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Warm-Cool Emotions of LED Lightings around 5,000K

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Abstract

In this study, warm-cool feelings of near-white lightings were investigated after the subjects' eyes being adapted to 5,000K. The psychophysical experiment was carried out in a dark room using 5 channels LED lighting booth. In the experiment, total of 48 test lightings around 5,000K were generated using the booth. Total of 20 subjects evaluated warm-cool feelings of each test lighting. The results showed that lower CCT tended to have 'Warm' feeling, while higher CCT tended to arouse 'Cool' feeling. When CIECAM02 H is in the range of 0-100 and 380-400, 'Warm' feeling was strongly evoked and when H is in the range of 250-300, 'Cool' feeling was strongly aroused. Also, when test lightings have same hue, the one having higher chroma aroused stronger feeling on either 'Warm' or 'Cool'. Emotion model test results showed Koo's model, which is based on lighting colors, showed better performance than the model developed based on color patches.

Key Words : LED, Color Emotion, Warm-Cool, CIECAM02, Color Emotion Model

1. Introduction

1.1 Research background

Nowadays generating various lighting colors becomes easier thanks to the development of LED. Besides, LED has higher power efficiency than incandescent and fluorescent lightings which had been most widely used. Also LED is safe and eco-friendly. Therefore, so the LED market size is expected to grow continuously.

Overall atmosphere of the space is strongly affected by lighting colors. The same place can give different feelings by changing the room lighting colors. Therefore, by utilizing the color controllable characteristic of LED lamps, it is possible to change the atmosphere of the space in various ways.

To reproduce user's intended emotions by lighting colors, color emotion needs to be predicted properly. However, most previous studies about color emotion had been conducted with surface colors such as color patch and textile[1-3]. There were earlier studies regarding emotional lighting for interior space. One was about the effect of color temperature, illuminance, and color rendering on the preference of a space[4] and the other is the color

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emotion according to hue, brightness, and chroma of lighting[5].

Also, in most previous studies about color emotion of lighting, test stimulus was presented after adapting to dark condition[6-8]. However, the dark-adaptation situation is not common in a real life. Therefore, to apply the previous research results to the real life situation, it needs to be verified with the experiment under similar environment of actual lighting experience.

1.2 Aim and method of the study

In this study, 'Warm-cool' feelings of near-white lightings were investigated by conducting the psychophysical experiment using forced-choice experimental method after the participants' eyes were adapted to 5,000K. Choosing 5,000K as the adaptation lighting reflects the most common lighting condition in the office. Also the adjective set 'Warm-cool' is one of the most widely used one to evaluate emotion of lighting[1-3, 9].

Two warm-cool emotion models, Ou[1] and Koo[9], were tested with the experimental data. Ou's model is based on the experiment of using color patches on the monitor in a dark condition. Equation 1 represent the Ou's 'Warm-Cool' emotion model. To calculate Ou's model, CIELAB values are needed as an input. In the Equation 1, h and C* represent CIELAB hue angle and Chroma, respectively.

$$WC_{Ou} = -0.5 + 0.02(C^*)^{1.07}\cos(h - 50^\circ)$$

Equation 1. Ou's model about 'Warm-cool' feeling

Koo's model is developed based on the experiment using the 2-degree lightings under a dark condition and it is calculated based on CIECAM02 color space [10] as shown in Equation 2, where h and M represent hue angle and Colorfulness, respectively.

$$WC_{Koo} = k_0 + k_1(M)^n\cos(k_h h - k_2)$$

$$where\ k_0 = 0.36, k_1 = 0.32,\ k_2 = 60,\ k_h = 1.04, n = 0.38$$

Equation 2. Koo's model about 'Warm-cool' feeling

2. Psychophysical experiment

2.1 Experimental setting

Figure 1 shows the experimental setting. The psychophysical experiment was carried out in a dark room using 5 channels LED lighting booth. The size of booth was 67.3x57.2x55.5(cm) as width, depth, and height, respectively. The inside of the booth is painted with Munsell N7 mid-grey colour and the channels consist of red, green, blue, warm white and cool white.

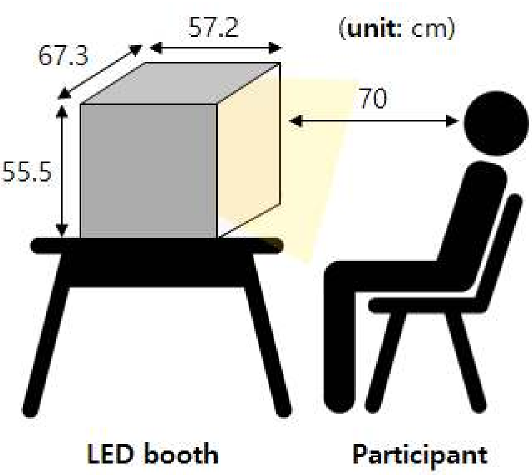

Fig. 1. Experimental setting

2.2 Test lighting

Figure 2 shows the test lightings represented on CIE u'v' color space. In the experiment, total of 48 test lightings around 5,000K were generated using the LED lighting booth. Illuminance of the colors was fixed as 3500lx. Illuminance of every lighting was measured at the center bottom of the booth using chromameter CL-200.

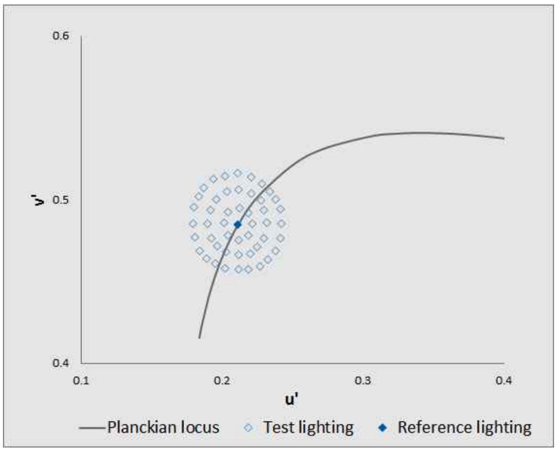

Fig. 2. Test lighting

2.3 Participant

Total of 20 participants with a normal color vision participated in the experiment. There were 10 males and 10 females.

2.4 Experiment procedure

Before starting the experiment, Ishihara test was conducted for each participant to verify a normal color vision. Then participant was asked to be adapted to the reference lighting condition having 5,000K. Then test lighting was shown for 10 seconds to judge 'Warm' or 'Cool' based on the feeling. If a color change was too small to perceive difference from the reference, 'Neutral' response was allowed. After finishing the judgement, the reference lighting was shown again for adaptation followed by another test lighting. The order of showing test lightings was randomized per each subject.

For data analysis, 'Warm' evaluation was converted to 1, 'Cool' for -1 and 0 was allocated for 'Neutral' responses. Then all subjects' responses were averaged.

3. Results

3.1 'Warm-cool' emotion results

Figure 3 shows the test lightings having either 1(Warm) or -1(Cool) as average score on CIE u'v' space. Neutral points represent the ones having from 0.25 to 0.25. The straight line in the Figure is 5,000K CCT line.

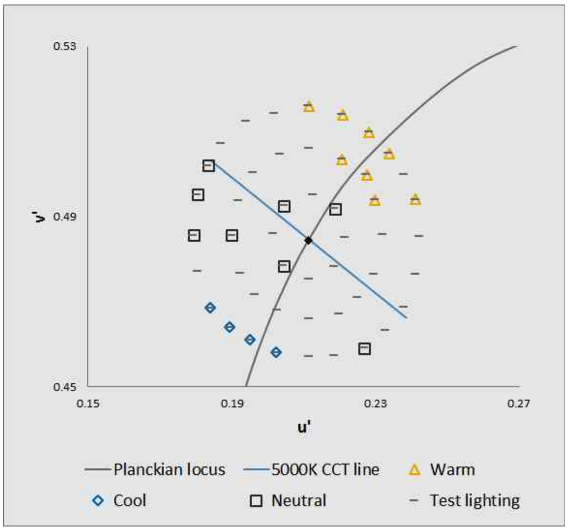

Fig. 3. 'Warm-cool' experiment result

As shown in the Figure, the 'Warm-cool' result roughly follow the Planckian locus. Lower CCT tended to evoke 'Warm' feeling, but higher CCT arouse 'Cool' feeling. In case of 'Neutral' responses, they tended to be distributed along the 5,000K CCT line.

'Warm-cool' emotion was compared with CIECAM02 Hue quadrature(H). CIECAM02 H is the value about Hue appearance having a number from 0 to 400, where 0, 400-unique red, 100-unique yellow, 200-unique green, 300-unique blue[9]. Unique hue means a color which does not contain any others, but only one specific hue. The others, except unique hue, are mixed with two neighboring unique hues. For example, if H value is 130, it means that the color is mixed with 30% green and 70% yellow.

To calculate CIECAM02 H value, it needs some initial input values. Table 1 summarizes the parameters used for the calculation.

Table 1. CIECAM02 parameters

L_A	Y_b	c	N_c	F	X_w	Y_w	Z_w
700	20	0.69	1	1	98.1	100	86.5

Figure 4 shows the 'Warm-cool' experimental data as a function of CIECAM02 H. As shown in the Figure, 'Warm-cool' emotion changed as hue perception changed. When CIECAM02 value was around 200, 'Warm' feeling started to change into 'Cool'. Likewise, 'Cool' emotion was changed to 'Warm' when H was around 320.

Especially, the emotion became strong in a specific range. The warm feeling was mostly evoked in the red-yellow area (H=0-100 and 380-400) and cool feeling was dominantly aroused in the green-blue area (H=250-300).

Also, the effect of chroma on the 'Warm-cool' emotion was investigated. The emotion change was tracked according to CIECAM02 C for the test lightings having similar CIECAM02 H values. CIECAM02 C is the value about chroma.

Figure 5 shows the 'Warm-cool' emotion changes by CIECAM02 C of the test lightings having CIECAM02 H in between 25-90 and 225-295, respectively.

The Figure shows that higher CIECAM02 C tended to evoke stronger 'Warm-cool' feelings. In case of the lightings having CIECAM02 H from 25 to 90, 'Warm' feeling became stronger with increase of chroma. Likewise, 'Cool' feeling increased for the lightings having CIECAM02 H from 225 to 295.

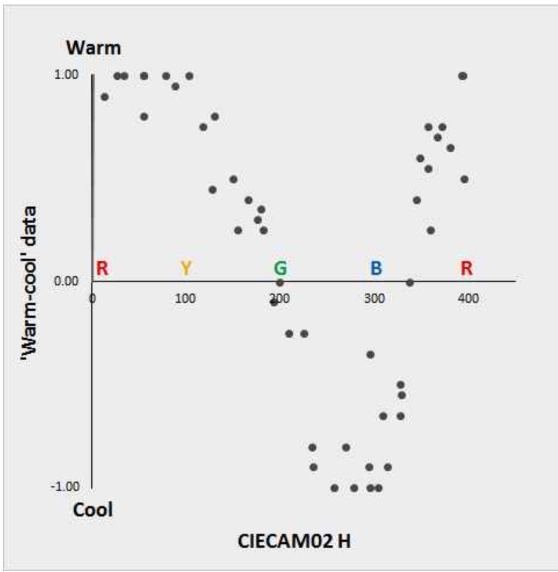

Fig. 4. Comparison result between 'Warm-cool' data and CIECAM02 H

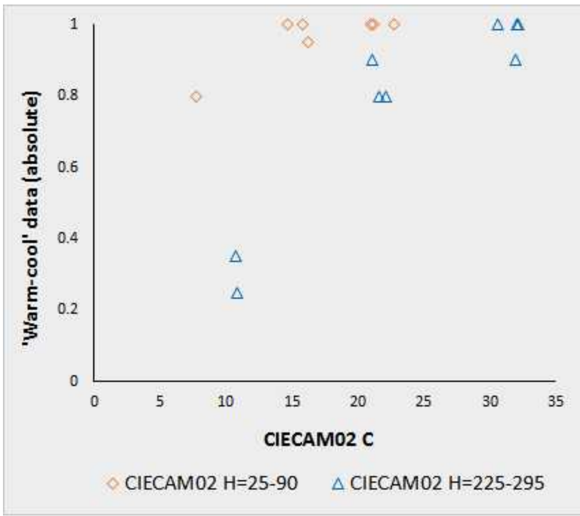

Fig. 5. Comparison result between 'Warm-cool' data(Absolute value) and CIECAM02 C

3.3 Emotion model performance test

In this study, two emotion models – Ou's[1] and Koo's[9] – were tested with the experiment data. In case of Ou's, it takes input values from CIELAB space and reference white was set as reference lighting. Koo's model estimates the emotion based on CIECAM02. Originally, for the case of perceiving unrelated color, reference white is set as equi-energy white. However, in this study, reference white was set as reference lighting which participants were being adapted.

3.3.1 Ou's model

Figure 6 shows the comparison result between the 'Warm-cool' experiment data and Ou's model estimated values.

As shown in the Figure, in overall, it has a linear relation ship between the experiment data and Ou's values, but most data points are distributed below x-axis. It means that Ou's model estimated most of the colors arousing 'Cool' emotion.

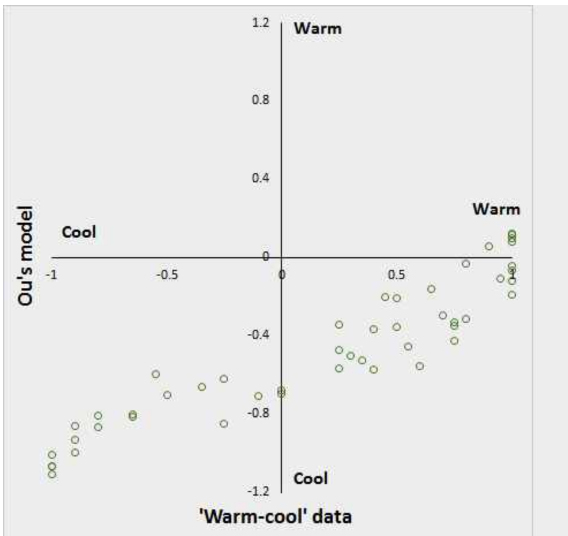

Fig. 6. Comparison result between the 'Warm-cool' data and Ou's model values

Figure 7 shows the comparison result between the 'Warm-cool' experiment data and Ou's estimated values when CIELAB C* was 20 and 80, respectively.

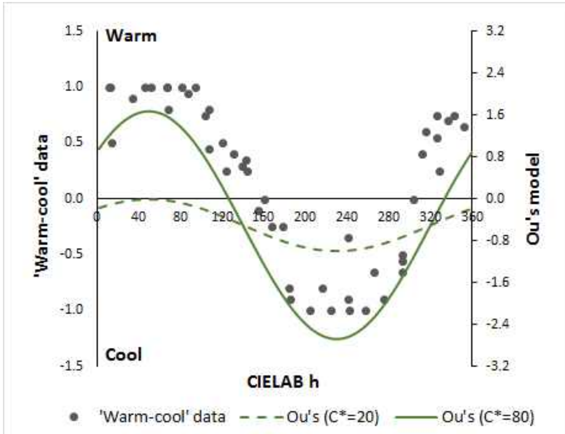

Fig. 7. Comparison result between the 'Warm-cool' data and Ou's model when CIELAB C* is 20 and 80, respectively

As shown in the Figure, Ou's model estimates 'Warm-cool' emotions differently according to chroma. When CIELAB C* value was 80, Ou's model could give better estimation result while low chroma lights are predicted to evoke 'Cool' feeling regardless of hue.

Also, there was a difference in the range of 'Cool' feeling between the experiment data and Ou's model. Ou's one showed wider hue range for 'Cool' emotion than that of the experiment data.

Note that Ou's model was developed based on the experiment perceiving color patches, but this experiment was in the situation looking at lighting colors. Therefore, 'Warm-cool' emotion could be affected by this viewing condition.

3.3.2 Koo's model

Figure 8 shows the comparison result between the 'Warm-cool' experiment data and Koo's estimated values. As shown in the Figure, Koo's model estimates the experiment data relatively better than Ou's model does.

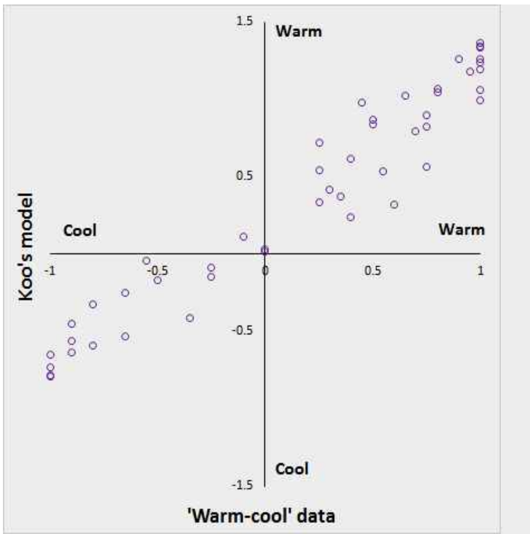

Fig. 8. Comparison result between the 'Warm-cool' data and Koo's model values

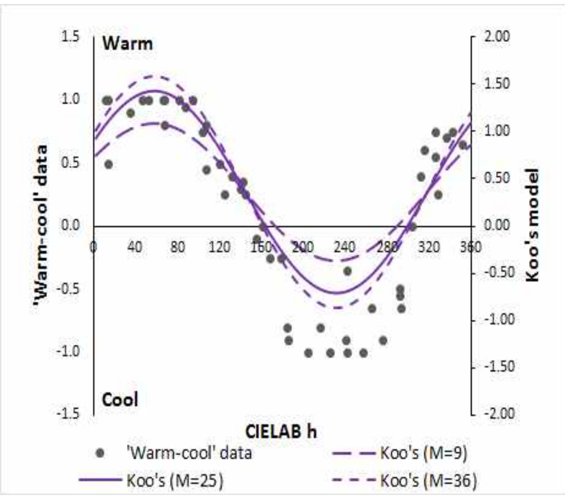

Fig. 9. Comparison result between the 'Warm-cool' data and Koo's model when CIECAM02 M is 9, 25, and 36, respectively

Like Ou's, Koo's model is also affected by chroma to estimate 'Warm-cool' emotion.

Figure 9 shows the comparison result between the 'Warm-cool' experiment data and Koo's estimated values when CIECAM02 M was 9, 25, and 36, respectively. The values came from the test lightings' average (M=25), minimum (M=9), and maximum (M=36) values of CIECAM02 M.

As shown in the Figure, Koo's estimated 'Warm-cool' emotion changed over chroma that higher chroma aroused stronger feeling. Also, the hue range for arousing 'Warm-cool' emotion was almost similar with the experiment data.

4. Conclusion

In this experiment, 'Warm-cool' feelings of near-white lightings were investigated after the participants' eyes were adapted to 5,000K. The experiment was carried out by using 5 channels LED lighting booth in a dark condition. Total of 48 test lightings were selected to have evenly distributed in CIE u'v' space near the reference lighting having 5,000K. Total of 20 participants with a normal color vision evaluated 'Warm-cool' emotion of each test lighting.

The experiment results showed that the 'Warm-cool' result roughly follow the Planckian locus. Lower CCT tended to evoke 'Warm' feeling, while higher CCT evoke 'Cool' feeling. The warm feeling was mostly evoked in the red-yellow area (CIECAM02 H=0-100 and 380-400) and cool feeling was dominantly aroused in the green-blue area (CIECAM02 H=250-300). Also higher chroma evoked stronger 'Warm-cool' feelings.

As a result of 'Warm-Cool' emotion model performance test, the experimental condition of the model affected the performance. Koo's model, which was based on lights, showed better performance than Ou's, which was established from the color patch based experiment. This result suggests that further color emotion studies using the light are required to develop the color emotion model for the lighting industry.

References

〔1〕 OU, Li Chen, et al. A study of colour emotion and colour preference. Part I: Colour emotions for single colours. Color Research & Application, 2004, 29.3: 232-240.
〔2〕 SATO, Tetsya, et al. Quantitative evaluation and categorisation of human emotion induced by colour. Advances in Colour Science and Technology, 2000, 3.3: 53-59.
〔3〕 CHENG, Ka-man. Quantitative evaluation of colour emotions. 2002. PhD Thesis. The Hong Kong Polytechnic University.
〔4〕 Yang, Byeongwoon, et al. Comparison of Studies on Chromatic Interior Space Light Source for Emotional LED Lighting. Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, 2013, 141-142.
〔5〕 Baek, Changhwan, et al. The Analysis of Color Emotion for LED light. Journal of Korean Society of Color Studies, 2010, 24.3: 67-79.
〔6〕 Jee, Soonduk, et al. Sensibility Evaluation on the Correlated Color Temperature in White LED Lighting. Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, 2008, 22.4: 1-12.
〔7〕 Lee, Jinsook; Kim, Wondo; Kim, Soyeon. Sensibility Evaluation of LED Lighting and Fluorescent Lamp based on Color Temperature. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Planning & Design, 2009, 25.4: 263-270.
〔8〕 Kim, Hyunsun; Kim, Yusin; Choi, Anseop. A Study on the Subjective Evaluation of Color Appearance under the Different LED CCT Conditions. Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, 2011, 25.2: 43-52.
〔9〕 KOO, Bonseok; KWAK, Youngshin. Color appearance and color connotation models for unrelated colors. Color Research & Application, 2015, 40.1: 40-49.
〔10〕 INTERNATIONAL COMMISSION ON ILLUMINATION. TECHNICAL COMMITTEE TC 8-01 "COLOUR APPEARANCE MODELING FOR COLOUR MANAGEMENT SYSTEMS". A colour appearance model for colour management systems: CIECAM02.

Biography

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