Proceedings of 2018 IEEE
International Conference on Mechatronics and Automation
August 5 - 8, Changchun, China

Research on Visual Comfort Based on Fuzzy Neural Network

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***Abstract* - Based on the typical parameters affecting the visual comfort of LED light source, this paper proposes a method to evaluate the visual comfort of light sources from the frame of physical evaluation parameters measurement. In the standard classroom environment, a comparative light source test system was established to measure the physical parameters of the LED light source under different color temperature conditions during day and night. Aiming at the visual comfort of different positions in standard classrooms, the subjective evaluation experiment based on visual comfort was carried out. an experimental scheme based on fuzzy neural network for visual comfort evaluation was proposed. Combining the subjective evaluation grade with physical parameters, modeling and simulating through fuzzy neural network, using the visual comfort evaluation model to explore the application strategy of the optimal LED light source, and providing data foundation and technical support for the development of human visual comfort evaluation standards.**

Index Terms - Visual comfort. LED. Fuzzy neural network. Color temperature system.

I. Introduction

With the continuous maturity of LED solid-state lighting technology, LED lighting replaced the traditional lighting has become a general trend.People's perception of vision will gradually shift from simple functional requirements to psychological, physiological and healthy demands. The quality of lighting, the comfort of the visual environment, and the effects of lighting on health have become the focus of attention.

At present, in the office and the classroom and other space lighting, people will pay attention to the harm of blue light, which is mainly reflected in the glare limitation.The new non-glare LED lamp is very suitable for the place of high lighting comfort [1].In the choice of lamps and lanterns, the size of the luminous flux, the height of color temperature, the rationality of the light distribution will affect the lighting comfort of the entire space [2].

In order to effectively evaluate the health and safety effects of lighting, From the perspective of combining the physical parameters with subjective evaluation of the light source,By constructing a subjective and objective evaluation model of the visual comfort of the standard classroom, an evaluation index, limit value/limitation range and light source matching model for human eye health comfort are proposed.It is of great significance to guide the healthy development of lighting products, and to develop healthier and more environment-friendly LED lighting products to alleviate the high incidence of myopia among primary and middle school students [3].

The organizational structure of this paper is as follows. Section II describes the selection of parameters and related standards. Section III proposes the visual comfort testing program, which is the physical parameters experiments. Section IV uses the fuzzy neural network to model and analyze the visual comfort, and evaluates the visual comfort of the 4500K and the 5500K color temperature system respectively. It gives a rating of different color temperature systems.Section V summarizes the effects of light on different positions in the standard classroom.

II. Parameter Selection and Related Standards

A. The Influencing Factors of Visual Comfort

The influencing factors of visual comfort are determined based on a set of factors that affect the health of the human eye [4].The optical performance of LED lighting products is mainly characterized by the color rendering index, color temperature, illuminance, stroboscopic index, and strobe frequency.Among these characteristics, According to research shows some factors have obvious influence on visual comfort. However, there is no experiment for multiparameter fusion.The following are the main explanations of these factors for some of the parameters.

Illumination: Illuminance is the luminous flux that is scattered over a unit area when the light is at a certain distance. The unit is lux [5].

Color rendering index: The color rendering index is the percent of the object's perception under the light source and the degree of realism perceived under sunlight [6].The light source with high color rendering index is more realistic to the color, and the object presented by the eye is close to the natural environment [7].

Color temperature: In general, the color temperature of 3000K-6000k is a natural light color with a pleasant and comfortable feeling. The color temperature above 5300k enables the LED lamp to have a bright characteristic and make people concentrate.

Strobe frequency: The strobe frequency is the number of repeated light flashes per unit time, The unit is Hertz. According to the IEEE study, low-frequency light flicker is too obvious for flicker. For the human eye, it may induce related diseases.

B. Standard Status of Visual Health Comfort

The National Semiconductor Lighting Engineering R&D and Industry Alliance Standardization Committee (CSAS) released "The Report of Health Lighting Standard Progress Report" for the field of health lighting.In this progress report, the current status of relevant lighting standards is described in detail.The following mainly elaborates the related standards of visual health comfort from two aspects.

Photobiological safety: Photobiological safety mainly describes the blue light hazard of light sources and lamps [8].In 2002, the International Commission on Illumination issued the Photobiological safety of lamps and lamp systems standard.In 2006, China also issued the "Photobiological Safety of Lamps and Lamps System" [9].

Lighting quality: In terms of color temperature, AN SIC78.377-2017 pointed out the color index of the solid-state lighting products.In terms of color rendering index, CIE 177:2007 released the color rendering index of white LED lighting sources.In terms of strobe, IEEE Std 1789:2015 released standards for the potential health effects of flashing LED lighting [10].

III. THE TEST OF VISUAL COMFORT

A. Physical Parameter Testing Scheme for Visual Comfort of LED Lighting Systems

The testing scheme of the physical parameter of this study selects the standard classroom of middle school as the research object, and divides the entire standard classroom into nine measurement points.This experiment is based on the study of visual health comfort, so the distance from the test point to the ground is set to 800mm. On this basis, the parameters of LED lamps with uniform distribution of nine test points are measured respectively. Because this experiment is based on the classroom vision health comfort transformation research, Therefore test the various types of volume parameters of the color temperature 4500k and 5500k lamps.Measure the optical parameters of the nine measurement points in daytime and evening classrooms under the color temperature system of 4500K and 5500k lamps.Compare the effect of LED light parameters at different color temperatures on human visual health and comfort during the day and night.According to the effect of the sample installed in the standard classroom,The directional, univariate, and large-sample human factors health experiments were performed on some parameters (mainly color rendering index and illuminance parameters) to complete the product's stereotyped improvement.According to the parameters optimization of products, improve the visual comfort of the LED lamps and lanterns.Figure 1 shows the distribution of measurement points in a standard laboratory classroom, and Figure 2 shows the test scene.

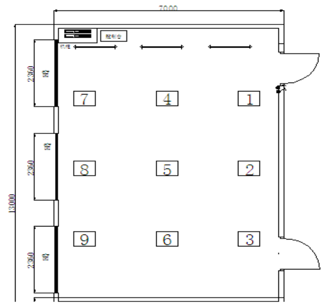

Fig. 1 The distribution of measurement points in a standard classroom


Fig. 2 The test real map of the 4500K system

B. Comparison of the Data of the Light Source Test System

1) The Data Graph of 4500k Test System (day, night)

The various data of day and night under the 4500K system were measured, including illuminance, color temperature, color rendering index, and strobe frequency. As shown in Figure 3 to Figure 6, The rounded top line graph represents daytime data, and the black square line graph represents nightly data.

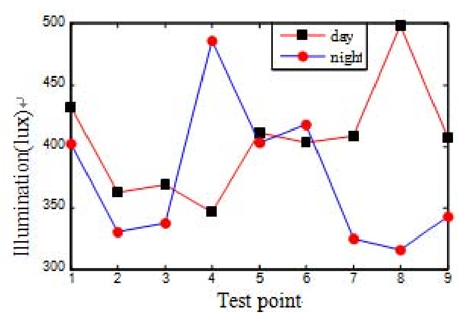

Fig. 3 The test data of the Illumination(day,night)

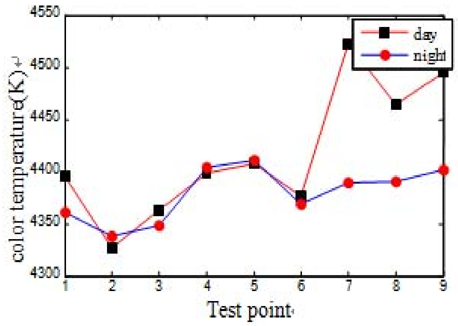

Fig. 4 The test data of the color temperature (day,night)

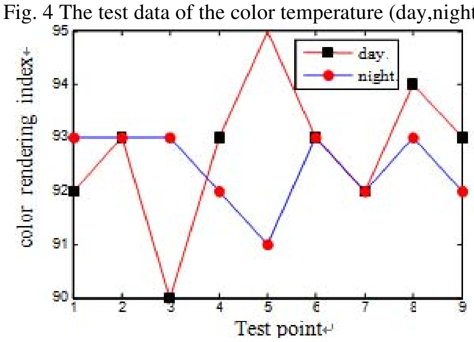

Fig. 5 The test data of the color rendering index (day,night)

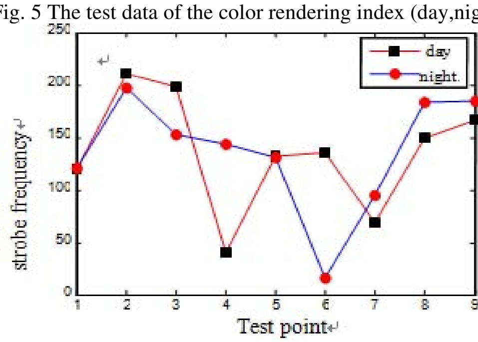

Fig. 6 The test data of the strobe frequency (day,night)

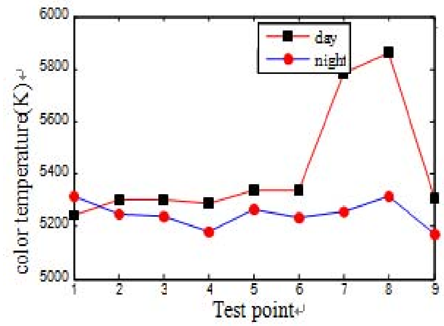

Fig. 8 The test data of the color temperature (day,night)

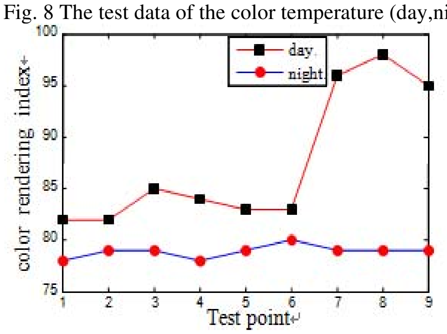

Fig. 9 The test data of the color rendering index (day,night)

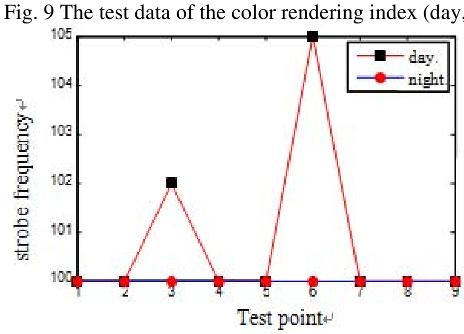

Fig. 10 The test data of the strobe frequency (day,night)

2) The Data Graph of 5500k Test System (day, night)

The various data of day and night under the 5500K system were measured, including illuminance, color temperature, color rendering index, and strobe frequency. As shown in Figure 7 to Figure 10, The rounded top line graph represents daytime data, and the black square line graph represents nightly data.

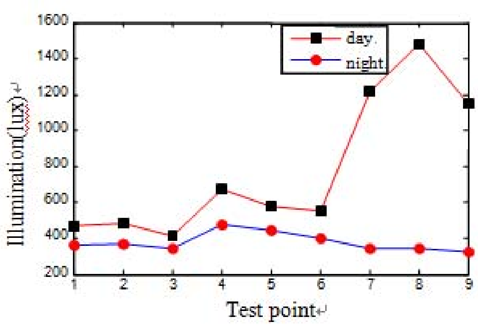

Fig. 7 The test data of the Illumination(day,night)

IV. MODELING AND ANALYSIS OF FUZZY NEURAL NETWORK.

A. The Influence Factors of Visual Comfort

The research algorithm of this paper adopts T-S fuzzy neural network.The T-S fuzzy neural network is divided into four layers: the input layer, the fuzzification layer, the fuzzy rule calculation layer, and the output layer. The input layer is connected to the input vector. The number of nodes is the same as the dimension of the input vector. The principle of the fuzzy neural network algorithm is as follows.

(1) Error calculation

$$e = \frac{1}{2}(y_d - y_c)^2 \tag{1}$$

In the formula, y_d is the expected output of the network; y_c is the actual output of the network; e is the error of the expected output and the actual output.

(2) Coefficient correction

$$p_j^i(k) = p_j^i(k-1) - \alpha \frac{\partial e}{\partial p_j^i} \tag{2}$$

In the formula, p_j^i is the neural network coefficient, α is the network learning rate; x_j is the network input parameter; w^i is the input parameter membership degree product.

(3) parameter correction

$$c_j^i(k) = c_j^i(k-1) - \beta \frac{\partial e}{\partial c_j^i} \tag{3}$$

$$b_j^i(k) = b_j^i(k-1) - \beta \frac{\partial e}{\partial b_j^i} \tag{4}$$

In the formula, c_j^i and b_j^i are the center and width of the membership function.

B. *The Evaluation Flow of Fuzzy neural network*

Combining subjective visual comfort evaluation with physical evaluation, the physical parameters under subjective visual comfort evaluation were measured. The corresponding physical index under different evaluation levels is not a single restriction but an adaptation scope. The corresponding instantaneous comfort degree corresponding to the subjective evaluation level is extended accordingly. The subjective evaluation system corresponding to the physical parameter range not only evaluates the visual comfort in terms of space, but also has the extendability in time as well as the completeness that the traditional instantaneous comfort evaluation does not have. In the test experiment, nine volunteers were investigated accordingly, and the measurement period was defined as 30 minutes in time. Table 1 shows the corresponding physical parameters under the subjective evaluation level.

TABLE I
THE PARAMETERS UNDER THE SUBJECTIVE EVALUATION LEVEL

Level / Parameter	I	II	III	IV	V
Illumination(lux)	300	350	400	450	500
Color temperature(k)	6000	5500	5000	4500	4000
Color rendering index	100	90	80	70	60
strobe frequency(Hz)	120	110	100	90	80

On this basis, the evaluation model of visual comfort based on fuzzy neural network is established.. The model is based on the theory of multi-parameter evaluation and fuzzy neural network. Algorithm flow of Visual comfort Evaluation based on fuzzy neural network as shown in Figure-11 below, The number of input and output nodes of fuzzy neural network is determined according to the dimension of training samples. The number of input nodes is four, which are illumination, color temperature, color rendering index, and strobe frequency. The number of output nodes is one, which is the evaluation level.The fuzzy neural network structure is 4-8-1,which has eight membership functions.

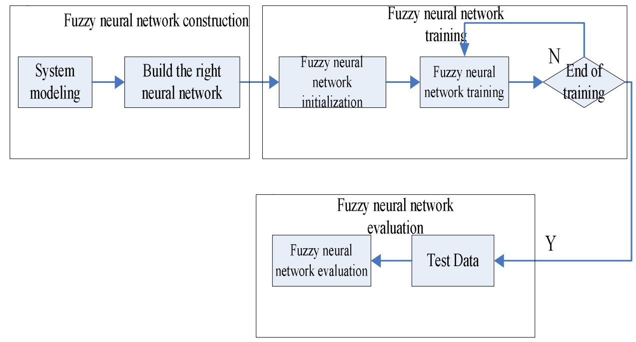

Fig. 11 The evaluation algorithm flow of the visual comfort

C. *Simulation and Analysis of Visual Comfort*

1) The Prediction of the Training Data

The training data prediction module sets data for 45 test points. The number of iterations is 100 times. Data normalization was performed on the original data. The experiment of 4500K color temperature system and 5500K color temperature system has been done in this paper. So the data of the training sample take the data of both, which can better reflect the universality of the sample data. As shown in Figure 12 below, it is a sample data training prediction chart. It can be seen that the training results are better and the error is basically maintained at around 0.

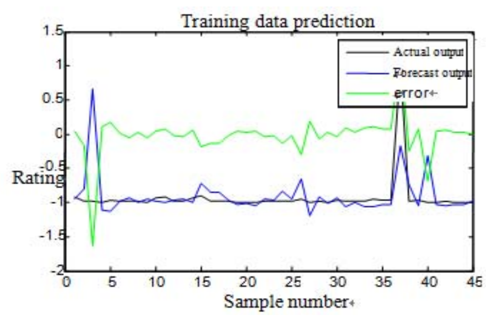

Fig. 12 The training data prediction

2) The Prediction of the Test Data

In the test prediction phase, 45 sample data are first set up on the basis of the training model, in which the number of iterations is 100. Under actual conditions, 45 sample data were tested according to 4500K color temperature system and 5500K color temperature system. According to the network prediction, the evaluation index of comfort level was obtained. When the predicted value is less than 1.5, the grade is 1, When the predicted value is between 1.5 and 2.5, the grade is 2, When the predicted value is between 3.5 and 4.5, the grade is 3, When the predicted value is between 3.5 and 4.5, the grade is 3, When the predicted value is more than 4.5, the grade is 5. As can be seen from Figure 13, the comfort rating of the 45 test data points is between 1-5. The highest level of 1 is specified here, which means that the higher the level of comfort, the lower the level of 5, and the worse the level of comfort.

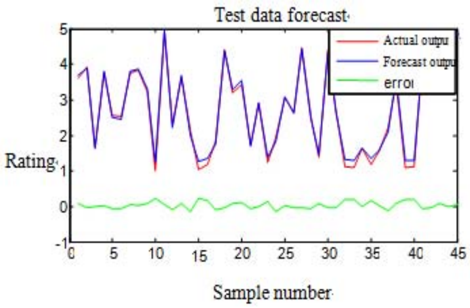

Fig. 13 The testing data prediction

3) Evaluation of the Comfort Degree of 4500K System

Under the 4500K color temperature system, evaluate the data of nine test points in the standard classroom. In figure 14 ,It can be seen that the nine test points are rated at daytime and night. It can be seen from figure 14 that the comfort level of each test point is different in the same color temperature system. The level of comfort in the middle and near the side of the window is higher than that near the side of the wall. According to the data of day and night, it can be seen that the external daylight has no significant effect on the comfort level of each point.

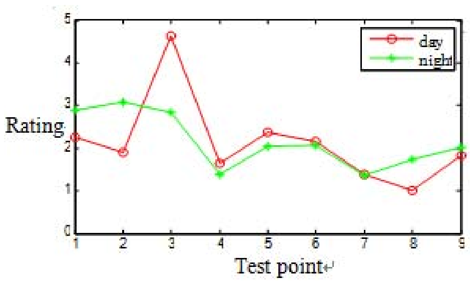

Fig. 14 The comfort evaluation level forecast of the 4500K system

4) Evaluation of the Comfort Degree of 5500K System

Under the 5500K color temperature system, evaluate the data of nine test points in the standard classroom. In figure 15,It can be seen that the nine test points are rated at daytime and night. From Figure 15 ,it can be seen that the rating of the nine test points is more decentralized. The evaluation point of the test point at night is higher than that of the daytime. It is also close to the window and the evaluation rating in the middle is higher than that near the wall.

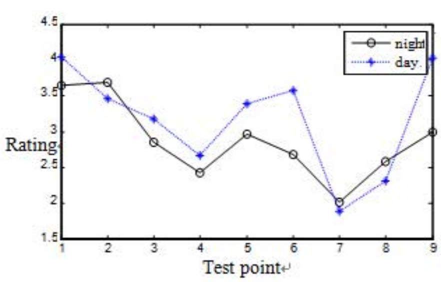

Fig. 15 The comfort evaluation level forecast of the 5500K system

V. Conclusion

In this paper, the light parameters of various positions in the standard classroom are tested under different conditions during the day and night, and the factors that affect the visual function and comfort are analyzed. The results of the study showed that, in both daytime and nighttime, the visual comfort near the wall was poor under the 4500K color temperature system and the 5500K color temperature system. In the 4500K color temperature system, the external ambient light has little effect on visual comfort. In the 5500K color temperature system, the external ambient light intensity has a significant effect on the visual comfort of each test point. The visual comfort of the 4500K color temperature system is higher than that of the 5500K color temperature system. For the results of this experiment, the selection and layout of the standard classroom LED daylight lighting parameters have certain data references.

Acknowledgment

This work was supported by the Young and Middle-aged Backbone Innovative Talents Training Project Foundation of Tianjin, China under Grant 20130830, and the Fundamental Research on Advanced Technology and Engineering Application Team, Tianjin, China under Grant 20160524, and the National Demonstration Center for Experimental Mechanical and electrical engineering Education (Tianjin University of Technology).The Corresponding authors of this article are Kun Zhang and Dahua Li.

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