Research on the Visual Comfort for Small Spaces in Different Illuminance Environments

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Abstract. This paper conducted an ergonomic experiment based on the visual comfort of users by simulating 5 external illuminance environments of night, kitchen, living room, common supermarket and high-end market. It studied the comfortable and acceptable illuminance levels for three doors refrigerator with ceiling lamps separately in the case of vacancy and filling with items. The experiment involved 40 subjects. Results showed that with ceiling lamps, there was no significant difference between the two status of vacancy and filling with items; however, they was different in 5 different external lighting environments. Based on the experimental data, this paper established a regression mathematical model in order to illustrate the relationship between the external lighting environments and the internal comfortable illuminance levels for the three doors refrigerators. The result will provide the reference for the optimization data for the lighting design of three doors refrigerators.

Keywords: Visual comfort · Lighting environment · Illuminance · Mathematical model

1 Introduction

Visual comfort, which largely depends on psychological perception, is the comfortable degree of people's psychological feeling about the lighting environments. There are many factors affecting the visual comfort, mainly including the lighting environment, illuminance, hue, age, etc. In lighting engineering, it is necessary to know the standard value of lighting level with good visual effects. In fact, this is to establish the internal relationship between subjective perception and objective physical quantity. Consequently, the psychophysical research results are usually used, which means under certain conditions, by ways of questionnaire, scaling and value evaluating, the quantities of physical stimulus and subjective perception should be linked together, i.e., establishing a relationship between qualitative and quantification.

There are a number of literatures about visual comfort and visual brightness, which have made certain achievements. Through experiments, document [1] gets the data of the relationship between satisfaction degree and illuminance in living room lighting.

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Based on [1]'s data, document [2] establishes the evaluation equation of the lighting environment comfort level, which could reflect the relationship between comfort level and illuminance. Su Yanchen [3] studied the mathematical model relationship between illumination and human visual comfort based on specific circumstances of high-speed train, and made the multiple-regression analysis on internal illumination comfort of the high-speed train, with the application of statistics principle. Chen Zhonglin established the relationship between subjective sense and physical measurement in lighting engineering, the qualitative and quantitative analyses are connected through generalized Weber-Fechner Law for practical application problems of lighting engineering, a proximate function of subjective sense deduced from physical measurement was brought forward [4]. During 2002–2004, Boyce et al. [5] did a research about the office lighting and connected the lighting conditions, subjective comfort level and visual performance together, which shows the correlation among luminance, uniformity, comfort and dazzle. According to this, they also evaluated the interaction among the parameters in environmental space. Their results show that brightness-comfort and uniformity-comfort are all in positive correlation, that is to say the brighter the room is, the evener the light will be and people will feel more comfortable. Mark Rea et al. [6] used the method of semantic differential to study how lighting environment influence people's subjective preference. Their results show that when the brightness level rose from 0.96 cd/m2 to 1000 cd/m2, visual task performance and part of the subjective evaluation grades also rose correspondingly.

Overall, in the field of interior lighting comfort, the objects of related studies were mainly focused on building space, locomotive, airplane, etc. Refrigerators are closely related to our daily life. In order to look over the items inside, identify and take them out, it is necessary to have good internal illuminations, which will also influence the user experience. When choosing a proper lighting level for the internal space of refrigerators, it is necessary to take the aspects of visual ergonomics, visual satisfaction and effective utilization of energy into consideration. As for the refrigerator, its external lighting environment will also have an impact on its internal illuminating comfort. Currently, the studies of internal illuminating comfort for the refrigerators haven't covered the aspect of different external lighting environments. What's more, there is no relevant mathematical modeling. Consequently, it is of great necessity to study the visual comfort for the refrigerators.

2 Methods

2.1 Subjects

In all, 40 participants, comprising 21 men and 19 women were recruited, respectively. The mean ages of the participants were 40.13 (±11.14) years. They all have normal sight and corrected vision, without the problem of color blindness or weakness. During the whole process of experiment, all the participants were in good physical and psychological states.

2.2 Experimental Environment

To avoid the influence of natural lighting, ambient temperature and humidity, this experiment was done in dark rooms, and the external lighting environment was designed according to the selling and using environments of refrigerators. Usually, refrigerators are sold in supermarkets or special markets and placed in kitchens or living rooms. According to the mandatory standards GB 50034-2013 "Standard for lighting design of buildings" [7], the lighting standard value of normal supermarkets should be 300 lx and of high range market should be 500 lx. Moreover, the lighting standard values of kitchens and living rooms should be 100 lx–150 lx and 100 lx–300 lx respectively. Considering that refrigerators may also be used at night without any lighting, hence the night environmental conditions should also be taken into account. During the experiment, the internal illuminance level was controlled by regulating the lights installed on the roof of the laboratory, which could also satisfy the needs of external illuminance level (Chart 1) (Table 1).

Table 1. External environment Illuminance level

Experimental environment	Illuminance standard value (lx)	Experimental illuminance value (lx)
Nighttime conditions	/	5
Kitchen conditions	100 lx–150 lx	100
Living room conditions	100 lx –300 lx	170
Common supermarket environment	300 lx	300
High-end store environment	500 lx	580

2.3 Experiment Material

This study was mainly focused on refrigerators with three doors. The refrigerator cabinet liner was made of inner container materials and with the size of 52*65*45 cm (length*height*depth). The lighting system in freezer were lamp set on top of the inner cabinet, using the cold light LED point light source, with color temperature of 6500 k and CRI (Color Rendering Index) of 70. In the experiment, refrigerator was kept in two states: empty and filled with 60 % conventional food. In both cases, the ceiling lights were in external attachment with dimming devices.

2.4 Experiment Procedure

Before starting, the experimental process should be introduced to the participants. In the experiment, after changing the external environment illuminance, participants should firstly adapt to the environment visually. Then experiment began. Under the guidance of experimenters, participants adjusted the dimming devices in the cases of vacancy and with items respectively. They should adjust them to the level of brightness

which made them feel the most comfortable, the minimum acceptable brightness and the maximum acceptable brightness. Experimenters recorded the gear numbers.

After experimenting, the XYI-III type all-digital portable illuminometer was used to make a stationing measurement inside the refrigerator. The illuminance of the left, right and back side walls in the refrigerator and of every baffle layer were all be measured. The measurement points were distributed uniformly on every level. Then the average measurement of illuminance value was worked out according to the measurement data.

3 Result and Discussion

3.1 The Comfort Illuminance Level in Cases of Empty Inner and Inner with Items

The comfortable illuminance level for refrigerators in cases of empty inner and inner with items in 5 external environments are described in Table 2 and Fig. 1.

Table 2. The comfortable illuminance level in different status

Experimental environment	Environmental illuminance (lx)	Most comfortable illuminance (lx)	
		Refrigerator inner with items	Empty refrigerator inner
Nighttime conditions	5	50	37
Kitchen conditions	100	69	64
Living room conditions	170	82	84
Common supermarket environment	300	123	122
High-end store environment	580	192	181

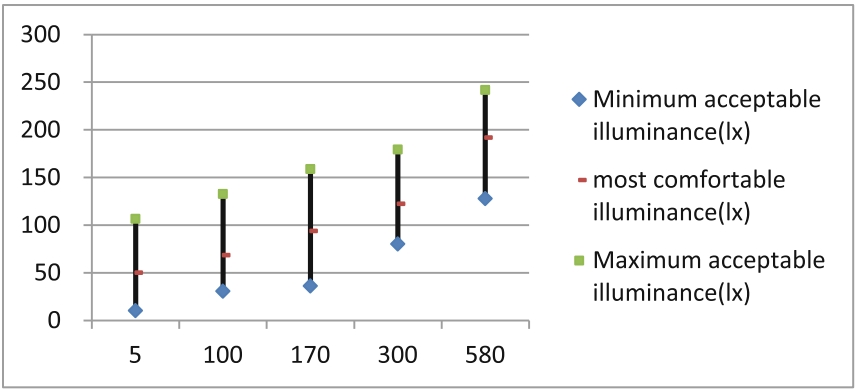

Fig. 1. Comfortable Illuminance level in case of inner with items

The experiment results show that the environmental main effect is remarkable (F = 138.252, P = 0.000). The most comfortable illuminance levels are significantly different among the 5 external lighting environments except between the kitchen environment and living room environment.

The Table 2 shows that when the external lighting environment ranges from 5 lx to 580 lx, the most comfortable illuminance level inside the refrigerator also rises accordingly. In low light situations, people need lower comfortable illuminance. The higher the exterior environment illuminance is, the higher the visual comfortable illuminance inside the refrigerator will be. This study reflects properly the objective law of inner visual comfortable illuminance and exterior environment illuminance. The most comfortable illuminance level for the inner with items is higher than the one with empty inner, and their difference in value are 13 lx, 4 lx, 8 lx, 1 lx and 11 lx in the 5 exterior lighting environments of nighttime, kitchen, living room, common supermarket and high-end store respectively. However, there is no significant difference from the view of statistics.

Figures 1 and 2 show the minimum and the maximum illuminance level inside the refrigerator also rises accordingly that in these two cases of inner with items and empty inners, and the former of the most comfortable illuminance level, and minimum and the maximum illuminance level (inner with items) is higher than the latter one (empty inner) in the 5 exterior lighting environments of nighttime, kitchen, living room, common supermarket and high-end store respectively.

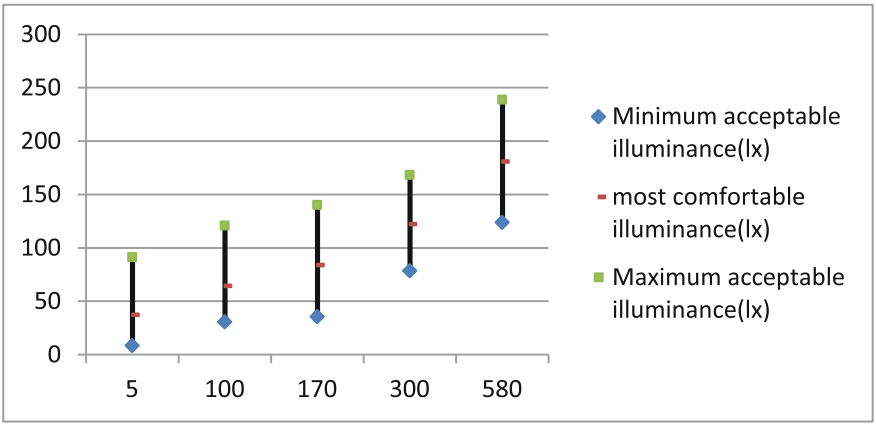

Fig. 2. Comfortable illuminance level in case of empty inner

3.2 The Mathematical Model for the Most Comfortable Illuminance Levels in Different External Lighting Environments

In order to establish the regression relationship between the external environment illuminance and the comfort inner illuminance of the refrigerator, we regarded the external environment illumination as the independent variable, the refrigerator comfort illumination levels as the dependent variable, while introduced whether the refrigerator

is placed items as classification variables. Using the method of least squares fitting, the linear regression analysis was conducted.

The correlation coefficient for the regression equation R is 0.998, and the coefficient of determination R^2 is 0.995, which show the strong representative regression equation. Regression analysis of F = 752.620 statistics, the concomitant probability $p < 0.001$ for the regression analysis, which shows a plurality of dependent and independent existence of linear regression relationship between the variables, the regression equations that have significance. The mathematical model for the comfort inner illuminance of the refrigerator is:

$$y = 47.884 + 0.249x_1 - 7.615x_2 \quad (1)$$

x_1 is the environment illuminance, and x_2 is whether the refrigerator is placed items. When $x_2 = 0$ represents the refrigerator with empty inner, and $x_2 = 1$ represents the refrigerator with items in it.

4 Conclusions

Illumination design may influence the user experience greatly. The refrigerator inner comfortable illuminance levels are variable in different exterior lighting environments. Consequently, the illumination design should take the users' using environments into consideration. As for Chinese consumers, there are other factors, such as different living space, different areas in the north and south, different types of refrigerators and different placing locations. The illumination design of refrigerators should give full consideration to their target users and estimate their location scientifically.

As for the high-end refrigerators, the intelligent lighting control devices are feasible. Based on the exterior lighting environments and the mathematical models in this paper, the interior lights can be regulated infinitely, which will satisfy people's needs of visual comfort.

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