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"In-Between Area" Design Method: An Optimization Design Method for Indoor Public Spaces for Elderly Facilities Evaluated by STAI, HRV and EEG

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Abstract: The indoor public spaces of most elderly facilities in China have a monotonous space form, which, thus, causes low comprehensive performance and is less likely to satisfy participants' various requirements. This study proposes an optimization design method of "In-Between Area" for a space form operation to improve the performance of indoor public spaces. First, two models were established: Model A to reflect current indoor public spaces and Model B to represent the indoor public spaces designed by using the "In-Between Area" method. Second, a walk-through video was created from each model, with a duration of 196 s. Subjective assessment (STAI) data and objective physiological data (HRV and EEG), were collected from 40 participants while they were watching walk-through videos. The comparison analysis showed statistically significant differences between Model A and Model B. The results of STAI, HRV and EEG proved that the "In-Between Area" method, as an optimization design method, created a more pleasant and comfortable environment for the elderly and improved the overall efficiency of the indoor space.

Keywords: elderly facility; in-between area; EEG; HRV; STAI; architectural scheme design

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1. Introduction

People's daily life is inseparable from the built environment [1] and the quality of the built environment profoundly affects people's living experience [2,3]. Space is one of the most critical elements in the built environment and also the only carrier of other built environment elements [4]. Therefore, space plays a special and critical role in the built environment. As an important topic of space design, the discussion of form has always been carried out, because it not only stipulates the basic physical form of the space [5], but also decisively affects the performance of all aspects of the space.

At present, the indoor public activity space design of most elderly facilities in China has significant disadvantages and cannot fully meet the needs of various participants [6]. The participants of the elderly facilities were mainly composed of the elderly and their children who come to visit, as well as various staff. Among them, the elderly need to be particularly considered in designing the interior space, because they spend most of their time in interior space [7], conducting their social, leisure and sports activities in the indoor public spaces of these elderly facilities [8]. Therefore, good indoor public space design is critical to their positive experience, such as comfort, health and happiness [9], and the success of elderly facilities design [10]. However, the indoor public spaces of most elderly facilities in China are short of transitional connection with other spaces due to the lack of effective design-method guidance. Hence, a single, rigid, oppressive and dull spatial form is generated, which results in overall performance deterioration, as shown in Figure 1.

Figure 1. Status of indoor public activity space in elderly facilities.

Some effective design methods were proposed by enriching indoor public spaces, including promoting the functional carrying capacity and visual pleasure. Hertzberger believed that the semi-public and semi-private space environments were more interesting and more likely to stimulate the occurrence of behavioral events [11]. Newman mentioned that it was vital to create a buffer area between residential and urban streets, which could improve the comfort and vitality of urban public spaces [12]. Zhou proposed to set up a certain number of open spaces along the corridors of elderly facilities, which was conducive to improving the willingness of the elderly to communicate [13]. These researchers advocated the idea that "gray" spaces with ambiguous attributes need to be established in designing space form. Inspired by these works, this study proposes an "In-Between Area" design method to improve the current low performance of indoor public spaces in most Chinese elderly facilities.

At the heart of the "In-Between Area" design approach is the idea to enhance the user's sense of control over the space and increase their participation. The boundary of the corridor space is richly processed and some leisure and entertainment areas of different sizes are set up, so that the elderly walking around them can feel the interesting and rhythmic spatial changes. These areas provide more choices for the elderly, thereby enhancing the possibility and flexibility of corridor spaces for interaction and increasing the user participation. What deserves special attention is the entry space, which can be flexibly arranged according to the user's own preferences and mood and strengthen the user's sense of control over the space. At the same time, this area is good in terms of sight and interaction and the most relaxing and casual social environment.

Due to the fact that the method is experience based, its effectiveness was tested using subjective and objective evaluation methods for space performance. A large number of studies used subjective voting methods to evaluate the comprehensive performance of various living spaces [14,15]. However, studies solely based on subjective methods are limited by the ambiguity of the methods, for they lack a complete, systematic and reliable evaluation standard [16]. To overcome the limitation imposed by subjective methods, some other studies employed objective methods. Studies have shown that emotional changes are usually produced under the stimulation of the external environment, accompanied by physiological and psychological reactions [17,18]. In terms of heart rate variability (HRV), the variation in heartbeats is suppressed when subjects are anxious and depressed and returns to normal in a relaxed state [19,20]. As an important test method, Electroencephalography (EEG) can reflect the cognitive state of subjects comprehensively [21,22]. Maryam et al. used EEG to study the influence of interior morphology on emotions [23]. Parastou et al. used

EEG to observe the emotional changes in people facing different building facades [24]. Li et al. explored the correlation between subjective questionnaires and EEG and established a method to use EEG to characterize people's feedback on building space [25,26]. Using physiological indicators can well measure the physiological changes in users in different spatial environments. At the same time, the scientificity of the subjective architectural design can be verified using physiological indicators, which are more objective and authentic and can better clear up the ambiguity caused by subjective evaluation. Subjective evaluation facilitates qualitative analysis, while objective evaluation can achieve quantitative analysis of emotions. Therefore, the combination of subjective and objective evaluation can be used to better evaluate the architectural space design scheme.

Aiming at the low performance and its causes of indoor public space in most Chinese elderly facilities, this study proposed an optimal design method, "In-Between Area", in terms of spatial form operation. The subjective and objective evaluation method was used to verify the effectiveness of the method, as well as to try and achieve two research goals and value significance. One is to propose a design method that can effectively improve the performance of space and provide assistance for improving the indoor public space of Chinese elderly facilities. The other is to provide a set of feasible evaluation methods for spatial performance under the influence of space form differences. We also aimed to explore the scientific evaluation theory of subjective design in order to promote the development of the research field of built environment evaluation.

2. Materials and Methods

2.1. Laboratory Environment

The experiment was carried out in an artificial climate chamber (5.10 m × 3.50 m × 2.80 m), as shown in Figure 2, at Qingdao University of Technology. The chamber was equipped with a constant temperature and humidity air conditioning system.

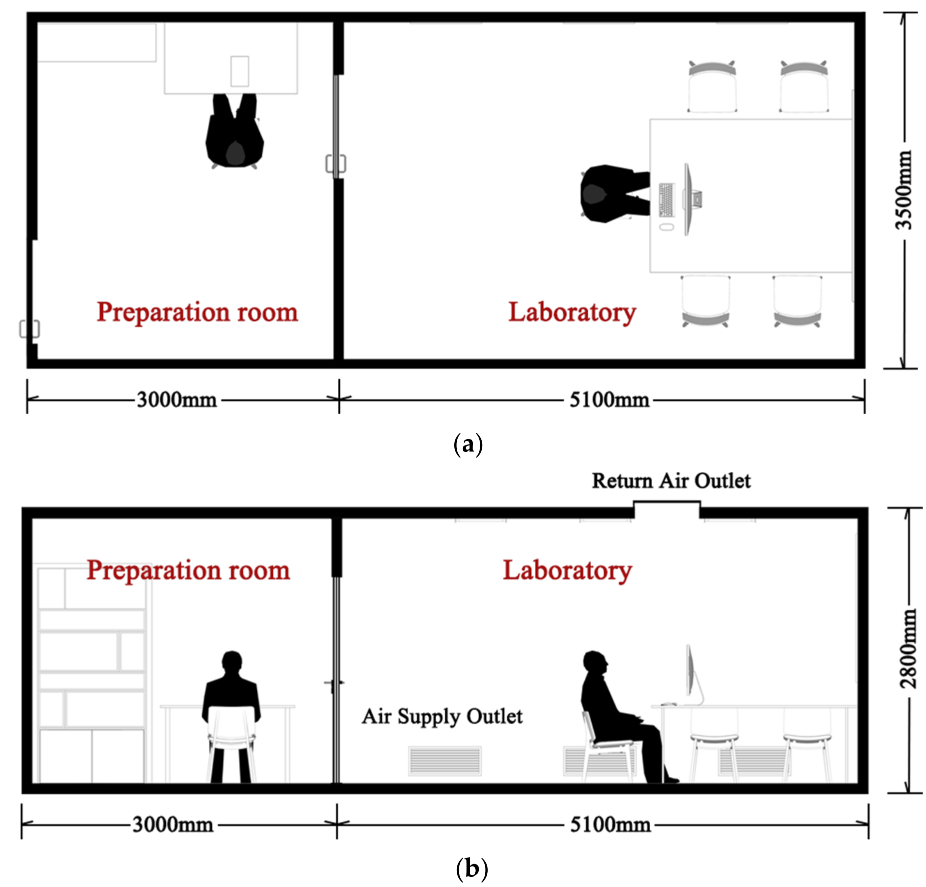


Figure 2. (**a**) Layout of artificial climate chamber; (**b**) section of artificial climate chamber.

Previous studies have shown that environmental factors, such as indoor light environment [27,28], temperature [29], air quality and ventilation rate [30], are important, because they affect the environmental quality of building spaces. The air temperature, relative humidity, horizontal illuminance on a work plane, color temperature and sound pressure levels were controlled in order to reduce the influence of physical environment (Table 1).

Table 1. Physical environment parameter settings.

Parameter	Range
Air temperature/°C	24 ± 0.5
Relative Humidity/%	60 ± 5
Wind Speed/m·s^{-1}	<0.2
Illuminance/lux	500 ± 50
Color Temperature/K	4000 ± 100
Sound pressure level/dB	<40

2.2. Participants

G*power (Version 3.1, Düsseldorf, Germany) [31] was used to calculate the sample size required for the study, the effect size was set to 0.5 and α was set to 0.05. The calculation results showed that to achieve a statistical power of 0.8, the study required a total of 34 subjects. Different age groups have different needs for living space [32], so we recruited the participants for this experiment that were young, middle aged and elderly. Forty participants were recruited from volunteers: the elderly, their families and staff of pension institutions. The participants included 22 men and 18 women (21 young people, 9 middle aged and 10 elderly). Due to the greater impact of COVID-19 on the elderly, it is more difficult to organize the elderly to participate in the experiment and, thus, the numbers of participants in the three groups were adjusted. All participants were informed of the aim of the study, experiment procedure and confidentiality issues before the experiment began. The participants were all physically and mentally healthy. Smoking and alcohol consumption were prohibited for 48 h before the experiment. Table 2 presents the demographic information of 40 participants.

Table 2. Participants' demographic information.

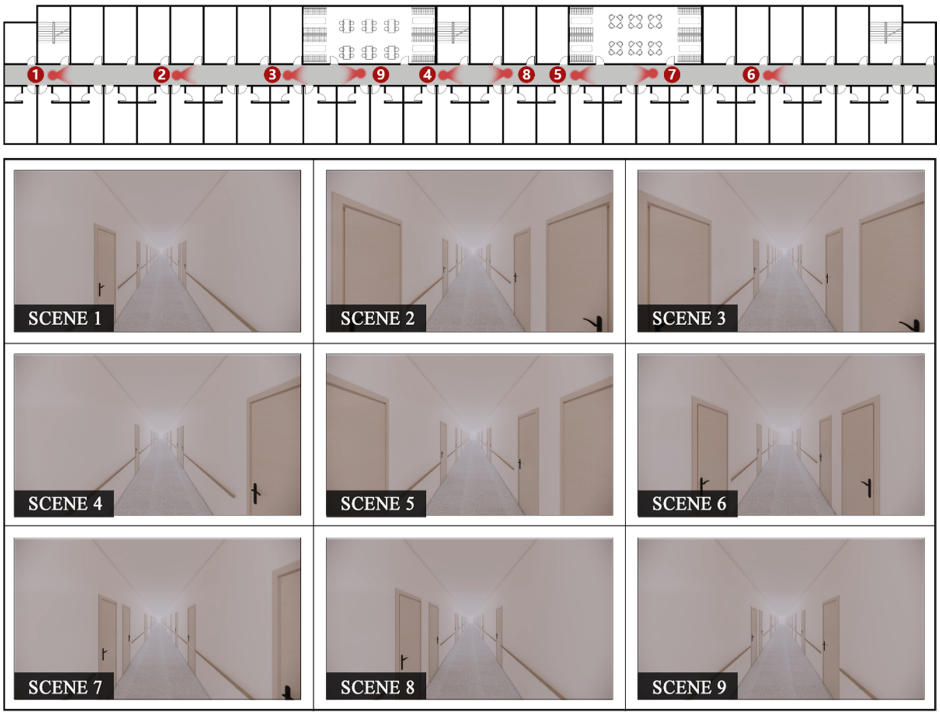
	Number (Male/Female)	Maximum Age	Minimum Age	Average Age	Standard Deviation
Young people	21 (15/6)	26	20	22.51	1.64
Middle age	9 (7/2)	37	30	33.84	2.61
Elderly	10 (5/5)	80	59	66.52	5.63
Total	40 (27/13)	-	-	36.06	18.45

2.3. Experimental Design

Three-dimensional software makes it possible to do near-reality modeling and visualize changing and complex environments [33]. In this study, Google SketchUp (Version 2020, Trimble, Sunnyvale, CA, USA) [34] was used to set up the experimental scene and Enscape (Version 3.1, Enscape GmbH, Karlsruhe, Germany) [35] was used to render the video as the emotion-evoking environment.

First, a survey was conducted in elderly facilities located in the urban area of Qingdao. There was a total of 265 elderly facilities registered in Qingdao in 2022, among which 141 facilities were in the urban area. The survey was carried out on the spatial environment and spatial form of these 141 elderly facilities. To a large extent, the data collected about these urban elderly facilities of Qingdao can presumably represent the situation of elderly facilities in the city. The survey results show that "Inner corridor" and "Stub-end type" are the main modes of corridor space in these facilities. In addition, typical spatial patterns, floor plans, colors, interior materials and appearance of facilities are also summarized.

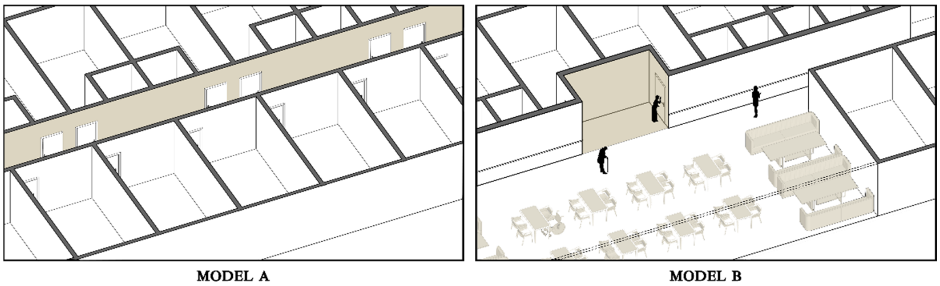
Based on this prior investigation, Model A was designed. The time of video A was set to 196 s, considering the duration of the experiment and subjective fatigue [26]. Since the normal walking speed of adults is around 1.1 m/s, the corridor length of Model A was determined as 112 m. The corridor of Model A was designed as two long and straight parallel lines. There was no buffer area between the elderly living room and the corridor, and the activity spaces for dining or games were closed independent rooms along the corridor. Figure 3a shows the layout and nine interior perspectives for Model A.



(**a**)

(**b**)

Figure 3. *Cont.*



(**c**)

Figure 3. (**a**) Model A of a corridor without centralized activity spaces; (**b**) Model B of a corridor with centralized activity space; (**c**) axonometric drawing comparisons between Models A and B.

Compared to Model A, Model B was optimized in the following way: (1) reducing bedroom spaces and expanding the corridor space to create common spaces in the corridor and (2) eliminating the walls of the dining rooms and game rooms to create common spaces in the corridor. The increase in the accessibility of space leads to a higher level of living for all [36]. Apart from the two points, Model B and Model A were identical. Figure 3b shows the layout and nine interior perspectives for Model B. Video A and video B entailed a round trip of a walking experience in the two models.

2.4. Measures

2.4.1. Survey Questionnaire

Many systematic and in-depth studies are carried out on the issue that the space environment of elderly facilities affects the physical and mental health of the elderly. The results of the study show that lack of personal privacy in indoor public spaces makes the elderly feel that they are losing control over the personal field, which may lead to negative emotions of anxiety and stress [37]. The State–Trait Anxiety Inventory (STAI), developed by Spielberger et al., is a commonly used measure of trait and state anxiety and can provide a more reliable psychological state test for clinical practice [38,39]. Therefore, this study selected the State–Trait Anxiety Inventory (STAI) to explore the effects of different spatial forms on the emotions of the elderly.

The scale is self-rating and consists of 40 descriptive items divided into two subscales. Among them, items 1–20 are the State Anxiety Inventory (S-AI) to measure short-term unpleasant emotional experiences such as tension, fear and worry. Items 21–40 are the Trait Anxiety Inventory (T-AI) to describe underlying and long-term anxiety tendencies. For more details, please refer to Appendix A.

The scales vary from 1 to 4 and the subjects were required to choose the most appropriate grade according to their feelings. The scores of S-AI and T-AI were obtained by adding up all the relevant questions, respectively. Table 3 presents the STAI scores.

Table 3. Scores for STAI.

Question Number	Not at All or Almost Never	Somewhat or Sometimes	Moderately So or Often	Very Much So or Almost Always
3, 4, 6, 7, 9, 12, 13, 14, 17, 18, 22, 25, 28, 29, 31, 32, 35, 37, 38, 40	1	2	3	4
1, 2, 5, 8, 10, 11, 15, 16, 19, 20, 21, 23, 24, 26, 27, 30, 33, 34, 36, 39	4	3	2	1

2.4.2. Heart Rate Variability

Heart rate variability (HRV) refers to the variation in heartbeat cycle differences and is an important indicator to reflect the activity of the autonomic nervous system and the balance of sympathetic and parasympathetic nerves [40]. HRV is more suitable for characterizing the health, resilience and stress resistance of a human body in a resting state [41]. Generally speaking, a low HRV value indicates that a human being is under stress from exercise, psychological events or other stressors, while a high HRV value indicates that a human being has a strong ability to tolerate stress or a human being is in the process of stress recovery. In a resting state, a high HRV value is generally favorable, compared to a low HRV value. The main analysis methods of HRV include time-domain analysis and frequency domain analysis [42]. Time-domain analysis is more intuitive, while frequency-domain analysis is more comprehensive. In terms of analysis time, there are two main types of HRV analysis in clinical medicine: short-range analysis (5 min) and long-range analysis (24 h). The short-range analysis method has a short recording time and the experimental conditions are easy to control. The commonly used parameters and characteristics are shown in Table 4. It should be noted that HRV is referred to as SDNN in this paper, unless otherwise stated.

Table 4. Common parameters and characteristics of HRV.

Parameter	Meaning	Domain	Characteristic
SDNN	Standard deviation of beat interval	Time Domain	The lower the value, the more active the sympathetic nerves, manifested as fatigue and tension. On the contrary, the more active the parasympathetic nerves, manifested as relaxation.
RMSSD	RMS of consecutive beat intervals	Time Domain	Decreases when fatigued and increases when recovering from fatigue.
LF/HF	The ratio of low frequency to high frequency	Frequency domain	Increases when fatigued and decreases when recovering from fatigue.

Polar® H10 chest strap heart rate sensor (Polar, Kempele, Finland) was used to monitor HRV and Polar® Unite (Polar, Kempele, Finland) for recording and storing data [43,44] (Figure 4). Before the experiment, the Polar® H10 and Polar® Unite were worn on the chest and left wrist separately with the sensors fitting snugly on the skin. The raw data stream was preprocessed with ARTiiFACT software (T. Kaufmann, Würzburg, Germany) [45,46] and the parameters, such as LF, HF, LF/HF, SDNN and RMSSN, were calculated using Kubios-HRV-Standard (Kubios Oy, Kuopio, Finland) [47,48].

(**a**) (**b**)

Figure 4. (**a**) Polar H10; (**b**) Polar Unite.

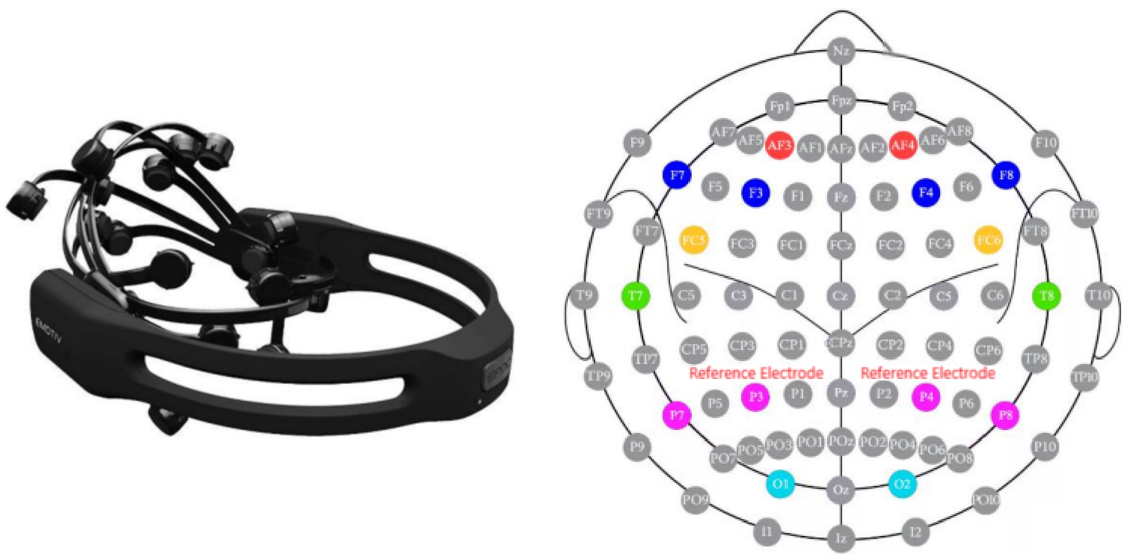
2.4.3. EEG Signals

Cognitive electrophysiology studies cognitive functions at the neuron population level, including perception, memory, emotion, language and behavior. EEG is an important part of cognitive electrophysiology which is a method of collecting and recording the activity in the cerebral cortex using sophisticated instruments [49,50]. The collected data are an overall reflection of nerve cells on the surface of the cerebral cortex or scalp.

Many neurological studies have shown that EEG rhythms are closely related to the working state of the brain [51]. In the process of excitation conduction, the "passive diffusion" and "active entry" of Na^+ and K^+ cause EEG to produce oscillations and the level of oscillation frequency is related to the state of the human body. Generally, EEG signals can be divided into 5 bands [52]. For adults, a range of 0.5–4 Hz is denoted as the Delta band, which is mainly related to deep sleep. A range of 4–8 Hz is denoted as Theta band, which is considered the transition between drowsiness and consciousness. A range of 8–13 Hz is denoted as the Alpha band, which is prominent in relaxed awareness but attenuates or disappears with concentration or attention. A range of 13–30 Hz is denoted as the Beta band, which is related to active thinking, attention and solving specific problems. A range of 30–50 Hz is denoted as the Gamma band, whose amplitude is often smaller than those of the other bands.

Higher temporal resolution and lower spatial resolution are two significant features in EEG [53]; therefore, the following considerations were taken in this study. First, the high temporal resolution allows us to monitor millisecond-level signals, which also increases the amount of data. Considering that the subjects were active for a long time, the excessive temporal resolution may cause data redundancy. Second, the low spatial resolution means that it is difficult to pinpoint exactly where the signal source is generated. Usually, the data collected by an electrode from the EEG is the sum of the voltages in the vicinity of the point and this experiment did not involve traceability.

Based on the above two considerations, Emotiv Epoc (Emotiv Systems, San Francisco, CA, USA) [54] was selected and the sampling rate was set to 256 Hz. The device had a total of 16 metal electrodes, corresponding to 16 standard points in the 10–20 system developed by the International Society of Electroencephalography. Among them, P3 and P4 are located at the mastoid as reference electrodes. Figure 5a is a physical view of the device and Figure 5b shows the relative positions of the 16 electrodes on the scalp.



(**a**) (**b**)

Figure 5. (**a**) Physical map of Emotiv Epoc; (**b**) channel location.

Before the test, the experimenter made sure that the equipment was fully charged and the sponge pad was immersed in physiological saline. The fully wetted pad acted as a physical bridge between the scalp and the metal electrodes to enhance the conductivity. Subjects were required to wash and blow their hair dry to avoid the effects of oil and skin keratin on conductivity. When the equipment was worn, the measuring points fully touched the scalp. The subject was required to sit still on the seat to minimize unnecessary activities. The test could be started only after the impedance was stable and met the requirements.

MATLAB® 2019b (MathWorks, Natick, MA, USA) and the EEGLAB plugin [54] were used to process the EEG data. Figure 6 shows the basic processing process. First, apparent spikes or oscillations outside the normal range of EEG signals were manually rejected, which were due to abnormal point contact or slight movement of the subject. Second, the AC working frequency caused the EEG spectrum sag at 50 Hz. For this reason, the 1–48 Hz signal was retained by bandpass filtering. Third, the EEG signals contained noises such as eye movement artifacts, ECG artifacts, EMG artifacts and skin artifacts. To identify and remove them, the independent component analysis function was used in the EEGLAB plugin. Finally, the time domain signal was converted to the frequency domain by Fast Fourier Transform (FFT), which well separated the Delta, Theta, Alpha and Beta bands. The total power of a band was the sum of the squares in the frequency-domain sequences of the band, as shown in Formula (1).

$$P_{total} = \sum_{n=i}^{j} \left| X_n^2 \right| \tag{1}$$

where P_{total} is the total power of EEG, i is the lower limit of frequency, j is the upper limit of frequency and X_n is frequency domain sequence.

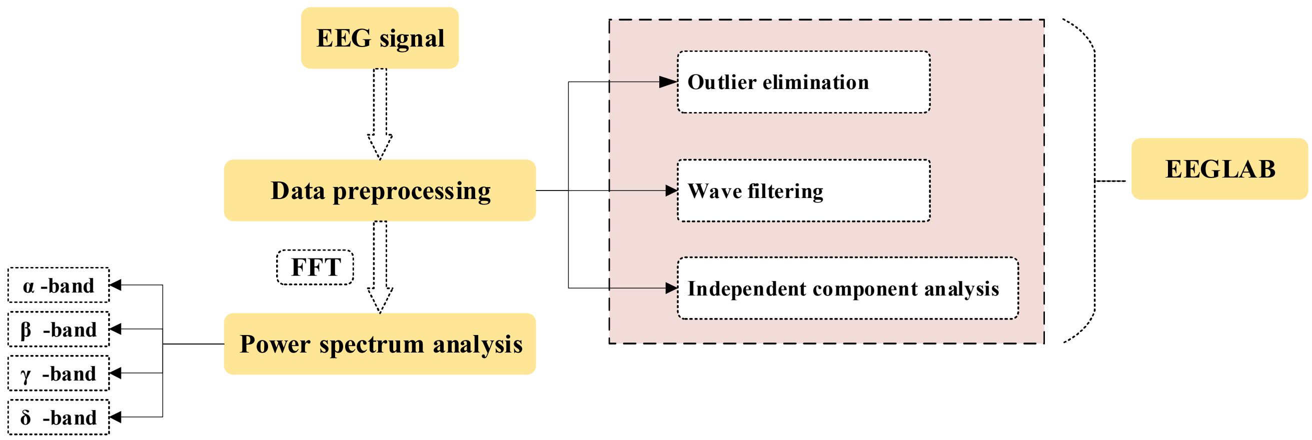


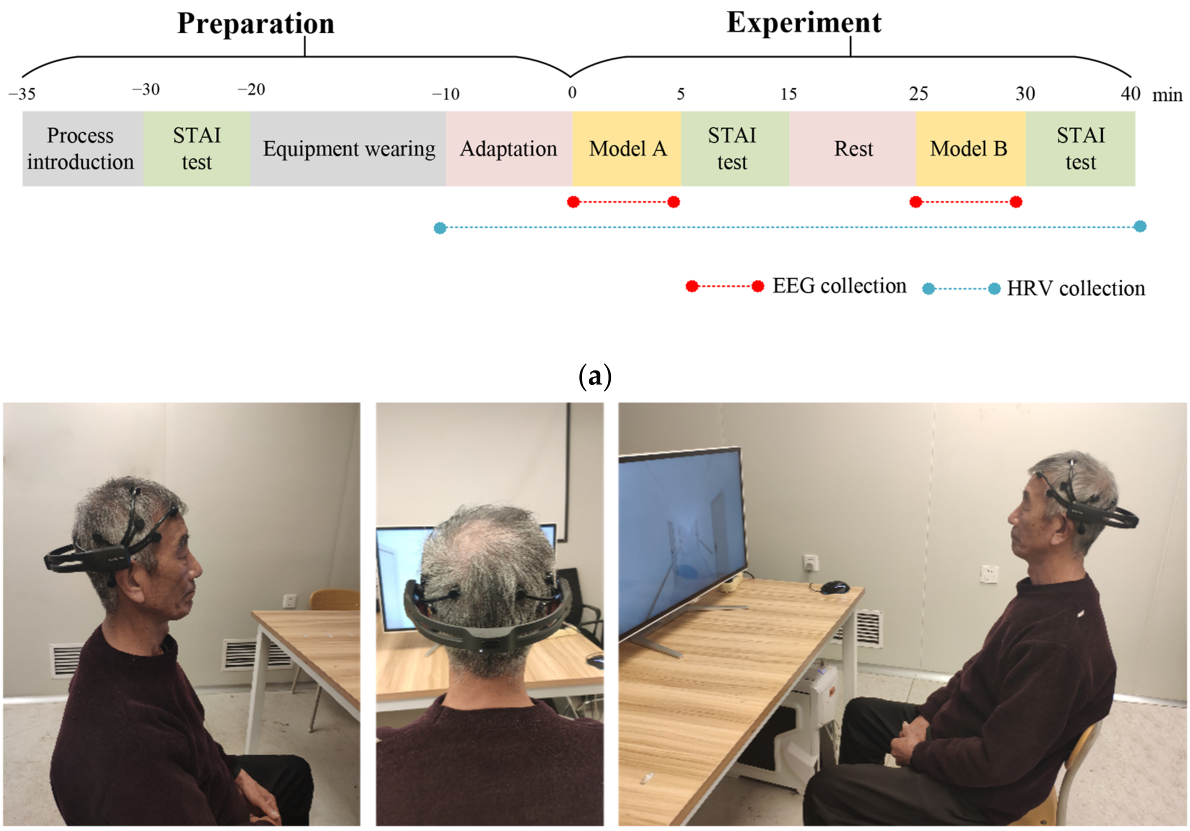
Figure 6. EEG data processing.

Based on Formula (1), the total EEG power of 14 channels for each subject was obtained. Due to the large magnitude of the value, Formula (2) was used for logarithmic processing.

$$P_{total}^{'} = log_{10}(P_{total}) \tag{2}$$

2.5. Experiment Procedure

Before the experiment, the basic situation was introduced to the participants in the preparation room. Then, the participants took the STAI test and wore the equipment with the assistance of staff. After the experiment began, the participants had 10 min to rest and adapt to the physical environment. They were required to successively take Model A test and STAI test, each for about 20 min. Model B test was the same as the Model A. The experiment totally took about 40 min. The experimental procedure is shown in Figure 7.



(**a**)

(**b**)

Figure 7. (**a**) Experimental procedure; (**b**) experimental photos.

3. Results

3.1. Subjective Evaluation

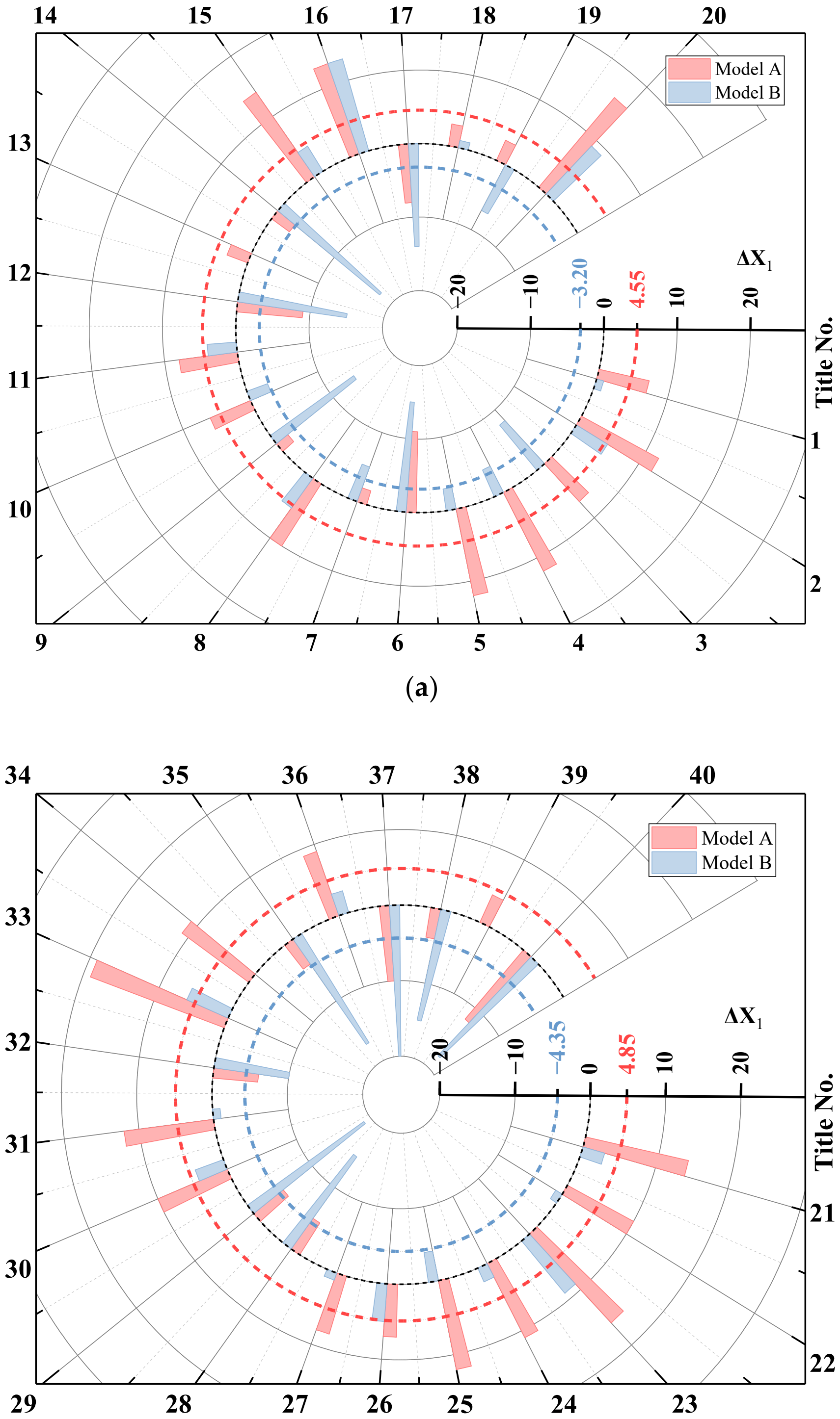
Each subject conducted two experiments, Model A and Model B. According to the scoring rules in Table 3, the STAI scores of 40 subjects in the preparation stage (pre-experiment) and the experimental stage (post-experiment) were calculated. Further, the post-experiment value minus the pre-experiment value is the outcome variable (Δx_1) for the paired samples *t*-test. A Kolmogorov–Smirnov test was performed using SPSS and the results showed that the data conformed to a normal distribution. The exploratory data analysis showed a group of outliers, which, thus, was eliminated, resulting in 39 groups of valid data. The results of the paired samples *t*-test show that there is a significant difference in Δx_1 between Model A and Model B, as shown in Table 5.

Table 5. STAI paired sample *t*-test results.

	T	*p*
S-AI	2.270	0.029 *
T-AI	3.530	0.001 **

Note: * means $p < 0.05$. ** means $p < 0.01$.

The comparison of S-AI and T-AI is shown in Figure 8a,b. The Δx_1 of Model A is positive, indicating that Model A with a single spatial form is likely to cause psychological pressure to participants. Because the activity space in Model A is almost a closed room, lacking the connection and interaction with other functional areas, which is less likely to stimulate the participant's communication behavior, the subjects tended to be more nervous and anxious in this kind of environment.



(**a**)

(**b**)

Figure 8. (**a**) Comparison of S-AI between Model A and Model B; (**b**) comparison of T-AI between Model A and Model B.

On the contrary, the Δx_1 of Model B is negative. It shows that the "In-Between Area" design relieved the visual fatigue, enriched the space form, improved the overall efficiency of the indoor public activity space and used the space in a more abundant and diverse way; the optimized design provided a more pleasant and comfortable environment for the elderly at the psychological level, which would be beneficial to physical and mental development and disease prevention in the elderly.

3.2. Heart Rate Variability

The post-experiment value minus the pre-experiment value is the outcome variable (Δx_2) and a paired samples *t*-test was performed on the heart rate, LF, HF, LF/HF, SDNN and RMSSD of Model A and Model B. The normal distribution test generated 39 groups of valid data and the results are shown in Table 6. The results are not statistically different in heart rate and RMSSD, but are in LF, LF/HF and SDNN.

Table 6. STAI paired samples *t*-test results.

	Heart Rate	HRV				
		LF	HF	LF/HF	SDNN	RMSSD
p	0.643	0.046 *	0.077	0.002 **	0.011 *	0.086

Note: * means $p < 0.05$. ** means $p < 0.01$.

The SDNN difference (Δx_2) between Model A and Model B is shown in Figure 9. It is not difficult to find that the SDNN mean value of Model A is lower than that of pre-experiment, while the SDNN mean value of Model B is slightly higher than that of pre-experiment. On the one hand, SDNN is an important indicator to measure the activity in the autonomic nervous system. Decreased SDNN is found in patients with anxiety, depression, insomnia, etc. On the other hand, SDNN reflects the ability to withstand stress and an increase in SDNN value indicates an increase in the complexity of HRV and an increase in the body's ability to adapt to environmental changes. This result indicates that the abundant space form in Model B creates a transitional space with dual properties: (1) the participant's sense of security is enhanced by strengthening control over the territory and (2) the penetration and interaction of the space improves the user's participation, which, in turn, enhances the participant's ability to adapt to the environment.

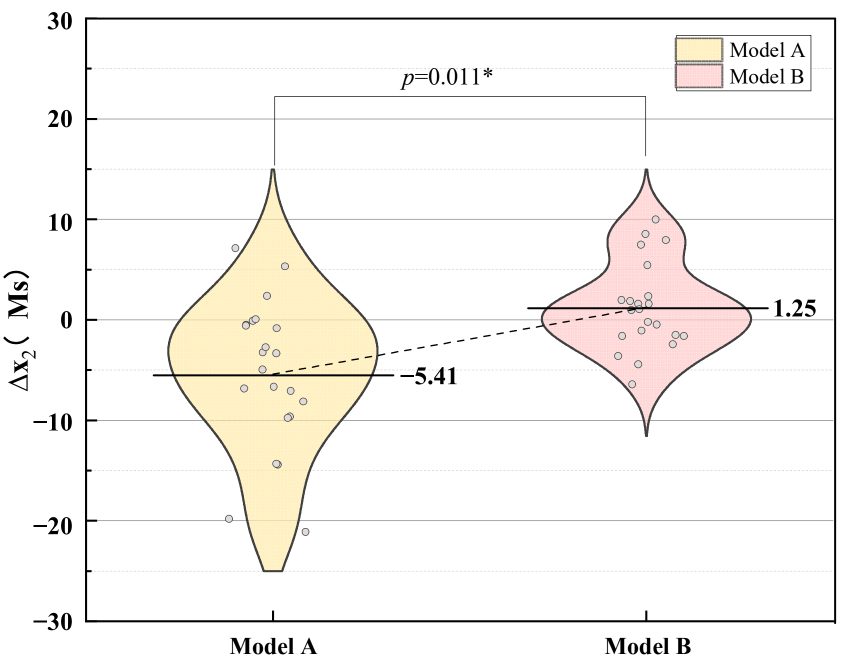


Figure 9. Comparison of Δx_2 between Model A and Model B.

3.3. EEG Signal

Emotiv Epoc provides 14 channels, corresponding to 14 points on the cerebral cortex distributed in different functional areas of the left and right brain. Power spectral density (PSD) is a measure of EEG energy per unit frequency and the PSD of a subject with typical characteristics is shown in Figure 10. The energy of the frontal lobe is higher than that of other regions and the high-frequency components are more distributed in the right brain, which is in line with Sperry's theory [55]. Further, maximum values of 2.0 Hz and 6.0 Hz in Model A are higher than in Model B, indicating that the energy of EEG in Model A is higher.

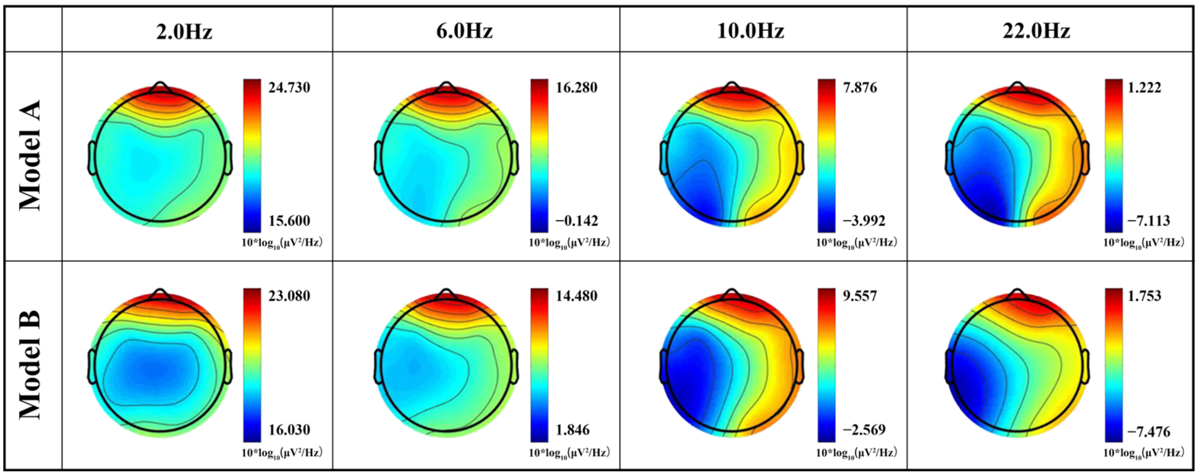


Figure 10. PSD of a subject between Model A and Model B.

Considering the functional division of the left and right brain is not precise enough while the mutual influence between functional areas is ubiquitous, the paired samples *t*-test was used to find the eigenvalues that can significantly distinguish the difference between Model A and Model B under 14 channels and four bands. The data generated by the Kolmogorov-Smirnov test conformed to a normal distribution. The exploratory data analysis showed three groups of outliers, which, thus, were eliminated, resulting in 37 groups of valid data. The results are shown in Table 7.

Table 7. Paired samples *t*-test results for EEG logarithmic power.

Channel	*p*-Value				
	Delta	Theta	Alpha	Beta	Total
AF3	0.069	0.064	0.308	0.379	0.004 **
AF4	0.393	0.371	0.962	0.704	0.030 *
F3	0.223	0.485	0.928	0.972	0.480
F4	0.120	0.105	0.349	0.111	0.081
F7	0.687	0.991	0.925	0.307	0.721
F8	0.391	0.674	0.623	0.443	0.629
FC5	0.243	0.375	0.529	0.735	0.323
FC6	0.956	0.474	0.979	0.099	0.505
T7	0.184	0.205	0.276	0.225	0.213
T8	0.482	0.132	0.457	0.032 *	0.141
P7	0.415	0.622	0.524	0.622	0.279
P8	0.676	0.340	0.891	0.091	0.392
O1	0.434	0.891	0.111	0.447	0.736
O2	0.466	0.548	0.573	0.731	0.683
Total	0.152	0.029 *	0.307	0.110	0.108

Note: * means $p < 0.05$. ** means $p < 0.01$.

Among them, AF3 and AF4 are located in the frontal lobe, which are the closest to the eyes among the 16 electrodes in Emotiv Epoc. Since the frontal lobe is mainly responsible for learning, language, decision-making, abstract thinking, emotions and other functions, we analyzed the logarithmic average power of AF3 and AF4, as shown in Figure 11.

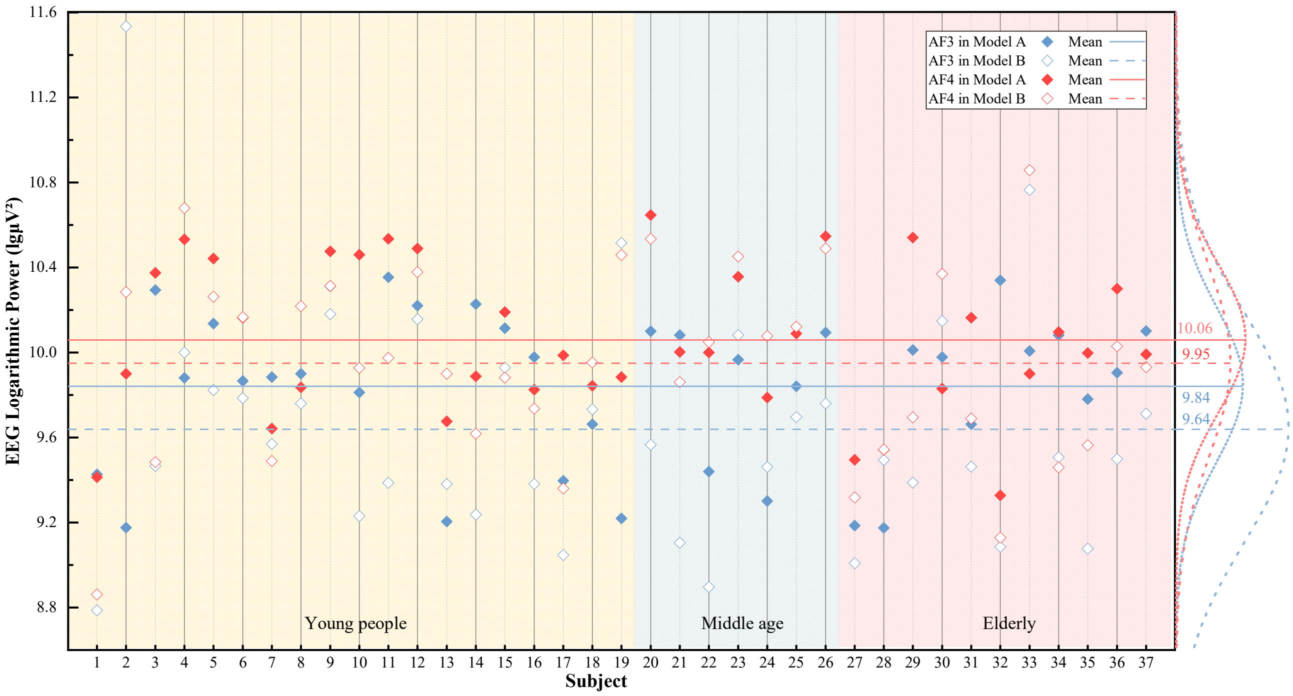


Figure 11. Comparison of AF4 logarithmic average power between Model A and Model B.

The logarithmic average power of Model B is lower than that of Model A: 28.8% in AF4 and 58.5% in AF3. Among the 37 subjects, 23 had this pattern, accounting for 62.2% (young people account for 63.2%, middle aged account for 42.9% and elderly account for 80%).

Low power means low neuronal activity, that is, weak intensity of EEG signal oscillations. Our findings showed that the total EEG power of subjects in an uncomfortable environment is higher than that in a comfortable environment, which is consistent with Guan et al. [56]. Compared to Model A, subjects were more relaxed and comfortable in Model B.

4. Discussion and Conclusions

This study proposes a design method for improving indoor public spaces in elderly facilities. Aiming at the disadvantages of corridor space in most elderly facilities in China, this study clarified the core reasons for the problem first and then proposed a design strategy. The psychological and physiological data of the participants were collected to obtain a more comprehensive and accurate evaluation. Based on the data analysis, the following conclusions were drawn:

(1) The STAI results show that the anxiety and psychological stress of the participants in Model A were higher than those of the pre-experiment, while those in Model B were lower. That indicates that Model B is better than Model A in terms of the psychological dimension.

(2) The HRV results show that the SDNN was statistically different in the two models. Autonomic nervous system was more active in Model B, which means that Model B improved the participants' ability to withstand the stress while adapting to the environment.

(3) The EEG results show that the EEG power of Model B is significantly lower than that of Model A. From a neurophysiological perspective, Model B consumes less energy and is more comfortable for participants.

In conclusion, the "In-Between Area" design method could enrich the spatial form and relieve the visual fatigue caused by separated monotonous spatial forms by enhancing the connection between activity spaces and other functional areas, as well as im-proving the overall efficiency of interior spaces. Moreover, this design method also strengthens user sense of control over the space and enhances user participation.

Since the impact of COVID-19 has dramatically increased the difficulty of organizing more participants for each age group, future research will increase the number of subjects to achieve comparative analysis between different populations. Compared with the actually built scene or the virtual reality (VR) scene, the video-based scene used in the current study lacked the immersion experience, which may cause insufficiency in the emotional arousal of the subjects. Therefore, future research may consider implementing VR to increase immersion.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the *Research Ethics Committee of Qingdao Innovation Center for CIM + Urban Regeneration* (protocol code 2022-08-10-01 and 10 August 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

HRV	Heart rate variability	LF	Low frequency
EEG	Electroencephalography	HF	High frequency
STAI	State–Trait anxiety inventory	LF/HF	The ratio of low frequency to high frequency
S-AI	State Anxiety Inventory	SDNN	Standard deviation of beat interval
T-AI	Trait Anxiety Inventory	RMSSD	RMS of consecutive beat intervals
EMG	Electromyography	VR	Virtual reality
FFT	Fast Fourier Transform	Δx_1	The post-experiment value minus the pre-experiment value of STAI
PSD	Power spectral density	Δx_2	The post-experiment value minus the pre-experiment value of SDNN

Appendix A

Table A1. (**a**) Self-evaluation questionnaire: STAI Form Y-1; (**b**) self-evaluation questionnaire: STAI Form Y-2.

(**a**)				
Self-Evaluation Questionnaire—Stai Form Y-1				
Please provide the following information:				
Name: Date: Age: Gender (*Circle*):M F				
Directions:				
A number of statements that people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel right now, that is, at this moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer that seems to describe your present feelings best.				
Meaning of options:				
1: Not At All; 2: Sometimes; 3: Moderately So; 4: Very Much So				
1. I feel calm	**1**	**2**	**3**	**4**
2. I feel secure	**1**	**2**	**3**	**4**
3. I am tense	**1**	**2**	**3**	**4**
4. I feel strained	**1**	**2**	**3**	**4**
5. I feel at ease	**1**	**2**	**3**	**4**
6. I feel upset	**1**	**2**	**3**	**4**
7. I am presently worrying over possible misfortunes	**1**	**2**	**3**	**4**
8. I feel satisfied	**1**	**2**	**3**	**4**
9. I feel frightened	**1**	**2**	**3**	**4**
10. I feel comfortable	**1**	**2**	**3**	**4**
11. I feel self-confident	**1**	**2**	**3**	**4**
12. I feel nervous	**1**	**2**	**3**	**4**
13. I am jittery	**1**	**2**	**3**	**4**
14. I feel indecisive	**1**	**2**	**3**	**4**
15. I am relaxed	**1**	**2**	**3**	**4**
16. I feel content	**1**	**2**	**3**	**4**
17. I am worried	**1**	**2**	**3**	**4**
18. I feel confused	**1**	**2**	**3**	**4**
19. I feel steady	**1**	**2**	**3**	**4**
20. I feel pleasant	**1**	**2**	**3**	**4**

Table A1. *Cont.*

(b)					
Self-Evaluation Questionnaire—Stai Form Y-2					
Please provide the following information:					
Name:	Date:	Age:	Gender (*Circle*):M F		
Directions:					
A number of statements that people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you *generally* feel.					
Meaning of options:					
1: Almost Never; 2: Sometimes; 3: Often; 4: Almost Always					
21. I feel pleasant		**1**	**2**	**3**	**4**
22. I feel nervous and restless		**1**	**2**	**3**	**4**
23. I feel satisfied with myself		**1**	**2**	**3**	**4**
24. I wish I could be as happy as others seem to be		**1**	**2**	**3**	**4**
25. I feel like a failure		**1**	**2**	**3**	**4**
26. I feel rested		**1**	**2**	**3**	**4**
27. I am "calm, cool, and collected"		**1**	**2**	**3**	**4**
28. I feel that difficulties are piling up so that I cannot overcome them		**1**	**2**	**3**	**4**
29. I worry too much over something that really doesn't matter		**1**	**2**	**3**	**4**
30. I am happy		**1**	**2**	**3**	**4**
31. I have disturbing thoughts		**1**	**2**	**3**	**4**
32. I lack self-confidence		**1**	**2**	**3**	**4**
33. I feel secure		**1**	**2**	**3**	**4**
34. I make decisions easily		**1**	**2**	**3**	**4**
35. I feel inadequate		**1**	**2**	**3**	**4**
36. I am content		**1**	**2**	**3**	**4**
37. Some unimportant thought runs through my mind and bothers me		**1**	**2**	**3**	**4**
38. I take disappointments so keenly that I can't put them out of my mind		**1**	**2**	**3**	**4**
39. I am a steady person		**1**	**2**	**3**	**4**
40. I get in a state of tension or turmoil as I think over my recent concerns and interests		**1**	**2**	**3**	**4**

References

1. Shan, X.; Yang, E.H.; Zhou, J.; Chang, V.W.C. Neural-signal electroencephalogram (EEG) methods to improve human-building interaction under different indoor air quality. *Energy Build.* **2019**, *197*, 188–195. [CrossRef]
2. Miao, Y.; Ding, Y. Indoor environmental quality in existing public buildings in China: Measurement results and retrofitting priorities. *Build. Environ.* **2020**, *185*, 107216. [CrossRef]
3. Alkabashi, B.H.A.; Dokmeci Yorukoglu, P.N. Evaluating Indoor Environmental Quality of a Wellness Center Through Objective, Subjective and Architectural Criteria. *Megaron* **2019**, *14*, 483–494. [CrossRef]
4. Lee, K. The Interior Experience of Architecture: An Emotional Connection between Space and the Body. *Buildings* **2022**, *12*, 326. [CrossRef]
5. Han, Y.J.; Kotnik, T. A Tomographic computation of Spatial Dynamics. In *Ecaade 2020: Anthropologic—Architecture and Fabrication in the Cognitive Age*; Werner, L.C., Koering, D., Eds.; Ecaade-Education & Research Computer Aided Architectural Design Europe; eCAADe: Berlin, Germany, 2020; Volume 2, pp. 89–94. Available online: https://www.webofscience.com/wos/alldb/full-record/WOS:000651200700009 (accessed on 5 August 2022).
6. Su, X.; Wang, S. Research on functional space of community-based medical-nursing combined facilities for the aged in small cities. *J. Asian Archit. Build. Eng.* **2022**, *21*, 1399–1410. [CrossRef]
7. Zhan, H.; Yu, J.; Yu, R. Assessment of older adults' acceptance of IEQ in nursing homes using both subjective and objective methods. *Build. Environ.* **2021**, *203*, 108063. [CrossRef]
8. Li, M.; Liu, Q.; Li, X. Research on the Influence of Environmental Art Design Based on Environmental Science on the Indoor Environment of Old-age Buildings. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *617*, 012053. [CrossRef]
9. Leung, M.Y.; Wang, C.; Famakin, I.O. Integrated model for indoor built environment and cognitive functional ability of older residents with dementia in care and attention homes. *Build. Environ.* **2021**, *195*, 107734. [CrossRef]
10. Wang, C.; Lu, W.; Ohno, R.; Gu, Z. Effect of Wall Texture on Perceptual Spaciousness of Indoor Space. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4177. [CrossRef]
11. Herman, H. *Lessons for Students in Architecture*; NAi010 Publishers: Rotterdam, The Netherlands, 2017.
12. Newman. *Defensible Space: Crime Prevention through Urban Design*; Macmillan: New York, NY, USA, 1972.
13. Zhou, Y.; Cheng, X. *Housing for the Elderly*; China Architecture & Building Press: Beijing, China, 2011.
14. Xu, H.; He, P.; Hsu, W.L.; Lee, Y.C.; Ho, C.Y. Establishment of Assessment Indexes for Intelligent Elderly Residential Space by Analytic Hierarchy Process. In Proceedings of the 2019 IEEE Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (IEEE Ecbios 2019), Okinawa, Japan, 31 May–3 June 2019; pp. 69–72. Available online: https://www.webofscience.com/wos/alldb/full-record/WOS:000539483300019 (accessed on 5 August 2022).
15. Song, Y.; Li, J.; Wang, J.; Hao, S.; Zhu, N.; Lin, Z. Multi-criteria approach to passive space design in buildings: Impact of courtyard spaces on public buildings in cold climates. *Build. Environ.* **2015**, *89*, 295–307. [CrossRef]
16. Li, J.; Lu, S.; Wang, Q. Graphical visualisation assist analysis of indoor environmental performance: Impact of atrium spaces on public buildings in cold climates. *Indoor Built Environ.* **2016**, *27*, 331–347. [CrossRef]
17. Ojha, V.K.; Griego, D.; Kuliga, S.; Bielik, M.; Buš, P.; Schaeben, C.; Treyer, L.; Standfest, M.; Schneider, S.; König, R.; et al. Machine learning approaches to understand the influence of urban environments on human's physiological response. *Inf. Sci.* **2019**, *474*, 154–169. [CrossRef]
18. Kong, Z.; Zhang, R.; Ni, J.; Ning, P.; Kong, X.; Wang, J. Towards an integration of visual comfort and lighting impression: A field study within higher educational buildings. *Build. Environ.* **2022**, *216*, 108989. [CrossRef]
19. Tarvainen, M.P.; Cornforth, D.J.; Jelinek, H.F. Principal Component Analysis of Heart Rate Variability Data in assessing Cardiac Autonomic Neuropathy. In Proceedings of the 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (Embc), Chicago, IL, USA, 26–30 August 2014; pp. 6667–6670. Available online: https://www.webofscience.com/wos/alldb/full-record/WOS:000350044706160 (accessed on 5 August 2022).
20. Alvarez-Gonzalez, M.; Vila, X.A.; Lado, M.J.; Mendez, A.J.; Rodriguez-Linares, L. Web Site on Heart Rate Variability: HRV-Site. In *Computing in Cardiology 2010*; Murray, A., Ed.; IEEE: New York, NY, USA, 2010; Volume 37, pp. 609–612. Available online: https://www.webofscience.com/wos/alldb/full-record/WOS:000328956000153 (accessed on 5 August 2022).
21. Shemesh, A.; Leisman, G.; Bar, M.; Grobman, Y.J. A neurocognitive study of the emotional impact of geometrical criteria of architectural space. *Archit. Sci. Rev.* **2021**, *64*, 394–407. [CrossRef]
22. Hu, L.; Shepley, M.M. Design Meets Neuroscience: A Preliminary Review of Design Research Using Neuroscience Tools. *J. Inter. Des.* **2022**, *47*, 31–50. [CrossRef]
23. Banaei, M.; Hatami, J.; Yazdanfar, A.; Gramann, K. Walking through architectural spaces: The impact of interior forms on human brain dynamics. *Front. Hum. Neurosci.* **2017**, *11*, 477. [CrossRef]
24. Rad, P.N.; Shahroudi, A.A.; Shabani, H.; Ajami, S.; Lashgari, R. Encoding pleasant and unpleasant expression of the architectural window shapes: An ERP study. *Front. Behav. Neurosci.* **2019**, *13*, 186. [CrossRef]
25. Li, J. Building environment information and human perceptual feedbackcollected through a combined virtual reality (VR) andelectroencephalogram (EEG) method. *Energy Build.* **2020**, *224*, 110259. [CrossRef]
26. Li, J.; Wu, W.; Jin, Y.; Zhao, R.; Bian, W. Research on environmental comfort and cognitive performance based on EEG plus VR plus LEC evaluation method in underground space. *Build. Environ.* **2021**, *198*, 107886. [CrossRef]

27. Hattar, S.; Liao, H.W.; Takao, M.; Berson, D.M.; Yau, K.W. Melanopsin-Containing Retinal Ganglion Cells: Architecture, Projections, and Intrinsic Photosensitivity. *Science* **2002**, *295*, 1065–1070. [CrossRef]
28. Kong, Z.; Jakubiec, J.A. Evaluations of long-term lighting qualities for computer labs in Singapore. *Build. Environ.* **2021**, *194*, 107689. [CrossRef]
29. Tao, Y.; Gou, Z.; Yu, Z.; Fu, J.; Chen, X. The challenge of creating age-friendly indoor environments in a high-density city: Case study of Hong Kong's care and attention homes. *J. Build. Eng.* **2020**, *30*, 101280. [CrossRef]
30. Hormigos-Jimenez, S.; Padilla-Marcos, M.Á.; Meiss, A.; Gonzalez-Lezcano, R.A.; Feijó-Muñoz, J. Assessment of the ventilation efficiency in the breathing zone during sleep through computational fluid dynamics techniques. *J. Build. Phys.* **2019**, *42*, 458–483. [CrossRef]
31. Faul, F.; Erdfelder, E.; Lang, A.G.; Buchner, A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* **2007**, *39*, 175–191. [CrossRef]
32. Katunsky, D.; Brausch, C.; Purcz, P.; Katunska, J.; Bullova, I. Requirements and opinions of three groups of people (aged under 35, between 35 and 50, and over 50 years) to create a living space suitable for different life situations. *Environ. Impact Assess. Rev.* **2020**, *83*, 106385. [CrossRef]
33. Barriuso, A.; De la Prieta, F.; Villarrubia González, G.; De La Iglesia, D.; Lozano, Á. MOVICLOUD: Agent-Based 3D Platform for the Labor Integration of Disabled People. *Appl. Sci.* **2018**, *8*, 337. [CrossRef]
34. Macris, V.; Weytjens, L.; Geyskens, K.; Knapen, M.; Verbeeck, G. Design Guidance for Low-Energy Dwellings in Early Design Phases Development of a simple design support tool in SketchUp. In *Ecaade 2012, Digital Physicality*; Ecaade-Education & Research Computer Aided Architectural Design Europe; Achten, H., Pavlicek, J., Hulin, J., Matejovska, D., Eds.; eCAADe: Brussels, Belgium, 2012; Volume 1, pp. 691–699. Available online: https://www.webofscience.com/wos/alldb/full-record/WOS:000330322400073 (accessed on 25 June 2022).
35. Dhanda, A.; Fai, S.; Graham, K.; Walczak, G. Leveraging Existing Heritage Documentation for Animations: Senate Virtual Tour. In *Icomos/Isprs International Scientific Committee on Heritage Documentation (Cipa) 26th International Cipa Symposium—Digital Workflows for Heritage Conservation*; Hayes, J., Ouimet, C., Quintero, M.S., Fai, S., Smith, L., Eds.; Copernicus Gesellschaft Mbh; Copernicus GmbH: Allegheny County, PA, USA, 2017; Volume XLII-2-W5, pp. 171–175. [CrossRef]
36. Alonso, F. The benefits of building barrier-free: A contingent valuation of accessibility as an attribute of housing. *Eur. J. Hous. Policy* **2002**, *2*, 25–44. [CrossRef]
37. Hou, K. *Space Evaluation and Optimal Desigin of Pension Facilities*; Southeast University Press: Nanjing, China, 2020.
38. Rossi, V.; Pourtois, G. Transient state-dependent fluctuations in anxiety measured using STAI, POMS, PANAS or VAS: A comparative review. *Anxiety Stress Coping* **2012**, *25*, 603–645. [CrossRef]
39. Knowles, K.A.; Olatunji, B.O. Specificity of trait anxiety in anxiety and depression: Meta-analysis of the State-Trait Anxiety Inventory. *Clin. Psychol. Rev.* **2020**, *82*, 101928. [CrossRef]
40. Zhu, J.; Ji, L.; Liu, C. Heart rate variability monitoring for emotion and disorders of emotion. *Physiol. Meas.* **2019**, *40*, 064004. [CrossRef]
41. Yang, Y.; Hu, L.; Zhang, R.; Zhu, X.; Wang, M. Investigation of students? short-term memory performance and thermal sensation with heart rate variability under different environments in summer. *Build. Environ.* **2021**, *195*, 107765. [CrossRef]
42. Salo, M.A.; Huikuri, H.V.; Seppanen, T. Ectopic Beats in Heart Rate Variability Analysis: Effects of Editing on Time and Frequency Domain Measures. *Ann. Noninvasive Electrocardiol.* **2001**, *6*, 5–17. [CrossRef] [PubMed]
43. Hinde, K.; White, G.; Armstrong, N. Wearable Devices Suitable for Monitoring Twenty Four Hour Heart Rate Variability in Military Populations. *Sensors* **2021**, *21*, 1061. [CrossRef]
44. Müller, A.M.; Wang, N.X.; Yao, J.; Tan, C.S.; Low, I.C.C.; Lim, N.; Tan, J.; Tan, A.; Müller-Riemenschneider, F. Heart Rate Measures from Wrist-Worn Activity Trackers in a Laboratory and Free-Living Setting: Validation Study. *JMIR mHealth uHealth* **2019**, *7*, e14120. [CrossRef]
45. Kaufmann, T.; Suetterlin, S.; Schulz, S.M.; Voegele, C. ARTiiFACT: A tool for heart rate artifact processing and heart rate variability analysis. *Behav. Res. Methods* **2011**, *43*, 1161–1170. [CrossRef]
46. Martino, P.F.; Miller, D.P.; Miller, J.R.; Allen, M.T.; Cook-Snyder, D.R.; Handy, J.D.; Servatius, R.J. Cardiorespiratory Response to Moderate Hypercapnia in Female College Students Expressing Behaviorally Inhibited Temperament. *Front. Neurosci.* **2020**, *14*, 588813. [CrossRef]
47. Lundell, R.V.; Tuominen, L.; Ojanen, T.; Parkkola, K.; Raisanen-Sokolowski, A. Diving Responses in Experienced Rebreather Divers: Short-Term Heart Rate Variability in Cold Water Diving. *Front. Physiol.* **2021**, *12*, 649319. [CrossRef] [PubMed]
48. Pino-Ortega, J.; Rico-Gonzalez, M.; Gantois, P.; Nakamura, F.Y. Level of agreement between sPRO and Kubios software in the analysis of R-R intervals obtained by a chest strap. *Proc. Inst. Mech. Eng. Part P J. Sports Eng. Technol.* **2021**, 17543371211031144. [CrossRef]
49. Azzazy, S.; Ghaffarianhoseini, A.; Ghaffarianhoseini, A.; Naismith, N.; Doborjeh, Z. A critical review on the impact of built environment on users' measured brain activity. *Arch. Sci. Rev.* **2021**, *64*, 319–335. [CrossRef]
50. Park, H.-R.; Lim, D.-Y.; Choi, E.-H.; Lee, K.-S. Analysis on the Domestic and International Illumination Research Trends in 2012 and Further Study Suggestion. *J. Korean Inst. Illum. Electr. Install. Eng.* **2013**, *27*, 28–37. [CrossRef]
51. Verma, G.K.; Tiwary, U.S. Multimodal fusion framework: A multiresolution approach for emotion classification and recognition from physiological signals. *Neuroimage* **2014**, *102*, 162–172. [CrossRef] [PubMed]

52. Stach, T.; Browarska, N.; Kawala-Janik, A. Initial Study on Using Emotiv EPOC+ Neuroheadset as a Control Device for Picture Script-Based Communicators. *IFAC-PapersOnLine* **2018**, *51*, 180–184. [CrossRef]
53. Ahn, M.; Ahn, S.; Hong, J.H.; Cho, H.; Kim, K.; Kim, B.S.; Chang, J.W.; Jun, S.C. Gamma band activity associated with BCI performance: Simultaneous MEG/EEG study. *Front. Hum. Neurosci.* **2013**, *7*, 848. [CrossRef]
54. Martínez-Cancino, R.; Delorme, A.; Truong, D.; Artoni, F.; Kreutz-Delgado, K.; Sivagnanam, S.; Yoshimoto, K.; Majumdar, A.; Makeig, S. The open EEGLAB portal Interface: High-Performance computing with EEGLAB. *Neuroimage* **2021**, *224*, 116778. [CrossRef]
55. Pearce, J.M.S. The "split brain" and Roger Wolcott Sperry (1913–1994). *Rev. Neurol.* **2019**, *175*, 217–220. [CrossRef] [PubMed]
56. Guan, H.; Hu, S.; Lu, M.; He, M.; Zhang, X.; Liu, G. Analysis of human electroencephalogram features in different indoor environments. *Build. Environ.* **2020**, *186*, 107328. [CrossRef]