4.516129032	4.129032258	4.032258065
Environment3	4.870967742	5	4.741935484	3.516129032

Environment1 Environment2 Environment3

Figure 4-16. Mean value of four psychological perceptions in different environments (Environment 1 is the national museum of western art. Environment 2 is the Aichi Prefectural museum of art. Environment 3 is the Yamazaki Mazak museum of art).

If the value of CCTs and illuminance is low, it will result in the lack of brightness that is required to view the works and the decline in clarity. On the whole, the lighting in 3 is the most comfortable and enjoyable for the observers. The error bar for comfort, clarity and warmth in environment 1 and 2 are not at the same level as the lowest. The error bar of the four dimensions of environment 1 and environment 3 quite differ, and the psychological evaluation level of observers is quite different.

In a bid to investigate the relationship between CCT and psychological perception factors (comfort, clarity, preference and warmth), we used the correlation analysis in the mathematical statistics method and the results are shown in Table 4-13.

Table 4-13. Correlation between psychological perception and lighting environment.

Correlation						
		Lighting-Environment	**Comfort**	**Clarity**	**Preference**	**Warmth**
Lighting-environment	Pearson correlation	1	0.997 **	0.974	0.992	−0.983
	Significant		0.047	0.146	0.080	0.118
Comfort	Pearson correlation		1	0.988	0.980	−0.994
	Significant			0.099	0.127	0.071
Clarity	Pearson correlation			1	0.938	−0.999 *
	Significant				0.226	0.028
Preference	Pearson correlation				1	−0.952
	Significant					0.198
Warmth	Pearson correlation					1
	Significant					

* Significant correlation at the 0.05 level (bilateral). ** Most significant correlation at the 0.01 level (bilateral).

As it shows in Table 4-13, the significance of comfort and lighting environment was 0.047 < 0.05, and the correlation coefficient was 0.997, demonstrating that comfort was significantly correlated with the lighting environment. The significance of clarity, preference and warmth to the lighting environment was >0.1, but not much higher than 0.1, demonstrating that there was a correlation but the significance was not high. The significance of comfort and clarity, preference and warmth was >0.1, but not much higher than 0.1, indicating that there was a correlation but the significance was not high. The significance of clarity and warmth was 0.028 < 0.05, and the correlation coefficient was −0.999, demonstrating a significant negative correlation between clarity and warmth.

The results show that the comfort levels found in this study are partially consistent with Kruithof's rule. The lighting environment in this thesis takes 3 typical illuminances and CCTs levels.

That is to say, low CCT and low illuminance, middle CCT and middle illuminance, and high CCT and high illuminance. Through a series of experimental data analysis, we find that high illuminance and high CCT are the most popular lighting environment standards among observers. The lighting environment is restricted by lots of factors, and only the matching mode of CCT and illuminance is studied as the benchmark. The results are analyzed, and the four dimensions of the lighting environment are affected by illuminance and CCT.

4.3.4 Discussion

This part adopts the visualization principle of SVOE model to make experiments, and adopts different lighting methods to create different feelings for vision to conduct experiments. In this experiment, the influence of psychological perception factors on observers in three different environments was investigated via psychophysical studies. The subjective evaluation data of four kinds of psychological perceptions (comfort, clarity, preference and warmth) in different environments were investigated, and univariate analysis of variance and Pearson correlation analysis were carried out on the data. The results demonstrated that in the three illuminated environments, comfort was a significantly correlated factor. The scores of comfort, clarity and preference were consistent, while the scores of clarity and warmth were negatively correlated. The best lighting environment reported by observers had high CCT and high illuminance. Also, it is most suitable for observers to visit the art museum in the best lighting choice. The experimental results show that under the condition of similar illumination, the visual influence of different lighting methods on observer is more significant.

To make the study more rigorous, we also explained a few things. In the future, new experiments will be performed for the next steps. Firstly, parameters of daylight affecting artificial lighting in the art museum will be tested. The lighting of the three museums used in this thesis were all artificial lighting, and none was daylight-illuminated environment. In this experiment, the illuminance of three art museums' lighting environment conformed to the specification of museums, and met the requirements of annual exposure, UV, and Glare. Secondly, different lighting environments have differed visual effects on young observers and older observers. In this study, the observers evaluated three different art museums. The observers of different ages will be added in future research. This result of the thesis explained the small sample data used in this experiment to determine the response of an age group. And future research will expand the age range of the subjects to analyze and discuss the emotional responses of different age groups in the art museums. Thirdly, the blue paint on the walls in the Yamazaki Mazak Museum may have some effects on the observer's perception in the space. This thesis mainly discusses the impact of lighting on observers, while color of environment space has not been described and analyzed in details. Whether different background colors of the walls would have any impact on the observation and response of the subjects will need further discussion. In the future research on the lighting environment of the art museum exhibition hall, we will give more in-depth attention and analysis on different background colors. The lighting mode was used to reflect different visual feelings, and this index will be added to the evaluation system.

4.4 Summary

The purpose of this study was to accurately characterize the status of exhibition lighting so that design can be improved through informed decision making. With this knowledge, sound design recommendations can be developed based on documented evidence rather than speculation [85]. This study expounded the synthesis and design process of artificial lighting to improve the emotional response level of museum visitors and highlighted that the key to the design of museum lighting was based on tourists' visual factors. The primary research topics presented in this study were lighting design methods and thinking process theory. Improvement of the perceptual lighting design mainly includes factors of environment lighting and light source. First, from the perspective of basic artificial lighting design, this study provides three aspects in art museum lighting design. Through innovative thinking, the space element was first solved by classification of the visual factors. The second condition was the integration of interdisciplinary theoretical elements, in which artificial theory and optical engineering theory in human-computer interactions were integrated and classified. The third condition was the level of emotional response, which utilized the interactive model of lighting design. The lighting design process can be driven by these three innovative elements of the evaluation model.

This chapter used interdisciplinary theory of lighting design through studying indoor environment conditions that have been unified by optical architecture engineering experiments. The influence of the visual factors of rod cells and cone cells was also examined, and the experimental data used for the emotional effects of optical engineering were classified and analyzed. The scores were combined to determine the relevant and interactive elements of emotional response levels. Factor analysis was used to integrate the data. In addition, four emotional response models suitable for small-scale and large-scale museum indoor space lighting were found through experiments, namely the visibility model, the comfort model, the preference model and the warm model. Finally, the various characteristics of artificial lighting design concepts were discussed, and the application of interdisciplinary theory in the field was analyzed to improve emotional response levels in the design process, which will have innovative significance.

We have found that most museums use artificial lighting. The artificial lighting environment can be evaluated by the SVOE evaluation model, but some parts are still not perfect. There are limitations in introducing human factors in evaluation experiments in real museums such as that the lighting cannot be changed at will. Different art museums have different conditions. In order to overcome this difficulty, we adopted software simulation and laboratory simulation methods in the following experiments to successfully study the relationship between the museum's environment lighting and human emotions. In addition to subjective evaluation methodology, we also combined psychological knowledge and used eye movement tracking to objectively analyze changes in observers' emotions.

CHAPTER 5

The Experiment of and Art Museum Laboratory Simulation

5.1 Introduction

The fifth chapter mainly introduces the relationship between space, environment lighting, vision and emotional response in the museums, which can reflect the most authentic experience of observers. The scope of the test was wide but not targeted. And there was no relevant predictive research based on the future development of museums. Therefore, this chapter introduces the influence of laboratory simulated museum environment on human visual and psychological emotions from two aspects. The first aspect is the way of exhibition. According to the current research on museums. The exhibition mode of museums in the future will not be limited to offline exhibitions. Offline dynamic display and online exhibition will gradually develop into an important branch of exhibition.

Therefore, the first part of this chapter mainly focuses on the impact of environmental space and optical parameters on the observers in the virtual visual experience. The second part introduces the impact of dynamic display on the visitors in the simulated museum environment, which focuses on the interaction of light, space and dynamic display on the visual and emotional impact of visitors. In the two parts of this chapter, the experiment data were obtained by subjective evaluation, which is more traditional.

This subjective evaluation methodology can accurately evaluate the changes of physical environment, but for the accuracy of emotional evaluation, more data support is needed. Therefore, in the third part, we collected the psychological emotions of observers from the eye movement tracking experiments. It can not only obtain data from multiple angles, but also verify the accuracy of subjective data with a small amount of data. This part mainly obtained the relevant data from physiological indexes of eye movement tracking, and focused on the combination of space, lighting environment and physiology to explore the degree of observers' preference for the environment.

5.2 Experiment of Software Simulating Lighting Environment of Art Museum

5.2.1 Experimental Introduction

In the experiment, DIALux Evo was used to simulate six kinds of environment lighting of the art museums, and the control variable method was used. The DIALux Evo is a simulation program for environment lighting. This program was widely applied to the calculation of lighting in indoor and outdoor environments. The reason why this program was chosen is that it extends the realistic visualization ability of ray tracing and provides a new variety of visual displays. It can provide a new experimental method for lighting environment evaluation.

By controlling a specific indicator of lighting mode or CCT, we can find out how the change of another indicator affects observers' emotional response and the relationship between each part of the variables. This experiment was mainly divided into three stages, i.e. making the lighting design of art museums and 3D modeling of different design schemes, conducting psychophysical experiments and collecting experimental data, and analyzing the experimental data. Using the correlation analysis and one-way ANOVA, this study explored the influence of six different lighting modes on ten pairs of evaluation keywords. This experiment analyzes the subjective evaluation of the lighting environment of each art museum by the experimenter in order to explore the lighting design, which was most in line with the observers' psychological feelings.

5.2.2 Experimental Design based on Lighting Models

The space size of the art museum in this experiment is 8 x 24 meters, with an area of 192 square meters and a height of 4 meters. The exhibits choose classic and colorful high-definition paintings. This study considering the situation of most art museum, this lighting environment space only has an artificial light source, no natural light, this experiment doesn't attention factor of daylight.

Each design is based on the calculation, and a representative visualization effect and simulation results are generated in DIALux Evo lighting simulation software. This program is widely used in the lighting calculation of indoor and outdoor environments [86]. The reason why this program is chosen is that it extends the realistic visualization ability of ray tracing and can be used in the database of lamp manufacturers. Several studies have shown that DIALux Evo is a simulation program validated by the International Commission on illumination CIE technical report CIE 171:2006 – test [87-93]. B Li and XY Liu investigates the atmosphere perception of dynamic colored lighting over warm and cool hue ranges in a lighting environment. Through correlation analysis revealed the effects of lighting properties on atmosphere factors. High chroma are helpful in creation of liveliness, while low chroma can increase coziness. [95,96] Their study uses the Spearman's rho correlation method of ANOVA. The experimental conditions include 2 luminance, 2 chroma, 3 hue range types. This experiment uses the Spearman's rho correlation method of ANOVA to research.

In the space of the art museum, the standard lighting methods are general lighting, accent lighting, and mixed lighting. The difference in color temperature will cause the difference of person's psychological feeling. According to the lighting standard of the art museum, the color temperature of the direct lighting source in the regular exhibition room shall be less than or equal to 4,000 K. In this experiment, by changing the lighting mode and color temperature, six kinds of lighting environments of the art museum were simulated by DIALux Evo.

The setting space type is a painting exhibition hall based on the simulation carried out at the National Museum of Western Art in Japan. The simulated exhibition hall only uses artificial lighting, without natural light. Its length is 24 m, width is 8 m, height is 4 m, and total area is 192 m2.

Table 5-1. Overall and partial lighting design of the art museum.

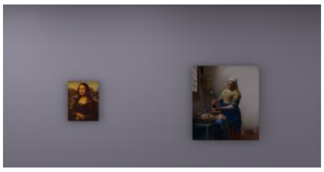
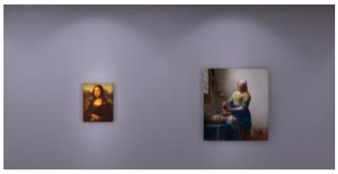
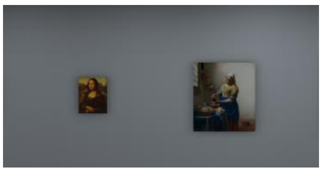
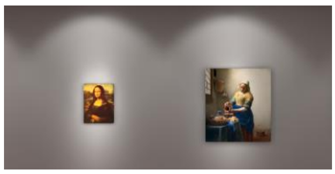
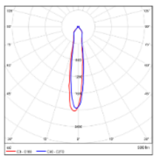
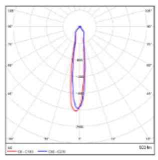
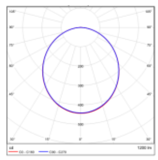
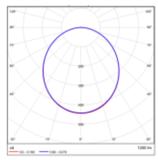
	General lighting	**Accent lighting**	**Mixed lighting**
	Mode A.	Mode C.	Mode E.
4000 K			
			
	Mode B.	Mode D.	Mode F.
2700 K			
			

Table 5-1 shows the overall and partial lighting design of the art museum. The mode A was General lighting mode and CCT was 4,000 K, the mode B was General lighting mode and CCT was 2,700 K, the mode C was Accent lighting and CCT was 4,000 K, the mode D was Accent lighting and CCT was 2,700 K, the mode E was Mixed lighting and CCT was 4,000 K the mode F was Mixed lighting and CCT was 2,700 K. The LED lamps are used in this experiment test. As shows in Table 5-2. This table lists the lamp information used in the lighting design of the art museum experiment. The 18 lamps L3 are used in mode A, the 18 lamps L4 are used in mode B, the 17 lamps L1 in set C, the 17 lamps L2 in set D, the 17 L1 and 18 L3 in set E, the 17 L2 and 18 L4 in set F.

Table 5-2. Information on the lamps and luminaires used in museum lighting design.

	L1	**L2**	**L3**	**L4**
Lamp type	Track spotlight	Track spotlight	Recessed downlight	Recessed downlight
Color temperature (K)	4000	2700	4000	2700
Lamp luminous flux (lm)	1000	1000	1200	1200
Power (w)	7	7	16	16
Luminaire image				
Luminaire luminous intensity distribution				
Ra	＞90	＞90	＞90	＞90

The questionnaire of this experiment consists of two parts including the information of the experimenter and the score of six lighting environments. The first part is to guide the experimenter, including gender, age, discipline, and vision test. The second part collects the Psychophysical experimental data of the participants, which is composed of ten pairs of words including Comfortable / Uncomfortable, Beautiful / Ugly, Classical/Modern, Natural / Unnatural, Relaxed / Tense, Warm / Cold, Colorful/ Monotone, Interesting / Boring, Artistic / Non artistic, Like / Dislike. They are selected from 30 pairs of words by online voting. Each word pair has a maximum score of 6 and a minimum score of 1. Comfortable is 6 points, uncomfortable is 1 point, beautiful is 6 points, ugly is 1 point, modern is 6 points, traditional is 1 point. As shown in Table 5-3.

Table 5-3. An example of scoring (Comfort levels score).

Choice by	**Observer Score**	**Meaning**
Comfort 1	1	Extremely not comfort
Comfort 2	2	Not comfort
Comfort 3	3	Less comfort
Comfort 4	4	Relatively comfort
Comfort 5	5	Comfort
Comfort 6	6	Very comfort

The participants in this experiment are all undergraduates aged 18-24, these experiment observers are 31 in total, including 11 male students and 20 female students. For the subjective questionnaire observers, according to the previous subjective questionnaire, if the number of subjects in the questionnaire is more than 20, it is enough to describe the overall trend of the experiment. The experiment was carried out in a dark room. Place the projector and computer in the laboratory, connect them, and the simulated art museum space will appear on the wall. The simulation process is as follows.

1. Draw a sketch. Make a sketch of the art museum in software Auto CAD. The length is 24m, the width is 8m, the height is 4m, and the wall thickness is 0.2m.

2. Build a 3D model. Import the sketch into DIALux Evo 7.1 to create a 3D scene of the museum.

3. Arrange exhibits. Arrange the selected pictures on the wall as the exhibits of the museum. The resolution of these pictures is greater than 1080P and the colors are bright. As shown in Figure 5-1.

4. Choose materials for walls, ceilings and floors. The ceiling and walls are made of gray-white cement material with a reflectivity of 58%, and the floor uses a Bologna log floor with a reflectivity of 10%.

5. Arrange the lamps. A spotlight was installed above each painting to provide accent lighting. The illumination angle of the spotlight is 15°, and the horizontal distance from the wall is 1.7m. Downlights were installed on the ceiling to achieve general lighting.

6. Calculate and save results.

7. Repeat steps 5 and 6 until all design schemes are completed

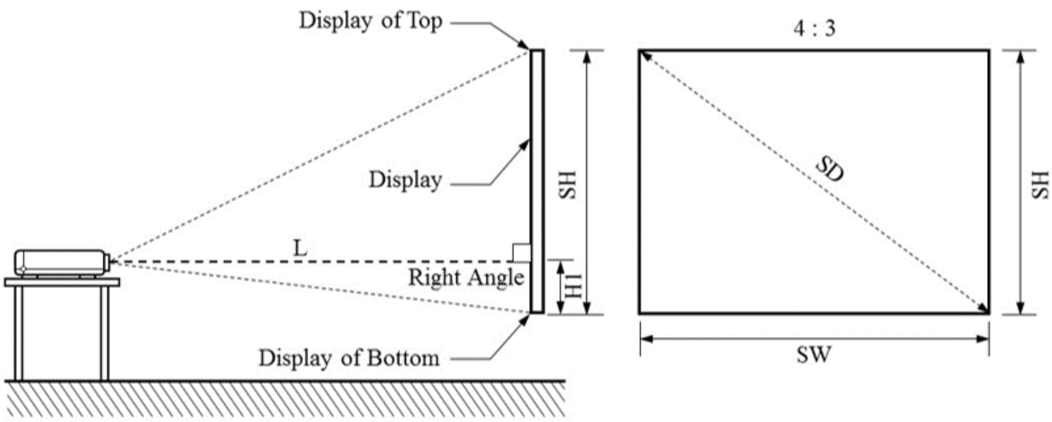


Figure 5-1. The experimental simulation of projection.

5.2.3 Experimental Data Analysis

In this study, a combination of descriptive and inferential statistics is applied to analyze the collected subjective data. The SPSS analysis was used to analyze the experimental data. The reliability analysis value is 0.95 from this experiment data, when the data is more than 0.70. Which is of high reliability, so the experimental data is reliable.

According to the collected data, we can get the preliminary results by sorting out the overall situation of six art museum in the lighting environment and the average value of ten pairs of words. The overall average value of each lighting environment is shown in Figure 5-2, The observers were watching the space through the DIALux EVO simulated lighting environment. The visual tasks of this experiment were mainly to feeling the space and watching the exhibits. And the average value of ten pairs of words is shown in Figure 5-3.

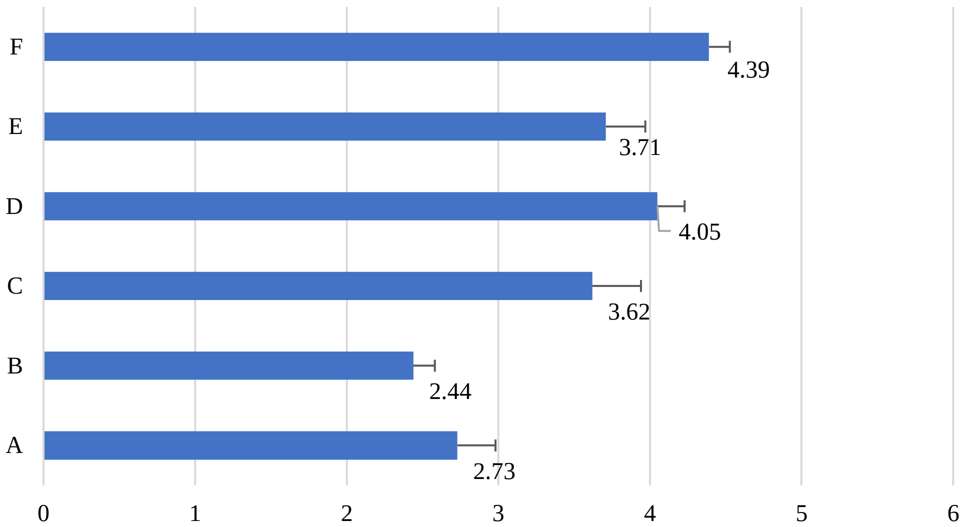


Figure 5-2. Average values of six lighting environments.

Set F (General lighting 2,700 K) has the highest average score, while set B (Mixed lighting, 2,700 K) has the lowest average score. Only the average value of D (Accent lighting 2,700 K) and F (Mixed lighting 2,700 K) is more than 4 points, the average value of A (General lighting 4,000 K) and B (General lighting 2,700 K) is less than 3 points, and both C and E are between 3.5 and 4 points with little difference. The statistics show that general lighting scores lower than both accent lighting and mixed lighting.

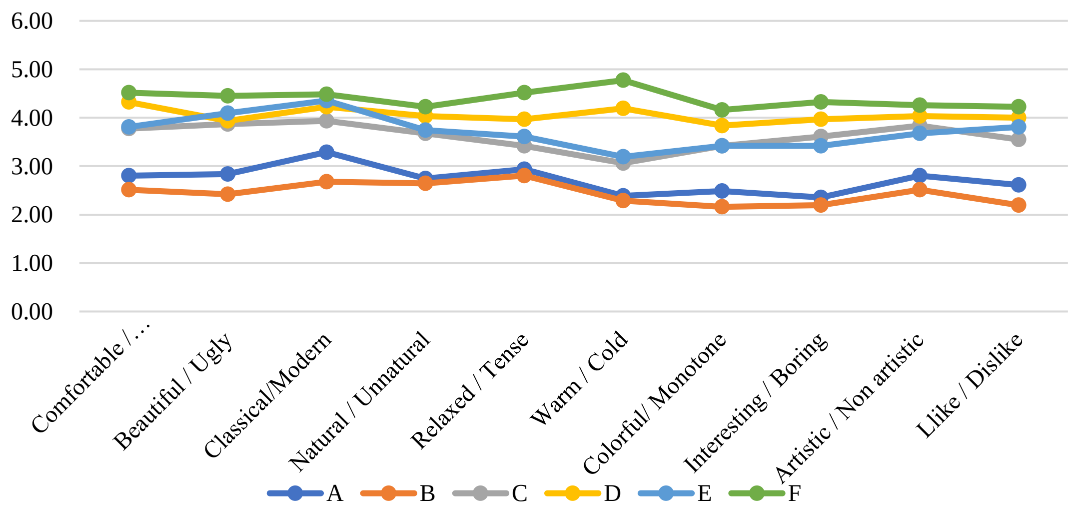


Figure 5-3. Line chart of ten pairs of words in six environments.

Set B has the lowest score for each pairs of words. Set A is slightly higher than set B, but still significantly lower than the other four sets. Set F scores the highest for each pairs of words. It is worth noting that the word "warm/cold" has a significant difference in six environments, where environment D and environment F rise, and the other four lighting environments fall. Set E and set C are very close in value and trend of change at each point.

The One-way ANOVA was used. When the significance p-value is less than 0.01, there is a significant difference. When the significance p-value is more excellent than 0.01 and less than 0.05, there is no significant difference; when the significance p-value is more excellent than 0.05, there is no difference.

Table 5-4. One-way ANOVA of gender factors.

	Mean		**F**	**P**
	Male	**Female**		
Comfortable / Uncomfortable	66	120	0.741	0.390
Beautiful / Ugly	66	120	0.618	0.433
Classical / Modern	66	120	1.302	0.255
Natural / Unnatural	66	120	0.560	0.455
Relaxed / Tense	66	120	0.074	0.786
Warm / Cold	66	120	0.016	0.899
Colorful / Monotone	66	120	0.576	0.449
Interesting / Boring	66	120	0.866	0.353
Artistic / Non artistic	66	120	0.716	0.399
Like / Dislike	66	120	0.092	0.762

11 male students and 20 female students participated in the experiment, their through six groups experiment of lighting modes obtain this data. One-way ANOVA of variance was used to analyze gender by this experiment data, and the results are shown in Table 5-4. In this experiment, this table show the p-value all more 0.05, so there was no difference between gender factors.

2,700 K and 4,000 K color temperature lamps are used in this lighting environment design. Under these two color temperature conditions, the histogram of the average value of each pairs of words are shown in Figure 5-4. The figure shows that the most lighting environment evaluation score of 2700K was higher than 4000K. But the score of pairs of word Beautiful / Ugly is same. Only the score of pairs of word Classical / Modern is difference.

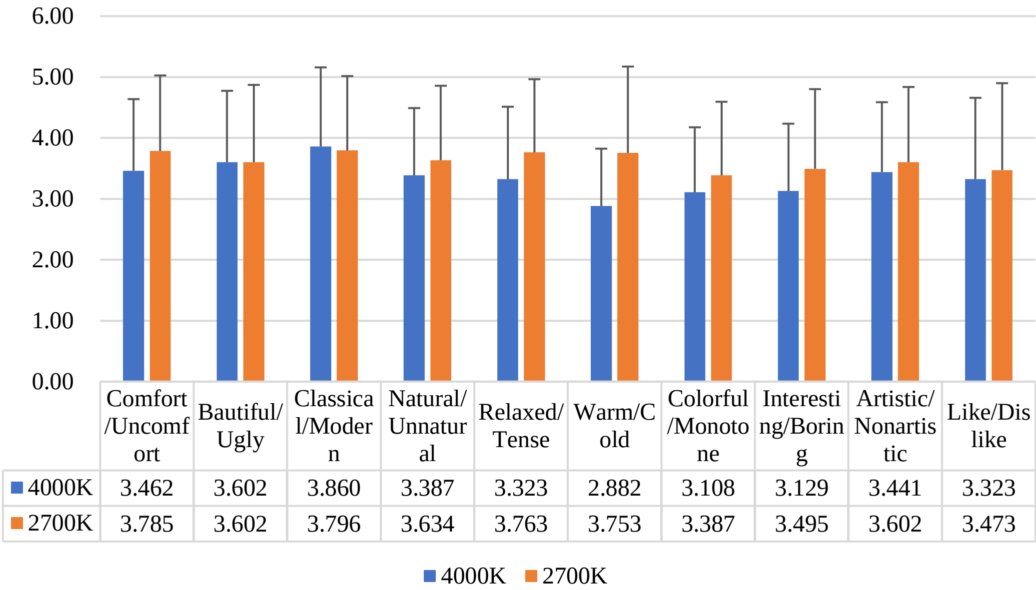


Figure 5-4. Average value under a different CCTs.

Except that the mean value of warm/cold pairs at 4,000 K is less than 3, the others are greater than 3 and less than 4. Under the two-color temperature conditions, warm/cold has the most significant difference in scores, while beautiful/ugly, modern/traditional two pairs of words have almost the same scores. As a whole, the score at 2,700 K is higher than that at 4,000 K. Next the one-way ANOVA of color temperature is carried out.

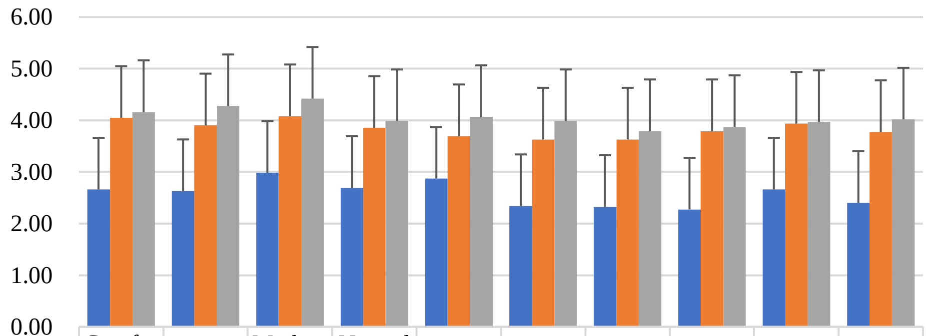
Table 5-5. The one-way ANOVA of CCT.

	Mean			
	4,000 K	**2,700 K**	**F**	**P**
Comfortable / Uncomfortable	3.46	3.78	3.312	0.070
Beautiful / Ugly	3.60	3.60	0.000	1.000
Classical / Modern	3.86	3.80	0.122	0.727
Natural / Unnatural	3.39	3.63	2.096	0.149
Relaxed / Tense	3.32	3.76	6.320	0.013
Warm / Cold	2.88	3.75	24.308	0.000
Colorful / Monotone	3.11	3.39	2.798	0.096
Interesting / Boring	3.13	3.49	4.240	0.041
Artistic / Non artistic	3.44	3.60	0.852	0.357
Like / Dislike	3.32	3.47	0.552	0.459

According to Table 5-5, the significance of Relaxed / Tense, Interesting / Boring is $0.01 \leq P \leq 0.05$, and the significance of Warm / Cold is $p < 0.01$. The influence of color temperature on Relaxed / Tense and Interesting / Boring was significant, and it was more relaxed and interesting at 2,700 K. The influence of color temperature on Warm / Cold is very significant. The significance of Warm /

Cold at 4,000 K and 2,700 K, the values are 3.75 and 2.88, respectively. This result shows the low color temperature 2,700 K environment will give person a warm feeling.

In this experiment, there are three lighting modes, general lighting, accent lighting, and mixed lighting. In these three different lighting modes, the histogram of the average value of ten pairs of words is shown in Figure 5-5. This figure shown average values of words in different lighting modes.



	Comfort / Discomfort	Beautiful / Ugly	Modern / Traditional	Natural / Unnatural	Relaxed / Tense	Warm / Cold	Rich / Monotonous	Interesting / Boring	Artistic / Non artistic	like / dislike
General lighting	2.66	2.63	2.98	2.69	2.87	2.34	2.32	2.27	2.66	2.40
Accent lighting	4.05	3.90	4.08	3.85	3.69	3.63	3.63	3.79	3.94	3.77
Mixed lighting	4.16	4.27	4.42	3.98	4.06	3.98	3.79	3.87	3.97	4.02

General lighting   Accent lighting   Mixed lighting

Figure 5-5. Average values of words in different lighting modes.

The score of each pairs of words of general lighting is significantly lower than that of accent lighting and mixed lighting. The overall score of mixed lighting is higher, but it is not so different from that of accent lighting. As the difference between general lighting and the other two lighting methods is very obvious, the next One-way ANOVA is only focused on the accent lighting and mixed lighting.

Table 5-6. The one-way ANOVA of lighting mode.

	Mean		**F**	**P**
	Accent lighting	**Mixed lighting**		
Comfortable / Uncomfortable	4.05	4.16	0.441	0.508
Beautiful / Ugly	3.90	4.27	4.830	0.030
Classical / Modern	4.08	4.42	3.345	0.070
Natural / Unnatural	3.85	3.98	0.505	0.479
Relaxed / Tense	3.69	4.06	3.543	0.062
Warm / Cold	3.63	3.98	2.878	0.092
Colorful / Monotone	3.63	3.79	0.977	0.325
Interesting / Boring	3.79	3.87	0.196	0.658
Artistic / Non artistic	3.94	3.97	0.032	0.858
Like / Dislike	3.77	4.02	1.274	0.261

This study can find that the two ways of accent lighting and mixed lighting only have a significant impact on beautiful/ugly pairs of words, P-value 0.030 < 0.05. The scores of other pairs of words did not differ in two different lighting modes. Therefore, the two ways of accent lighting and mixed lighting have little influence on visitors' psychology. As shown in Table 5-6.

Paired T-test

In this part, we will control one of the variables and compare the results of different designs. Table 5-7 indicates the T-test results of different CCTs under the same lighting mode, which are the comparison between Scheme A and Scheme B, Scheme C and Scheme D, and Scheme E and Scheme F.

Table 5-7. T-test of different CCTs.

	CCT 4,000 K			**CCT 2,700 K**			**T**	**Sig.**
	N	M	SD	N	M	SD		
A-B General lighting	31	27.26	9.459	31	24.42	6.994	1.560	0.129
C-D Accent lighting	31	36.16	6.497	31	40.52	6.439	-3.472	0.002
E-F Mixed lighting	31	37.13	8.269	31	43.94	7.348	-3.908	0.000

There's no significant difference between mode A and mode B (P-value is 0.129 (P >0.05)). This demonstrates that in the general way of lighting, the two CCTs on the visual impression of painting did not have a great impact. However, significant difference was found between mode C and mode D, P-value is 0.002 (P <0.01), the mode E and mode F, P-value is 0.000 (P <0.01). In other words, under the conditions of accent lighting and mixed lighting, CCT has a very significant impact on person's feelings. Table 5-8 is obtained by paired sample T-test for schemes with the same CCT and different lighting modes.

Table 5-8. T-test of different lighting modes.

	Accent lighting			**Mixed lighting**			T	Sig.
	N	M	SD	N	M	SD		
C-E 4,000 K	31	36.16	6.497	1	37.131	8.269	-6.722	0.617
D-F 2,700 K	31	40.52	6.439	3	43.941	7.348	-9.223	0.019

In line with the above average data, it is found that the difference between general lighting and the other two is very significant no matter what the color temperature. As a result, we focus on accent lighting and mixed lighting. It shows that when the CCT was 4,000 K, there was no significant difference between Scheme C and Scheme E, P-value is 0.617(p >0.05). On the contrary, when the CCT was 2,700 K, there was a significant difference between the two lighting methods, P-value is 0.019 ($0.01 < P < 0.05$).

5.2.4 Discussion

This experiment takes an innovative approach to setting the lighting environment, this method has not been used in other studies before, using DIALux to simulate the lighting environment. The way SVOE was evaluated is a good complement. In order to reduce variables in this experiment. This experiment did not pay attention to illuminance, but mainly considered the change of lighting mode and color temperature. In this experiment, psychophysical experiments were carried out in the form of subjective questionnaires. The experimenters evaluated six different illuminated environments simulated by the software. Low color temperature is more suitable for use in the art museums. At 2,700 K, visitors feel relaxed, interested, and especially warm. The visitors would rate it as undesirable when the general lighting is used, whether it is high or low in color temperature. This mode is not suitable for the lighting design of the art museums. Mixed lighting is slightly better than accent lighting. When mixed lighting is adopted, visitors think the overall environment is more beautiful. However, the analysis showed that the two lighting modes brought little difference to visitors' psychology.

The data of the psychophysical experiment was analyzed by means of one-way ANOVA and a paired sample T-test. The results showed that CCT affects the visual perception of the observers via three pairs of words including relaxation/tension, fun/boredom, and warm/cold. Accent lighting and mixed lighting only have a significant impact on beauty/ugliness. Under the condition of general lighting, the change in CCT has little effect. Nevertheless, under the condition of accent lighting and mixed lighting, the CCT has a very obvious influence. When the CCT is 4,000 K, there is no significant difference between the accent lighting and mixed lighting. However, when the CCT is 2,700 K, there are significant differences between the two methods. No matter how much the CCT is, the general lighting is very different from the other two ways. At the same time, the results of this experiment also showed inconsistencies with Kruithof's Rule. The lighting environment evaluation model of SVOE, since the visual experiment was conducted in three different spaces, in order to uniformly quantify the spatial environment. In the simulation of lighting environment, the same space was used for the simulation of lighting environment, the different lighting methods and color temperatures to simulate the lighting environment, the obtained results improve the evaluation method of lighting design.

5.3 The Experiment of Eye Movement Tracking

5.3.1 Experiment Introduction

This experience mainly explores the influence of environment lighting factors on observers' psychological emotions through subjective and objective aspects in a simulated art museum. The experiment simulated four different lighting environments. The 39 observers subjectively evaluated the paintings under different lighting conditions and their eye movement indicators were measured.

Finally, the subjective questionnaire and objective eye movement data obtained are sorted and analyzed. This experiment mainly discussed the effects of the observer's 10 subjective evaluation indicators and three objective eye movement indicators under four conditions combining illuminance and correlated color temperature (CCT), and then chose the most suitable illuminance and color temperature matching for exhibition lighting. This experiment hypothesized that there was an interaction between color temperature and illuminance to verify the experimental results of eye movement tracking.

This experiment assumed that there was an interaction between color temperature and illuminance. When the color temperature is constant, with the increase of illuminance, the more attention the viewer pays to the region of interest, the higher the degree of attention concentration. When the illuminance is constant, the lower the color temperature is, the lower the degree of attention the viewer has. The higher the degree of attention to the environment lighting, the more suitable for people to watch.

This study used evaluation model of SVOE to experiment, and spatialization theory to simulate the exhibition space of an art museum and let visitors observe the exhibits. This experiment used the theory of optical engineering to simulate four different lighting environments and digitalize the parameters of the optical environment. It used the principle of vision to determine the visual process of experiments, and it identified the main influencing factors in visual physics experiments. It used the theory of affective data, the pairs of evaluation keywords for the definition of lighting environment. It used subjective questionnaires and eye movement tracking equipment to collect visitors' data. It used the logical method of argument to discuss the evaluation methodology and criteria of lighting design in art museums. The experimental results showed that when the color temperature is constant, the observer paid more attention to the region of interest with the increase of illuminance and color temperature. When the illuminance was constant, the color temperature was lower, and the lower the degree of attention the observer has. The higher the degree of attention is to the lighting environment, the more suitable it is for people to watch. The index of eye movement tracking can verify this hypothesis in this experiment.

5.3.2 Experimental Design based on Eye Tracking

In this experiment, the control variable method is used. By controlling a specific index of color temperature or illuminance, this study can find out how the change of another index changes their psychological response, strictly explore the relationship between various parts of variables, and analyze the influence of ten psychophysical terms under four different lighting modes by using correlation analysis and One-way ANOVA. In this experiment, the concept of eye tracking is used for the first time, and various data are obtained by an eye tracking to find out which mode of lighting conditions the experimenter likes most. Colorful / Monotone, Bright / Dark, Visibly / Fuzzy, Warm / Cold, Soft / Hard, Comfortable / Uncomfortable, Vivid / Not Vivid, Natural / Unnatural, Like / Dislike, Clarity / Messy. That is to feel the experimental paintings intuitively.

This experiment simulates the lighting environment of the museum in a room. It conducts a questionnaire of psychophysical experiments and eye tracking experiments on the lighting parameters in the four modes. As shown in Figure 5-6, the experimental equipments are TobII Pro-Glasses 2 head-mounted eye-tracking, remote SFIM-300 scintillation spectrophotometer.

Figure 5-6. TobII Pro-Glasses 2.

In the experiment 39 observers were selected for eye tracking test, and their ages were 20-24 years old. Therefore, the number of subjects selected in the experiment is 39. Since many observers in the eye tracking experiment could not detect the eye tracking data, the number of observers different from the previous experiments was invited. However, due to the uncertainty of the subjective data, some of the data do not conform to the logical rules when selecting the data, so the number of subjects will vary. Simulate the museum lighting environment in real experiment space. The four lighting environments be used in the experiment. The environment 1 has color temperature 3,000 K and 150 lx. The environment 2 has color temperature 3,000 K and 300 lx. The environment 3 has color temperature 4,000 K and 150 lx. The environment 4 has color temperature 4,000 K and 300 lx. This experiment was used two different sets of color temperature and illumination.

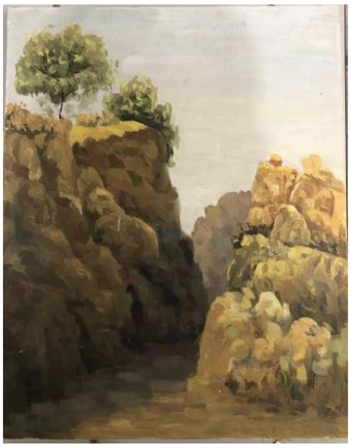
The experimental process is as below:

First, each environment that the experimenter fills in the questionnaire.

Second, each observers wears an eye tracking (TobII Pro Glasses2), looks at the artwork for 90 seconds, and collects the total fixation duration in areas of interest (AOI) during this period.

Third, the experiment will record parameters, including time to the first fixation in AOI and number of visits. The experiment uses a painting of the landscape. As shown in Figure 5-7.

The experimental environment is shown in Figure 5-8. The average distance between the person and the painting is 2.0 m, and the elevation angle of the person looking up at the painting is about 15 °, this angle is hypothesis the eye sight line angle is 0°.



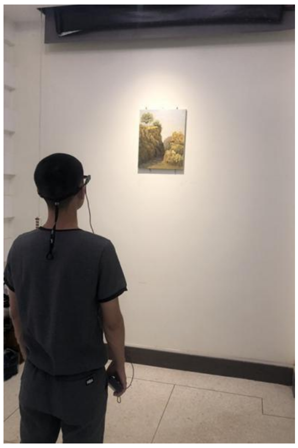
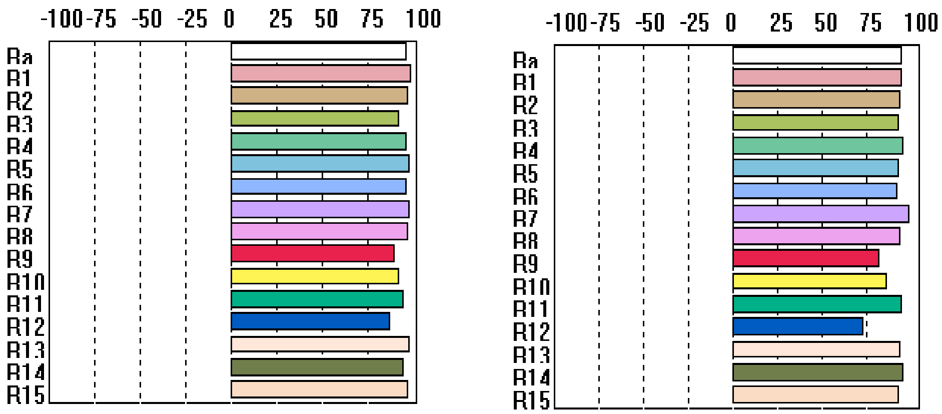


Figure 5-7. The oil painting of the landscape. Figure 5-8. Experiment environment.

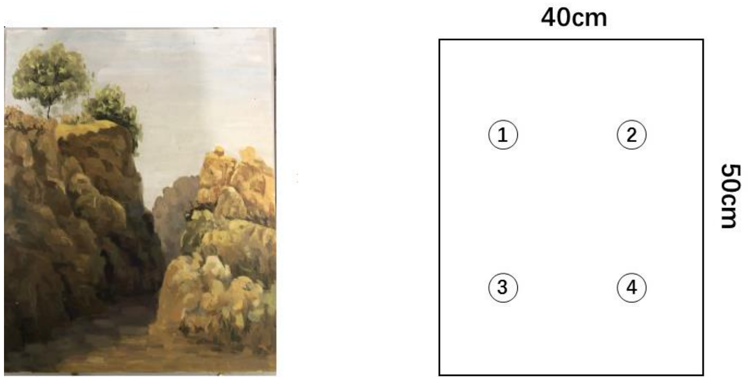
The chromatogram of the four environment is shown in Figure 5-9. The first figure is the CCT of 3,000 K in environment 1 and environment 2, Ra value is 97.5, R9 value is 91. And the second figure is the CCT of 4,000 K in environment 3 and environment 4. Ra value is 95.1, R9 value is 83.



CRI of environment 1 and environment 2 CRI of environment 3 and environment 4

Ra=97.5 R9=91 Ra=95.1 R9=83

Figure 5-9. Color rendering index (CRI) of four environments.



Environment 1	**No.**	**1**	**2**	**3**	**4**	**AVG**
3,000 K, 150 lx	Illumination	89.1 lx	94.5 lx	197.0 lx	224.4 lx	151.3 lx
Environment 2	**No.**	**1**	**2**	**3**	**4**	**AVG**
3,000 K, 300 lx	Illumination	248.1 lx	252.3 lx	364.4 lx	369.4 lx	308.6 lx
Environment 3	**No.**	**1**	**2**	**3**	**4**	**AVG**
4,000 K, 150 lx	Illumination	94.5 lx	99.8 lx	198.7 lx	200.5 lx	148.4 lx
Environment 4	**No.**	**1**	**2**	**3**	**4**	**AVG**
4,000 K, 300 lx	Illumination	277.0 lx	294.4 lx	304.2 lx	315.2 lx	297.7 lx

Figure 5-10. Landscape painting with four modes of illumination.

As shown in Figure 5-10. This experiment was applied a landscape painting, showing four lighting distribution test points in the painting. The painting size is 40 x 50cm, the average illuminance of environment 1 is 151.3 lx, the average illuminance of environment 2 is 308.6 lx, the average illuminance of environment 3 is 148.4 lx, and the average illuminance of environment 4 is 297.7 lx. This experiment did not collect the illuminance data of the wall. In this experiment, a combination of descriptive and inferential statistics is applied to analyze the collected subjective data.

Table 5-9. The CV of evaluation score under different lighting environments.

CV1	Colorful / Monotone	Bright / Dark	Visibly / Fuzzy	Warm / Cold	Soft / Hard	Comfortable / Uncomfortable	Vivid / Not Vivid	Natural / Unnatural	Like / Dislike	Clarity / Messy
Environment 1 3,000 K, 150 lx	23.68	22.83	28.40	18.26	19.30	17.70	19.96	20.93	28.98	22.90
Environment 2 3,000 K, 300 lx	18.45	18.97	19.78	17.04	18.32	14.26	18.12	16.46	18.35	19.78
Environment 3 4,000 K, 150 lx	25.87	20.66	22.62	23.95	24.34	24.75	24.73	24.02	25.46	22.91
Environment 4 4,000 K, 300 lx	17.92	21.21	21.34	25.11	21.41	21.66	22.28	17.47	19.78	21.10

The SPSS analysis was used to analyze the experimental data. The reliability analysis value is 0.892 from this experiment data, when the data is more than 0.70. Which is of high reliability, so the experimental data is reliable. This can be concluded that the data of the 39 observers are all stable.

As shown in Figure 5-16. The ordinate is the difference coefficient of variation used to judge the parameters stability between observers. Through the coefficient of variation analysis data (CV ＜40). After the experimental data verification, the data of table 5-9 were within the normal range of psychophysical experiment CV, so the data is reliable. [94]

5.3.3 Experimental Data and Analysis

The different factors in this experiment are environment, gender, and specialty. The One-way ANOVA of variance were conducted for three elements, and a significant discussion was undertaken.

Gender factors, this experiment included male of 18 and female of 21. The female students majored in art, male students majored in science. Use the significance p-value to determine whether there is a substantial difference in the evaluation of different evaluation items under various conditions. The significance of the p-value is less than 0.01. There is a significant difference in the assessment. It means there is no significant difference. The significance of the p-value is more excellent than 0.05. It means there is no significant difference.

Table 5-10. The one-way ANOVA about factors of gender.

Evaluation Index	Mean		F	P
	Male	Female		
Colorful / Monotone	72	84	5.202	0.024
Bright / Dark	72	84	2.666	0.105
Visibly / Fuzzy	72	84	2.079	0.151
Warm / Cold	72	84	1.883	0.172
Soft / Hard	72	84	0.121	0.729
Comfortable / Uncomfortable	72	84	6.918	0.009
Vivid / Not Vivid	72	84	1.760	0.187
Natural / Unnatural	72	84	2.311	0.131
Like / Dislike	72	84	6.522	0.012
Clarity / Messy	72	84	4.973	0.027

As shown in Table 5-10. The variables related to gender are significance $p < 0.05$, they are colorful, comfortable, like, and clarity. The observers of this experiment include art and science students.

Table 5-11. The one-way ANOVA about factors of discipline.

Evaluation Index	Mean		F	P
	Science	Art		
Colorful/ Monotone	72	84	0.000	0.988
Bright / Dark	72	84	0.042	0.839
Visibly / Fuzzy	72	84	1.641	0.202
Warm / Cold	72	84	0.919	0.339
Soft / Hard	72	84	4.102	0.045
Comfortable / Uncomfortable	72	84	0.832	0.363
Vivid / Not Vivid	72	84	0.571	0.328
Natural / Unnatural	72	84	0.571	0.451
Like / Dislike	72	84	0.942	0.333
Clarity / Messy	72	84	0.003	0.958

As shown in Table 5-11, the experimental results show that only the Soft/Hard psychophysical vocabulary is different from their professional thinking ($P < 0.05$), and there is no significant difference in the other nine evaluation index between art students and science students.

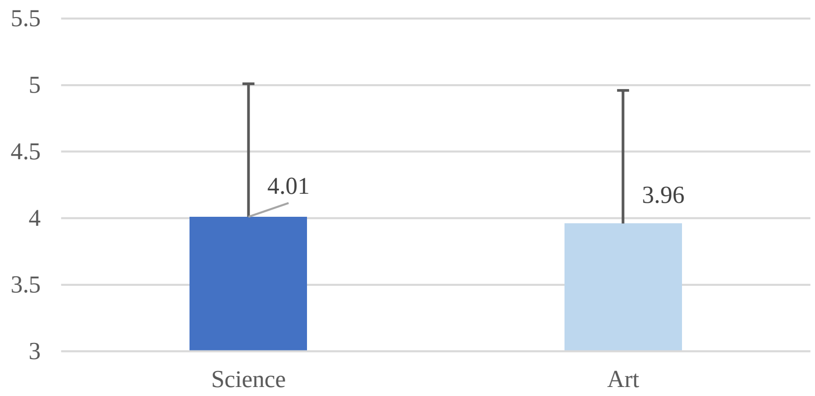


Figure 5-11. Soft/hard average for factors of discipline.

As shown in Figure 5-11, the average value of science students is greater than art students 4.01 (4.01 > 3.96), which indicates that science students tend to visibly and feeling soft to painting, while art students tend to feeling soft when observing paintings. Due to the large amount of experimental data of eye tracking test, this experiment by analyzing the average value, this experiment can get the result to prove hypotheses. The detailed data of average value shows appendix.

The four environments of this experiment environment 1 are color temperature 3,000 K and 150 lx. The environment 2 is color temperature 3,000 K and 300 lx. The environment 3 is color temperature 4,000 K and 150 lx. The environment 4 is color temperature 4,000 K and 300 lx.

As can be seen from Table 5-12, except for the adjective Colorful / Monotone, all the significances are $P > 0.05$, which means that the variance is uniform, and one-way ANOVA data analysis can be performed.

Table 5-12. Test of homogeneity of variances about environmental factors.

Evaluation Index	**Levene Statistic**	**P**
Colorful / Monotone	2.98	0.033
Bright / Dark	1.888	0.134
Visibly / Fuzzy	0.715	0.544
Warm / Cold	0.329	0.804
Soft / Hard	0.641	0.590
Comfortable / Uncomfortable	0.837	0.475
Vivid / Not Vivid	2.037	0.111
Natural / Unnatural	0.837	0.475
Like / Dislike	0.221	0.881
Clarity / Messy	0.348	0.791

It can be seen from the analysis that the Clarity / Messy, Bright / Dark, Visibly / Fuzzy, Warm / Cold, Soft / Hard, Comfortable / Uncomfortable, Vivid / Not viable, Natural / Unnatural, Like / Dislike. Their data are not significant differences from environmental factors. Only the Colorful / Monotone $P<0.05$, this value is significantly different from the lighting environment. The scores of environment 4 (except for warm/cold, soft/hard) are higher than those of the other three environments, indicating that students' preference for artworks in the art museum is more inclined to high illumination and high color temperature 4,000 K and 300 lx, and the high color temperature gives person a feeling of cold, not soft. It can also confirm the environment of 3,000 K on the side. The environment illumination of 300 lx shows warm and soft, this data was proved accurate.

The eye tracking experiment part is the objective evaluation factor part of this experiment. This eye tracking experiment mainly collected three kinds of eye tracking data for SPSS analysis. Total fixation duration in AOI including the total duration of all fixation points in an interesting area, or all interest areas belonging to an interest area group. Time to the first fixation in AOI including the duration of the first fixation point that appears in the interest area. Number of Visits including the number of visits to an interesting area or group of interest areas. Each visit refers to moving from the first fixation point in the interest area to the next fixation point out of the interest area. This experiment divided an area of interest that is where the artwork is located. As shown in Figure 5-12. The location of artworks in an art museum exhibition hall, eye tracking interested the focus area of visual. The lighting environmental parameters in this area, the total fixation duration and the parameters of subjective evaluation are typically correlated. This is a typical application of SVOE model in the study of lighting environment evaluation.

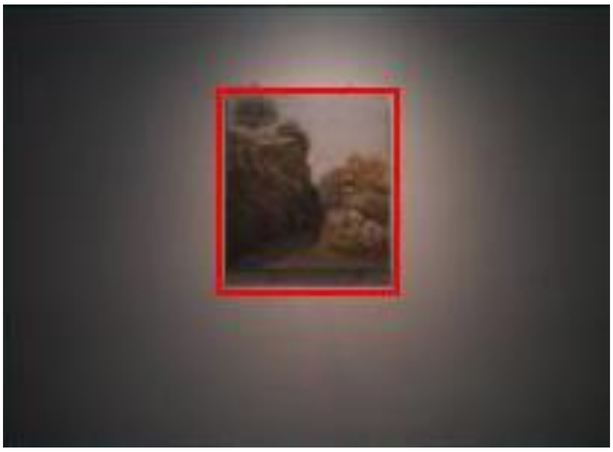
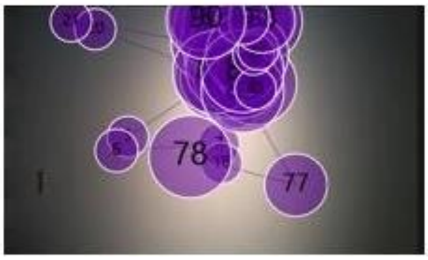
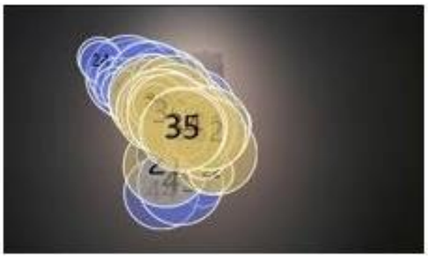


Figure 5-12. Division of interest area in eye tracking experiment.

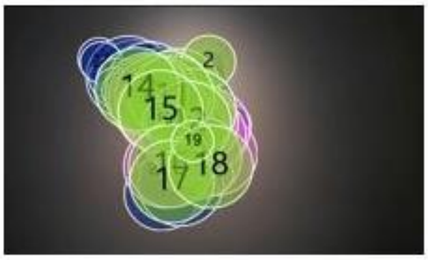
Through sight analysis shows the of length stay of eye tracking experiment, the size of the circle show length stays and number of times. This study can judge whether the visitors are absorbed in the artworks and immersed in the artistic conception of the artworks. As shown in Figure 5-13.

The eye tracking sight track of the students under the selected typical mode 4. As shown in Figure 5-13. The sightline of environment 1 is messy and stays outside the interest area for a long time. The difference between environment 2 and environment 3 is not significant. It can be seen that they are more concentrated in the field of interest area, and the most substantial part of the circle is in the middle of the painting, which shows that the time to stay in the picture is more than that outside the visual region.





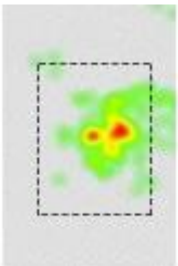
Environment 1 Environment 2

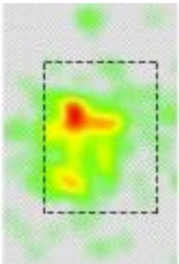


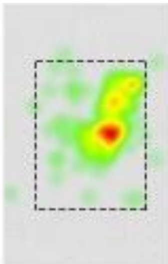
Environment 3 Environment 4

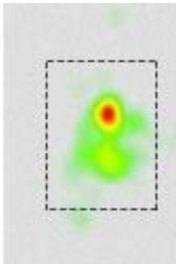
Figure 5-13. Eye tracking trajectory in four environments.

The line of sight of environment 4 is most concentrated in the area of interest, and the most significant part of the circle, that is, the point with the longest residence time, is also in the middle of the area of interest. Person are most immersed in this environment, indicating that the optical parameters in this environment are the most suitable for museums appreciate the visual indicators of the artwork.









Environment 1 Environment 2 Environment 3 Environment 4

Figure 5-14. Hot spot map in four modes.

As shown in Figure 5-14. It is a heat map from the experiment of eye tracking. The heat map uses different colors to show the subject's focus on an image or to show the subject's visual residence time in a particular area. Red usually indicates the field with the most fixation points or the longest fixation time, followed by green, with many transitional levels in between. There are many red hot spots in environment 1, 2, and 3, which shows that the places of concentration are distributed in many areas. At the same time, there is only one place of attention in environment 4 hot spot map, which focuses on the field of artworks.

As shown in Table 5-13, it can be seen that there is no significant difference between the p-value of the first fixation of AOI and the environment. The p-value of total fixation time and visit times in the region of interest was less than 0.05. This data shows there was a significant difference between the whole fixation time and the environment.

Table 5-13. One-way ANOVA about eye tracking test data.

		Mean ± SD					
	N	Environment 1	Environment 2	Environment 3	Environment 4	F	P
Total fixation duration in AOI	39	67.40±9.470	71.34±13.166	71.12±10.044	82.06±8.117	11.505	0.000
Time to first fixation in AOI	39	1.85±1.036	1.81±1.814	2.00±1.877	1.97±1.400	0.102	0.959
Number of Visit	39	10.61±4.580	12.03±6.395	10.74±4.95	19.42±7.094	15.955	0.000

The average value of full fixation time and visit times in the interest area of environment 4 is the largest. This data shown the optical parameters of environment 4 are the most favorable parameters for students to enjoy artworks. From an objective point of view, the lighting parameters of environment 4 have a good feedback in the eye tracking experiment. The total fixation time and visit times of students are the most in secondary lighting experiment, indicating that the lighting parameters most suitable for students to visit the art museum should be the lighting distribution environment 4, high illumination and high color temperature.

5.3.4 Discussion

In this experiment, using innovative methods to conduct experiments, using eye tracking data to assist in the validation of subjective questionnaires. The most important step in establishing evaluation methods, the evaluation of emotional factors solves the problem of uncertainty in subjective questionnaire. In this experiment, the interaction between color temperature and illumination was discussed to understand the subjective psychological evaluation of the students in four different lighting environments, and the objective evaluation of the students in four different lighting environments was understood through eye movement tracking experiment. The combination of subjective and objective methods was used to explore the most suitable lighting index for the students to visit the art museum. One-way ANOVA study of personal evaluation data and objective evaluation data was used. According to the results, under the condition of low color temperature and low illumination, the observer's attention to the area of interest was the lowest, and the degree of attention concentration was the lowest.

The visual attention under high color temperature and low illumination was the same as that of low color temperature and high illumination, high color temperature and high illumination (4,000 K, 300 lx). The average value of the 10 psychophysical terms was the highest. The total fixed time and the number of visits were the most, the students paid the highest attention to the area of interest, and the degree of attention concentration was the highest. So their feedback was the best. Through a small amount of eye movement tracking sample data, this chapter has proved the scientific nature of subjective questionnaire experiments. This is the best lighting environment for the art museum. The results of this experiment showed that there was a very typical correlation between the parameters of subjective evaluation and eye-tracking data. Through the emotional response analysis between subjective questionnaires and optical parameters, a lighting environment evaluation methodology based on SVOE model was established. This experiment showed that eye tracking data verified the scientific nature of subjective evaluation, let evaluation method of SVOE have certain significance.

5.4 Summary

In this chapter, the interaction among space, vision, optics and emotion was obtained through two simulated environment experiments. The part mainly introduced the visual and emotional feelings when watching paintings in the virtual museum environment created by DIALux Evo. The experimental results showed that the general lighting mode is not suitable for museum lighting, and the change of color temperature does not have a great impact on the psychological changes of the observers. Although the mixed lighting and accent lighting had little impact on the psychological changes of visitors, they felt that the environment was more suitable for observer under the mixed lighting mode, and the color temperature had a great impact on the two lighting modes.

The part mainly obtained the relevant data from the physiological indexes of eye movement tracking, and mainly discussed the audience's preference for environment from three aspects of space, lighting environment and physiology. This study from the eye movement tracking index obtained related parameters. While in the museums, when the color temperature and illumination lighting conditions are high, observer's psychological comfort and attention level is higher, which means the environment is more suitable for visiting. So, in this condition, the visitors' visual observation of the details and color reduction of the works is also higher. This study showed the illumination, color temperature, lighting mode and physiological aspects together to discuss the impact on the observers' emotional aspects, and provided more evaluation model support for the establishment of the museum lighting environment. The evaluation model of SVOE takes an interdisciplinary approach, using innovative research ideas. Through the data and analysis from multiple experiments, it continuously improves the logic of the evaluation model and the evaluation process. The innovation theory gained from this complete process has greatly facilitated the evaluation method of lighting environment.

CHAPTER 6
Conclusion

6.1 Research Summary

In this thesis, the most commonly used lighting environments in art museum exhibitions were presented. This study showed that illuminance and color temperature were the main elements that affect lighting comfort, and the SVOE evaluation model index was constructed on this basis. The study incorporated experiments to demonstrate the four attributes of the SVOE evaluation model. For the part “S” (Spatial), spatial parameters are defined, which provide the basis for the software simulation in the optical engineering phase. The classification of spaces was done to demonstrate that an art museum is a holistic space composed of multiple spaces, which impresses the visitors by conveying to them a perception of the space. In the case of the Liaoning Provincial Museum, the experimental conclusions show that the quality of the lighting environment in the small spaces of a permanent exhibition hall is the key differentiator among the different types of spaces, which provides crucial information for the spatialization of the SVOE evaluation model.

Through the questionnaires and eye movement tracking experiments, visual data on lighting comfort for various lighting environments in art museums was collected for evaluation. The established lighting comfort index was based on the emotional response and affected by color temperature and illumination level obtained from the SVOE model. Optical engineering parameters cannot be relied on as the sole means of accurate reflection of the experience of visitors. Therefore, using the general evaluation methodology makes it impossible to effectively evaluate the quality of art museums in general. In this study, a lighting design evaluation model is proposed that better combines subjective evaluation with data of eye movement tracking. This model includes four aspects—spatialization, visualization, optical, and emotional. This model was applied in some existing art museums and received good feedback.

In the experimental phase of visualization, the researcher conducted surveys in three Japanese art museums, and the most important exhibition space was tested for three different illuminance levels and color temperatures. These two variables provide obvious difference in visual perception. The data obtained by questionnaire survey were analyzed and verified, and the result shows that the visual perception of color temperatures and illumination mode is the key point among the four lighting environments, and that visitors’ perception and requirements of the spatial lighting environment vary depending upon the purpose of visit. This visual requirement is a key reference indicator for the evaluation model. The lighting environment evaluation experiments in the Japanese art museums prove the Kruithof curve and the evaluation methods of the color temperature and illuminance variation under different lighting environments.

This study adopts an innovative lighting environment simulation for measuring optical engineering parameters with the help of DIALux software, it describes the advantages of this software in the methods section. Evaluation of optical engineering parameters in the same space by varying the lighting mode and color temperature is difficult. However, by means of color calibration, the impact of color differences on the experiment is effectively avoided, and the color calibration makes the whole experiment suitable to have a lighting environment that is similar to an art museum, so that the visitors get a realistic simulation effect, and the lighting environment is simulated more effectively.

The study uses eye-movement experiments and questionnaires to obtain visitors' visual-related information, which is key to the formation of emotion in that lighting environment. The study is innovative in that it quantifies the spatial, lighting environment, and emotional responses. Specifically, emotion is quantified by psychological experiments, and eye-movement data are used to verify the scientific validity of the questionnaires, which constitute the most important process of emotion formation in the SVOE evaluation model. The indexes and methods of SVOE evaluation model were verified by experiments. It is an innovative method in the knowledge sciences, as well as a multidisciplinary approach to evaluation. Finally, this study involved two experiments that simulated the lighting conditions in art museums, to apply the model.

Through subjective questionnaires and eye movement tracking experiments, the hypothesis of emotional response was verified. The subjective responses and objectivity were verified using eye movement tracking devices to test the consistency of the predicted results. For example, the experiment of thinking and understanding integrated the lighting comfort model based on color temperature and illuminance suitable for the lighting environment of an art museum. A lighting design evaluation theory of artificial lighting comfort evaluation methodology under various lighting environments was established. In practical applications, the critical color temperature and illuminance can be adjusted through the evaluation methodology, which evaluates the emotional comfort of the observer in the art museum lighting environment.

To summarize, a series of research work was implemented through the establishment of the SVOE model and the interdisciplinary approach to establish a visual evaluation methodology for LED indoor lighting comfort. This study first determined the general purpose of the art museum space multi-factor research, and experiments were performed on the comfort level of the artificial lighting environment in the space of human visual and non-visual factors.

The study established the lighting comfort model based on color temperature and illuminance adopting objective optical parameters such as illuminance, color temperature, and color rendering index in an ordinary general indoor space based on optical parameters. Finally, it used ornamental experiments and experiments of thinking and understanding to verify the applicability of theoretical methods from the theoretical model as the key to emotional response.

Through the original data from questionnaires, eye movement tracking experiments, and the established lighting evaluation model for SVOE, this study broke the limitation of using subjective responses to evaluate the lighting comfort of space lighting parameters. The experiment used eye movement tracking to provide new theoretical support for innovation in museum design and artificial lighting technology. The proposed evaluation methodology can supply corresponding standards for the museum industry and provide important basic data and theoretical support for lighting design.

6.2 Suggestions for Further Works

After selecting the topic, a project plan was constructed for the final implementation, and the thesis was formulated upon the results of these procedures. It reached the expected research goal and achieved the corresponding research results. Nevertheless, since the research content of lighting comfort spans across multiple disciplines such as lighting engineering, vision, psychology, and psychophysics, it is impossible to achieve a lighting comfort model that is completely consistent with visual data. In addition, due to limitations such as personal ability and time, this thesis still has some shortcomings, which need to be further improved.

The proposed method gave a theoretical basis for the realization of artificial lighting environment evaluation in the space of art museums. The proposed emotional response index, in which optical parameters affect viewers' emotions, can be used to realize the design of scenarios in different spaces. The lighting quality and comfort model on account of only the color temperature coordinates, comprised the CCT coordinate parameters without embedding the illuminance parameters. The basic data established by the model was derived from the fixed illuminance value of the lighting environment. This study showed that the experimental results conformed to the rules of the Kruithof's curve. At the same time, the conclusions drawn from the data completed the response model and established a new index for the emotional response of different space types. Future research will include people of different age groups to this experiment in art museums. The SVOE model will add different indexes that need further verification and experiments.

The lighting comfort model was based on the illumination of the environment and the quality of lighting in the art museum space, while the influence of the background color of the artworks on the observers and the influence of the background contrast are still missing in this study. By using the chromaticity coordinates, the background color can be converted into a brighter one, and the theoretical mathematical model can be fitted by means of the emotional response parameters of the background and various lighting environments. Some parameters in the theoretical model under SVOE may be variable. This offers support for the use of artificial intelligence. The data was processed and calculated quickly using computer software, but this model of pure data may not reflect the essential relationship between various data. Therefore, in the future research, a true evaluation model should be established for the relevant factors.

The lighting quality and comfort studied in this thesis merely involved the three objective physical quantities of illuminance, color temperature, and lighting mode of the illuminated environment. Whereas, due to the existence of non-visual effects of light, spectral components also turned into objective factors that affected the comfort of lighting. As a result, in future research, we should focus on the impact of multiple optical parameters on lighting quality and comfort.

Due to personal limitations such as the author's energy and time, it was not possible to have a broader selection of different museum spaces. Accordingly, we will perform research and analysis in future on a more diversified range of viewing facilities and an understanding of artworks in the art museums. The studied emotional response model can be applied to the comfort evaluation of the lighting environment combining artificial lighting and natural lighting. This study aimed to establish the emotional response based on human visual factors in the museums, which is not limited to the comfort evaluation model of environment lighting. This result can effectively evaluate the emotional response of the observers on the illuminated environment, which will be beneficial to the design of lighting environment in human life.

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Journal Article

[1] **Zhisheng Wang,** Yukari Nagai*, Zhi Sun, Cong Zhang, Nianyu Zou. Research into the Improvement of Museum Visitor's Emotional Response Levels to Artificial Lighting Designs Based on Interdisciplinary Creativity. Journal of Engineering Research. 2020. Vol.8 (2). pp. 163-182. (SCIE, Scopus)

[2] **Zhisheng Wang,** Yukari Nagai*, Jiahui Liu, Nianyu Zou, Jing Liang. Artificial Lighting Environment Evaluation of the Japan Museum of Art Based on the Emotional Response of Observers. Applied Sciences. 2020; 10(3):1121. doi.org/10.3390/app10031121. (SCIE, Scopus)

[3] **Zhisheng Wang,** Yukari Nagai*, Dan Zhu, Jiahui Liu, Nianyu Zou. Based on Creative Thinking to Museum Lighting Design Influences to Visitors Emotional Response Levels Theory Research. IOP Conference Series: Materials Science and Engineering. 2019. Vol.573. doi:10.1088/1757899X/573/1/012093. (EI, Scopus)

Conference Proceeding and Presentation

[1] **Zhisheng Wang,** Yukari Nagai*, Eunyoung Kim, Nianyu Zou, Jiaojiao Hou, Xinyuan Liu, Dan Zhu. Research on Lighting Style and Colour Temperature to Emotion Response in Architecture Illumination of the Historic Buildings in Dalian. International Conference on Computer Engineering and Application (ICCEA2020). Guangzhou, China. March 27-29, 2020. (EI, Scopus)

[2] **Zhisheng Wang*,** Dan Zhu, Cong Zhang, Haiwen Gao, Yukari Nagai, Nianyu Zou. Museum Visitor's Emotional Response Levels to Artificial Lighting Designs Based on Interdisciplinary Creativity. International Conference on Green Communications and Networking. International Conference on Green Communications and Networking (GreeNets2020). Harbin, China. May 23-24, 2020. (EI, Scopus)

[3] **Zhisheng Wang,** Yukari Nagai*, Nianyu Zou, Zhi Sun, Jiahui Liu. Research on Museum Lighting Design Method: Emotional Effects Based on the SVOE Model and Creative Thinking. The 13th International Conference on Knowledge, Information and Creativity Support Systems (KICSS2018). pp.112-117. Pattaya, Thailand. November 15-17, 2018. (IEEE) (Oral Presentations)

[4] **Zhisheng Wang,** Yukari Nagai*, Nianyu Zou. Based on Interdisciplinary through Creativity Artificial Lighting Design of Improve Museum Visitor Emotional Response Level Theory Research. The 11th Asia Lighting Conference (ALC2018). pp.167-171. Kobe, Japan. September 13-14, 2018. (Oral Presentations)

[5] **Zhisheng Wang,** Yukari Nagai*. Research into the Improvement of Museum Visitor's Emotional Response Levels to Artificial Lighting Designs Based on Interdisciplinary Creativity. The International Conference on Creativity and Innovation (ICCI2018). pp.330-346. Osaka, Japan. September 10-12, 2018. (Oral Presentations)

APPENDIX

Experience and Emotional Response Questionnaire

JAIST JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY 1990 | School of Knowledge Science

Name of Project: Interdisciplinary Approach for Design of the Lighting Environment in Art Museum by Focusing on Emotional Evaluation

Investigator: Mr. WANG, Zhisheng (Ph.D Candidate, Japan Advanced Institute of Science and Technology)

Museum Experiences Survey

Participant Consent and Research Ethics Statement

This survey is part of a doctoral research project that has gained approval from the School of Knowledge Science at the Japan Advanced Institute of Science and Technology. Your responses will remain completely anonymous. Further details of the study are given in the Participant Information Sheet provided. Thank you for agreeing to participate in this research. The survey will take approximately 5-10 minutes to complete. Remember your participation in this study is completely voluntary and you may withdraw at any stage.

Survey Instructions

For each question, please indicate your response by filling in the applicable circle as shown:

❍ ❍ ❍ ❍ ❍ ❍ ❍

↑

Your response

Choose the circle which is closest to your desired response – please do not put responses in intermediate positions between the circles.

If you make a mistake, put a cross through the incorrect response and fill in another circle:

❍ ❍ ❍ ● ⊗ ❍ ❍

Please note that there are questions on BOTH SIDES of the paper.

Please turn the page to start the survey →

Midpoint

Warm	❍	❍	❍	❍	❍	❍	❍	**Cool**
Relaxed	❍	❍	❍	❍	❍	❍	❍	**Tense**
Modern	❍	❍	❍	❍	❍	❍	❍	**Classical**
Masculine	❍	❍	❍	❍	❍	❍	❍	**Feminine**
Bright	❍	❍	❍	❍	❍	❍	❍	**Dark**
Exciting	❍	❍	❍	❍	❍	❍	❍	**Calming**
Animated	❍	❍	❍	❍	❍	❍	❍	**Quiet**
Happy	❍	❍	❍	❍	❍	❍	❍	**Sad**
Encouraged	❍	❍	❍	❍	❍	❍	❍	**Dejected**
Like	❍	❍	❍	❍	❍	❍	❍	**Dislike**
Usual	❍	❍	❍	❍	❍	❍	❍	**Unusual**
Healthy	❍	❍	❍	❍	❍	❍	❍	**Ill**
Beautiful	❍	❍	❍	❍	❍	❍	❍	**Ugly**
Romantic	❍	❍	❍	❍	❍	❍	❍	**Realistic**
Elegant	❍	❍	❍	❍	❍	❍	❍	**Vulgar**
Pleasant	❍	❍	❍	❍	❍	❍	❍	**Unpleasant**
Distinct	❍	❍	❍	❍	❍	❍	❍	**Vague**
Active	❍	❍	❍	❍	❍	❍	❍	**Respectful**
Dynamic	❍	❍	❍	❍	❍	❍	❍	**Undynamic**
Festive	❍	❍	❍	❍	❍	❍	❍	**Distressed**
Peaceful	❍	❍	❍	❍	❍	❍	❍	**Horrible**

Survey continues-please turn the page →

Which of the following statements best describes the main purpose of your visit to the museum today?

(Please choose ONE ONLY)

❍ To see things I have a particular interest in
❍ To satisfy a general interest or curiosity
❍ To take time out from the stresses of daily life
❍ To accompany my children/partner/friends
❍ Because it is one of the city's main attractions

Please indicate your age range:

❍ 18-29 ❍ 50-59
❍ 30-39 ❍ 60+
❍ 40-49

Please indicate your gender:

❍ Male ❍ Female

This lighting environment engages all my senses.

❍	❍	❍	❍	❍	❍	❍
Disagree strongly	Disagree	Disagree slightly	Neither agree nor disagree	Agree slightly	Agree	Agree strongly

This lighting environment really invites me to explore it.

❍	❍	❍	❍	❍	❍	❍
Disagree strongly	Disagree	Disagree slightly	Neither agree nor disagree	Agree slightly	Agree	Agree strongly

I don't really pay attention to the exhibition lighting environment – I just like to look at the exhibits.

❍	❍	❍	❍	❍	❍	❍
Disagree strongly	Disagree	Disagree slightly	Neither agree nor disagree	Agree slightly	Agree	Agree strongly

Thank you for participating! Please return this survey to the researcher.

Table 7-1. The original data of software simulating of mode A.

No.	Gender	Comfortable/Uncomfortable	Beautiful/ Ugly	Classical/Modern	Natural/Unnatural	Relaxed/Tense	Warm/ Cold	Colorful/Monotone	Interesting/ Boring	Artistic/ Non artistic	Like/Dislike
1	Female	2	3	3	3	2	2	2	2	2	2
2	Female	3	2	5	3	2	2	3	1	2	1
3	Male	5	4	5	4	3	2	3	4	5	6
4	Male	4	4	4	4	6	2	3	2	2	2
5	Male	2	3	2	2	2	3	3	3	3	1
6	Male	4	4	4	3	3	3	3	3	3	3
7	Male	3	2	5	3	3	2	2	4	3	3
8	Male	2	2	2	2	2	2	2	1	2	1
9	Male	4	4	4	4	4	3	3	4	4	4
10	Male	2	3	4	3	3	3	3	2	4	3
11	Female	2	3	2	3	3	3	2	2	3	3
12	Female	4	3	4	4	3	3	3	3	3	3
13	Female	1	1	2	2	2	1	1	2	2	3
14	Female	1	1	1	2	3	1	1	1	1	1
15	Female	1	1	2	1	1	2	1	1	1	1

16	Female	2	2	4	2	2	2	2	3	3	2
17	Female	2	1	2	2	2	2	1	1	1	2
18	Female	3	4	4	3	3	2	3	3	4	3
19	Female	5	5	6	4	6	3	6	3	4	5
20	Female	1	1	1	1	1	1	1	1	1	1
21	Female	4	4	3	4	4	4	3	3	3	3
22	Female	3	2	2	3	3	3	2	3	4	2
23	Female	4	3	3	3	4	3	3	3	3	3
24	Female	2	2	3	2	2	2	2	2	3	2
25	Female	3	3	4	3	3	3	2	2	3	2
26	Male	5	5	4	3	4	3	3	4	3	4
27	Female	2	3	3	1	3	3	1	1	3	3
28	Male	2	3	3	3	2	2	2	2	3	2
29	Female	1	2	1	1	2	2	2	2	2	2
30	Female	3	3	4	3	2	2	3	2	3	3
31	Male	5	5	6	4	6	3	6	3	4	5
Average		***2.81***	***2.84***	***3.29***	***2.74***	***2.94***	***2.39***	***2.48***	***2.35***	***2.81***	***2.61***

Notes: The mode A was General lighting mode and CCT was 4,000 K.

Table 7-2. The original data of software simulating of mode B.

No.	Gender	Comfortable/Uncomfortable	Beautiful/Ugly	Classical/Modern	Natural/Unnatural	Relaxed/Tense	Warm/Cold	Colorful/Monotone	Interesting/Boring	Artistic/Non artistic	Like/Dislike
1	Female	3	3	3	2	2	2	3	3	4	3
2	Female	2	2	2	3	3	2	2	3	2	1
3	Male	5	5	2	4	2	4	3	4	6	5
4	Male	1	2	2	2	4	1	1	3	1	1
5	Male	3	1	4	1	4	4	2	3	4	1
6	Male	3	2	4	4	2	3	2	2	3	2
7	Male	2	1	3	2	4	2	3	2	3	2
8	Male	2	2	2	2	2	1	1	1	1	1
9	Male	1	2	3	1	2	2	1	1	2	2
10	Male	3	4	5	3	2	2	3	3	3	4
11	Female	2	2	2	1	2	1	2	2	1	1
12	Female	2	2	2	2	2	1	2	2	2	2
13	Female	2	3	2	5	5	2	2	2	2	2
14	Female	2	2	1	2	3	2	1	1	1	1
15	Female	4	3	3	4	3	3	2	1	2	2

16	Female	2	2	2	3	4	4	2	2	2	3
17	Female	2	1	1	1	2	2	3	2	1	1
18	Female	2	1	3	3	3	2	2	1	2	1
19	Female	3	3	2	2	3	3	2	2	3	3
20	Female	2	2	1	2	2	2	2	2	2	2
21	Female	2	4	4	4	2	2	3	3	4	2
22	Female	1	1	2	1	1	1	1	1	1	1
23	Female	3	3	3	3	4	3	3	3	3	3
24	Female	2	2	2	2	2	1	1	1	3	1
25	Female	2	2	4	3	2	1	2	2	2	2
26	Male	3	3	3	3	4	4	3	3	3	3
27	Female	3	3	3	3	2	2	2	2	2	3
28	Male	4	3	4	4	4	3	3	3	4	4
29	Female	4	3	3	4	4	3	3	3	3	3
30	Female	3	3	4	4	3	3	3	3	3	3
31	Male	3	3	2	2	3	3	2	2	3	3
Average		***2.52***	***2.42***	***2.68***	***2.65***	***2.81***	***2.29***	***2.16***	***2.19***	***2.52***	***2.19***

Notes: The mode B was General lighting mode and CCT was 2,700 K.

Table 7-3. The original data of software simulating of mode C.

No.	Gender	Comfortable/Uncomfortable	Beautiful/Ugly	Classical/Modern	Natural/Unnatural	Relaxed/Tense	Warm/Cold	Colorful/Monotone	Interesting/Boring	Artistic/Non artistic	Like/Dislike
1	Female	3	2	3	2	3	3	3	3	4	3
2	Female	3	3	4	2	2	2	3	3	3	3
3	Male	4	6	6	4	3	2	4	3	2	5
4	Male	4	4	1	5	3	2	4	4	3	3
5	Male	6	5	5	5	6	5	4	5	6	5
6	Male	4	4	5	5	4	4	4	5	4	5
7	Male	4	3	2	4	4	2	2	2	2	2
8	Male	4	5	2	4	3	3	3	3	4	2
9	Male	2	2	4	2	2	2	2	2	3	2
10	Male	3	5	4	3	4	3	4	4	5	4
11	Female	4	3	3	3	4	4	3	2	2	2
12	Female	5	5	4	4	5	4	3	4	4	3
13	Female	3	3	5	2	2	2	2	2	4	2
14	Female	4	4	4	4	4	3	3	3	4	3
15	Female	3	4	4	4	4	2	4	4	4	4

16	Female	4	3	3	3	4	3	2	3	3	2
17	Female	4	3	3	3	3	3	4	4	4	4
18	Female	4	4	3	4	4	4	5	4	3	4
19	Female	2	3	4	3	2	3	4	5	4	5
20	Female	4	4	3	4	2	4	3	3	3	3
21	Female	4	4	4	4	4	3	3	3	4	4
22	Female	5	5	6	4	3	3	4	6	6	5
23	Female	4	4	4	4	4	3	4	4	4	4
24	Female	4	4	4	4	3	3	3	4	5	4
25	Female	4	4	4	4	4	3	3	3	4	4
26	Male	4	3	5	3	4	3	3	4	5	3
27	Female	5	5	5	5	4	4	4	4	3	4
28	Male	4	4	5	4	3	4	4	4	4	4
29	Female	5	5	5	5	5	4	4	4	5	5
30	Female	2	4	4	4	2	2	4	3	4	2
31	Male	2	3	4	3	2	3	4	5	4	5
Average		***3.77***	***3.87***	***3.94***	***3.68***	***3.42***	***3.06***	***3.42***	***3.61***	***3.84***	***3.55***

Notes: The mode C was Accent lighting mode and CCT was 4,000 K.

Table 7-4. The original data of software simulating of mode D.

No.	Gender	Comfortable/Uncomfortable	Beautiful/Ugly	Classical/Modern	Natural/Unnatural	Relaxed/Tense	Warm/Cold	Colorful/Monotone	Interesting/Boring	Artistic/Non artistic	Like/Dislike
1	Female	4	3	3	3	4	2	2	2	3	2
2	Female	4	3	5	4	3	3	3	2	4	3
3	Male	6	4	4	2	3	4	3	4	5	5
4	Male	3	3	5	3	5	4	6	6	1	2
5	Male	3	3	3	3	3	3	3	3	3	2
6	Male	5	5	5	5	5	5	4	5	5	5
7	Male	5	2	3	5	4	5	4	4	5	4
8	Male	5	4	3	4	4	4	4	5	4	4
9	Male	3	3	4	3	3	3	3	2	3	3
10	Male	4	4	3	4	4	5	4	4	4	5
11	Female	4	3	3	3	4	4	3	3	3	3
12	Female	5	5	5	5	5	4	4	4	4	4
13	Female	5	4	5	5	4	5	4	4	4	5
14	Female	4	4	4	4	5	4	4	5	4	4
15	Female	5	5	5	5	4	5	4	5	4	5

16	Female	5	4	4	5	4	4	4	4	4	4
17	Female	4	4	4	4	4	4	3	4	4	3
18	Female	4	4	4	5	5	5	5	4	4	4
19	Female	4	3	4	3	3	4	4	3	4	3
20	Female	4	5	5	4	4	4	3	5	5	5
21	Female	5	4	4	4	4	4	3	3	4	4
22	Female	6	6	6	4	3	6	6	6	6	6
23	Female	4	4	4	4	4	4	4	4	4	4
24	Female	4	4	5	5	5	5	4	4	5	5
25	Female	4	4	4	4	4	4	4	4	4	4
26	Male	4	4	5	4	3	4	3	4	4	4
27	Female	4	4	4	4	4	4	4	4	4	4
28	Male	3	4	4	4	3	4	5	4	4	4
29	Female	6	6	6	6	6	6	4	5	5	6
30	Female	4	4	4	4	4	4	4	4	4	5
31	Male	4	3	4	3	3	4	4	3	4	3
Average		***4.32***	***3.94***	***4.23***	***4.03***	***3.97***	***4.19***	***3.84***	***3.97***	***4.03***	***4.00***

Notes: The mode D was Accent lighting mode and CCT was 2,700 K.

Table 7-5. The original data of software simulating of mode E.

No.	Gender	Comfortable/Uncomfortable	Beautiful/Ugly	Classical/Modern	Natural/Unnatural	Relaxed/Tense	Warm/Cold	Colorful/Monotone	Interesting/Boring	Artistic/Non artistic	Like/Dislike
1	Female	5	5	5	6	5	5	4	4	4	5
2	Female	4	3	3	4	4	4	4	3	4	4
3	Male	4	5	6	5	3	2	4	2	5	6
4	Male	4	4	6	3	4	2	4	5	4	4
5	Male	4	4	5	3	3	3	4	4	5	4
6	Male	5	5	6	4	5	4	4	4	5	5
7	Male	3	4	5	2	2	2	3	2	3	2
8	Male	3	3	3	3	2	2	2	2	1	1
9	Male	5	5	6	5	5	5	5	5	4	5
10	Male	3	4	4	3	3	2	3	4	4	4
11	Female	3	3	3	4	3	3	3	3	3	3
12	Female	4	3	3	3	3	3	4	3	4	3
13	Female	1	2	2	2	2	2	2	3	3	3
14	Female	3	4	3	4	5	3	3	3	4	4
15	Female	2	2	4	2	2	1	2	3	3	2

16	Female	4	4	5	5	4	3	4	4	4	5
17	Female	3	4	4	4	3	3	4	4	4	4
18	Female	4	5	5	4	4	3	3	4	5	6
19	Female	4	5	5	4	6	5	4	4	4	5
20	Female	5	5	5	5	2	2	2	2	5	5
21	Female	5	4	4	4	4	4	3	4	3	5
22	Female	3	4	6	4	3	3	5	4	6	4
23	Female	5	5	5	5	5	4	4	4	4	5
24	Female	3	4	5	4	3	3	2	2	4	2
25	Female	5	5	5	5	5	5	5	5	4	4
26	Male	5	5	4	4	4	3	4	4	4	4
27	Female	3	3	3	1	3	3	3	3	1	1
28	Male	4	3	3	2	3	3	3	2	2	2
29	Female	4	5	2	3	3	3	2	3	2	2
30	Female	4	5	5	5	3	4	3	3	2	4
31	Male	4	5	5	4	6	5	4	4	4	5
Average		***3.81***	***4.10***	***4.35***	***3.74***	***3.61***	***3.19***	***3.42***	***3.42***	***3.68***	***3.81***

Notes: The mode E was Mixed lighting mode and CCT was 4,000 K.

Table 7-6. The original data of software simulating of mode F.

No.	Gender	Comfortable/Uncomfortable	Beautiful/Ugly	Classical/Modern	Natural/Unnatural	Relaxed/Tense	Warm/Cold	Colorful/Monotone	Interesting/Boring	Artistic/Non artistic	Like/Dislike
1	Female	5	5	5	6	5	5	3	4	4	4
2	Female	4	3	4	4	4	5	3	4	4	4
3	Male	4	5	5	2	3	4	2	3	4	3
4	Male	4	6	6	4	4	6	5	5	5	4
5	Male	3	2	4	3	3	2	3	2	4	2
6	Male	6	5	4	5	6	6	4	4	5	5
7	Male	4	3	3	3	3	4	4	4	2	2
8	Male	5	5	5	5	5	5	4	4	4	4
9	Male	5	5	4	5	5	5	4	5	5	5
10	Male	4	5	4	4	4	4	4	4	5	5
11	Female	4	4	4	4	4	4	4	4	3	4
12	Female	5	5	5	4	5	5	4	4	5	5
13	Female	4	4	6	3	4	3	5	5	5	4
14	Female	5	5	5	5	5	5	5	5	5	5
15	Female	5	5	5	5	4	6	5	6	5	5

16	Female	3	4	3	4	4	4	4	5	4	3
17	Female	3	4	4	2	2	5	4	4	3	2
18	Female	4	3	3	3	6	5	4	3	3	2
19	Female	5	4	5	4	6	5	4	5	4	5
20	Female	4	4	4	5	6	6	5	5	4	6
21	Female	5	4	4	4	4	4	4	4	4	5
22	Female	6	6	6	6	6	6	6	6	6	6
23	Female	5	5	5	5	5	6	5	5	5	6
24	Female	5	5	5	5	6	5	5	5	5	5
25	Female	6	6	6	6	6	6	6	5	5	5
26	Male	4	4	3	4	4	6	5	5	4	4
27	Female	5	5	5	4	4	3	4	4	4	4
28	Male	4	3	3	4	4	5	3	3	3	3
29	Female	5	5	4	4	4	4	4	4	5	5
30	Female	4	5	5	5	3	4	3	3	4	4
31	Male	5	4	5	4	6	5	4	5	4	5
Average		***4.52***	***4.45***	***4.48***	***4.23***	***4.52***	***4.77***	***4.16***	***4.32***	***4.26***	***4.23***

Notes: The mode F was Mixed lighting mode and CCT was 2,700 K.

Table 7-7. The original data of eye tracking experiments of environment 1.

Environment 1（3000 K，300 lx）										
Observers	**Colorful/Monotone**	**Bright/Dark**	**Visibly/Fuzzy**	**Warm/Cold**	**Soft/Hard**	**Comfortable/Uncomfortable**	**Vivid/Not Vivid**	**Natural/Unnatural**	**Like/Dislike**	**Clarity/Messy**
1	3	3	5	3	3	4	3	4	2	5
2	3	3	2	4	4	4	4	4	2	3
3	2	3	4	3	4	3	3	4	3	4
4	4	4	3	6	5	5	4	5	4	6
5	4	4	2	5	4	4	3	5	4	5
6	4	5	4	5	4	6	5	4	2	5
7	5	4	4	5	5	5	5	4	5	4
8	3	3	2	4	4	4	4	4	2	5
9	3	3	4	5	6	5	4	6	4	4
10	3	4	5	4	3	4	4	4	3	4
11	4	3	2	4	4	4	5	4	2	3
12	2	3	3	4	4	4	4	4	4	4
13	5	5	3	5	5	4	4	4	2	5
14	3	2	3	4	4	5	4	3	4	4
15	4	4	3	5	2	5	5	4	2	3
16	3	3	4	4	4	4	4	3	4	5
17	3	3	3	5	4	5	3	3	2	2
18	3	3	3	5	6	4	4	5	4	5
19	4	3	5	5	5	4	5	4	2	4

20	4	5	5	5	4	5	4	4	3	5
21	3	3	2	5	5	4	5	6	2	3
22	3	3	3	4	4	3	2	2	2	3
23	3	4	5	5	3	3	3	4	4	2
24	3	2	3	5	5	4	2	2	2	3
25	3	3	4	5	4	4	4	4	3	4
26	3	3	2	4	4	4	4	4	3	3
27	5	3	5	6	5	5	5	4	3	3
28	4	3	4	3	3	4	3	4	3	4
29	5	3	4	4	4	4	4	4	3	4
30	2	3	3	2	4	4	3	4	3	3
31	2	3	4	4	4	3	4	4	3	4
32	3	3	3	4	4	2	3	3	2	4
33	4	5	5	5	5	4	4	3	4	4
34	4	3	3	4	4	4	4	3	2	4
35	4	3	3	4	4	4	4	4	3	4
36	3	3	4	4	5	4	4	4	4	4
37	3	3	4	5	4	5	5	5	3	5
38	3	2	3	5	3	4	4	5	3	5
39	4	3	2	5	4	5	4	4	4	3
Average	***3.41***	***3.28***	***3.46***	***4.44***	***4.15***	***4.15***	***3.90***	***3.97***	***2.97***	***3.95***

Notes: This experiment of eye tracking included male of 18 and female of 21. The female students majored in art, male students majored in science.

Table 7-8. The original data of eye tracking experiments of environment 2.

Environment 2（3000 K，500 lx）										
Observers	**Colorful/Monotone**	**Bright/Dark**	**Visibly/Fuzzy**	**Warm/Cold**	**Soft/Hard**	**Comfortable/Uncomfortable**	**Vivid/Not Vivid**	**Natural/Unnatural**	**Like/Dislike**	**Clarity/Messy**
1	4	4	4	4	4	3	3	4	2	4
2	4	3	3	4	5	3	3	4	2	4
3	3	2	4	4	4	3	4	4	3	5
4	5	5	4	6	5	3	4	5	2	6
5	4	4	4	4	4	3	5	5	5	4
6	5	4	5	5	5	4	4	5	5	4
7	3	4	5	3	3	4	4	3	4	4
8	4	5	5	5	5	5	5	4	5	5
9	3	3	4	4	5	5	4	5	5	4
10	3	4	4	4	4	4	4	4	4	4
11	4	4	5	5	5	4	4	4	2	4
12	4	4	4	5	5	5	4	4	4	4
13	5	4	5	4	5	4	4	4	4	4
14	5	5	5	3	4	3	5	3	5	5
15	5	4	4	5	2	4	5	4	4	2
16	3	4	4	3	3	4	3	3	4	4
17	5	6	5	5	3	5	6	5	5	6
18	4	6	5	5	5	5	4	5	4	5
19	4	5	6	5	5	4	5	5	5	5

20	5	5	5	5	4	5	4	5	5	5
21	3	4	2	5	4	4	5	4	4	3
22	4	5	5	5	5	5	5	5	5	4
23	4	4	4	6	4	5	3	3	4	3
24	4	4	4	4	4	4	4	4	4	4
25	4	4	4	5	4	4	4	4	5	5
26	3	3	3	4	4	4	4	4	4	3
27	4	5	6	6	5	5	4	5	5	5
28	5	4	5	5	5	5	5	5	4	5
29	3	4	3	4	3	4	2	3	3	4
30	2	3	3	5	4	4	4	4	4	3
31	4	4	3	5	4	4	4	4	4	4
32	4	5	4	5	4	6	5	4	5	5
33	4	4	5	5	5	5	5	5	5	5
34	4	5	5	5	5	5	4	3	5	4
35	4	5	5	6	5	5	5	5	4	4
36	4	5	5	6	6	5	5	4	5	6
37	5	5	5	4	4	5	5	5	4	5
38	4	4	4	4	4	4	4	5	5	4
39	4	4	4	5	4	4	4	4	5	4
Average	***3.97***	***4.26***	***4.33***	***4.67***	***4.31***	***4.28***	***4.23***	***4.23***	***4.18***	***4.31***

Notes: This experiment of eye tracking included male of 18 and female of 21. The female students majored in art, male students majored in science.

Table 7-9. The original data of eye tracking experiments of environment 3.

Environment 3（4000 K，300 lx）										
Observers	**Colorful/Monotone**	**Bright/Dark**	**Visibly/Fuzzy**	**Warm/Cold**	**Soft/Hard**	**Comfortable/Uncomfortable**	**Vivid/Not Vivid**	**Natural/Unnatural**	**Like/Dislike**	**Clarity/Messy**
1	4	5	5	5	5	5	5	5	5	4
2	4	5	4	4	3	3	3	3	3	4
3	3	4	4	3	5	2	3	2	2	5
4	5	5	4	4	4	6	4	5	4	5
5	4	5	5	3	3	5	4	5	5	5
6	5	5	5	5	4	6	5	5	5	5
7	2	4	4	3	3	3	4	4	4	4
8	4	5	5	4	3	5	5	5	5	6
9	4	5	6	3	4	4	5	6	4	5
10	3	5	5	4	3	4	4	4	4	4
11	2	2	2	4	4	3	2	3	3	3
12	2	4	4	4	4	4	4	4	3	3
13	4	4	4	4	4	4	3	4	3	5
14	3	3	3	5	5	4	3	4	3	3
15	3	5	5	4	4	4	4	3	4	5
16	3	3	4	4	4	3	4	4	4	4
17	2	2	2	3	2	2	2	4	2	2
18	4	5	3	5	5	4	4	4	4	4
19	4	4	3	3	4	3	3	3	3	3

20	2	3	3	4	2	3	3	4	3	3
21	3	4	3	4	3	3	5	5	4	3
22	4	5	5	2	2	4	4	2	2	5
23	2	5	4	2	3	3	2	4	4	5
24	4	5	5	2	3	4	4	4	5	5
25	5	4	5	5	4	5	5	5	5	5
26	4	4	3	4	4	4	4	4	4	3
27	3	5	3	3	2	3	3	2	3	3
28	3	4	5	3	3	4	4	5	2	4
29	3	4	4	3	3	4	2	3	2	3
30	3	4	4	4	4	4	3	4	3	4
31	4	4	4	3	4	4	3	4	4	4
32	5	4	5	5	4	4	5	5	5	4
33	3	3	5	3	3	6	5	5	5	6
34	3	3	4	3	3	4	4	2	4	4
35	3	4	4	3	3	3	3	4	4	4
36	4	5	5	5	3	3	5	4	4	6
37	4	4	4	3	3	5	5	4	4	5
38	5	4	5	3	4	5	4	5	5	4
39	4	3	3	3	2	4	4	4	4	4
Average	***3.49***	***4.13***	***4.10***	***3.62***	***3.46***	***3.92***	***3.79***	***4.00***	***3.74***	***4.18***

Notes: This experiment of eye tracking included male of 18 and female of 21. The female students majored in art, male students majored in science.

Table 7-10. The original data of eye tracking experiments of environment 4.

Environment 4（4000 K，500 lx）										
Observers	**Colorful/Monotone**	**Bright/Dark**	**Visibly/Fuzzy**	**Warm/Cold**	**Soft/Hard**	**Comfortable/Uncomfortable**	**Vivid/Not Vivid**	**Natural/Unnatural**	**Like/Dislike**	**Clarity/Messy**
1	4	6	5	3	4	5	3	4	2	4
2	4	3	3	5	5	5	4	4	5	4
3	3	4	4	4	4	5	3	4	3	2
4	4	4	3	4	5	4	5	5	4	5
5	4	4	3	4	4	4	4	4	5	5
6	5	5	5	4	5	4	3	5	5	5
7	4	4	4	3	4	4	4	4	4	3
8	4	5	3	4	4	4	6	5	4	4
9	3	3	3	4	4	4	5	5	5	4
10	4	5	5	4	5	5	5	5	5	4
11	5	5	5	5	5	6	5	5	5	5
12	3	4	4	4	4	4	4	4	4	4
13	4	5	6	5	3	4	6	4	5	5
14	5	4	5	4	5	3	5	5	4	4
15	5	3	5	5	4	4	5	4	5	5
16	4	4	4	4	4	4	4	4	4	4
17	6	6	6	3	2	6	6	6	5	6
18	4	6	6	4	4	4	5	5	5	5
19	4	4	4	3	4	3	4	4	3	4

20	4	5	5	5	4	4	5	5	5	5
21	3	5	3	5	4	5	4	3	4	3
22	5	5	5	2	2	5	5	5	6	5
23	3	6	6	1	3	4	2	5	5	6
24	5	5	5	4	5	5	5	5	5	5
25	3	3	4	4	4	4	4	4	3	3
26	4	4	3	4	4	4	4	4	4	3
27	4	6	5	3	3	4	2	3	3	4
28	5	4	5	5	5	6	5	5	5	5
29	4	4	4	3	3	2	3	3	3	3
30	4	3	4	4	4	4	4	5	4	4
31	4	5	5	3	5	6	5	4	4	4
32	5	5	5	3	5	5	6	6	5	6
33	4	3	5	3	3	4	5	5	5	5
34	4	5	5	3	4	4	4	3	4	4
35	3	3	3	3	4	3	4	4	4	4
36	3	6	6	6	6	5	5	6	5	6
37	4	5	5	4	3	5	5	5	5	5
38	4	5	5	3	3	4	4	4	3	4
39	5	5	4	3	4	4	4	4	4	4
Average	***4.08***	***4.51***	***4.49***	***3.77***	***4.03***	***4.33***	***4.38***	***4.46***	***4.31***	***4.36***

Notes: This experiment of eye tracking included male of 18 and female of 21. The female students majored in art, male students majored in science.