# Research on Multi-disciplinary Museum Lighting Design's Emotional Response to Visitors: A Case Study of Dalian Modern Museum

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**Abstract.** The main research direction of this article is to explore the artificial lighting of the museum emotionally by adopting the innovative thinking and design methods of multidisciplinary cross integration. Three main innovations are proposed. 1. The theory of tourists' demand and space is analyzed. 2. We use creative thinking to answer the relationship between optical engineering and the time that tourists stay in the exhibition area. 3. Interactive formulas are used to quantify emotions. This experiment takes the Dalian Modern Museum as the research object. Firstly, for the space division of the museum and the tour route, we analyzed and discussed it according to the needs of tourists and the size of the exhibition space. Under a certain space size condition, the illuminance, color temperature and color rendering index were measured and then we collated and analyzed the data obtained. Under different light environment conditions, we obtained the relationship between the R9, Rf and Rg values in the color rendering index and the residence time of visitors in the exhibition area. Finally, the factor analysis method is used to analyze the experimental data. This experiment provides theoretical support for the emotional design of artificial lighting, and has creative thinking and research significance.

**Keywords:** Artificial lighting design · Emotional response level · Creativity

## 1 Introduction

As a carrier of cultural exchange, the museum's lighting environment greatly affects the visitors' viewing experience. At the same time it is also a functional facility, its main purpose is to display, educate and spread culture [1]. The rationality of lighting design is an important indicator to measure the level of museum construction. Different types of museums should have different display themes, which means different lighting technologies [2]. For the museum, the design of the lighting environment should not only consider the protection of cultural relics, but also consider the color performance of the


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exhibits and the texture clarity of exhibits [3],we must also pay attention to whether the vision conveys the information inside and around the museum's collection [4]. The lighting in the museum not only meets the visual requirements of tourists, but also makes tourists feel comfortable and enjoy during the visit of the museum [5]. The psychological experience of museum visits and the emotional and educational significance to the visitors need to be conveyed. Therefore, a suitable lighting condition needs to be determined by combining space theory and optical indicators in a multi-disciplinary way. According to the purpose of museum visitors, different tour routes and space attributes are divided. We combine it with the color temperature and color rendering index in the light environment of the corresponding area to provide tourists with a high-quality viewing experience while meeting people's psychological and physiological needs.

In order to ensure the reliability and authenticity of the data, we selected Dalian Modern Museum as the research object and conducted a field survey. This experiment mainly explores the factors that affect tourists' emotions through a combination of subjective evaluation and objective evaluation. Objective experimental data mainly test the relevant parameters of the lighting in the display area (such as illuminance, color temperature, color rendering index (hereinafter referred to as CRI) and the size of the exhibition space. In subjective evaluation, we invite tourists to complete a subjective questionnaire survey. The survey object is to randomly select visitors at the museum site. The objective experimental data is combined with the purpose and route of tourists in the subjective questionnaire survey to analyze, so as to determine the most appropriate lighting environment when visiting the museum. The overall survey has innovative practical and research significance.

## 2 Measurement and Analysis of Museum Light Environment

### 2.1 Spatial Theory and Psychological Needs

Tourists have different psychological needs and purposes when visiting the museum, such as visiting the museum as a tourist attraction, accompanying their family or friends, alleviating the pressure on life, etc. The relationship between space and psychological needs is complementary. For example, different space shape, height and size, color and texture of wall paint will affect the psychological experience of tourists [5]. We sum up the two points as Fig. 1 and Fig. 2. Figure 1 is the tour route of most tourists. The investigation of Dalian modern museum mainly divides visitors' visiting purposes into six categories. As shown in Fig. 2, most tourists regard the museum as a scenic spot or accompany their families to visit, and these people are in a happy mood. There are relatively few people who are decompressed, and they are calm when they visit the exhibits.

### 2.2 Measurement and Analysis of Lighting Conditions

**Illuminance Measurement**

The illumination measurement mainly adopts the central point method, dividing the area into square grids on average. The central point of the grid is the test area [6]. The

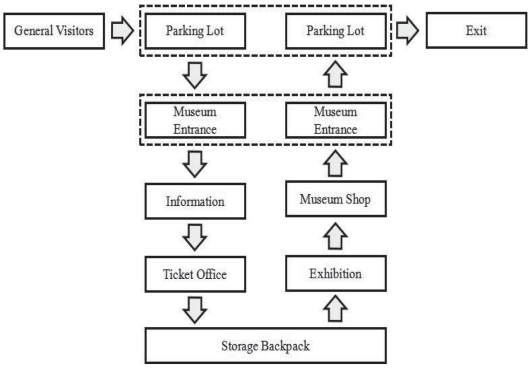


**Fig. 1.** Museum visit process for general visitors.

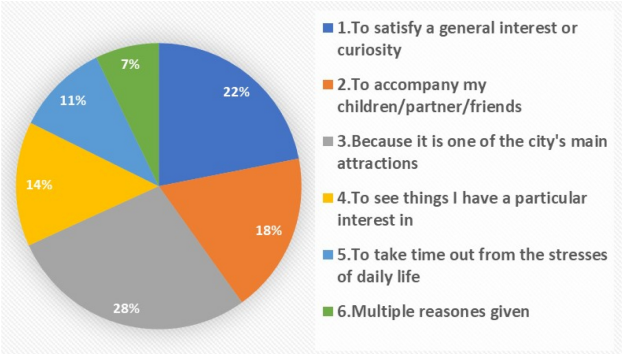


**Fig. 2.** Visitor's purpose

objective measurement is mainly aimed at the educational exhibition hall, the modern military exhibition hall, the modern life exhibition hall and the street exhibition area. The ground uniformity and the light color test uses the central point method to take the points, taking the average (Eq. 1) and the average of the reflectivity of nine points. The illumination uniformity of the whole environment is obtained by Eq. (2).

*E*av is the average illuminance value, the unit is Lux (Lx), *Ei* is the illuminance value of a point, *Emin* is the minimum of illumination M is the longitudinal measuring point, and N is the transverse measuring point (Eq. 1 and 2):

$$Eav = \frac{1}{M \cdot N} \sum Ei \tag{1}$$

$$U_0 = \frac{Emin}{Eav} \tag{2}$$

As shown in Fig. 3, Fig. 4 and Fig. 5, the education exhibition hall mainly relies on LED panel lights and natural light for lighting, because the exhibition hall mainly carries out the education function without cultural relics display, so the overall level of

illumination is relatively high. The average illumination is 145.3 lx (Eq. 1) for 9 points. The illumination uniformity of the whole environment is 0.7 by Eq. 2.

**Fig. 3.** Education exhibition hall

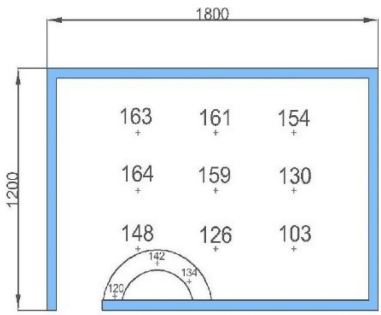


**Fig. 4.** Illumination distribution of Education exhibition hall

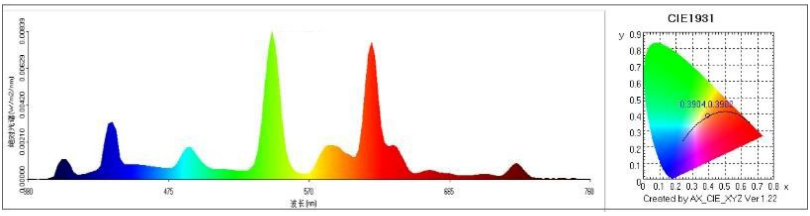


**Fig. 5.** Education exhibition hall illumination spectrum

Figure 6 is a modern living exhibition hall, which mainly relies on track metal halide lamp for lighting. The test points are 2 * 6, the average is 16 lx, and the illumination uniformity is 0.625. Modern Life Exhibition Hall Illumination Spectrum is shown in Fig. 7.

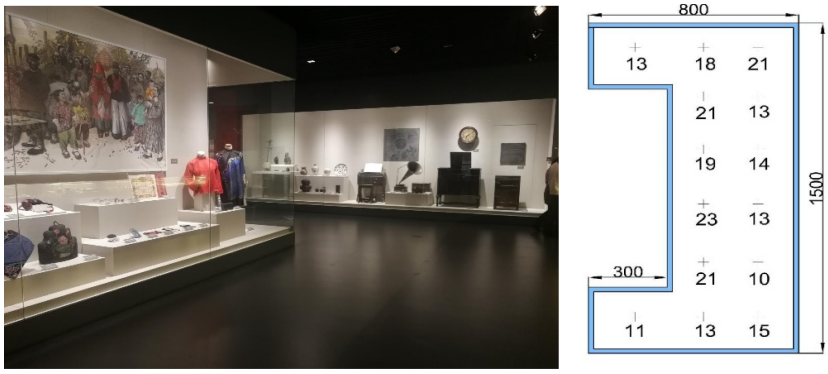


**Fig. 6.** Illumination distribution and scene of modern life exhibition hall

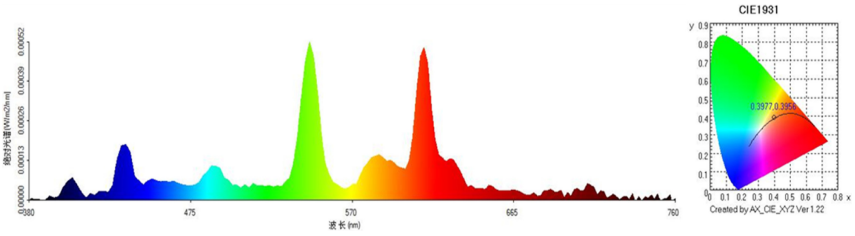


**Fig. 7.** Modern life exhibition hall illumination spectrum

**Fig. 8.** Modern military exhibition hall

Figure 8 is a modern military exhibition hall. The LED panel and guide metal halide lamp are used for lighting. The test points (Fig. 9) are 4 * 3, the average illumination is 16 lx, the illumination uniformity is 0.625. The illumination spectrum of modern military exhibition hall is shown in Fig. 10.

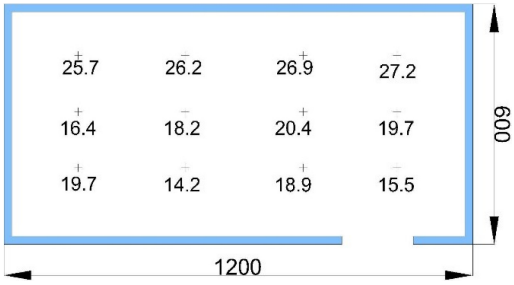


**Fig. 9.** Illumination distribution of modern military exhibition hall

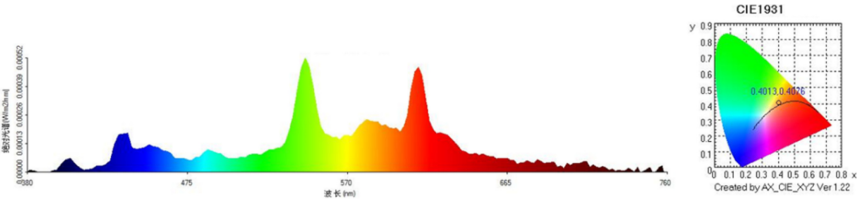


**Fig. 10.** Illumination spectrum of modern military exhibition hall

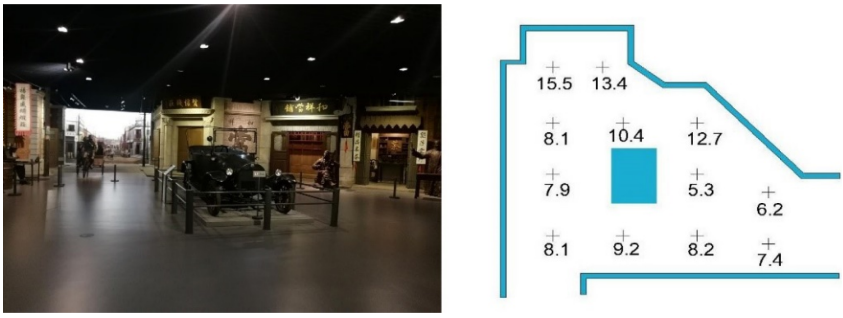


**Fig. 11.** Illuminance distribution and scene map of street exhibition area

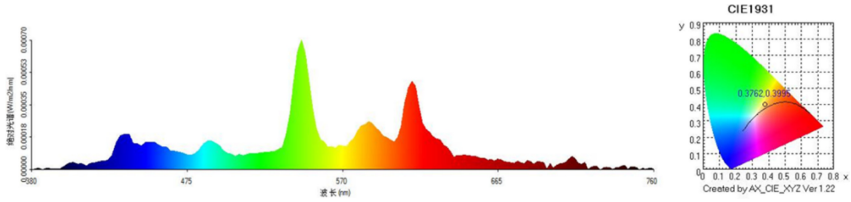


**Fig. 12.** Illumination spectrum of street display area

Figure 11 is a street display area with LED. The panel lamp is illuminated, and the test point is 4 * 3, the average is 16 lx, and the illumination uniformity is 0.625. the illumination spectrum of street display area is shown in Fig. 12.

The results show that in the four exhibition halls, only the illumination value of the education exhibition hall is relatively standard. The illumination of the other three exhibition halls is usually low. The details, stereoscopic sense and texture clarity of the exhibits cannot be well guaranteed. As a result, tourists spend less time in this environment than expected.

**Color Temperature Measurement**

Color temperature conditions have a subtle influence on our viewing experience. In the study of interior lighting design, kruithof defined "comfortable area" by comparing the correlation between color temperature (CCT) and illuminance, and proposed a method to achieve "pleasant area" [5]. kruithof's rule shows that the specific area of high (low) CCT corresponds to high (low) illuminance, which makes the view Observers feel happy [6], 3000–4000K is a relatively popular color temperature range, or a relatively high visual comfort range, which makes people feel more comfortable and bright [7], different types of museums have different emotions to convey to people. Flexible use of the relationship between light and color temperature enables visitors to have different sensory experience during the visit. In this experiment, we use spectroradiometer to measure the color temperature in the field. The number of measuring points in each area shall not be less than 9, and each functional area shall have more than three measuring points. The color temperature of each light source or mixed light source under different light sources is measured. The results show that the average color temperature of education exhibition hall is 3643k, modern life exhibition hall is 3273k, modern military exhibition hall is 2953k, and street display area is 3010k. The CCT of the four exhibition halls is in the comfortable area, the modern life exhibition hall, the modern military exhibition hall and the street exhibition area is at a low CCT level, which will make the tourists have a heavy and depressing mood in the process of visiting.

**CRI Measurement**

Lighting with high CRI can truly restore the original appearance, color and texture of the cultural relics, and can better spread the culture [9]. For the museum, where there are abundant collections, exhibits with different attributes need different light sources to display. The CRI of light sources directly affects the hue and saturation of the color of the exhibits. For displayed paintings, color fabrics and other places with high color identification requirements, The CRI of commonly used light source shall not be less than 90. For places with general color identification requirements, The CRI of commonly used light source shall not be less than 80 [10].

The measurement results of the color rendering index of the modern museum are shown in the Table 1. It suggests that higher color rendering index of education exhibition hall can make people feel clear and relaxed. Modern life exhibition hall has a higher overall color rendering index because of its rich silk fabrics and high color temperature. At the same time, the main lighting fixtures in the exhibition area are metal halide lamps with guide rails, R9 is normal. For the modern military exhibition hall and street display area, the requirements of collection protection and color rendering are not high, and the

lighting lamps mainly use LED panel lamp. Because of the inherent shortcomings of LED lamp and the lack of red band, the R9 value and overall CRI are low.

**Table 1.** Measurement results of the color rendering index of modern museums

| Hall | Ra | R9 | Rg | Rf | SDCM |
|---|---|---|---|---|---|
| Education Exhibition Hall | 90.1 | 81 | 96 | 90 | 3.2 |
| Modern Life Exhibition Hall | 92.1 | 83 | 97 | 91 | 2.7 |
| Modern Military Exhibition Hall | 82.3 | −7 | 96 | 92 | 4.9 |
| Street Exhibition Area | 80.3 | −7 | 79 | 97 | 5.1 |

## 3 Emotional Response Model

### 3.1 Sensory Questionnaire

The subjective evaluation is carried out by inviting tourists to fill in a questionnaire on the spot, which is reliable. A total of 117 sets of data were collected from more than 20 individuals. The exhibition area is education exhibition hall, modern life exhibition hall, modern military exhibition hall, painting exhibition hall and street exhibition area, and non exhibition area is corridor. Measurements are made at the following levels: A is 10, a - is 8, B is 7, B - is 6, C is 5, C - is 4, D is 3, D - is 0. 11 indicators, such as the size of the authenticity color, the preference of the light source color, the detail expressiveness of the exhibits, the visual adaptability and the pleasure of viewing the exhibits, can be calculated. According to each evaluation, the corresponding scores are above 80, above 70, above 60 and below 60. It is divided into four levels: excellent, good, medium and poor [11]. Get illumination of the display area. As can be seen from Fig. 12, the lighting conditions in the basic display area are of general grade.

| Item\Sample\Score | A+10 | A-8 | B+7 | B-6 | C+5 | C-4 | D+3 | D-0 | mean value | Secondary weights | WeightingX10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Realistic color of exhibits | 2 | 10 | 5 | 4 | 1 | 1 | 0 | 0 | 7.30 | 20% | 14.60 |
| Light source color preference | 1 | 11 | 7 | 2 | 0 | 2 | 0 | 0 | 7.26 | 5% | 3.63 |
| Exhibits' detail expressiveness | 2 | 6 | 12 | 1 | 0 | 1 | 0 | 1 | 7.04 | 10% | 7.04 |
| Three-dimensional expressive force | 1 | 8 | 7 | 4 | 2 | 0 | 1 | 0 | 6.95 | 5% | 3.48 |
| Texture clarity of exhibits | 1 | 5 | 7 | 9 | 0 | 1 | 0 | 0 | 6.82 | 5% | 3.41 |
| Outer Contour Clarity of Exhibits | 1 | 7 | 9 | 4 | 1 | 1 | 0 | 0 | 7.04 | 5% | 3.52 |
| Brightness Acceptance of Exhibits | 2 | 9 | 7 | 5 | 0 | 0 | 0 | 0 | 7.43 | 5% | 3.72 |
| Visual adaptability | 6 | 8 | 5 | 3 | 0 | 1 | 0 | 0 | 7.86 | 5% | 3.93 |
| Psychological pleasure | 1 | 10 | 5 | 5 | 1 | 1 | 0 | 0 | 7.13 | 5% | 3.57 |
| Lighting artistic preference | 2 | 9 | 6 | 4 | 2 | 0 | 0 | 0 | 7.30 | 20% | 14.60 |
| Infectivity | 2 | 11 | 4 | 3 | 1 | 2 | 0 | 0 | 7.26 | 10% | 7.26 |
| Total | | | | | | | | | | 100% | 68.745 |

**Fig. 13.** Basic display subjective assessment results

### 3.2 Emotional Response

The purpose of this study is to define the relationship between emotional perception and the different combinations of CCT, CRI and various illumination values. The uncertainty of the experimental evaluation data was tested by the root mean square (RMS) on the emotional response level table through the variability between the observer and the observer (Eq. 3). The smaller the RMS value, the greater the consistency between the two data sets [12]. The higher the RMS value, the worse the consistency within or between observers. For variability among observers, $y_i$ is the score of the individual observer for the I stimulus. $x_i$ is the average score of all observers for the I stimulus; N is the total number of stimuli. As shown in Table 2 the root mean square values of variability between and within observers in this experiment.

**Table 2.** RMS values of variability between and within observers

| Emotional Scale | Observer Change | Internal Observer Change |
|---|---|---|
| Pleasant | 0.92 | 0.38 |
| Comfort | 0.92 | 0.37 |
| Bright | 0.89 | 0.38 |
| Color | 0.92 | 0.36 |
| Clean | 0.88 | 0.33 |
| Nature | 0.96 | 0.38 |
| Lively | 0.92 | 0.36 |
| Ease | 0.90 | 0.37 |
| Soft | 0.83 | 0.34 |
| Classical | 0.85 | 0.35 |
| Warm | 0.84 | 0.35 |
| Average | 0.89 | 0.36 |

$$RMS = \sqrt{\frac{\sum_{i1}^{n} (y_i - x_i)^2}{n}} \tag{3}$$

By adding the measured data to the emotional quantification evaluation and substituting it into formula (3), we can get a high consistency with the quantitative value of RMS below. Emotional indicators are 11 phrases in Fig. 13. According to the results of the visitors' evaluation of each index, different experimental conditions of light environment were constructed subjectively. Finally, by changing the objective parameters such as illuminance, color temperature and color rendering index, combined with the different lighting environment constructed according to the subjective, the emotional response of museum lighting can be obtained.

## 4 Discussion and Summary

Through the experiment of Dalian Modern Museum, we can draw a conclusion that the tourists' visiting purpose is directly related to the size of the space. For different tourists' visiting purposes, most tourists who aim at visiting scenic spots or accompanying family and friends will complete the whole process. The visiting time is shorter and most of them will stay in small space and exhibits-intensive areas for a long time. For pressure relief tourists, they spend longer time visiting places with large space and do not choose to go to Museum stores. For visitors who visit designated exhibits and satisfy their curiosity, they are more excited. They usually go directly to designated exhibits and follow-up visits are slower. At the same time, combined with the relationship between residence time and illumination, color temperature and color rendering index, under the same illumination condition, R9 value of some spatial rendering index using LED as the main light source is lower or negative, which is due to the inherent disadvantage of the ratio of LED light source - less red band, and with the increase of the efficiency of LED light, the reduction of the red part will be more serious. In these places where the R9 value is low, most of the tourists are not very happy, and the sense of ornamental experience will decrease. According to these data and analysis, four kinds of emotional models of museum lighting are determined by interactive formula.

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