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STUDY ON THE TRESPASS THRESHOLD OF STATIC LIGHT TRESPASS ON INDOOR ACTIVITIES OF RESIDENTS

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Abstract

The influence of light trespass caused by static light sources for functions, signs and others is becoming seriously. Research shows that it's one of the interference factors affecting residents' indoor activities. Based on the residents' subjective feelings, through subjective evaluation experiments, combined with the operation definition of threshold, and calculated the trespass thresholds of two kinds of light colours (yellow and white light), four area ratios (full windows, 1/4 windows, 1/16 windows, 1/64 windows) of urban static light trespass with normal indoor lighting conditions. Although the colour temperature isn't related to the degree of static light trespass, there is a difference between the static light trespass thresholds of the two light colours; the area ratio is negatively correlated with the degree of trespass; the power function equation of the luminance threshold and area ratio is obtained. These Lay the foundation for the prevention and control of static light trespass.

Keywords: Urban lighting; Static light trespass; Residential area; Threshold; Subjective evaluation

1 Background

The residential area adjacent to the road is affected by the light trespass of night road lighting. The green landscape lighting and parking lot lighting in the residential area are also sources of light trespass. The static light source of the above categories has a large amount of stock, wide distribution, high brightness and long duration, which causes the problem of light trespass in residential areas to become more and more serious.

CIE No.150 document ^[1] specifies the maximum luminous intensity of the luminaire and the illuminance value on the vertical plane of the window for the prevention of light trespass. In addition, it ^[2] also specifies the threshold increment for night lighting, advertising signs, etc. CY Ho and HT Lin pointed out that although the luminance of Taiwan billboards meets the CIE regulations, due to its large coverage area, high density distribution and improper installation still cause serious light trespass, and solutions are proposed from the perspective of urban planning ^[3-4]. CY Ho in-depth studied of the common advertising signs and LED screen light trespass and energy consumption, and recommended to strictly control the LED screen area and luminance ^[5]. The CIE standard also provides relevant recommendations for the prevention of light intrusion ^[6]. In 2018, CIE established the TC4-58 Technical Conference on Night Light Trespass Prevention ^[7].

The china's standard ^[8] "equivalent adoption" CIE prevention requirements. Most studies ^[3-4] have also explored light intrusion prevention measures based on the requirements of the specification. In fact, "vertical illumination" doesn't represent the actual feeling of residents' light trespass, and the current discomfort glare evaluation methods and simulation software can't effectively evaluate the residents' actual perception of light trespass ^[9]. In addition, the interference of light trespass on sleep activity in the dark environment has been studied in depth ^[10], but the previous investigation ^[11-13] showed that, light intrusion also interfered with the indoor visual tasks of residents under normal indoor lighting conditions. Therefore, this paper carries out the research on the judgment and evaluation of the degree of static light trespass interference on residents' indoor activities: the indoor environment was reproduced in the laboratory, to study the influence of static light trespass with different colour temperature and

area ratio on TV watching by residents under normal indoor lighting conditions. The research results will provide basic research theories for the formulation of standards for indoor trespass and the revision of design standards for road lighting and landscape lighting.

2 Typical static light trespass subjective evaluation experiment

2.1 Experiment setup

The experiment used the Likert Scales questionnaire, which used five grades: 1 for “no interference at all” and 5 for “serious interference”. The experimental parameters were sorted by means of random arrangement within the group and Latin square design between groups to offset the result error or irrelevant variable effect caused by the sequence factor and the difference factors of the subject [15].

The participants were 36 students of Tianjin University, China, aged 18-30, who passed the Ishihara Colour Blindness Test. Before the experiment, they were in good mood, no physiological diseases, no intensive work in the near future, etc.

Laboratory simulates living room layout (Fig. 1-1). Spatial size: width 3170 mm, length 4050 mm, height 3000 mm; window size: 1500 mm * 1500 mm, window sill height 900 mm, window fixed in movable partition; LED screen size: 2000 mm * 2000 mm, adjust the height of the LED screen to 830 mm, and the left side of the window is 982 mm from the wall surface to ensure that the LED screen displayed at the viewpoint (sitting position) at the center of the sofa is full of the entire window.

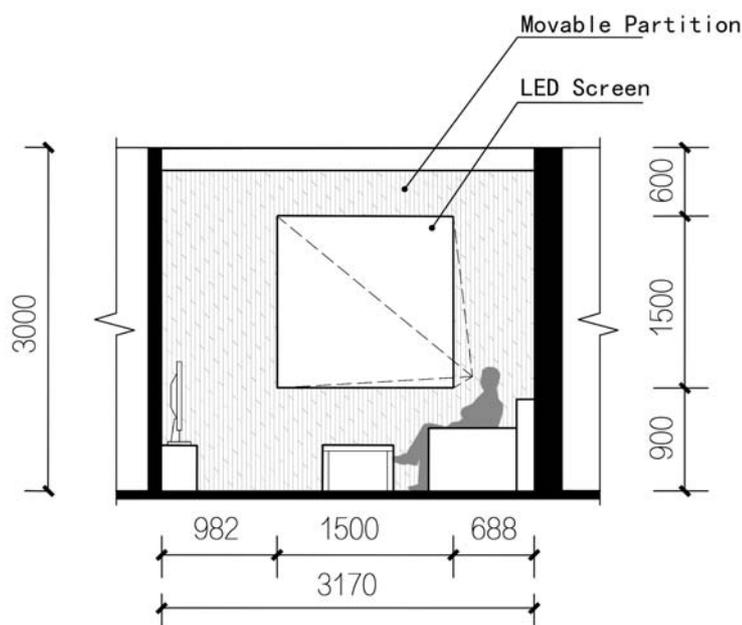


Figure 1 – Laboratory profile and interior layout

In order to eliminate the influence of "colour contrast" on static light intrusion experiments, all visible surfaces in the laboratory are made of gray materials with low saturation. The surface reflection coefficients are all within the range recommended by the standard [14]. Indoor lighting source is T5 light tube, colour temperature is 5000K. The measured illumination of 0.75 m horizontal plane is 324 lx, which meets the standard requirements of writing and reading 300 LX in the living room [13]. The sound environment in the laboratory is good. The air conditioner is installed in the laboratory, allowing the subjects to adjust the air conditioner independently to ensure comfortable indoor temperature.

Select TV activities to ensure the focus of the participants on visual assignments. The content is a black and white pencil hand-drawn animated short film series, each story content is different but the degree of wonderfulness is almost the same. In addition, the experiment set the

answering prompts to ensure the smooth progress of the subjective evaluation experiment without affecting the attention of the subjects to the visual work.

2.2 Experimental variables

Through pre-evaluation experiment, the parameters of non-interference and serious interference were screened out, and the experimental variable step size was adjusted. The final experimental parameters were 44 groups (22 sets of different static light trespass parameters for each of yellow and white light. Pre-evaluation experimental data showed no significant effect on colour temperature and interference degree. Therefore, the final experiment only retained the experimental variables of two common colour temperatures of 2000k and 5000k for yellow and white light, and four kinds of area ratios (experimental variables of full window, 1/4 window, 1/16 window, 1/64 window). See the table below:

Table 1 – Experimental variable parameters

grade	Numerical category	Corresponding luminance of area ratio (cd/m ²)			
		1	1/4	1/16	1/64
1	Target value	25	25	25	-
	Yellow light calibration value	29.2	29.2	29.2	-
	White light calibration value	26.5	26.5	26.5	-
2	Target value	50	50	50	-
	Yellow light calibration value	56.4	56.4	56.4	-
	White light calibration value	51.9	51.9	51.9	-
3	Target value	100	100	100	-
	Yellow light calibration value	104.8	104.8	104.8	-
	White light calibration value	103	103	103	-
4	Target value	200	200	200	-
	Yellow light calibration value	196.8	196.8	196.8	-
	White light calibration value	203	203	203	-
5	Target value	400	400	400	-
	Yellow light calibration value	416.9	416.9	416.9	-
	White light calibration value	423	423	423	-
6	Target value	-	800	800	-
	Yellow light calibration value	-	806.7	806.7	-
	White light calibration value	-	790	790	-
7	Target value	-	1600	1600	1600
	Yellow light calibration value	-	1617	1617	1617
	White light calibration value	-	1669	1669	1669
8	Target value	-	-	3200	3200
	Yellow light calibration value	-	-	3225	3225
	White light calibration value	-	-	3208	3208

Note: 1 yellow light is a warm yellow with a color temperature of 2000K, and white light is a neutral white with a colour temperature of 5000K;
2 The error range between measured and calibrated luminance values is 0.3%~12.8%.

2.3 Experimental procedure

- Screening subjects

Participants entered the laboratory, filled out the screening questionnaire, conducted a colour blind test, and determined whether the subject was suitable for the experiment.

- Pre-experiment preparation

The participants were in position, adapted to the experimental environment, and self-regulated air conditioning to a comfortable state. When the experimental environment is stable, the main participant fills in the experimental record form (including the experimental date and time, Latin square experiment number, indoor temperature and humidity, etc.).

- Explain experiment

The main test explained the experimental requirements, experimental steps, etc. and confirmed that the participants had no doubt about the content of the explanation.

- Familiarity with experiments

The participants were familiar with the process through two groups of experiments. After confirming that the participants were familiar with the process, they quit the laboratory and began the formal experiment.

- Formal experiments

The participants sat on the sofa in the middle of the room and looked directly at the TV, watched the TV program, and the LED screen played the interference light. When the TV program is paused and prompted to answer the question, fill out the questionnaire.

- Return to the experiment

After the formal experiment, the participants were interviewed (fill in the interview paper and interview).

3 Experimental results and threshold calculation

3.1 Experimental data analysis

A large batch of subjective evaluation experiments obtained a total of 1584 sets of experimental data (36 participants * 44 sets of experiments).

3.1.1 Test score

The percentage of the arithmetic mean score/ ≥ 4 score (%) of the test scores was counted, see Table 2:

Table 2 – Arithmetic average score of subject score ≥ 4 points percentage (%)

grade	luminance (cd/m ²)	Colour temperature	Percentage of area ratio corresponding to the average score / ≥ 4 points (%)			
			1	1/4	1/16	1/64
1	25	Yellow light	1.53/8.33	1.28/5.56	1.31/0.00	-
		white light	2.17/5.56	1.89/0.00	1.39/2.78	-
2	50	Yellow light	1.56/25.00	1.61/8.33	1.44/2.78	-
		white light	2.81/0.00	2.36/2.78	1.69/0.00	-
3	100	Yellow light	2.28/36.11	1.86/13.89	1.50/2.78	-
		white light	3.11/8.33	2.42/2.78	1.86/0.00	-
4	200	Yellow light	2.83/47.22	2.14/36.11	1.58/2.78	-
		white light	3.33/22.22	3.14/0.00	1.94/0.00	-
5	400	Yellow light	4.03/86.11	2.78/41.67	2.06/2.78	-
		white light	4.42/77.78	3.11/25.00	1.89/2.78	-
6	800	Yellow light	-	3.67/63.89	2.33/16.67	-
		white light	-	3.92/58.33	2.53/5.56	-
7	1600	Yellow light	-	4.22/94.44	2.83/13.89	1.78/0.00
		white light	-	4.50/75.00	2.58/27.78	1.64/2.78
8	3200	Yellow light	-	-	3.31/63.89	2.08/13.89
		white light	-	-	3.83/41.67	2.19/5.56
Average score ≤ 2 total			2	4	9	2
Average score ≥ 4 total			2	2	0	0
$\leq 2\%$ of the total score $> 50\%$			0	0	0	0
$\geq 4\%$ of the total score $> 50\%$			2	4	2	0

The score (≥ 4) corresponded to "comparative interference" and "serious interference", while the score (≤ 2) corresponded to "no interference at all" and "a little interference". There were 4 groups with average score (≥ 4), accounting for 9.09% of the total, and 17 groups with average score (≤ 2), accounting for 38.64% of the total. According to the operational definition of threshold, the size of the stimulus that triggers the response is 50% of the time. The percentage of score (≤ 2) $> 50\%$ totaled 0 groups, and the percentage of score (≥ 4) $> 50\%$ totaled 8 groups, accounting for 18.2% of the total.

3.1.2 Questionnaire credibility

The reliability coefficients of the yellow and white light trespass experiments were 0.939 and 0.933, respectively, both of which were greater than 0.8, and the agreement was the best.

3.1.3 Relevance analysis

According to the results of SPSS analysis, the Pearson correlation coefficients of the average scores of the yellow and white light trespass experiments and the luminance and area ratios were all greater than 0.9, which were significantly correlated.

3.2 Threshold calculation

According to the operational definition of the threshold, the threshold is 50% of the size of the stimulus that caused the reaction [15]. In this paper, the 50% threshold value obtained when the score is ≥ 4 (corresponding to the evaluation of "comparative interference" and "serious interference") is the interference evaluation threshold of static light intrusion (hereinafter

referred to as “threshold”), that is, the control for static light intrusion control. Low standard. The 50% threshold value obtained when the subjective evaluation score is ≤ 2 is the threshold value that can just cause people to feel, that is, the higher standard for static light intrusion control.

When the yellow light trespass experimental area ratio is 1, the percentage result of the score ≥ 4 is taken as an example, and the calculation threshold is as follows:

Table 3 – Percentage Result of Score (≥ 4) when Area Ratio of Yellow Light Trespass Experiment is 1

luminance (cd/m ²)	400	200	100	50	25
Data statistics					
Percentage of score ≥ 4 (%)	86.11	47.22	36.11	25.00	8.33

Use the linear interpolation method [15] to find the absolute threshold, and set the absolute threshold corresponding to the 50% stimulus value to X.

$$\frac{400-200}{86.11-47.22} = \frac{X-200}{50-47.22} \tag{1}$$

$$X=214.29$$

That is, the luminance threshold value when the yellow light trespass experimental area ratio is 1, is 214.29 cd/m².

Similarly, the typical static light trespass luminance threshold is shown in Table 4.

Table 4 – Threshold calculation results

category	2000K yellow light trespass				5000K white light trespass			
	1	1/4	1/16	1/64	1	1/4	1/16	1/64
luminance threshold with score ≤ 2	44.44	56.25	1694.12	4200	150	325	1028.57	6080
luminance threshold with score ≥ 4	214.29	550	2755.56	7360	300	700	4160	28800

Referring to the concepts of current value and target value, the 50% threshold value obtained when the subjective evaluation score (≥ 4) is defined as the current value to be achieved, and the 50% threshold value obtained when the subjective evaluation score (≤ 2) is defined as the target value to be achieved in the future development. Comparing the luminance thresholds of lower and higher standards, it is found that there is a great difference between lower standards (current values) and higher standards (target values). Reviewing the actual investigation, it is suggested to adopt a lower standard (current value) for the measurement and observation of static light trespass, which is more in line with the current situation of static trespass in China. In the follow-up discussion of this paper, the luminance threshold with score (≥ 4) is adopted.

4 Static light intrusion interference evaluation threshold analysis

4.1 Comparative analysis of the interference degree of yellow and white light trespass

Subjective evaluation scores ≥ 4 luminance threshold (Table 4, Figure 2), demonstrating that the subject's resistance to white light intrusion is greater than the yellow light intrusion.

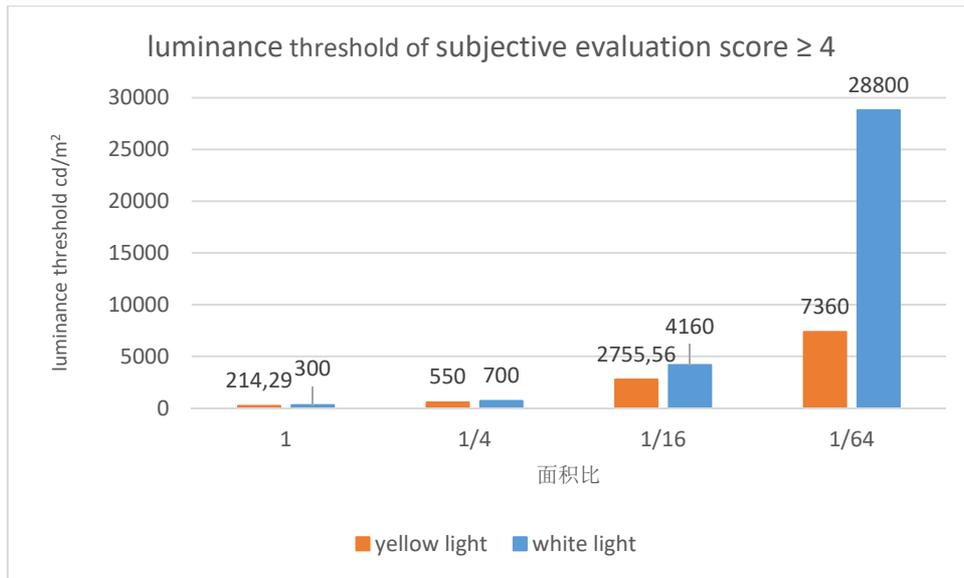


Figure 2 – Luminance threshold of subjective evaluation score threshold ≥ 4

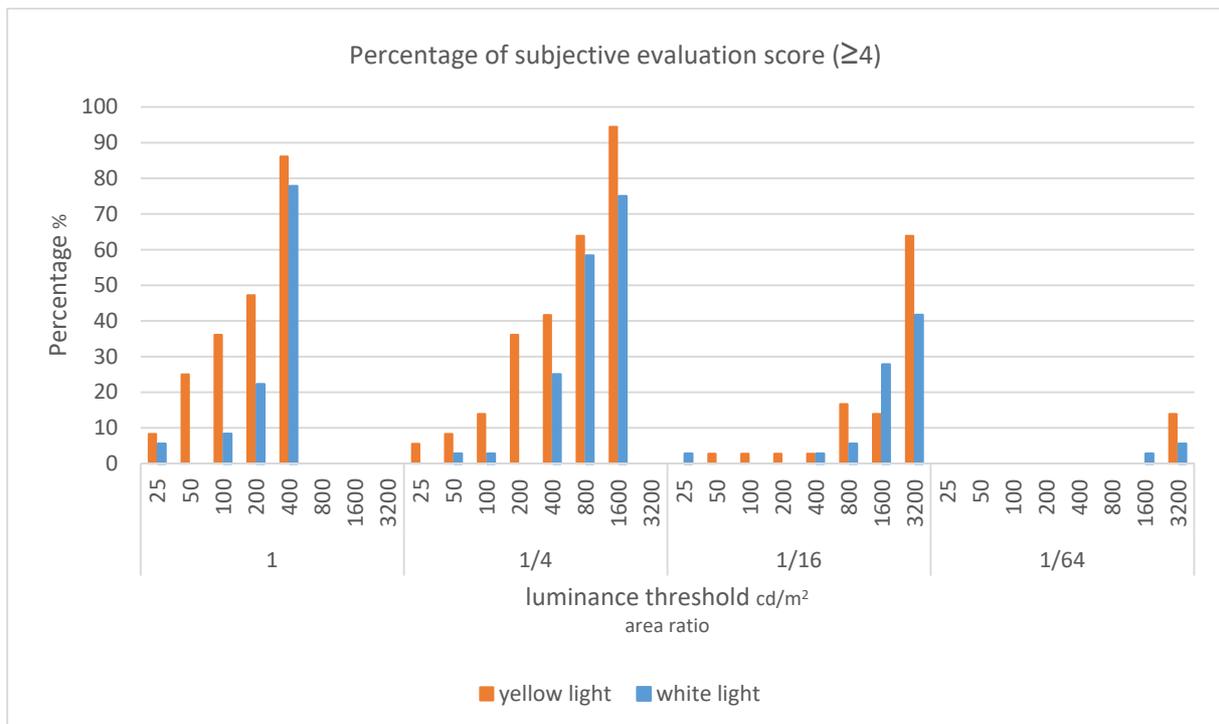


Figure 3 – Percentage of subjective evaluation score ≥ 4

Comparing the percentages of the two light colours, as shown in Figure 3, it was found that when the area ratio was 1 and 1/4, the degree of white light interference was higher than that of yellow light interference under the condition of the same luminance. When the area ratio was 1/16 and 1/64, three groups of experimental results showed that the degree of white light interference was lower than that of yellow light interference. It was found that when the area ratio was small, people resisted light interference. There is no obvious relationship between the degree of interference and light colour. The possible reasons are as follows:

(1) When the experiment lasts for August, the participants may prefer cold colour in hot weather. In addition, the ambient illumination colour temperature in the laboratory is 5000K, which is similar to the experimental variable white light colour temperature, which may lead to high white light tolerance.

(2) When the area ratio is 1/16 and 1/64, it is beyond the participants' main visual field and is insensitive to colour discrimination. Therefore, there is no obvious relationship between the degree of light resistance and yellow and white light.

4.2 Effect of static light trespass area ratio on interference degree

According to Fig. 2, Table 4 shows that the luminance threshold of yellow and white light increases with the decrease of the area ratio, and the area is inversely proportional to the luminance threshold of yellow and white light, and the area ratio and the degree of static light trespass are significantly affected.

When the area ratio is in the range of 1-1/4, the change trend of luminance threshold of yellow and white light is slow, and the increase of luminance threshold is slow with the decrease of area ratio. Therefore, the luminance value of static trespass light in windows should be strictly controlled within this area ratio range, not exceeding 700 cd/m², so as to limit the interference of light trespass; when the area ratio is in the range of 1/4-1/16, the luminance threshold increases with the decrease of area ratio, and the luminance value should be controlled at 500 cd/m²-4160 cd/m², to limit the interference effect of light trespass; When the area ratio is in the range of 1/16-1/64, the luminance threshold increases sharply with the decrease of the area ratio, and the degree of interference caused by light interference is very small.

4.3 SPSS Curve Regression Analysis

Based on the conclusion that the above area ratio significantly affects the trespass luminance threshold, this study further carried out the regression model study of the two, the results are as follows:

- Yellow light trespass experiment

As shown in Table 5, the curve equation is a power function curve, and the R² value is 0.989. The function model is statistically significant.

The function equation is:

$$y = 198.84x^{-0.88} \tag{2}$$

where

- y is the luminance threshold;
- x is the area ratio;

Table 5 – Estimated parameters of yellow light

Equation	Model summary			Parameter estimate	
	R ²	F	Sig.	Constant	b1
Power	0.989	176.490	0.006	198.835	-0.882

- White light trespass experiment

As shown in Table 6, the curve equation is a power function curve, and the R² value is 0.973. The function model is statistically significant.

The function equation is:

$$y = 219.81x^{-1.12} \tag{3}$$

where

- y is the luminance threshold;
- x is the area ratio;

Table 6 – Estimated parameters of white light

Equation	Model summary			Parameter estimate	
	R ²	F	Sig.	Constant	b1
Power	0.973	73.395	0.013	219.814	-1.116

5 Conclusion

In this paper, the subjective evaluation experiments of static light trespass with different luminance, light colour and area ratio are carried out in the laboratory, and the quantitative research of static light trespass is realized. The luminance thresholds obtained by different light colours and different area ratio are compared and analyzed, and preliminary results are obtained. In conclusion:

1. From the percentage of score (≥ 4) points, the colour temperature has no significant effect on the luminance threshold from the previous correlation analysis, but there is a difference between the static light trespass thresholds of the two light colours. It is found that the difference in luminance thresholds of different light colours is small, and the smaller the area ratio is, the less the degree of resistance to light trespass is related to the colour of light;
2. The area ratio is strongly correlated with the degree of trespass. The larger the area ratio, the smaller the luminance threshold and the greater the degree of trespass. Therefore, it should be controlled in the prevention and control of static light trespass in China;
3. Perform curve regression on the obtained luminance threshold to obtain the power function equation of area ratio and luminance threshold of yellow and white light, and characterize the relationship between light trespass luminance threshold and area ratio, and provide support for quantitative prevention and control of static light trespass. .

This study provides a theoretical basis for further research in the future, and also provides basic research theories for the formulation of normative standards for night indoor trespass of residential buildings and the revision of design standards for road lighting and landscape lighting.

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