Research on Emotional Features of Virtual Eye-movement in Low-Carbon Building Design

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Abstract
With the acceleration of urbanization in China, how to improve the carbon sequestration effect of the construction sector has become a hot research topic of common concern. In this paper, the virtual eye-movement experiment of emotional features is introduced in to provide new evidence for the significant impact of low-carbon building design by observing the distribution of tracked saccade trajectories and fixation hot spots of the subjects. The results show that: (1) Tracked saccade trajectories are consistent with the low-carbon control parameter value preset in the design schemes, indicating a positive correlation between the two. (2) The emotional preference of stress color is consistent with the trend of fixation hot spots of subjects, which provides new evidence for studying the effect of low-carbon building design. (3) It is confirmed that virtual eye-movement emotional feature experiment has a significant impact on low-carbon building design effect. The results provide a new method and reference for the action plans for peaking carbon dioxide emissions.

Keywords:
Saccade tracking trajectory; fixation hot spots; eye-tracking emotional features; low-carbon building design

Introduction

General Secretary Xi Jinping announced at the 75th United Nations General Assembly that China aims to peak carbon dioxide emission by 2030 and achieve carbon neutrality by 2060 (Aladdin et al. 2018). According to statistics, CO2 emission in 2018 reached approximately 2.1 billion tons, taking up about 20% of total emission nationwide (Alwisy et al. 2019; Chao et al. 2021; Chen et al.

2016). In contrast, the construction industries in developed countries such as Japan and South Korea have reached carbon emission peak at the beginning of the 21st century.

Virtual Reality (VR) technology uses the principle of infrared light reflection to track the eye movement by measuring the emotional changes of the subjects or the movement of the eyes relative to the head, and synchronically record the 3D spatial position of the eyes or the head, fixation duration, blink times and other data (Fang 2019). Jonsdottir (2021) used the concepts of eye-movement fixation rate and fixation entropy in eye-movement tracking data to prove that people's learning efficiency in online learning by using the first language is better than that by using the second language. Wang (2018) and Lv (2018) proposed an emotion perception algorithm based on eye-movement information by simultaneously collecting and analyzing EOG signals and eye-movement videos, confirming that the emotional features of eye movement can effectively reflect the emotional state of adolescents.It is proved that VR technology plays an auxiliary role in "situation simulation", "design communication" and "scheme determination" to complete the construction of high-quality and indoor color environment suiTablele for the old. Maffei (2016) employed VR technology to simulate whether acoustic and visual stimuli in the environment are consistent with the corresponding elements in the real environment, confirming that modern multi-sensory VR technology can represent an intelligent and innovative tool for enhancing participatory planning and predicting the impact of community complexity on the environment. Niu (2016) esTablelished a Pre-OE design framework to help architects collect occupancy information and determine design patterns using VR technology, demonstrating that the framework can help designers understand the behavior of occupants and determine how residents can implement design alternatives according to design intentions.

This paper intends to evaluate the design effect of low-carbon buildings with the tracked eye-movement data in VR technology, and meanwhile introduce in the stress color emotional feature experiment that represents the low-carbon concept to test the feasibility of the design effect of low-carbon buildings. The research objective is to inject green and low-carbon concept from the stage of architectural design scheme, and promote the construction sector to gradually strive forward towards green and low-carbon action and achieve the goal of carbon emission peak.

Materials and methods

Study area

In this study, the design of university complex building in Wuhan, China, was selected as a practical case. The preliminary field study showed that the building advocates green, low-carbon and sustainable principles, and the bidding for implementation scheme design was launched worldwide,

with a total of 15 design companies signing up for the bidding. Experts in the field of low-carbon building design reviewed the conceptual design scheme and identified the top six schemes submitted by the design firms as candidates schemes.

Research Hypothesis

In order to explore the positive impact of VR eye-movement emotional preference experiment on the green and low-carbon architectural design, this paper will carry out an experimental study on eye movement emotion in low-carbon building design and propose the following hypotheses:
H1: Under the influence of instructions such as thermal conductivity coefficient, specific heat capacity and floor area ratio, the subjects with different job roles have emotional preference for the low-carbon design effects of different building schemes, prompting the subjects to produce stress response to the variables of low-carbon design schemes.

H2: The tracked saccade trajectory distribution of the subjects is generally consistent with the advantages and disadvantages of the preset green and low-carbon control parameter value of the design scheme, reflecting that the emotional preference degree of the subjects is positively correlated with the green and low-carbon effect of the building scheme.

Experiment 1: Experiment of the influence on the design effect

This paper combines VR and ErgoLAB man-machine environment synchronization (ErgoLAB) platform for test experiments, which can visualize the tracked eye-movement data of the subjects. It is conducive to monitoring the green and low-carbon effect of different building schemes, and plays a role in improving the low-carbon monitoring efficiency of the whole process from design, construction to operation(Lin et al. 2021; Lin et al. 2016).

Experimental Design

This research focuses on whether VR eye movement tracking experiment has a positive impact on the selection of low-carbon architectural design schemes. The single-factor two-level (high and low interest) between-subject design is adopted, that is, the experimenter refers to the green and low-carbon parameter values set in the design scheme and divide the subjects into experimental group and control group. The experimental group involves participants in the virtual eye movement tracking experiment while the control group consists of expert interviewers after the experiment.

Subjects and Materials

(1) Design of Subjects. According to the preliminary interviews, 40 low-carbon building design experts, scholars and workers were randomly invited from the research area as the subjects, with the average age of 35±2 years old, and the male / female ratio of 1:1. The uncorrected or corrected visual acuity was 5.0 and above, and no symptoms of color blindness and color weakness were observed.

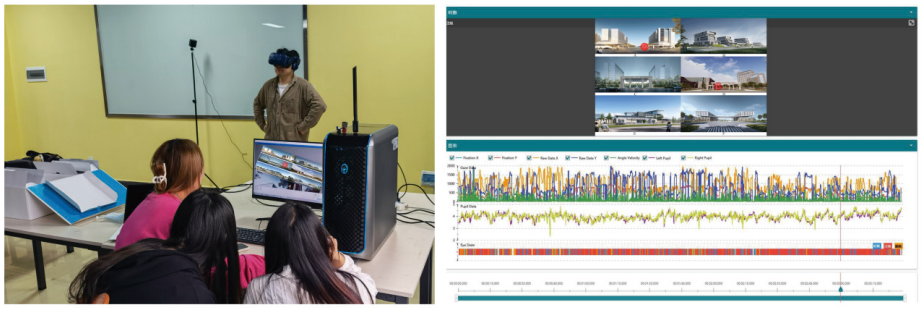
(2) Stimulus Materials. According to standards of the national Carbon Emission Peaking Initiative, modeling software 3D MAX and model BIM were adopted to extract the virtual renderings of low-carbon buildings and junctions, and output a total of 120 pieces of image data in 20 groups with the precision of 1024*1024 pixels, 300 dpi, in order to guarantee a comforTablele fixation distance for subjects when they are answering the questions on emotional preferences and spatial perception.

Experimental Process and Settings

All the subjects were organized to the site to familiarize themselves with the environment, process, instructions, etc. to ensure the accuracy and reliability of the experimental process and to eliminate possible interference. Before the experiment, the instructions (technical parameters of the design schemes) were practiced repeatedly so that the subjects could be immersed in the experiment within a shorter period of time, and their anxiety, excitement and other emotions could be relieved, the experimental scenario was shown in Figure 1. The whole process was divided into three stages: the pre-experiment stage, the experiment stage and the post-experiment stage.

Pre-experiment Stage: All subjects first filled in the demographic information including gender and age and they were divided into different groups by job attributes. Then, all the devices were calibrated on the ErgoLAB platform to ensure the error of 5 view points was within 20 pixels. Once the mapping function generated by virtual eye-tracking parameters has been determined, the test could be started and the test time was set to 1min to guarantee the integrity of the experimental process.

Figure 1 Experimental Environment and Data Monitoring Interface



Experiment Stage: During the experiment, the subjects were required to recognize and read the stimulus materials for 3mins independently in accordance with the instructions, and recorded their virtual eye-movement parameters in real time and mapped the fixation points. The above steps were repeated until 20 subjects completed the experiment.

Post-experiment Stage: The experiment director imported experimental data into EXCEL and eliminated 1 piece of data with larger error to obtain 19 tracked saccade data. Subsequently, SPSS21 was used to analyze reliability of experimental and control data. The results showed that α1 and α2 value are 0.882 and 0.767 respectively, $0<\alpha1<1$, $0<\alpha2<1$, indicating that the data quality of both experimental and control groups was reliable.

Analysis of experimental results

(1) Comparison of degree of subjects' emotional preference. The independent-sample T test was conducted and the results showed that there was a significant difference between the two groups in emotional preference ($P = 0.171 > 0.05$). This result indicated that the scores of the two groups in the degree of emotional preference were not statistically significant and were comparable.

(2) Comparison of the effect of emotional preference on green and low-carbon. The results showed that there was no statistically significant difference in the mean of tracked saccades in the emotional preference degree of the experimental group ($P1>0.05$). In the control group, the mean of that with emotional preference was higher than that without emotional preference ($P1<0.05$), as shown in Table 1.

Group	Category	N	M	SD	P
Experimental group	With behavioral preference	19	7.01	1.79	>0.05
	Without behavioral preference		6.91	1.76	
Control group	With behavioral preference	20	6.54	3.54	<0.05
	Without behavioral preference		6.11	3.32	

Table 1 Comparison of emotional preference of experimental group and control group

Experiment 2: Experiment of the influence of color stress on the design effect

Experimental Design

In experiment 2, green, blue and gray with strong sense of science and technology were selected as the research objects in terms of reducing thermal conductivity coefficient, specific heat capacity and floor area ratio of buildings correspondingly to explore the influence of stress emotions generated by the subjects in the three color scenarios on the design effect of low-carbon buildings. The 2 (strong stress emotion / weak) *2 (strong influence / weak) two-factor between-subject completely random design was adopted.

Subjects and Materials

With the same subjects and materials as in Experiment 1, the green and blue concentration areas, as well as gray in the glass curtain wall of large area with strong sense of science and technology will be set to AOI region based on 6 low carbon building colors, a total of 72 pieces of stress materials in 12 groups, to ensure that the emotion stress of participants generated in different decoration colors significantly influences the effect of low carbon building design.

Experimental Process and Settings

Pre-experiment Stage: All subjects first filled in the demographic information including gender and age and the 40 subjects were randomly divided into experimental group and control group. Then, all the devices were calibrated on the ErgoLAB platform to ensure the error of 5 view points was within 20 pixels.

Experiment Stage: During the experiment, the subjects were required to independently recognize and read the green and blue concentration areas and the gray in the glass curtain wall with strong sense of science and technology for 3mins independently, and recorded their virtual eye movement parameters in real time and mapped the fixation points.

Post-experiment Stage: After the experiment, the director organized the subjects in control group for questionnaire and imported the data in experimental group and control group into EXCEL to obtain 40 data. Subsequently, SPSS 21 was used to analyze reliability of experimental data. The results showed that the values of $\alpha 1$ and $\alpha 2$ were 0.811 and 0.724 respectively, $0<\alpha 1<1$, $0<\alpha 2<1$, indicating that the data quality of experimental group and control group was reliable.

Analysis of Experimental Results

In this study, variance analysis was conducted on the influence of the stress emotion of the subjects on the design effect of low-carbon buildings, and descriptive statistical analysis and variance analysis were conducted on the influence between the two groups.

(1) Comparison of stress emotion between groups. The results showed that the scores of the subjects in the low-carbon building design effect were different (F=40, P2=0.094>0.05), indicating that there was no statistical difference in the low-carbon building design effect of the subjects in four groups, which was comparable.

(2) Comparison of design effect of low-carbon buildings. Table 2 shows that in the experimental group, the difference between the average score of the experiment with color influence and that of the experiment without color influence was not statistically significant (P2>0.05). In the control group, the average score with color influence was higher than that without color influence (P2<0.05).

Classification	Group	N	M	SD	P2
Experimental group	with influence	20	7.32	1.81	>0.05
	without influence		6.98	1.74	
Control group	with influence	20	6.62	4.02	<0.05
	without influence		6.14	3.76	

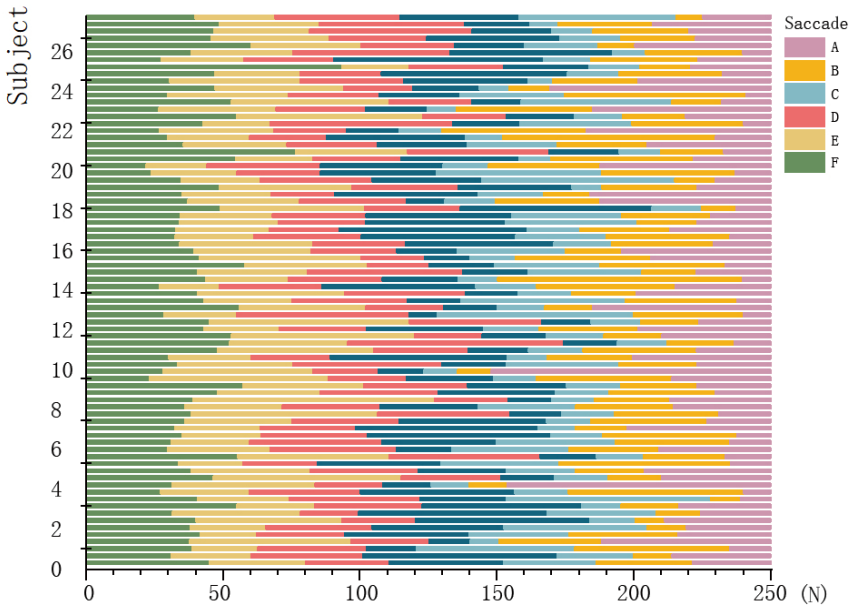
Table 2 Comparison of experimental results between experimental group and control group

Results

Tracked saccade trajectories are consistent with the low-carbon control parameter value preset

This study is to obtain the correlation between emotional preference of subjects in eye movement tracking experiment and green and low-carbon control parameters, and further explore the interaction between architectural design scheme and low-carbon design effect. The eye-movement fixation rate data of 19 subjects were obtained according to formula (1). Meanwhile, ErgoLAB platform was used for the visualized interactive processing of virtual eye-movement data of the subjects, and tracked eye-movement trajectory distribution was obtained, as shown in Figure 2.

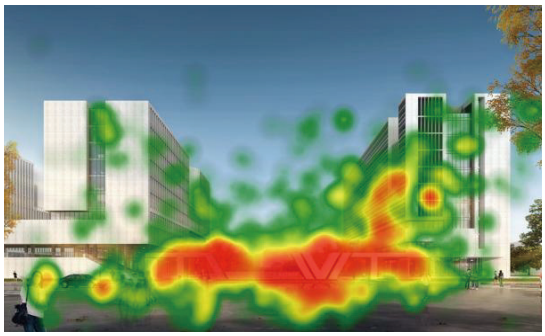
Figure 2 Tracked Saccade trajectory distribution in AOI region



According to the visualized results shown in Figure 2, among tracked saccade trajectories of the 19 subjects when seeing 6 groups of 120 pieces of stimulus materials in three minutes, schemes A and C have the largest number of total tracked saccades, which is 236 and 214 respectively; the total numbers of tracked saccades for schemes D, E and F are moderate, which are 205, 189 and 192 respectively; scheme B has the least saccades, which is 155. The experimental results found that the distribution characteristics of tracked saccade trajectories are highly consistent with the green energy-saving control parameters preset in the six design schemes, and these schemes are in the sequence of Scheme A > Scheme C > Scheme D > Scheme F > Scheme E> Scheme B according to the trends of tracked saccade trajectories from schemes A to F.

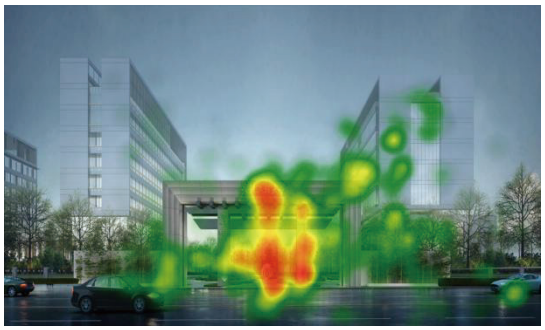
The emotional preference of stress color was consistent with the trend of fixation hot spots of subjects

In this study, three stress colors were selected to stimulate the change of emotional preference of the subjects. The experimental results showed that in the retention experiment, the three stress colors of the design scheme were the main effect causing the change of the fixation hot spots of the subjects, indicating an obvious orientation of eye-movement emotion. Figure 3 shows the distribution of the fixation hot spots by the subjects.

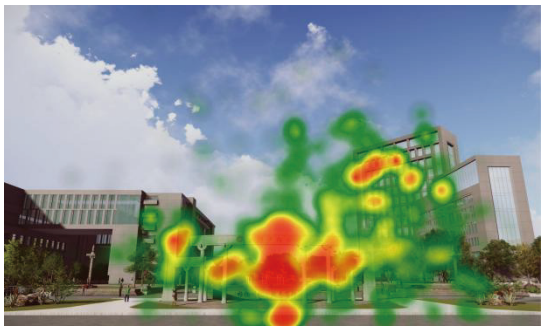


A. Change trend of fixation hot spots

B. Change trend of fixation hot spots

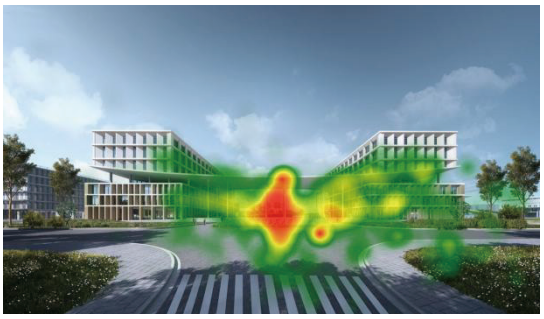


C. Change trend of fixation hot spots



D. Change trend of fixation hot spots

E. Change trend of fixation hot spots



F. Change trend of fixation hot spots

Figure 3 Change trend of eye-movement fixation hot spots in AOI region

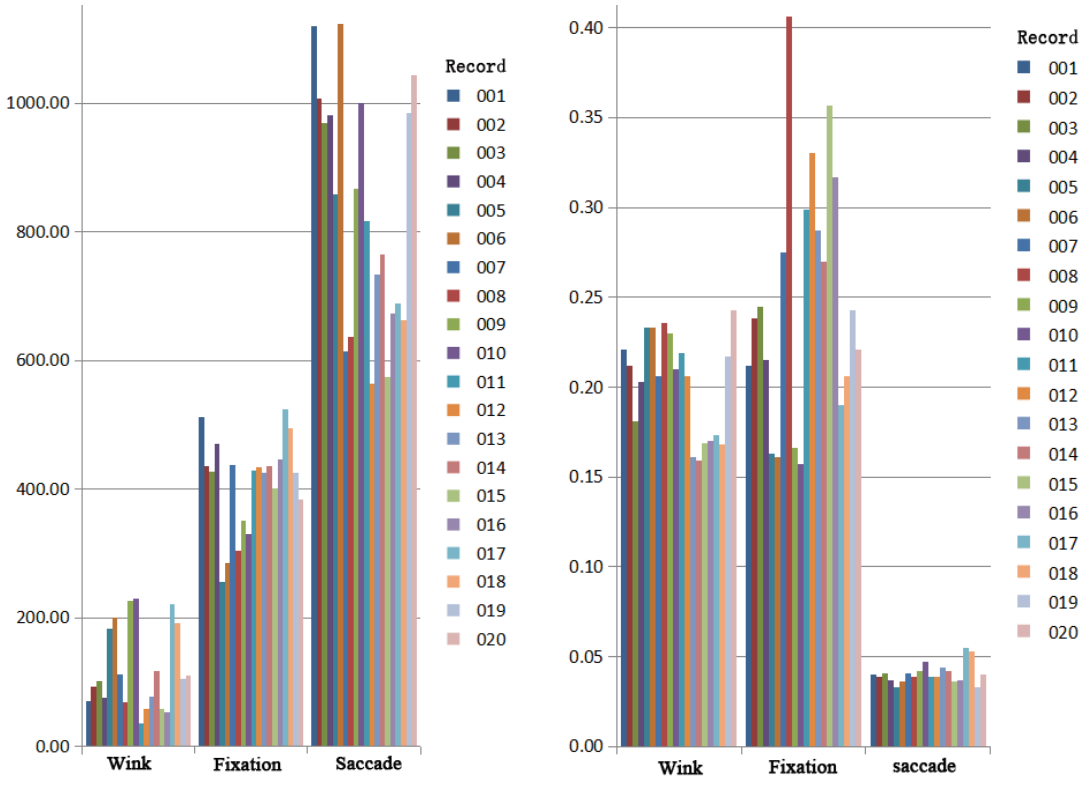
As shown in Figure. 3, through independent recognition and reading of the three stress colors in AOI region of the design scheme, it is shown that the eye movement emotions of the subjects have changed obviously, which is mainly reflected as follows: (1) In the experimental group and the control group, the fixation hot spots of the subjects mainly focused on the building schemes of green, blue and gray with strong sense of science and technology, and the distribution of fixation hot spots of different design schemes showed a trend of "high-medium-low". (2) According to formula (2), it was found that the fixation entropy of scheme A was the lowest, indicating that scheme A had the most fixations and the most intense emotional changes; In scheme C and D, fixation entropy was

low, indicating quite a number of fixations and mild emotional changes. The fixation entropy of scheme B, E and F was the highest, indicating the least fixations and insignificant emotional changes of the subjects.

The virtual eye-movement emotional feature experiment has a significant impact on low-carbon building design effect

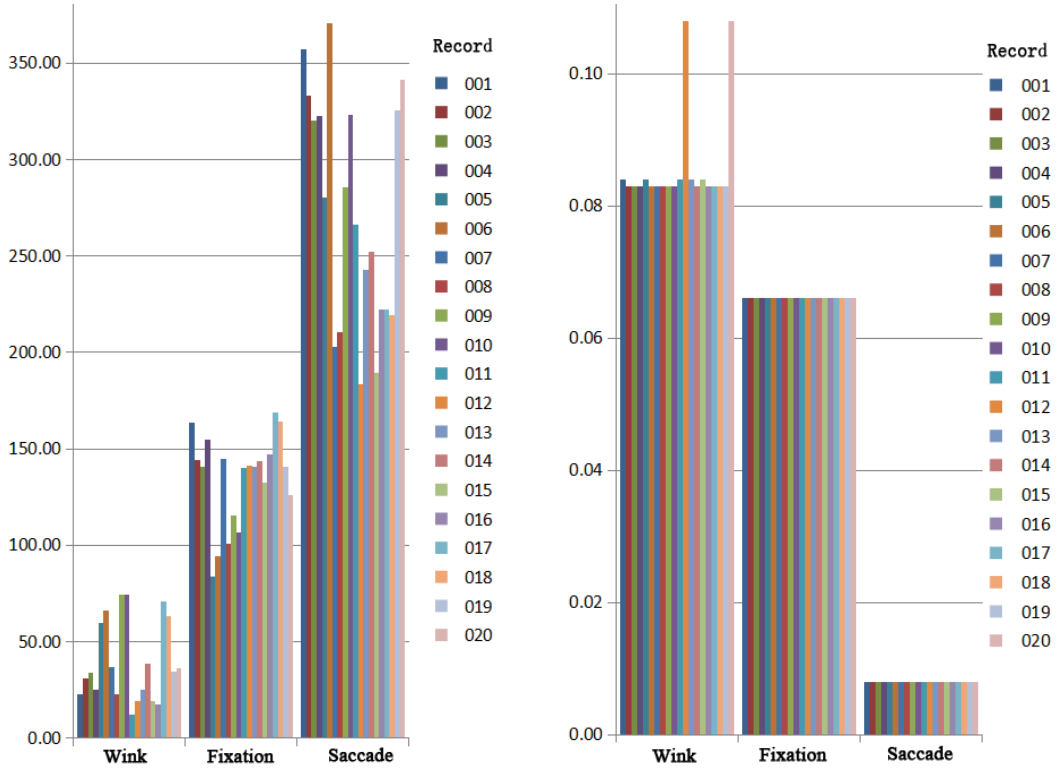
The design effect of low-carbon buildings can be analyzed and studied to verify the virtual eye-movement emotional features. In this paper, virtual eye movement experiment was conducted to verify whether the emotional preference of the subjects changed significantly. According to formula (2)-(3), the scores of the 6 groups of low-carbon building schemes before and after the experiment were not significantly different ($F=1.23$, $P=0.11>0.05$), indicating that the scheme had no statistical significance before and after the experiment and was comparable.

The evaluation of low-carbon building design scheme is closely related to the degree of eye movement emotional preference. Paired-sample T test showed that there was significant difference in eye movement emotional preference index among the 6 groups ($P<0.05$), but there was no significant difference in minimum fixation duration $F(1, 151)=9.20$ ($P>0.05$). In terms of fixation times, there were significant differences in blink times, fixation duration and saccades among the 6 groups ($P<0.05$), as shown in Figure 4.



A.Number of fixations (N)

B.Average fixation duration (S)



C. Frequency of fixations (N/min)

D.Minimum fixation duration (S)

(Source: The Groups A-D come from the statistical result of the subjects' degree of eye-tracking behavior)

Figure 4 The changes of eye movement emotional preference index

Figure. 4 shows that there were significant differences among the 6 design schemes in the eye movement emotional preference index, and the reasons are as follows: First of all, in the saccade tracking behavior of the subjects, the average fixation duration and frequency are 234 times and 149 times/min respectively, showing that the eye movement emotional preference of different low carbon building schemes is in proportion to the average fixation times and frequency. The higher the fixation times and frequency are, the higher the emotional preference of the subjects is.The higher the duration and fixation are, the higher the emotional preference of the subjects is. In Figureure B, the duration of blinking is inversely proportional to the maximum saccade time, indicating that under the influence of instructions, the subjects can clearly reflect the advantages and disadvantages of the carbon emission effect of the green schemes through the fixation time. The results of the study provide a new technical approach for the construction industry to develop more low-carbon design solutions and achieve the carbon emission peak action plan as soon as possible.

Conclusions and discussion

Virtual eye-movement emotional feature experiment enriched the evaluation method of low-carbon design effect. The experimental results show that with the implementation of the global carbon emission peak plan, the introduction of VR technology becomes an indispensable factor. This paper uses the eye movement emotional preference feature to conduct an experimental study on the low-carbon effect of architectural design, which is more objective than the effect of traditional expert review and questionnaire interview, and also enriches the technical means of implementing carbon emission plan in the construction industry. This is consistent with the feasibility assessment and research results of Bo (2019) & Dong (2018) on the implementation of carbon emission peak program in China's construction industry. Although the evaluation of low-carbon effect of architectural design not only includes concentrated areas of green and blue, as well as gray in the glass curtain wall with strong sense of science and technology, the above three colors are typical representatives of low carbon emission and play a boosting role in quantitative and qualitative research of green and low carbon. This is consistent with the research results of Kim (2019), Ammann (2020) & Latini (2021) using VR technology for visualized analysis of human and animal sensory recognition in the fields of environment, color and carbon emission. It is confirmed that the research on the influence of color stress emotion and color change on people's comfort has been applied to reduce the carbon emission of indoor and outdoor environment, which is of reference significance for verifying the low-carbon effect of building design observed from virtual eye movement emotional features in this paper.

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