博 士 論 文

Study on the influence of indoor environment on perceived comfort in elderly care buildings

高齢者介護施設における室内環境が知覚的な快適性に与える影響に関する研究

北九州市立大学国際環境工学研究科

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付 瑤

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Study on the influence of indoor environment on perceived comfort in elderly care buildings

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Preface

The paper takes a "human-centered" approach and aims to achieve "perceived comfort." It applies physiological sensing technology and eye tracking technology to the study of "perception-space" and quantifies the unobservable variable of "perceived comfort" through human factors technology. By analyzing the physiological indicators of different perceptual states obtained through measurements, and synchronously verifying the "representativeness" of the changes in various physiological indicators through subjective questionnaires, comfort states are determined, and corresponding spatial indicators and parameters are derived. Through experiments conducted in residential and restaurant spaces, one-way perceived comfort, room brightness under single functional behavior, spatial distance, appropriate sound pressure levels, comfortable temperature, humidity, and the use of warm and safe decorative materials are obtained as spatial indicators and features.

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ABSTRACT

The paper takes a "human-centered" approach and aims to achieve "perceived comfort." It applies physiological sensing technology and eye tracking technology to the study of "perception-environment" and quantifies the unobservable variable of "perceived comfort" through human factors technology. By analyzing the physiological indicators of different perceptual states obtained through measurements, and synchronously verifying the "representativeness" of the changes in various physiological indicators through subjective questionnaires, comfort states are determined, and corresponding spatial indicators and parameters are derived. Through experiments conducted in residential and restaurant spaces, one-way perceived comfort, room brightness under single functional behavior, spatial distance, appropriate sound pressure levels, comfortable temperature, humidity, and the use of warm and safe decorative materials are obtained as spatial indicators and features.

Chapter 1 Introduces the research background, research objectives, and significance of the paper.

Chapter 2 discussing the current research status in the world on elderly building environment under human factor experiments and the new technology of eye-tracking.

Chapter 3 Establishes a research model for the relationship between building environment and human perceptual experiences, focusing on methodology

Chapter 4 Focuses on visual comfort and investigates the brightness, spatial distance and color preferences of elderly residential spaces.

Chapter 5 Aims at auditory comfort and studies the spatial layout and form of living room in elderly buildings.

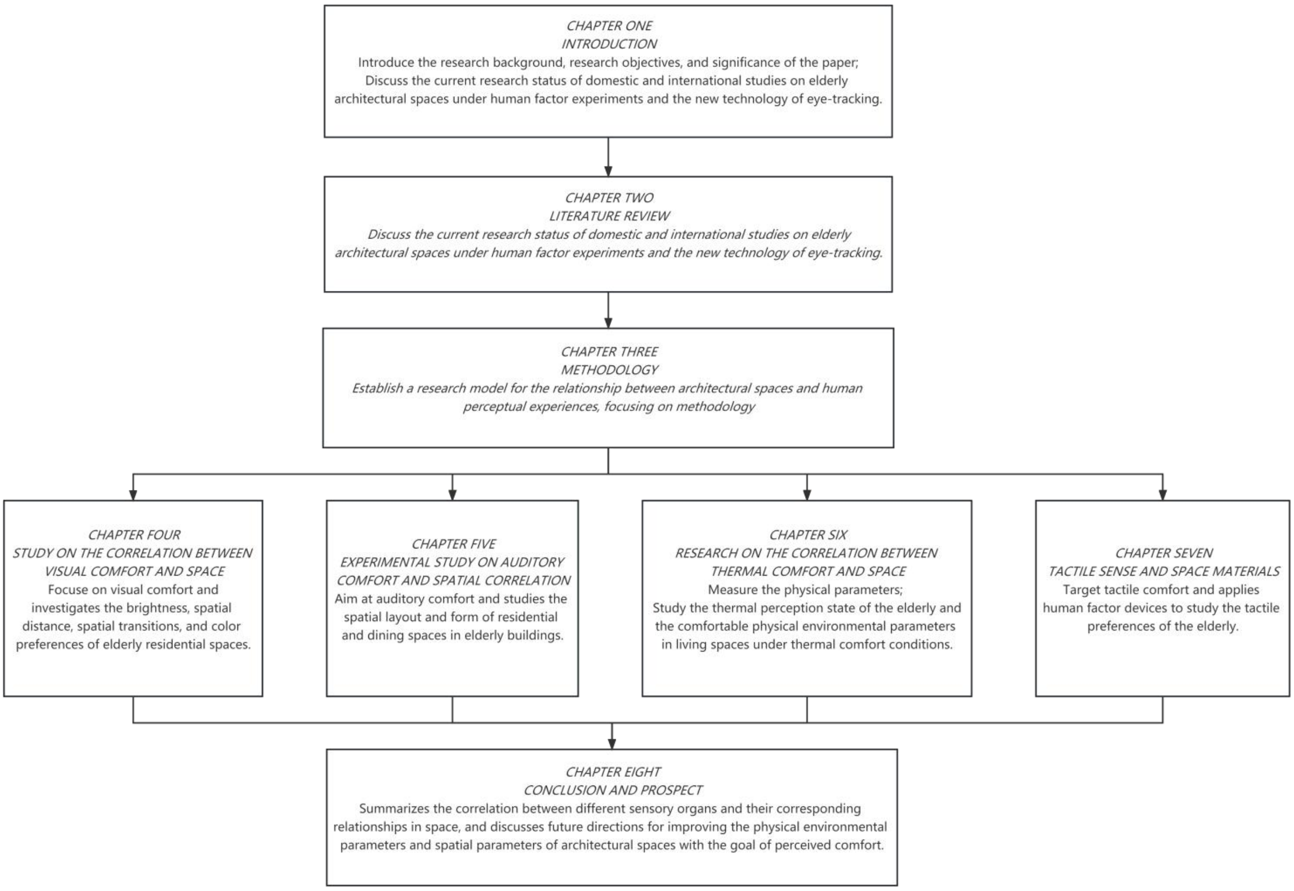
Chapter 6 Measures the physical parameters of temperature, humidity, and air velocity in living room, and simultaneously applies human factor devices to study the thermal perception state of the elderly and the comfortable physical environmental parameters in living room under thermal comfort conditions.

Chapter 7 Targets tactile comfort and applies human factor devices to study the tactile preferences of the elderly.

Chapter 8 Summarizes the correlation between different sensory organs and their corresponding relationships in space, and discusses future directions for improving the physical environmental parameters with the goal of perceived comfort.

付 瑶 博士論文の構成

Influence of indoor environment on the perceived comfort in the elderly care building



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Chapter 1

1. INTRODUCTION

CHAPTER ONE: INTRODUCTION

1.1 Research background

(1) The construction of Elderly friendly environment is urgently need

"Aging of Population" is a process in which the proportion of the elderly population increases due to the decrease of the young population and the increase of the old population in the total population. Population aging is an inevitable result of social development and continuous progress of science and technology. It means the decrease of human mortality and the extension of life cycle, which is the embodiment of the continuous progress of contemporary human civilization.

Internationally, if the population over 60 years old accounts for 10% of the total population, or the population over 65 years old accounts for 7% of the total population, the country or the region has entered the aging society.[1] Some countries which had entered elderly society on 70's of the last century such as France, Germany and Japan. Chinese population of above 60 elderly had exceeded 10% on 1992. The latest results of the seventh national census in 2020 show that China has ushered in a huge explosion of the elderly population. The number of people aged 65 and above has reached 191 million, accounting for 13.5% of the total population[2].By the year 2025, the elderly population will reach 300 million, accounting for 20.1% of the total population, and the aging problem will be more significant by then[3].

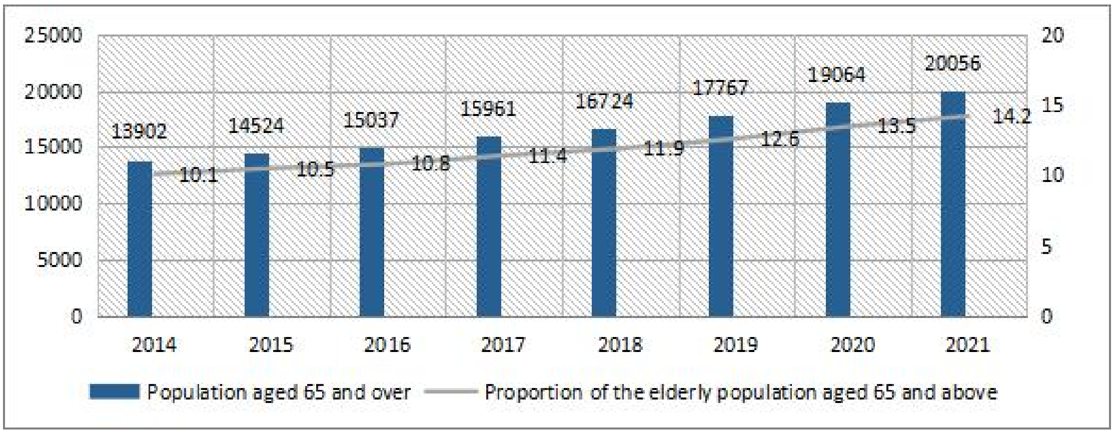

Fig. 1- 1The proportion of the elderly aged 65 years and over in the total population of China (Source: Author's own drawing based on National Bureau of Statistics data)

A series of problems caused by an increasing number of elderly population have arisen. How to deal with population aging has become a major problem facing the whole society in China[4], and how to design the friendly building for elderly by architects is urgently.

(2) Carry out the design index of friendly elderly environment is urgently need

Architecture was originally created to shelter people from wind and rain, so satisfying functional use is always the goal of space design. With the development of society and human civilization, the pursuit of architecture is more and more diversified and the goal is higher and higher. Architecture does not only need to meet the demand for use, but also need to create more emotional experience for human beings. At the same time, it should contribute to people's health, happiness and beauty. In the study of the relationship between human and space, theories such as environmental psychology, architectural behavior and POE were developed in combination with psychological research in the 1960s. In the 1970s, the indoor environmental quality problems caused by the extensive use of adhesives in interior decoration plywood began to attract attention. Then in 1982, “healthy building” was proposed in the Netherlands Healthy Building Conference. Since then, health and comfort have become the common concern of the world in the field of architecture.

Human perception in space is the basis of building design, and relevant content is the principle and common sense knowledge that must be mastered at the beginning of design. For example, what brightness is appropriate for specific room? What wall color is pleasant? What step height is appropriate for children and so on. The answers of these problems have become standards or specification through research, and then are applied. But different gender and age will have different requirements, so the design data set and design specification should be carried out especially for the elderly.

(3) How to research the characteristic of friendly elderly environment is urgently need

Traditional building design often uses subjective questionnaire survey, interview and other research methods to obtain cognition and evaluation of the environment. The subjective questionnaire is generally conducted after direct sensory stimulation through brain analysis, and brain cognition is related to personal experience, education level, behavior habits, character, etc. The elderly with low education level will be slow of understanding, so their cognitive results are less accurate. In many environmental evaluations that rely solely on sensation, such as the studies on brightness, color and space perception, this kind of unnatural subjective evaluations formed through brain cognition are often closely related to their own characteristics, so there is a gap between these evaluations and the actual environment. There are also problems in the reliability of the results of the spatial response because the elder’s body and brain function begin to decline. Therefore, traditional research methods such as questionnaire interview are often not suitable for the research of the elderly population in terms of the accuracy and efficiency of the results. At present, with the development of new research tools such as artificial intelligence and big data, more accurate and scientific tools and methods that can recognize the state of the person have been developed with the help of other disciplines in perceiving space.

1.2 Research purpose and significance

1.2.1 Research purpose

(1) Set up the research model of "human-enviroment"

To overcome the limitations of the traditional "enviroment-perception" paradigm, such as excessive subjective factors, low reliability and low validity, the perception is quantitatively measured under different spatial characteristics, and the research relationship between spatial characteristics and perceptual state is directly established. A new model of research on perceiving enviroment is proposed.

(3) Exploring the application of hunman fector in the enviroment

Human cause equipment has always been used in the field of psychology research, used for the study of human emotions, psychology, and other sensory perception. It is now gradually expanding into aerospace, automobiles, sports, and all other fields related to people. Now applied in the field of construction, through human equipment to obtain more scientific and quantitative indicators in the building and environment, and then get more accurate evaluation of the space, so as to carry out the design and optimization of more comfortable and reasonable architectural space or architectural environment design and optimization.

(3) Proposing the index of Aged friendly enviroment

Using the new technology, we correspond to the spatical characteristics when the people feel comfortable, and then put forward the space design index. According to different people's perception function level, the multilevel comfortable space index system is proposed to improve the basic information of building design data.

1.2.2 Research significance

(1) Updating the basic data of building design

Architectural spatial parameters and design indexes are important bases for architectural research. Space design index refers to the construction of space size, space form, space sound, light and heat environment, space structure details and other basic guiding parameters. People are users of building. Human behavior, physiological and psychological characteristics determine the size of space and other attributes. Accurate and reasonable design index is the fundamental guide to the health and comfort of users. With the development and changes of times, space types are changing. Variables related to people are also changing, and people's requirements for space experience are increasing. To study design indicators from the perspective of people's perceived comfort and then to propose parameter indicators of various type space is the fundamental work of architectural research, an important basis for building design application, and an inevitable way for architectural disciplines to adapt to social development. It is the requirement of the times to update and perfect the subject content.

(2) Innovating application of architectural research methods

The traditional application methods of people's perception feedback on space are questionnaire survey, interview, observation record and other forms. However, the questionnaire design requires reliability and validity check, and the number of samples should reach the level stipulated by scientific statistics. Especially in the space perception, there are too many inaccuracies of subjective cognition experience in the judgment of the state from being unsatisfied to being satisfied. It makes design research face technical barriers when answering the question of “man-space” relationship rationally and scientifically.

At present, new perceptual intelligence technologies which are represented by machine learning, virtual reality, physiological sensors and eye tracking have emerged in the basic research field of architecture. The new technology enables rational analysis of massive data samples and objective judgment of perceptual responses. With the help of research tools of psychology, artificial intelligence science, data science, information science and other disciplines, this paper provides more objective records on behavior and perception and scientific analysis for space perception research, innovates and establishes a new paradigm of building design research, reflects the development trend of interdisciplinary integration in the new era, and enhances the scientificness and rationality of building design research. It provides reference for other disciplines to enter the field of architecture and explores and provides practices for interdisciplinary research.

(3) Improving the quality of the built environment

After the basic survival needs are met, human beings are bound to pursue higher material and spiritual enjoyment along with the progress of society. “Eat enough and well. Dress warmly and gorgeously. Live safely and happily.” The space has also evolved from practicality to more multi-purpose experiences. The elderly are an important part of the family population, and the quality of life of the elderly is related to social stability and development. The deep-rooted culture of filial piety, the traditional thought of ritual system and the order of dignity also make the elderly people respected in our country. The quality of living space for the elderly has become the common concern of the society. Therefore, providing comfortable and healthy living space for the elderly is the guarantee of social harmony and has important social significance.

Reference

[1] Qi, et al. "Analysis on Investment and Financial Problems of the Elderly in Jinan City." 2018.

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[3] Zhang, N. , and Q. Sun . "The Design of Courtyard-Style Elderly Care Buildings in Cold Regions." Journal of Landscape Research 11.02(2019):5-7+11.

[4] Zhang Si Jie. "Research on the Present Situation and Problems of the Five Guarantees System for the Elderly in Rural Areas -- A case study of H Town in Gansu Province." Rural Practical Technology 11(2020):3.

Chapter 2

2. RESEARCH STATUS IN THE WORLD

CHAPTER TWO: RESEARCH STATUS IN THE WORLD

2.1 Achitectural Design of elderly care buildings

(1) Study on the space design of elderly care building in western countries

At present, western countries have done a lot of constructive discussion on the problem of population aging and buildings for the elderly. Aging in western countries occurred early. It is also the natural form of population structure transformation, so the aging process is a gradual and relatively slow process. This advantage enables these countries to adopt a gradual way to develop housing countermeasures to adapt to population aging, and the living level of the elderly in the whole society has been gradually improved. This natural progressive aging process in the west also makes the research on the architecture for the aged colorful, showing a trend of intercrossing and penetrating with many fields and disciplines in the society. Therefore, their research on the space environment of elderly care buildings and the psychology and behavior of elderly people is more detailed and in-depth[1]. As for the design of elderly care buildings, in 1943, Sweden published the Planning and Construction of Residence for the Elderly in Stockholm, which was the earliest systematic monograph in the world to study the residential buildings for the elderly. After World War II, a large number of studies involving residential buildings for the elderly appeared. From 1950 to 1970, western countries mainly explored the social, economic, cultural and architectural policies and regulations related to the elderly. Relevant works include Atchely Robertc's The Social Forces in Later Life: An Introduction to Social Gerontology[2], Lawton.M. owell's (1970) The Planner's Notebook:Planning Environments for older people people [3]. From 1970 to 1980, American scholars systematically summarized and formed the specifications and regulations of living facilities for the elderly based on their mature practical experience in the aspects of physiology, psychology and behavior of the elderly. Related works include Green. Lsaac.Etal's (1976) Housing for the Elderly the Development and Design Process Lawton[4]. M.Powell's (1980) Environment and Aging[5]. Since 1980, on the basis of a large number of mature residential and community for the elderly, a lot of research has been done on the social old-age security system. Related books include A Place to Grow Old: The Meaning Of Environment In Old Age by Diane[6]. Y.colstens (1986) From Sun Cities to The Villages by Judith Ann Trolander (2011)[7]. The problem of aging society in Japan is relatively serious, which has a great impact on the social and economic development of the country. Therefore, the architectural field has conducted in-depth research on the building space design system for the elderly, and achieved a lot of achievements. Research on elderly care building design in Japan mainly focuses on the living status of the elderly, care service system, day care, medical rehabilitation and other aspects. Relevant works include Daily Living Behavior and Environment of the Elderly, Study on the Living Space Form of the Elderly Residence, and Study on the Public and Semi-Private Space of Nursing Homes. Because of the similarities between Japanese population composition, living habits, cultural traditions and Chinese, it can be used for reference in related fields in China.

Table 2- 1 Research on space design of elderly care buildings in western countries

Year	Research direction	Representative works
1970~1980	From the physiological, psychological, behavioral and other aspects of the elderly, on the basis of the mature practical experience of the elderly residence,	Green. Lsaac. Etal (1976) Housing for the Elderly the Development and Design Process Lawton.M.Powell(1980) Environment

	systematically summarizing the formation of relevant specifications and regulations	and Aging
From 1980 till now	On the basis of a large number of mature residences and communities for the elderly, a lot of research has been done on the social endowment security system and system	Diane.Y.Carstens (1986) A Place To Grow Old: The Meaning Of Environment In Old Age Judith Ann Trolander (2011)From Sun Cities to The Villages

Compared with China which pays more attention to the aging society later, the construction of the design standard system related to the elderly in foreign countries is relatively complete. Among them, the International Organization for Standardization (ISO) has formulated 12 ergonomic design standards related to the elderly based on experimental data, among which the standard related to the design of elderly care buildings is ISO 7001: 2007/CD Amd 31-priority facilities for elderly people.The rest of the specifications are mostly design indicators for information technology products and equipment which are concerned with the convenience of elderly people. In addition to ISO, the European Union has also formulated a series of design standards for the elderly, namely the elderly care standard part of the European specification. It mainly involves three aspects of ergonomics, behavioral needs and living space, with a total of 5 parts, which are more focused on the reference index of service provision for the elderly. Japan has a relatively prominent social problem in the aspect of elderly care, and studies on relevant specifications for the elderly have been carried out earlier, so it has a relatively sound system. Relevant specifications are divided into two categories. One is national design standards, among which there are 33 national standards related to the elderly care mainly focusing on design indicators related to the life of the elderly. The second type is the building design guide atlas, such as building design Data 34- Nursing Home and Building Design Data 71- Special Care Nursing Home which are published by Architectural Data Research Society, Building Design Data Integration of Human Body Space[8] and Building Design Data Integration of Welfare and Medical Care[9] which are published by the Architectural Society of Japan, have made a detailed introduction to the spatial requirements of the elderly’s daily living behaviors and spatial comfort indexes. For example, Building Design Data Integration of Human Body Space[10] analyzes the space design index basis of elderly care buildings from the three aspects of the elderly’s form and movement, physiological perception, and space perception.

Through the collation of relevant regulations and design guidance in foreign countries, it can be seen that there is a relatively perfect theoretical system of elderly care building design index in foreign countries, and a large number of cases have been tested. In the future, there will be much reference for Chinese research of space design index of elderly care building.

The construction of the design standard system for the elderly in foreign countries is relatively perfect. Related space design indicators are mainly summarized from three aspects which are the International Organization for Standardization (ISO), the European Union code, the Japanese building code.

Table 2- 3 Specification for design indicators for the elderly (Source: Fu Yao 2019 National Fund Program Declaration Form)

Place of regulation	Specification of design indicators related to the elderly	Direction of attention
International Organization for Standardization (ISO)	There are 12 books in total, ISO 7001：2007/CD Amd 31-priority facilities for elderly people is related to the design of elderly care buildings.	Indicators for the design of information technology products and equipment for ease of use by the elderly
European Union	There are five elderly care standard divisions	To provide referential technical indicators for services to the elderly
Japan	Design standards - pension related national standards a total of 33	The design of details related to the life of old people
	Design Atlas - Building Design Materials 34-Nursing Home, Building Design Materials 71-Special Care Nursing Home, Building Design Data Integration of Human Body Space, Building Design Data Integration of Welfare and Medical Care	Spatial requirement and spatial comfort index of the elderly's daily living behavior

Japan has a detailed and comprehensive study on space design indicators, with a special "Human-space chapter", which sets out corresponding indicators for different populations and different spatial states, and lists relevant charts and data. For example, in terms of visual perception, according to the research on the difference of visual sensitivity between the elderly and the young, the "appropriate illuminance curve at 1m visual distance" and "age change and near vision curve" are listed for design reference.

(2) Research on space design of elderly care buildings in China

In China, from the 1990s, forced by the increasingly serious situation of population aging and the need of industrial structure adjustment, the government, academia and society began to pay attention to various social problems caused by population aging. Chinese studies on elderly care buildings began one after another, and the research scope involved specific studies on the design specifications of elderly care buildings, the actual use needs of the elderly and other aspects. For example, in 1995, the project of the National Natural Science Foundation, Research on the Urban Residential Building Environment for the Elderly, chaired by Mr. Hu Renlu of Southeast University, conducted a detailed investigation and analysis on the residential environment for the elderly in China. Among them, Living Environment Design for the Elderly by Hu Renlu (1995) first proposed the indoor and outdoor design of living environment for the elderly.

In the past ten years, there have been many achievements in the research of space design of elderly care buildings in China. Zhao Xiaozheng (2010), chief architect of Beijing Jinling United International, Elderly Care Facilities and Elderly Residential Buildings&Introduction to the Elderly Residential Buildings at Home and Abroad[11], combining the current situation of the pension policy of other countries, this book studied the elderly living and facilities of other countries. Starting from the situation of China, this book put forward the viewpoint of old-age care in the residential, and described the ideal living space form of the elderly under this mode. Zhou Yanmin of Tsinghua University (2011) Housing for the Elderly, described in detail the design methods of indoor and outdoor space, and gave some examples of indoor house design. Zhou Yanmin of Tsinghua University (2011), Discussion on the Residential Mode of Chinese Urban Family and Community Elderly Care[12], analyzed that most of the existing urban housing in China did not consider the special requirements of the elderly, and drew on international experience to put forward three types of building modes suitable for Chinese family and community elderly care. Wang Xiaomeng of Beijing University of Technology (2015), Basic Research on the Construction of Community Support System for the Elderly, clarified the service needs, necessary community supporting facilities and existing problems of home-based community for the elderly through investigation and analysis, and put forward preliminary suggestions on the construction of detailed community design requirements for the elderly. Li Xinyang of Tianjin University (2016) Evidence-based Research on External Health Behavior Space of Nursing Homes[13], innovatively introduced evidence-based methods to study and explore the design standards of external environment space of elderly care buildings.

In the process of collating and summarizing a large number of relevant literatures in recent years, it can be found that the research of space design of elderly care buildings has achieved positive results. In the study of elderly care building space, interdisciplinary and other research methods are also gradually adopted. However, in the field of architecture, there are few research contents and achievements based on the space perception and spatial comfort index of the elderly.

Table 2- 2 China research achievements in recent ten years

Year	Author	Representative works	Main content
2011	Zhou Yanmin	Housing for the Elderly	described in detail the design methods of indoor and outdoor space, and gave some examples of indoor house design.
2011	Zhou Yanmin	Discussion on the Residential Mode of Chinese Urban Family and Community Elderly Care	analyzed that most of the existing urban housing in China did not consider the special requirements of the elderly, and drew on foreign experience to put forward three types of building modes suitable for Chinese family and community elderly care.
2015	Wang Xiaomeng	Basic Research on the Construction of Community Support System for the Elderly	clarified the service needs, necessary community supporting facilities and existing problems of home-based community for the elderly through investigation and analysis, and put forward preliminary suggestions on the construction of detailed community design requirements for the elderly
2016	Li Xinyang	Evidence-based Research on External Health Behavior Space of Nursing Homes	innovatively introduced evidence-based methods to study and explore the design standards of external environment space of elderly care buildings.

According to the summary of Standard Quota Department of Ministry of Housing and Urban-Rural Development, building design index refers to the relevant principle index that provides guidance and standards for the design in the whole process of building design. Indicators related to building space design mainly focus on the space human scale, architectural sound, light, hot air, etc.

There are two main problems in the data sources for the formulation of human scale indicators. On one hand, the time of quoting data is early, and there is no sufficient research on the real human behavior space. Due to economic and social development, human scale has been significantly different from the early data. Relying on the old data will easily lead to a large deviation between the design index and the actual use. In Architectural Society of China (2017) Building Design Data Set, the Third Edition, Volume I, General Theory of Architecture, the human scale percentile is selected from the national standard General Rules for the Application of Human Body Percentile in Product Design GB/T12985-1991. Furniture space data came from National Natural Science Foundation Project - Furniture and Indoor Activity Space and Ergonomics.1990, and work position design data came from Zhu Zuxiang (1993) Ergonomics. The second aspect is that the content of human scale data in China is not comprehensive at present, and many of the data are cited from foreign achievements, which are quite different from the actual situation in China. The commonly used data of storage height of Architectural Society of China (2017) Building Design Data Set, the First Volume of the Third Edition, General Introduction to Architecture comes from Stephen Pheasant Bodyspace Second Edition CRC Press.1996 The basic size data of kitchen space comes from Grandjean.Ergonomics of the Home.1973 . The index of wheelchair-turning space for middle-aged and elderly people of Design Code for Residential Buildings for the Elderly GB 50340-2016 refers to (1994) 03J926 Barrier-free Design for Buildings and (1994) Data Set of Building Design, 2nd Edition 01 . These two books also refer to foreign values and have not been updated for many years. All the above enumerates are important space indicators of the behaviors of daily life. It is difficult to reflect the actual situation of our country objectively if our data are always based on the early data of foreign countries. In the acoustic, optical and thermal indexes of space environment design, most of the reference data come from the existing system of foreign achievements and lack of independent demonstration. Architectural Society of China (2017) building design Data Set, the First Volume of the Third Edition, General Introduction to Architecture . Sound-curve data of spatial acoustic environmental noise related indicators are derived from ISO532-1975, which is based on human experiment data in 1959. The indoor space thermal environment comfort index refers to ASHRAE STANDARD 55 (1970) of the United States.

In terms of the design index of elderly care buildings, Chinese researches are mainly conducted by the contributors to the specifications and the research direction is mainly the analysis of mandatory provisions on the standard elderly care setting planning and construction and safety evacuation. Chang Huaisheng et al. (2000) Review of the Specification of building design for the Elderly[14] made a comprehensive comment on the fortification principle and extension of the specification. Liu Zhiguo et al. (2016) Research on the Planning and Construction Standards of Elderly related Facilities in Urban Residential Areas under the Background of Advanced Aging[15], demonstrated the facility planning standards of elderly related communities. Zhang Hancheng et al. (2016) Comparison of Requirements of Old and New Codes for Elderly Buildings and Analysis of

Common Hidden Dangers[16] analyzed the changes of fire protection specifications for elderly care buildings. Until recent years, a small number of studies involved the specific demonstration and explanation of the basic index of elderly care building design. Wang Zhaoxia et al. (2015) Series Demonstration of Design Specifications for Residential Buildings for the Elderly (I) - Basic Experiment of Wheelchair-turning Space for the Elderly[17] demonstrated the indicators of wheelchair space requirements for the elderly in the codes through multiple sets of practical simulation experiments. The space design index of elderly care building is the basis of elderly care building design. But generally speaking, the Chinese architectural research is still not mature enough because it started late, and there are still many problems in the basic argumentation. In view of the current problems, it is necessary to seek scientific and effective research methods and technical means from the perspective of the users of buildings, namely the elderly, and to put forward the design index basis that is truly suitable for our national conditions and the living needs of the elderly in the current society.

Chinese researches on elderly care buildings started late, but it has made rapid progress in the formulation of design standards and specifications, and has been constantly revised, including design data set, specifications, and so on. So far it has formed a scientific, systematic design standards for elderly care buildings in line with its own characteristics. In terms of academic works on space design index, the thesis mainly discusses from the aspects of design cases and index analysis at home and abroad. In Zhou Yanmin (2018), a detailed analysis is made on the design system and spatial index of elderly care facilities providing care services for the elderly with rigid demands. Zhou Dian (2018) discussed community planning, layout and living space in Japan and summarized the experience of design indicators. Li Bin (2018) proposed indicators and suggestions on the relationship between individual characteristics and housing characteristics from the perspective of the elderly's attitudes and housing safety performance.

Table 2- 4 Design specification standard (Source: Author's drawing)

Specification name of elderly care building	Year	Main content
Standard for building design of elderly care facilities JGJ450-2018	2018	The main contents include general provisions, terms, basic provisions, site and general plan, building design, special requirements, construction equipment.
Design requirements and Standards for old-age housing and apartment (Architecture)	2017	Guiding the design of nursing homes and apartments projects of the group. Considering the needs of the elderly who need complete care on the basis of the healthy elderly, and increasing the content of humanized design for the elderly.

GB50867-2013 Specification for Building Design of elderly care facilities GB50867-2013	2013	The main contents include general provisions, terms, basic provisions, general plan, safety measures, construction equipment. Applicable to the construction design of new, rebuilt and expanded elderly care homes, nursing homes and day care centers for the elderly and other elderly care facilities.
GB50437-2007 Urban elderly facilities planning specification	2007	It is suitable for the construction, expansion and reconstruction of urban elderly facilities.
JGJ122-99 Building design for the elderly	2006	The main contents include general principles, terms, base environment design, building design, architectural equipment and indoor facilities, which are applicable to the construction, expansion and reconstruction of residential buildings and public buildings for the use of the elderly in urban areas.
GBT503402003 Design standard for residential buildings for the elderlyGBT503402003	2003	The main contents include general provisions, terminology, site and planning design, interior design, building equipment, indoor environment.

(4) Analysis of the architectural design by “Cite space” in the recent 20 years

Research on related design elements emerged around 2005, with the top keywords being: family care, long-term care institutions, nursing homes, mutual elderly care, the closest mutual aid principle, disease and prevention, evaluation and design. In 2005, the main research focused on the introduction of randomized trials based on medical treatment; since 2010, the research on design factors mainly focused on indoor physical environment.

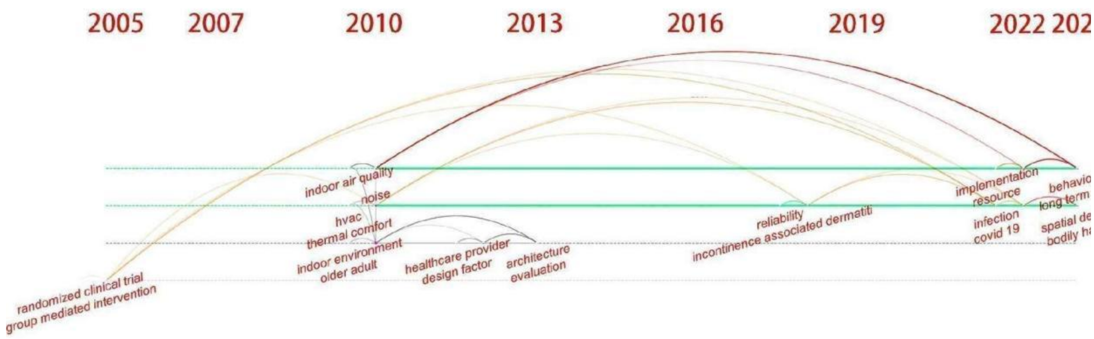

Fig. 2- 1The hot words of the architectural design by Citespace

2.2 Space perception based on new technologies

(1) Exploration of space perception of new technologies in the West

In the 1970s and 1980s, foreign scholars proposed the “space-perception-behavior” research method, which requires questionnaire survey, visual judgment and behavior labeling. It abstracts and extracts the built environment and the two dimensions of space perception and behavior, so as to explore rules, to predict the users’ perception and behavior preferences and finally to apply them to design. This research method has played an important role in the field of architecture, urban design and landscape, and provides a relatively systematic and comprehensive research method for the study of urban space and building space perception. On the basis of Likert gradient scale of psychology, L.b.luopold (1969) Landscape Thetics, Shafer.E.L (1977) How to Measure Preferences for Photographs of Natural Landscape[18] and other articles all made a preliminary exploration of outdoor landscape space perception through photo evaluation and factor analysis. B Emo, Dr.Kinda AlSayed et al. (2016) Design, Cognition & Behaviour: Usability in the Built Environment[19] discussed the relationship between spatial form and human behavioral mobility in space through spatial markers.

Although the “space-perception-behavior” research method has played a great role, it wastes time and energy, and only a small amount of data can be acquired. These characteristics limit the further study of related research to a certain extent. Researchers need to spend a lot of time and energy, such as using random sampling, repeated sampling, careful questionnaire design and other approaches to ensure sufficient research reliability. On one hand, relevant studies face technical barriers when answering the efforts of “human-space” interaction on a larger scale and in a deeper degree. On the other hand, it is not conducive to provide more accurate and comprehensive assistance for design practice.

With the development of information technology and scientific technology, a quantifiable and objective physiological feedback measurement method that can reflect people’s space perception is gradually applied in the research. In the 1980s, the United States Mental Health Department found through experiments that a large number of picture emotional stimulation can be better reflected through physiological signals such as EDA (electrodermic activity), ECG, EEG and facial muscle EMG. Firstly, space perception is linked with physiological index feedback. Ryuzo Ohno explored space perception and behavioral needs. In The Influence of The Environment On Stress Recovery Process[20] by Ryuzo Ohno (2007), the relationship between space environment and emotional stress was studied by analyzing the behavior pattern and electrodermic indexes of human in space. A recent study by the Centre for Advanced Spatial Analysis (CASA) at University College London (UCL) also explored the integrated use of various sensors in urban design. Participants were invited to wear portable EEG, electrodermic sensor and GPS trackers as they walked through streets with different traffic conditions and green levels to analyze the environmental characteristics of different physical spaces. This is a physiological feedback measurement using portable measuring instruments such as ECG, EMG, EEG and eye tracker. It can accurately and objectively measure people’s cognitive process and psychological feelings in the built environment, and convert people’s needs and feelings in real scenes into data that can be quantified and judged. This method is more suitable for the elderly with certain communication difficulties. J. van.Hoof and A.M.C.Schoutens, Holland (2008) High Colour Temperature Lighting For Institutionalised Older People With Dementia, temperature and vibration changes of tympanic membrane and rectal temperature of disabled elderly could be measured by changing the illumination and color temperature of indoor environment, so as to further observe the elder’s visual responses to changes in spatial light environment. In addition to physiological feedback, new technologies such as machine learning, virtual reality and eye-movement tracking have emerged in recent years. These technologies provide more accurate analysis and more intuitive presentation tools in the study of space perception, and offer the possibility of innovating the existing research paradigm.

In terms of machine learning, deep learning technology represented by deep convolutionalneural network architecture provides the basis for efficient image spatial element recognition. For example, “SegNet”, a tool developed by researchers at the University of Cambridge in 2015, can efficiently and quickly identify 12 elements such as sky, sidewalk, driveway, building and greening in the image data of human eyes. Under the inspiration, follow-up and “YOLO”, “Image Net”, “DeepLab” and a series of image recognition tool was developed. Based on this kind of deep learning framework, research can be realized by training relatively small samples of pictures.

Virtual reality is a technology that generates a three-dimensional virtual world through computer simulation and provides users with immersive experience. This technique provides the possibility of representation and control of real scenes in the laboratory environment, so it is widely used in experimental psychology and other fields. In recent years, virtual reality technology has been gradually applied to the field of architecture and urban design. It can not only provide immersive design scheme verification and results display, so as to assist participatory urban design, but also can assist environmental behavior research. In the laboratory environment, virtual environment similar to field research can be provided to effectively eliminate uncontrollable factors in field research and improve research reliability. Researchers at the Future Cities Lab at the ETH Zurich have built highly realistic virtual blocks using bicycles and head-mounted virtual reality displays to gather the public’s perception of bike-oriented street space design. To realize the evaluation of the design scheme of the preposition.

Eye Tracking refers to the analysis of eye focus by measuring the position of the eye’s fixation point or the movement of the eye relative to the head. The eye tracker based on this technology can accurately and directly reflect the focus of the eyes of the subjects, so as to analyze their cognition and psychology. The new information collected by this new technology provides important indicators for the quantitative measurement of the location and duration of attention for spatial cognition, psychology, cognitive linguistics and other studies. ETH Zurich’s use of eye tracking to analyze the logo design and spatial organization of Frankfurt Airport in Germany is a good example of this technology. Based on the analysis of the subjects’ sight allocation, reaction time, decision error rate and confidence level in the course of airport way finding, this study defined the sign design with potential for improvement, spatial streamline reorganization and local space perception optimization, which successfully improved pedestrian satisfaction and airport traffic efficiency.

In addition to the above several new space perception technologies which are widely used, other analysis methods such as “three-dimensional line of sight analysis and spatial network analysis” and “multi-source city data” have also begun to be put into practice in research fields related to space perception.

As can be seen from the above literature review, the new technologies on space perception emerging abroad in recent years can not only realize the direct observation of individual responses, but also can realize the large-scale analysis and observation of behavior activities while maintaining a certain precision. In this way, it is possible to construct a systematic analysis that considers multiple variables comprehensively, enabling designers to consider multiple variables and their interaction effects in the actual built environment as a whole, so as to build a relatively accurate nonlinear model, to facilitate the human-centered “environment-perception” research and design, and finally to provide a strong reference for our future research.

Table 2- 5 Literature review on new technology of spatial perception research

New technology category	Time	Research results
Machine learning technology	2015	Vijay Badrinarayanan, Anku rHanda,Roberto Cipolla (2015) Deep Convolutional Encoder-Decoder Architecture for Robust Semantic Pixel-Wise Labelling The “segnet” tool, developed by researchers at Cambridge University in 2015, can efficiently and quickly identify 12 elements in human eye image data, including sky, sidewalk, driveway, buildings and greenery. Through the extraction of various elements, the program can easily realize the quantitative measurement of various human scale spatial elements in the built environment.
Virtual reality technology	2016	1.G.Beato (2016) Bike to the Future: As Pedaling Goes Electric,Alternative Transport Goes Individualist ETH Zurich builds a virtual environment for blocks with high degree of pseudo-truth, and collects the public’s perception and opinions on bicycle-oriented street space design schemes through bicycles and head-mounted virtual reality display systems to realize the preliminary evaluation of design schemes.
Eye-tracking technology	2016	uchner S J, Holscher C, Kallert G, et al (2016) Improving Airport Signage Eye-Track for an Evidence Based Design Approach Based on the analysis of the subjects’ sight allocation, reaction time, decision error rate and confidence level in the course of way finding at Frankfurt Airport, this study defined the potential improvement of sign design, spatial streamline reorganization and local space perception optimization.
Physiological sensor technology	2008	J.van.Hoof、A.M.C.Schoutens (2008) High Colour Temperature Lighting For Institutionalised Older People With Dementia By changing the illumination and color temperature of the indoor environment, the temperature and vibration changes of the tympanic membrane and rectal temperature of the disabled elderly were measured, so as to further observe the elderly’s response to the change of the spatial light environment in terms of vision.
3D sight and spatial network analysis	2017	Y Lu, Y Ye (2017) Can people memorize multilevel building as volumetric map? A study of multilevel atrium building Through the participatory research in the commercial complex with atrium space,

		the accuracy of 3D spatial visibility analysis is improved, and its efficiency in space perception is verified and deepened.
Multi-source city data	2016	Y Ye, A Yeh , Y Zhuang, AV Nes, J Liu (2016) "Form Syntax" as a contribution to geodesign: A morphological tool for urbanity-making in urban design A design analysis tool is proposed which can assist urban planning and design practice based on the understanding of urban form elements and the impact on urban life by means of data analysis.

At present, in the field of psychology abroad, it is the mainstream to analyze and collect the physiological signals of people in the space environment and explore the emotional characteristics. In the field of architectural science, the research on space perception based on physiological sensors is in the preliminary exploration stage. Among them, J. Van.Hoof and A.M.C.Schoutens (2008) studied the visual comfortable lighting environment of the elderly by changing the illumination and color temperature of indoor environment and measuring physiological indicators. Seiko Goto and Bum-Jin Park (2013) analyzed the heart rate variability index (HRV) of the elderly, and studied the effect of landscape space for the elderly emotional EvdokimosI. Konstantinidis AntonisBillis (2017) acquired the elderly's body movement through the device image, analysis of different outdoor environment relation of the old people's emotions.

Eye tracking technology is a new human factor experiment device that has been put into practice in recent five years. There is only one article in the medical field related to the elderly, namely Pereira,Marta L.G.itas, Von Zuben A.Camargo (2014) analyzed the correlation between Alzheimer's disease and saccadic eye movement indexes in the elderly through eye-tracker data.

(2) A preliminary study on space perception of new technologies in China

At present, Chinese researches on space perception mostly stay at the level of qualitative research on spatial objects, and the research methods mainly focus on the traditional "space-perception-behavior" research method.

In the Research on the Livable Space Pattern of the Elderly in Northern Cities National Natural Science Foundation project chaired by Zhou Bo of Dalian University of Technolog, a preliminary exploration was conducted on the space perception experience of the elderly through questionnaire survey and visual judgment. Zhou Bo (2013) Comparative Study on space perception Experience Characteristics of Chinese and Japanese elderly care Buildings, discussed the perception degree and visual environment of the elderly in the living space by constructing the relationship between spatial perspective picture and space perception motion path.

In terms of studying space perception through new technology, Chinese architectural field has also begun to try a little.

In terms of machine learning, Long Ying of Tsinghua University (2017), Measurement of Street Spatial Quality in the Central District of Megacities - A Case Study of the Second and Third Ring Roads of Beijing and the Inner Ring roads of Shanghai, introduced machine learning mechanism and measured the street spatial quality in Beijing and Shanghai by using micro-scale image data of streets, objective composition analysis of elements and subjective evaluation of users.

In terms of physiological feedback, Chen Zheng of Tongji University (2016) Empirical Research on Urban Design Oriented Environmental Reality Perception[21] analyzed the impact of environmental cognitive ability on the basis of EEG and brain network and studied the impact of urban design environment space construction on people’s emotional perception on the basis of the measurement of autonomic neural feedback. Chen Zheng, Tongji University (2017) Evaluation and Design Aid of Built Environment Experience Based on Physiological Feedback[22] used portable physiological feedback sensors and geo-location service technology to try to measure and evaluate the environmental experience of indoor and outdoor space. This paper tries to establish a quantitative method of space perception based on the physiological changes of people's different feelings in the built environment.

At present, the research of space perception based on new technology in China is in the preliminary exploration, with few relevant theories and achievements. These new technologies and new data enable us to have new in-depth possibilities in the research means and new exploration ways in the research perspective, and also provide a new research development direction for the study of space design indicators of elderly care buildings. Therefore, in future research, new space perception technology can be combined with traditional research methods to give full play to their respective advantages. Through these new research methods, the design basis of space environment can be provided for the elderly to promote positive emotions, relieve stress and improve cognitive status.

At present, the study of space perception based on human factor technology in Chinese architectural disciplines is in the preliminary exploration, and the related theories and achievements are gradually appearing[23]. Ye Yu and Dai Xiaoling of Tongji University (2017), Space Perception and Design Application Possibility under New Technology and New Data, for the first time made a comprehensive analysis of human factor technology research methods represented by physiological sensors and eye movement tracking that have emerged in recent years. In the past three years, Chen Zheng from Tongji University has conducted a study on the relationship between urban space construction and people’s emotional perception by using EEG. In 2016, he published Empirical Research on Urban Design-oriented Environmental Reality Perception, and in 2018, Research on Urban Public Space Quality based on New Data and New Technology and Evidence-based Design under Wearable Interactive Technology.

Since 2014, the research group has also carried out more preliminary explorations on the application of physiological sensors and eye-movement tracker in the study of space perception. In 2018, Fu Yao et al. introduced the Preliminary Study of Indoor Public Space Design Based on the Concept of Healthy Architecture - Taking the Renovation Plan of LAB305.6 Healthy City and Comfortable Building Laboratory in Cold Areas as An Example at the conference. They used physiological sensors to assist the measurement of organ perception data of different temperature, humidity and light environments, and developed spatial indicators with comfort as the target. In 2016, Wang Sa et al published a Comparative Study on Visual Fixation Behavior of Contemporary Nonlinear Architecture and Linear Architectural Form -- A Case Study of Four Famous Buildings, which recorded the eye movement data of the subjects when they looked at architectural pictures with ETG eye movement tracking device. The characteristics of eye movement data are analyzed, and the eye movement characteristics and observation mode of nonlinear building form are summarized. In 2014, An experimental study on the restorative experience of typical urban soundscape based on EDA, published by Zhang Yuan et al., took EDA as an indicator. Through soundscape perception experiment, the physiological recovery response of subjects under typical soundscape conditions was determined.

(4) Analysis of the new technologies by Cite space in the resent 20 years

Related technology research emerged around 2010 and 2013. The top keywords are: machine learning, virtual reality, deep learning, artificial intelligence, energy efficiency, human thermal comfort, and building energy consumption. In 2013, the research focused on the shallow introduction of touch-based ergonomics and virtual reality. In 2016, the research mainly focused on energy transformation and in-depth research, including building information model (BIM), parametric design,

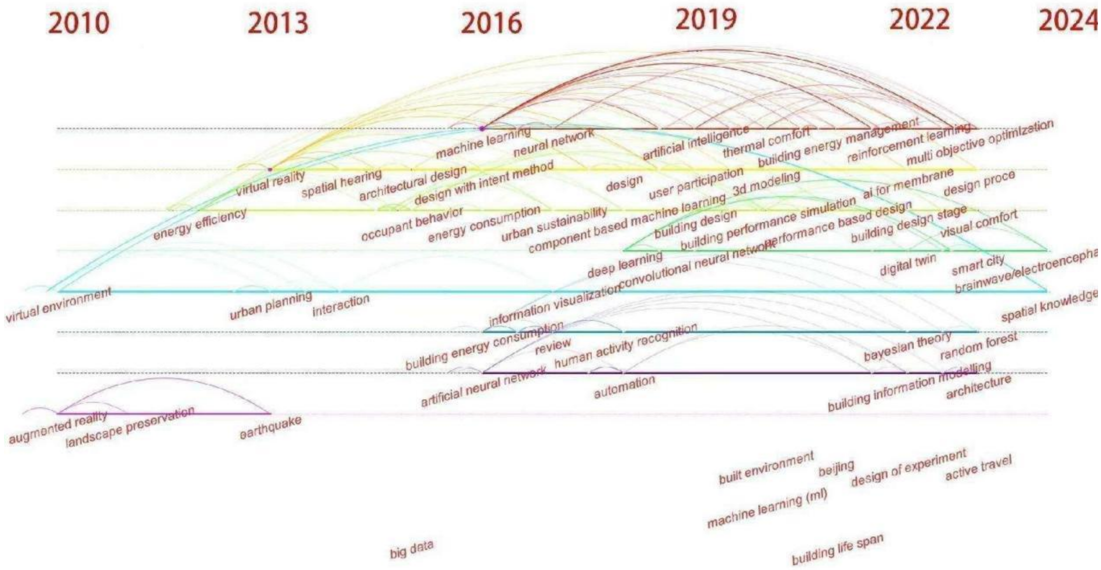

Fig. 2- 2 The hot words of the new technologies by Citespace

2.3 Space perceived comfort of elderly care buildings

(1) Studies on the space perceived comfort of elderly care buildings in foreign countries.

Foreign architectural research on space perceived comfort mainly focuses on the field of thermal environment comfort, which is also one of the earlier projects in the field of foreign architectural technology.

In an earlier study, Yagtou and Houshten (1947) proposed effective temperature based on thermal sensation indexes produced by the human body under different temperature, humidity and wind speed conditions. Burton et al. (1955) studied the relationship and influence of humidity on human comfort and reached corresponding conclusions. The discomfort index (DI) proposed by Thom (1959) is widely used. This was the origin of the Thermal Humidity Index later used by the US National Weather Service to predict comfort levels and working hours in summer. Tetjung(1966) formally proposed the concepts of Comfort Index and Wind Effect Index.

Later research on building comfort theory mainly starts from the perspective of human heat balance. Fanger of Danish Technical University proposed PMV (predict mean evaluation) and PPD (predicted percentage of dissatisfied) models through the study of human thermal comfort models, and verified their accuracy in the way of testing. The models provided favorable theoretical support for the future work of human thermal comfort. Later, the most authoritative indoor evaluation standards ASHRAE STANDARD 55 and ISO7730 are based on Professor Fanger's PMV model.

PMV/PPD model is also used to study the space comfort of elderly care buildings. Carolina A. Alves, Arch Denise, H. S. (2014) Thermal Comfort in Residential Buildings for the Elderly under Climate Changes Context studied the adaptability of the elderly to the thermal comfort of residential buildings under the current and future climate model changes. Federico Tartarini, Paul Cooper (2017) Thermal perceptions, preferences and adaptive behavior of occupants of nursing homes investigated the thermal perception, perceived preferences and adaptive behaviors of occupants in five nursing homes, and obtained the thermal comfort evaluation of existing nursing homes.

In addition to the perspective of thermal comfort, some scholars also studied the space perceived comfort of elderly care buildings from the comprehensive perspective of acoustics, optics and thermal comfort. J. van Hoof, Netherlands, Kort, H.S.M. (2009) The indoor environment and the integrated design of homes for older people with dementia observed changes in the environmental sensitivity of disabled elderly people according to various parameters of indoor environment, so as to help architects to create better living conditions for disabled elderly people. Johnny Kwok-Wai Wong, Martin Skitmore (2014) The effects of the indoor environment of residential care homes on dementia suffers in Hong Kong: A critical incident technique approach studied the influences of sound environment, light environment and heat environment on the behavior of disabled elderly people in Hong Kong nursing homes, and proposed the design basis of specialized residential facilities for disabled elderly people.

In books on perception, Art and Visual Perception by Rudolf Arnheim, an American, analyzed artistic aesthetics from the perspective of visual perception based on Gestalt psychology, and confirmed that visual image was a creative grasp of reality by citing psychological experiments and principles. In his book The Analysis of Feeling, based on physics and the study of sensory physiology, Austrian Mach scientifically analyzed the various elements of human feeling. The book Psychology of Design by Donald A. Norman mainly studied the matching of design and psychology, which provided strong theoretical support for industrial design experts. The book combines the psychology of designers with the psychology of consumers, and discusses how to design marketable design products to improve consumer satisfaction.

In the early 20th century, foreign countries successively paid attention to the research on the space of elderly care buildings, mainly focusing on the planning, functional configuration, spatial form and other contents of elderly care buildings. After 2000, the academic world began to pay attention to the space comfort. At present, the research results mainly focus on two directions. First, the traditional PMV/PPD model method combined with subjective questionnaire is used to study the comfort of thermal environment. Johnny Kwok-Wai Wong and Martin Skitmore (2014) proposed the design basis of residential facilities for disabled elderly people by studying the relationship between sound, light and heat environment in nursing homes and behaviors of disabled elderly people. Federico Tartarini, Paul Cooper (2017) investigated the thermal perception, perceptual preference and adaptive behavior of nursing home residents and evaluated the thermal perception of living space. Yoshihimitsu Inoue and Miaki Tokai (2016) studied the thermal environment perception state of the elderly, and analyzed the difference between physical thermal perception and actual temperature change of the elderly indoors. The second is combining the theories of environmental psychology and environmental behavior, analyzing the behavioral characteristics of the elderly and studying the comfort level of space environment with subjective questionnaires. Iketani Kengo et al. (2013) analyzed the elderly's perceived comfort in the living environment through sound, video, temperature and humidity recorders and other equipment and emotional evaluation. Nishiwaki Chiko et al. (2003) analyzed the elderly's perception of their living environment by classifying and making statistics on their physical and QOL indicators.

(2) Research on space perceived comfort of elderly care buildings in China

Chinese researches on space comfort was carried out late, and some research results were obtained in the 1990s. The research angle of space perceived comfort in the field of architecture generally focuses on the quantitative analysis of physical indicators such as sound, light and heat in the building space environment.

Wei Runbai of Tongji University (1985), People and Indoor Environment, took the lead in conducting research on the relationship between human body, environment and clothing and the theory of human thermal comfort in China. Wen Xuejun of Harbin Institute of Technology (1998) Fuzzy Comprehensive Evaluation of Human thermal Sensation in Steady-state Thermal Environment proposed that human body, environment and air conditioning system were regarded as a dynamic system interacting with each other, and a prediction model of human thermal sensation was established. Wang Yi (2003) Study on Indoor Thermal Environment of Residential Buildings in Cold Areas in Summer conducted quantitative calculation and analysis of the relationship between building characteristics and indoor thermal comfort under natural ventilation conditions by using quantitative thermal environment analysis and comfort evaluation calculation program. Chen xi of Harbin Institute of Technology (2016) Research on Acoustic Level Threshold of Underground Catering Space Based on Acoustic Comfort Level analyzed the spatial comfort level of underground catering building space from the perspective of subjective acoustic comfort level through the method of field questionnaire and actual measurement. Yang Li (2017) Comfort Simulation Research on Comfort of Indoor Space Environment in Buildings used CFD numerical simulation technology to conduct a comprehensive analysis of indoor space wind velocity field, temperature field and air age field.

As for the space perceived comfort of elderly care buildings, Chinese researches are mostly focused on the thermal comfort theory. Zhang Yujie (2016) Design Research of Apartment for the Elderly Based on Indoor Environment Comfort, taking indoor physical environment comfort of apartment for the elderly as the research object, based on thermal comfort theory, combined with field investigation and measurement, analyzed the relationship between thermal environment design and comfort of buildings for the elderly. Xie Yongpei (2014) Study on Comfort Design of Bedroom Space of Elderly Care Facilities in Southern Fujian studied the thermal comfort design of bedroom space of elderly care buildings in southern Fujian, and proposed design points and precautions from three aspects: temperature, humidity and ventilation.

As can be seen from the above literature review, there is a certain research basis for the perceived comfort of building space in China, but it started relatively late and mostly focused on the thermal environment comfort. In terms of single thermal comfort, there is no evaluation standard for thermal comfort based on the characteristics of the country, and the research is mostly based on ASHRAE STANDARD 55, ISO7730 standard and PMV/PPD model. In the aspect of elderly care buildings, there is a lack of comprehensive and comprehensive space perceived comfort research results.

Chinese researches on elderly care building design mainly focuses on design theory, design method and engineering practice. There are few basic researches on human perceived comfort, and the few existing research results on space comfort are also similar to those in western countries. First, PMV/PPD model and subjective questionnaire analysis are used. Zhang Yujie (2016) from Shandong Jianzhu University studied the relationship between thermal environment design and comfort of apartment buildings for the elderly from the perspective of building design and combined with the study of thermal comfort theory. Fan Guangtao (2017) from Beijing University of Technology studied the body perception and indoor comfortable temperature of the elderly in urban and rural areas of Beijing at different indoor temperatures during the winter heating period through subjective investigation and objective measurement. The second is mainly from the use of environmental psychology, behavioral science, and the behavior of the elderly. From the perspective of ergonomics and environmental behavior, Wang Yu et al. (2018) put forward suggestions on the aging design and renovation of residential toilet storage space. Li Bin (2018) analyzed the correlation between scenes and walking behaviors of the elderly in a specific environment through the study of walking and walking among the elderly, and then summarized the road design methods used by the elderly. Yu Yang et al. (2016) studied the vision and color vision of the elderly, providing a reference for the design of space environment suitable for aging. Lin Wenjie (2015) investigated the activity behaviors of the elderly and the places where they occurred, analyzed the behavioral characteristics of the elderly and the influence of different spatial relationships of facilities for the elderly on their behavior and activities. On this basis, the key suggestions of space design are put forward.

(3) Analysis of perceived comfort in the elderly building by Cite space in the resent 20 years

Research on comfort emerged around 2010 and 2013. The keywords in the top ranking are: people's thermal comfort, thermal environment, indoor air quality, urban heat island, skin temperature, environmental perception and thermal sensation In 2014, the main research focused on the shallow introduction of indoor air quality, indoor thermal experience and other comfort. Since 2015, the number of research papers began to explode, and the research.

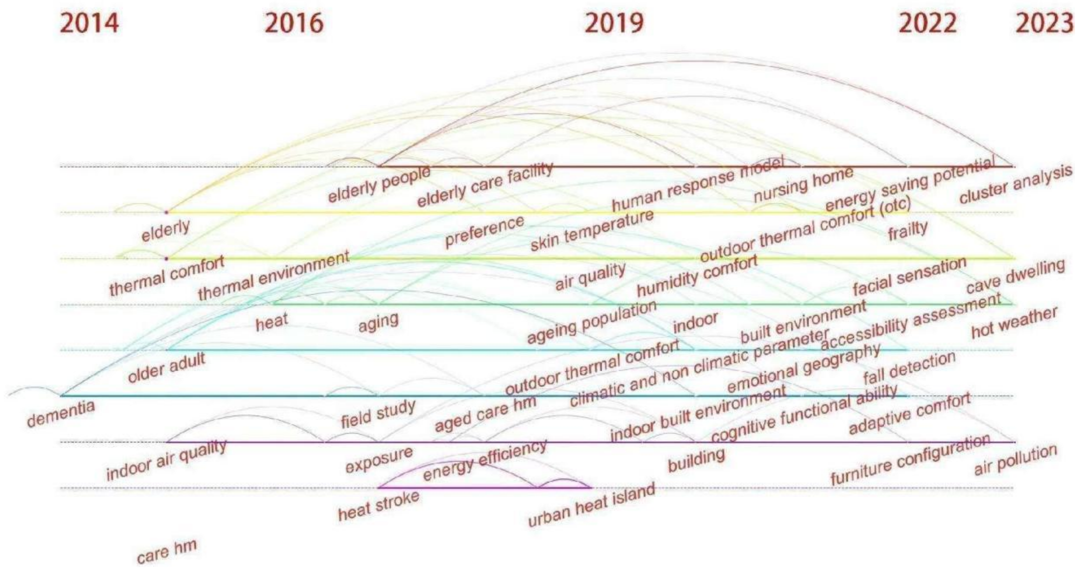

Fig. 2- 3 The hot words of perceived comfort by Citespace

2.4 Comprehensive review of research status

Through the analysis and review of relevant literature at home and abroad, it can be found that there are the following deficiencies in the current research on the space of elderly care buildings:

(1) Lack of specific research on regional elderly behavior habits and spatial indicators of pension buildings

The economic development of different geographical regions are different, and there are also great differences in geographical climate, social concept and behavior pattern. Taking Shenyang as an example, Shenyang is a typical cold region, and the body perception and living behavior habits of the elderly are greatly affected by the climate, which will inevitably lead to a great difference between the space requirements of the elderly buildings in Shenyang and those in other relatively warm regions. Therefore, the research on the comfort index of the elderly building space needs to be combined with regional consideration.

(2) Lack of "people-oriented" design ideas and elderly people's own perception and experience

At present, many researches on the functional and spatial layout of buildings for the elderly have the limitation of "path following", that is, they are limited to the functional indicators and spatial judgment indicators of existing theories and standards, and lack of understanding of the origin of these object indicators. The fundamental design of elderly care building is to provide comfortable and pleasant experience and service for the elderly. Therefore, the research on buildings for the elderly should start from the users, namely the elderly themselves, return to the "people-oriented" design idea, and really pay attention to the material and spiritual needs of the elderly themselves.

(3) Lack of relatively objective and quantitative measurement methods and interdisciplinary

research vision

Throughout the development of many disciplines represented by economics and sociology in social sciences, it can be clearly found that, with the development of disciplines and deepening of understanding, there is a common development of research methods from qualitative expression to the combination of qualitative and quantitative analysis, and the focus from “description” to “explanation” and then to “prediction”. At the present stage, the classical building space research usually makes qualitative analysis based on the description of people’s subjective perception, which is easily affected by subjective cognition and environmental factors. Therefore, quantitative research methods are bound to become a new direction in the field of architecture in the future. It can be seen from the foreign research status that in recent years, the close combination and cross of international science, engineering, design and computer technology has become an obvious trend. Such multidisciplinary research centers are emerging at an accelerating rate, exploring new ways to provide a better built environment. Therefore, new technologies and methods can be adopted to measure the process of people’s space perception through the cross of multidisciplinary fields, which can be combined with the classical analysis of space and place characteristics and the perception of practical problems to effectively and objectively help the corresponding research and design.

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Chapter 3

3. METHODOLOGY

CHAPTER THREE: METHODOLOGY

3.1 Research object: “perception-behavior-environment”

“Perception-behavior-environment” (PBE)are the key words in the paper, also are the core of the research.There are four sensation of perception that are vision,auditory,touch and heat sensation. The environment which is been researched should include acoustic environment,luminous environment and thermal environment. Some studies need behavior as intermediary.

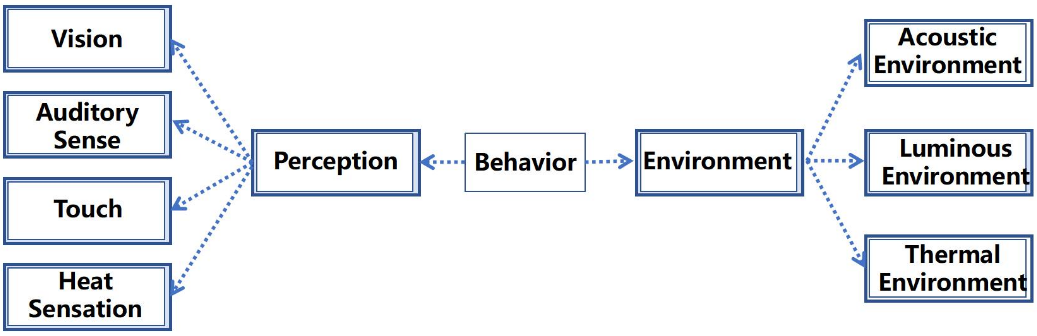


Fig. 3- 1 The frame work of PBE

3.1.1 Composition of “perception-behavior-environment”

The relationship between human and space environment consists of three basic parts: subject of perception, behavior state and environment of perception. In the process of space environment research, the three parts jointly complete space experience, influence each other and depend on another. When the space environment is perceived by people, the quality of the environment stimulates people to produce different senses and perceptions, and thus generates different emotional states. Negative emotions even affect people’s health. Behaviors occur in the space environment and depend on environmental conditions. Behaviors depend on the environment differently for different purposes. For example, “Students are having a class in the classroom.” What is reflected in this text description is: student -- the subject of the perception, class -- behavior, classroom -- environment of the perception. Space design is the main task of building design and architectural research. From the above relationship, it can be seen that space design is related to people’s perception and behavior. Therefore, it is the main goal of space design to satisfy people’s behavioral function and obtain comfort perception.

Each of the three components consists of several specific elements. The subject of perception is actually people, who see, hear and touch the environment through their own sensory organs, and generate emotions through cognitive experience of the brain. Different people have different emotions due to different sensory levels, and different cognitive experience of the world. Therefore, the subject of perception includes: different people’s attributes, individual sensory ability, and individual emotions. Behavioral state refers to people’s behaviors in the built environment. People have various behaviors, different motivations, different emotions and different associated behaviors. In order to avoid complicated research, the behaviors studied in this paper are mainly those generated in the designated functional space, including: sensory-dependent behaviors, functional corresponding behaviors and other behaviors. The environment for perception is the main research object of architecture. Environment includes two parts: environmental physical attributes and environmental spatial attributes.

Table 3- 1 “PBE” component composition

Component	Specific elements of Component	Content of specific description
Subject of perception	Attributes of different population	Groups differentiated according to age, gender, region, such as the elderly, children, women, etc.
	Individual perceptual ability	Sensory abilities determined by age and sex, such as vision, hearing, heat, etc.
	Individual emotion	The basic emotions defined by psychology: joy, anger, sadness, fear, disgust, surprise
Behavior	Sensory-dependent behavior	The behaviors that need to rely on the sensory organs, such as reading - visual dependence, listening to a lecture - auditory dependence, etc.
	Functional correspondence behavior	Behaviors determined by architectural functions, such as theater - audio-visual function, reading room - reading behavior, etc.
	Other behavior	Behaviors by individuals themselves, other than those mentioned above
Environment of perception	Physical attributes of environment	The sound, light, heat and other environmental parameters in the physical environment, such as temperature, humidity, fresh air volume and air change frequency
	Spatial attributes of environment	Material attributes of building space carrier, such as opening, depth, window opening, wall and ground material, wall color, etc.

3.1.2 Characteristics of each element of “perception-behavior-space”

The characteristics and nature of each element in the three parts of perception, behavior and space are different.

(1) Characteristics of the constituent elements of the perception subject

The subject of perception includes three parts: population attribute, feeling level and emotion. First of all, “population attributes” are differentiated according to gender, age and region. There are many categories of “people” in the broad study, including race, country, occupation, etc., which can extend a lot of content. However, since the main body of this study is “perception”, the attributes of subdivided groups are classified according to the characteristics with obvious perception differences. Different people have obvious differences in the perception of space, and the vision of the elderly is obviously different from that of children. People in different regions have different heat perception. Men and women have different senses of touch and so on... .

"Perception level" is an important basis for setting and proposing the parameters of the built environment. Each group of people presents different perception levels because of their age, gender and region. Take vision as an example, changes in the cornea of the eye affect people's vision. As people get older, the diameter of the cornea will become smaller and smaller, and gradually show a trend of flattening, which leads to a significant weakening of refractive power. In addition, the curvature of cornea thickens and becomes smaller, the cornea slowly lose luster. As a result, the ability to refract light deteriorates, astigmatism appears in the visual field, and furniture in the viewing space will have a series of disturbing phenomena such as blur and double shadow. While becoming older and older, people will turn a blind eye to unconspicuous objects. Zoble (1938), a researcher, tested the tactile threshold of the sensitive eyes and surrounding areas of subjects aged from 20 to 80, and the results showed that before 55 years old, people's sense of touch basically did not change with age, but after 55 years old, people's sense of touch became sharply dull.

"Emotion" is a general term for a series of subjective cognitive experience. The most common and popular emotions are joy, anger, sorrow, shock, fear, love, etc. There are also some delicate emotions such as jealousy, shame, pride, etc[1]. Emotions are closely related to people's mental health, and emotions can produce corresponding behaviors at the same time. Behavior is a factor of spatial evaluation.

(2) Characteristics of behavioral elements

The definition of "behavior" in a broad sense is the basic characteristic exhibited by different individuals or groups under the influence of social and cultural institutions and personal values, or their active response to stimuli from internal and external environmental factors.4 Specifically, it refers to the outward activity which is dominated by thought, such as making an action, making a sound, reacting and so on. People's dynamic response depends on their various consciousness and motivation. People with different consciousness and motivation will have different behaviors. Different environmental stimuli and different emotions will also produce different behaviors.

The "behavior" studied in this paper refers to the behavior corresponding to the primary function specified by space in building, including sensory dependent behavior, function corresponding behavior and other behaviors. Sensory dependent behavior refers to the necessary behaviors that need to be completed by the sensory organs in the building space, such as the visual dependent behavior of students looking at the blackboard and books in the classroom space, the auditory dependent behavior of listening to the opera in the opera house, and the tactile dependent behavior of the door handle outside the cold area. Sensory dependent behavior is related to the ability of the sensory organs and the position of the behavior. When students look at the blackboard, different visual distance is required by different visual level. In the same space, students lean against the window or the wall, and the degree of sensory dependence varies with different behaviors.

Function corresponding behavior is the "function" of form following function in modern architecture, which is used to clearly distinguish the "function" of different types of architecture. Function corresponding behavior is a necessary behavior and the basis of space research. A conference room is a space for meetings, and a theater is a space for movies. Function correspondence behavior and sensory dependent behavior are sometimes the same concept and sometimes related concepts. Sensory dependent behavior is the behavior under functional correspondence.

Other behaviors refer to behaviors that do not correspond to functions in space, which are not within the scope of this paper.

(3) Characteristics of environment components

Environment is the carrier of perception behavior in “PHE” and it is the core content. The environment consists of two parts: the physical parameters of the environment and the space entity of the building. The physical parameters of the environment are the conditional elements of the space environment. They are the traditional environmental parameters of sound, light and heat. They are the environmental characteristics to be achieved in order to satisfy people’s behaviors in the space, such as brightness, temperature, humidity and sound pressure level, etc. They are the main content of building physics in the traditional architectural research. Environmental space attributes have material characteristics and are the constituent elements of the building body, including the opening, depth, window size, height, wall color and so on. They are the material characteristics of the building body corresponding to the environmental target characteristics.

The goal of human perception is to create emotional pleasure or positive evaluation based on people’s perceived comfort. Human perception of the environment mainly relies on external sensory organs, including eyes, nose, ears and skin. Because smell has a weak relationship with human perception and space, it is excluded from the scope of this discussion. Behavior is basic functional behavior, divided into necessary behavior and unnecessary behavior. Necessary behavior is generally the main functional requirements of space. For example, in bedroom, sleeping is necessary behavior, reading is unnecessary behavior. In classroom, learning is a necessary behavior, but chatting during is not. Spatial elements include two levels. The first level is the target characteristics, and the second level is the entity characteristics, is the space material characteristics.

3.1.3 “Perception-Behavior--Environment” correlation

Space carries people’s behaviors. Different behaviors produce different perception and experience in space, while positive and negative perception and evaluation need space adjustment and change on the contrary. Clarifying the relationship between the three is the key to further study.

(1) Behavior - environment: not necessary but necessary relationship

Space is the basic material entity to satisfy people’s behavioral needs. Tracing back to the origin of primitive architecture, space is a place to shelter human from wind and rain and to meet the most basic survival needs of human beings. With the progress of civilization, various spiritual and material needs of human beings increase, multiple functions and different types of space keep appearing, and the correspondence between space and behavior is also constantly strengthened. From the development course of architectural history, the relationship between behavior and space presents the characteristics of multi-attribute, phased development and change. Depending on different conditions, the corresponding relationship is different. For example, from the perspective of the relationship between human and the natural environment, human beings did not master the corresponding technology and tools in the early stage, and they were afraid of nature. The cognitive philosophy of the world was worship of God. Building space is not a space for people, but a space for God and monarchy. The behaviors in the Greek temples, Egyptian pyramids, Roman Pantheon, Gothic churches and other buildings in western classical architecture were not based on the basic requirements of satisfying the basic physiological functions of human beings, but more to express the worship of gods under the social background at that time, and the behaviors are not corresponding to the space. In the development of modern architecture, the relationship between behavior and space gradually corresponds to Adolf. Luce who was an Austrian architect and architectural theorist, a pioneer of modernist architecture. He came up with the famous slogan “decoration is sin”. He advocated that architecture should be practical and comfortable, and believed that architecture “relies not on decoration but on the beauty of the form itself”. He was the first to put forward the “volume planning” of building space, which defined different internal space volumes through ceiling elevation. He believed that each different room should have different storey levels according to its function[2]. After that, modern architecture gradually developed and improved, corresponding to people’s modern life, building types increased, and the relationship between behavior and space gradually became clear. In the 1960s of last century, with the development of environmental psychology, the research on the relationship between human behavior and environment promoted the development of architecture, and thus formed a series of contents related to behavior that can guide space design.

Human behavior in space includes sensory dependence, functional correspondence and other behaviors. Sensation-dependent behavior has strong spatial demands.

(2) Behavior-perception: inevitable relationship

Sensory stimuli forms the first level of feeling. Knowledge and experience forms perception. Perception produces emotion and then corresponding emotions produce behavior.

(3) Causal relationship between perception and enviroment

Table 3- 2 Example of“Behavior-perception-environment”correlation

<table>
<tr><th colspan="3">Space type - behavior</th><th rowspan="2">Perception type</th><th colspan="3">Space design</th></tr>
<tr><th>Living space</th><th>Dining space</th><th>Public activity space</th><th colspan="2">Target characteristics</th><th>Entity characteristics</th></tr>
<tr><td rowspan="4">Reading newspaper
Watching TV
Handmaking
Having a meal</td><td rowspan="4">Having a meal</td><td rowspan="4">Playing mahjong
Watching TV
Chatting</td><td rowspan="4">Vision</td><td rowspan="3">Illumination</td><td>Horizontal illumination</td><td rowspan="3">Window to ground ratio, space, depth storey height
…</td></tr>
<tr><td>Vertical illumination</td></tr>
<tr><td>Appropriate illumination at 1m visual distance</td></tr>
<tr><td>Color temperature</td><td>Color temperature and color perception</td><td>Wall decoration</td></tr>
</table>

					Color temperature and wakefulness level	color …
				Color	Color preference order	
					Background color and degree of recognition	

3.2 Evaluation target: perception comfort

Perceived comfort is the research goal of this paper, and comfort is people's subjective experience. According to the Chinese interpretation of comfort, “give people a feeling of peace, happiness and comfort”, comfortable spatial experience is the goal that all buildings should pursue except for special spatial needs. In the relationship between “perceived comfort and enviroment”, it is necessary to identify “comfort”, and how to identify it is the first step of corresponding space research. Emotion is the main research object in the field of psychology. Emotion is divided into 7 original emotions and 42 acquired emotions, among which pleasure is one of the 7 original emotions and has the same comfortable experience as comfort. Therefore, emotion recognition method can be applied to comfort research.

3.2.1 Definition and characteristics of emotion

As early as 1884, the definition of emotion began to be discussed, but the exact definition of emotion has not been given. It is generally believed that emotions are physiological, psychological and behavioral functional reactions caused by the relationship between individual subjective needs and objective things. These reactions can be perceived and measured. Human emotions have long been a popular subject of study in the fields of psychology, physiology and neuroscience. “The constitutive theory of emotion holds that emotion is composed of five sub-systems, namely, cognitive component (evaluation), neurophysiological component (physical symptoms), motivational component (behavioral tendency), motor expression component (facial and voice representation method), and subjective sensation component (emotional experience)[3].”

Emotions can be classified into “basic emotions” that we are born with and “complex emotions” that we learn. Basic emotions are closely related to the survival of primitive humans, and complex emotions can only be learned through interpersonal communication. Basic emotions are common to humans and animals. They are acquired without learning. They are also called primitive emotions. There are different types of basic emotions. Happiness, anger, sadness and fear are often listed as the basic forms of emotions in modern research[4]. Therefore, each person has a different number of complex emotions and defines emotions differently.

Many schools of thought define emotions to reflect these characteristics and these kinds of relationships. For example, functionalism defines emotion as a psychological phenomenon that relates individuals to events of environmental significance. (Campos, 1983).

Arnold defined it as: “Emotion is the tendency to experience something beneficial towards perception and harmful away from perception. This tendency to experience is accompanied by a corresponding physiological change pattern of approach or retreat.” (Arnold, 1960).

Lazarus offered the same definition as Arnold Reis: “Emotion is the organization of physiological and psychological responses to good or bad information in the ongoing environment, which depends on short-term or continuous evaluation.” (Lazarus, 1984). These definitions identify the relationship of emotions to human needs and attitudes. Arnold and Lazarus also pointed out the characteristics of emotions that are associated with them, such as experience, physiological patterns, and evaluation.

3.2.2 Definition of Comfort

Comfort is the most ideal state of human pursuit, common in this professional field is comfort and comfort level. Building design research with comfort or comfort lever as the goal is rare. After searching domestic and foreign literature retrieval sources, 23 papers related to weather prediction and 35 papers related to building focused on thermal comfort were obtained. The discussion of thermal comfort is also mainly used as the index parameter of air conditioning design. This paper will comprehensively study comfort and comfort, and synthesize qualitative and quantitative research methods to obtain more accurate design indicators for the elderly.

The definition of comfort: feel at ease. Jia Sixie in the Northern Wei Dynasty Qi Min Yao Shu cattle, horses, and mules : “ Eat and drink as you like, you will feel comfortable. As for fecal drowning, there is no need to clean it up.”Poet Su Shi of Song Dynasty Sleeping land record also has an explanation of comfort: “The person is quiet and comfortable, with no disease pain.”

“Comfort” is the subjective feeling of people, and it is the pleasant psychological perception generated when people feel the external environment through the sensory organs under various activities. The term “comfort level” is widely used in the field of meteorology: The “comfort level” of human body refers to whether people feel comfortable in the natural environment and to what extent without taking any measures to prevent cold or heat. The “comfort” index of human body can be divided into nine levels: very cold, cold, cool, cool comfortable, most comfortable, hot comfortable, moderately hot, hot, very hot, stiflingly hot, extremely hot respectively. The body may produce a variety of physiological feelings to the outside natural environment. The most common reference to “comfort” in architecture is thermal comfort, a measurable measure of comfort developed by the American Air Conditioning Association in the 1970s. Different thresholds of thermal comfort in different climate zones are also proposed in Building Climatology by Professor Yang Liu from Xi ’an University of Architecture and Technology.

3.2.3 Perceived comfort

Comfort is felt through the human sensory organs, so what are the human sensory organs? From the perspective of human anatomy, human sensory organs refer to special receptors in the body, such as visual and auditory sensory organs, whose structures include receptors and their appendages. Sensory organs are widely distributed in the human body, and their structures are different. Some sensory organs can be very simple in structure. For example, free nerve endings related to pain in the skin are only simple endings of sensory nerves. Some are complex. In addition to sensory nerve endings, there are some cells or several layers of structure together formed a terminal organ, such as the tactile corpuscles, the ring layer corpuscles receiving stimulation such as touch and pressure. Some are more complex. In addition to peripheral organs, there are a lot of accessories. Such as for visual organs, in addition to the eyeball, there are lacrimal glands and eye muscles. Finally there are some special sensory apparatus or sensory apparatus.

From the perspective of architectural experience, people can get the cognition of an building space through the stimuli of various sensory organs. Skin can feel the temperature and humidity of the space, get cold and hot perception, and can also get the perception of building materials through the touch of hands and feet. Nasal mucosa is mainly used for taste stimuli, which can be used to determine whether the space air quality and ventilation are good or not. Vision is the most important receptor for the human body to perceive enviroment. Through the perception of light, the space size, color, the relationship between indoor and outdoor space and other features can be obtained, thus producing the inner feelings of narrow, spacious, noisy, pleasant and so on. Hearing can judge the size of space by the intensity of the sound heard...... All the receptors of human body can not only obtain the perception of space individually, but also form the result of perception comprehensively. These perceptions rise from the physical feeling to the subjective experience of space, and obtain the subjective evaluation of space.

From the classification of human receptors, it can be found that space perception is actually the comprehensive effect of all receptors in the human body. Objective perception of space can be obtained not only through physical or chemical stimuli of exteroceptors, but also through interoceptors. For example, changes in temperature and humidity can be sensed by internal receptors of blood vessels. The temperature change in turn constricts or dilates the blood vessels and reflects back to the head causing the sensation of cold and heat. Some space perception of human body can also be felt through proprioceptors. For example, height changes and material changes on the ground are obtained by the sense of touch on the sole of the foot and the equalizer of human cochlea.

From the perspective of psychology, people’s understanding of the external environment is actually a process of “sense-perception-cognition”, that is, a process of gradual rise from objective intuitive feeling to subjective cognitive impression. In the design of building space, the ideal design goal is to create a “comfortable” building space environment. As can be seen from the above psychological cognitive diagram, if the ultimate cognitive goal is comfort, people must have a comfortable feeling experience when tracing back to the perception level. How do you make people feel comfortable? Each subject’s feeling is different, and how to judge the people’s comfortable feeling in a broad sense?

3.3 Research route: "Human factor experiment + subjective report"

There are two conception in the paper, the one is "architectural experience comes from the physical interaction between human and the world", the other one is "physical and mental changes can be discerned through technical means".That means people are affected by the change of the enviroment and

Early psychological research belongs to the philosophical category, so it was called philosophical psychology. The research of philosophical psychology can be traced back to ancient civilizations such as China, Egypt, Greece and India. However, as an independent discipline psychology began in the 1870s and broke away from the maternal body of philosophy without its own research paradigm and research methods. If it wants to break away from the dilemma of pseudoscience and non-science as soon as possible, psychology have to imitate the research methods of physics and mathematics and to use experiments and data to prove its science. In 1874, the German physiologist Wilhelm Wundt proclaimed in the introduction to his textbook, Principles of Physiological Psychology, "to establish a new scientific field." Wundt was therefore called the "Father of Psychology". In his article "Psychology in the Language of Physics," Biecarnap writes, "All physiological discourse is a description of physiological processes, but also of the physiological behavior of humans and other animals. The words of psychology can be transformed or translated into the words of physics, because the language of physics is the most basic language. For example, if some language, then the study of emotions is a scientific study. Such extreme thinking has led scholone is angry, it can be translated that his heart beats faster and breathes heavily." If the psychological language describing individual emotions can be converted into physical ars to equate emotions with physiological reactions or changes in the body. Accordingly, physiological experiments have become the main methods of emotional research.

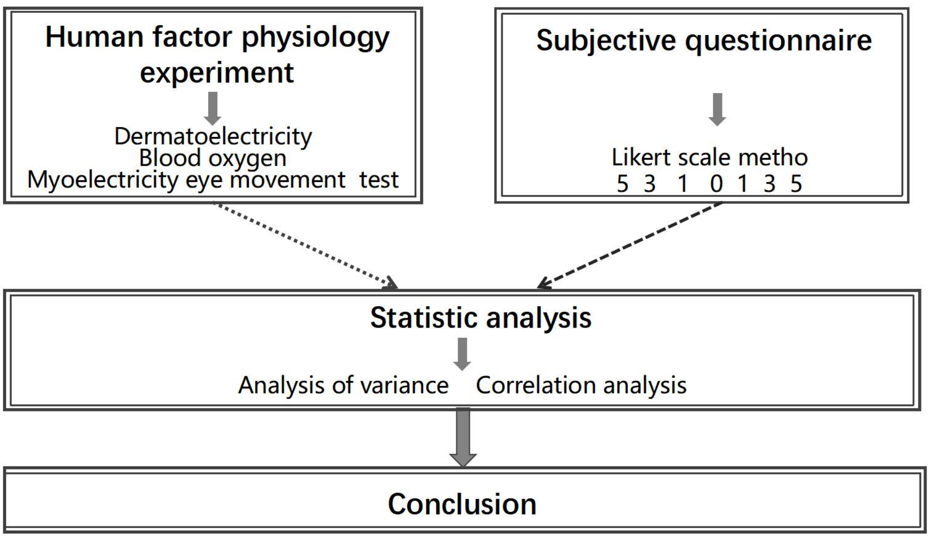


Fig. 3- 1 The layout of research route

3.3.1 Human factor experiment

(1) Human factor engineering

Human factor engineering is a marginal discipline developing in recent decades. It studies the optimization of human-machine-environment system from the perspective of human physiological and psychological characteristics, so as to improve the efficiency of the system and guarantee the safety, health and comfort of the customer. The field of human factors engineering involves almost all systems related to “people”. The foreign development of human factor engineering discipline have experienced the embryonic stage (scientific management), the initial stage (fatigue research, personnel selection and training), the growth stage (man-machine interface design), and the development stage (the application field and application scope are constantly expanding). Our research was 20 ~ 30 years later than overseas, and the real development was after 1980, mainly learning and introducing foreign engineering theory and methods.

Since foreign people studied engineering earlier, it can be seen from the published papers that most of them aimed at solving practical problems in production and life, and the research hotspot was constantly updated to adapt to the social and economic development, leading the academic frontier. In recent five years, foreign researches on human factor engineering include human body research, work load and occupational health, work environment research, workplace improvement and work methods research, human factor engineering and industry research, special population research, product design and evaluation, human-machine system overall research, human factor engineering research in organization and management, and human factor engineering project cost performance analysis. The number of foreign academic papers on work load and occupational health is the largest (17.01%), which reflects that foreign scholars are fully aware of the relationship between human characteristics and work tasks, and analyze and solve problems from the perspective of maintaining human health and sustainable development to achieve a win-win situation between human and work. At the same time, in the aspect of product and tool design evaluation (16.32 %), in addition to general industrial products and consumer goods, the research on special goods and product feeling characteristics design has also begun. As a special resource, human factors play an important role in production, management and life. Researchers have also conducted more studies on how to apply human factors engineering thought to solve practical problems in the process of organization and management (15.97%). The study of workplace and working method (12.50%) and man-machine system optimization (9.03%) are still important research directions. Research on special groups (10.42%) received attention, such as product design suitable for the disabled, product design for the elderly, computer users’ vision problems, etc., which is more in line with the people-oriented requirements of the times. Human studies (6.25%) mainly focused on digital anthropometry, human modeling and simulation, and health standard development. Industry research focuses on how to apply the knowledge and experience of various research fields of human factors engineering to a specific industry, such as agriculture, railway transportation industry, how to apply human factors engineering in the production process? Research papers in this direction also accounted for a certain proportion (4.51%). When implementing human-induced engineering projects or quoting human-induced engineering ideas, researchers began to consider the cost performance problems caused by them (3.82%).

As for the current situation of Chinese human factor engineering research, the field of for Chinese human factor engineering research can be divided into 11 directions which are human occupation and quality research, work environment research, product design and evaluation, human error and safety, work load and fatigue, work methods and site design improvement research, cognitive effects, man-machine system research, organization and management of human factors, human factors engineering research in advanced technology and human body research, etc. . From the longitudinal point of view, the number of papers published each year shows a small increase state. The largest proportion is human factor engineering in organization and management (15.97%), indicating that the theoretical circles can grasp this science from a macro perspective, and combine with human resource management and management science. The second is the study of people’s occupation and quality (5.28%), through which the health standards or career standards of employees are formulated. The proportion of work environment research (5.28%) and of man-machine system research (10.55%) is similar, which indicates that people’s work comfort, coordination between people and machines and man-machine interface issues are widely paid attention to. In addition, the study of human error and system safety (12.14%) is widely paid attention to, especially the analysis of traffic accidents and safety protection of production system. Work load and fatigue (5.01%), product design and evaluation (6.60%), work method and site improvement research (5.01%) account for a small proportion. Human factor engineering research in advanced technology (5.28%) began to appear. The study of human cognitive ergonomics (3.43%) involves human information processing system and human mental load measurement, which is of great significance to the design of modern man-machine system.

To sum up, the human factors project is a study with “human” as the research object and with “efficient work”, “safety and health”, “coordination and comfort” of people as the research goal. The research of human comfort will be done by means of human factor engineering.

(2) Comfort research in human factor experiment

Human factor engineering is the research of human - machine - environment system. Many problems in human factor engineering depend on experimental and statistical analysis results . In addition to the traditional investigation method, observation method, experiment method, sensory evaluation method, psychological testing method and schema model method, the research methods and means of other disciplines have also been introduced, such as fuzzy mathematics, hierarchical analysis, decision analysis and prediction and other ergonomics, and they have become effective tools for human factor engineering research.

Comfort is the subjective evaluation of people. The traditional research method is the sensory evaluation method, which can obtain people’s subjective feelings by setting questionnaires. With the development of science and technology, people began to consider that subjective feelings vary from person to person and have personality differences. On the basis of pursuing scientific and objective research results, sensors such as electrodermic apparatus and ECG appeared. They can be used to make objective evaluation based on objective comfort and stable physiological records of the human body, such as heart, brain and blood pressure. Then people use mathematical methods such as fuzzy mathematics and hierarchical analysis, comprehensively analyze the subjective evaluation and objective records, and finally construct a reasonable model formula to obtain a more accurate and scientific comfort research result.

Physiological signal measurement method: Identify emotions through the measurement of ECG, EDA, breathing and other autonomic physiological signals or EEG, cerebral blood oxygen signals based on central nervous signals. Physiological changes are controlled by human autonomic nervous system and endocrine system. Physiological signals are generated spontaneously by human body and cannot be disguised, so they can reflect people's emotions more truly and objectively. Therefore, emotional recognition can be carried out by using physiological signals. The results are more reliable and objective[5]. In 2001, Picard et al. conducted emotional recognition based on human physiological signals. The feasibility of physiological signal measurement was proved[6].

The human factor experiment method adopted in this paper is developed from the emotional recognition of psychology. It is a relatively objective and accurate method to collect physiological indicators of human body and then analyze the emotional changes of human body by using physiological signal measurement method.

3.3.2 Subjective questionnaire

Subjective reporting method: The evaluation and recognition of emotional states by self-testing questionnaires and psychological interviews[7]. Self-report method is a method to fill in the recent emotional response of the subjects by using various emotional rating scales and other relevant contents of the questionnaire. It is the simplest and easiest way to measure emotions, and is most commonly used to measure subjects' subjective emotional experience. It is generally believed that effective emotional self-reporting is an all-or-nothing phenomenal response. Robinson and Clore (2002) summarized the potential process of emotional self-reporting and proposed an accessible model of emotional reporting, arguing that the effectiveness of self-reporting varies with the type of self-reporting. Self-reporting based on current emotional experience (online state) gives accurate reports based on the information of an individual's current experience, while recalling past events The emotional experience report (offline state) was based on the reconstruction of contextual memory and semantic information, and the former appeared to be more effective. A large number of studies have supported this view. For example, researchers asked men and women to report their own overall emotional characteristics and current emotional responses to daily life events, and found significant gender differences in overall emotional characteristics, while very small gender differences in current emotional responses to daily events (Barrett et al., 1998), suggesting that characteristic reports of emotion are more likely to be biased than reports of immediate emotional experience after an event. Similar results were found when individuals were asked to rate their reactions to past or future emotional events (Mitchell et al.,1997). However, studies have shown that "online" reporting of emotions may also be highly biased among certain groups of people. For example, it is generally believed that individuals with high social expectations are more unwilling or unable to report negative emotional states (Welte & Russell, 1993). Another individual variable is alexithymia. Studies have shown that individuals with high alexithymia can respond to emotional stimuli, but cannot self-report their emotional experiences (Lane et al., 1997).In summary, there are often individual differences between conscious and willing reporting of emotional states. Emotional self-report method obviously supports the theory of emotional dimensions. Studies of such methods clearly believe that the classification of dimensions such as valence and arousal (Russell& Barrett, 1999), or approach and avoidance tendency (Watson et al., 1999) are the main sources of individual emotional differences. Therefore, the first task of any self-reported emotional characteristics is to examine the correlation of self-reported emotional dimensions (Watson, 2000).

Although the subjective reporting method is relatively simple, it requires the experience judgment of professionals and the high cooperation of subjects. The reliability of the final results will be affected if the subjects have a wrong understanding in the evaluation or deliberately conceal some problems. Therefore, subjective reporting has become an auxiliary method in emotion recognition.

3.3.3 statistic analysis

3.3.4 Summary

As a method of emotion study, emotion measurement has been concerned by researchers from the very beginning. This paper reviews the commonly used emotion measurement methods and their sensitive measurement objects. It can be found that there are two main problems affecting emotion measurement: one is the choice of research approach. The second is the suitability of different measurement methods.

①As mentioned above, emotion research has been divided into basic emotion approach and emotional dimension approach. The dimension view believes that emotion is organized by potential factors such as valence, arousal and driving state. On the other hand, the basic emotion view holds that each emotion has its own unique subjective experience, physiological arousal and behavioral response. It can be seen from the studies reviewed in this paper that most emotional measurements are based on the perspective of dimensions, such as ANS measurement, surprise response measurement, sound characteristics and other measurement indicators are sensitive to emotional dimensions. Even for the measurement of basic emotions, such as neuroimaging studies, facial behavior studies, etc., the dimensional framework seems to have important explanatory significance. The perspective of emotional dimension and the perspective of basic emotion are consistent in a sense, and different combinations of emotional dimension can define some basic emotion (e.g., anger = negative valence + high arousal + approach drive)(Carver,2004). Most of the existing research measures from the emotional dimension, which seems to be a more rigorous view. The use of multivariate methods (such as multivariate ANS combination measurement, FMRI measurement of brain circuits, etc.) may go beyond the current findings and provide some support for basic emotional ideas.

② The suitability of different emotional measurement methods

The suitability of different emotional measures is crucial to understanding individual emotional states. The degree of suitability of the emotion measurement model is the evaluation standard of the quality of emotion measurement results. Generally speaking, the construction of emotional theoretical models should have indicators to measure suitability, and different measurement methods will have different suitability results. Studies have shown that there is at most a moderate correlation between various emotional measurement results, and it is often difficult to maintain consistent research results (Mauss et al., 2004). Most previous studies have evaluated emotional consistency based on intersubject correlation, which measures whether individuals who react strongly to one emotional component also react strongly to another emotional component. However, researchers have noted that this is not the best measure, and that in-subject analysis over time can better measure the consistency of responses in emotional theory. The current research can completely solve the basic level of emotional research (such as subjective experience of an emotion, physiological arousal and behavioral response, etc.) by using reliable and effective measurement means and in-subject design (Mausset al., 2005). From the perspective of development trend, multiple measurement is the future direction of emotion research. Firstly, existing studies have shown that any emotion is superimposed, and it is difficult to ensure that it is one-dimensional as described by emotion theory. Therefore, any single measurement method cannot accurately construct an emotion model. Second, there may be errors in the results of different emotion measurements, which is normal, because different measurement methods may have different influencing factors. The test and adjustment of these influencing factors are very useful for understanding the nature of emotion. Third, when multiple measures of emotion differ significantly, finding a more specific approach is important to understanding the nature of emotional responses.

3.4 Technical route

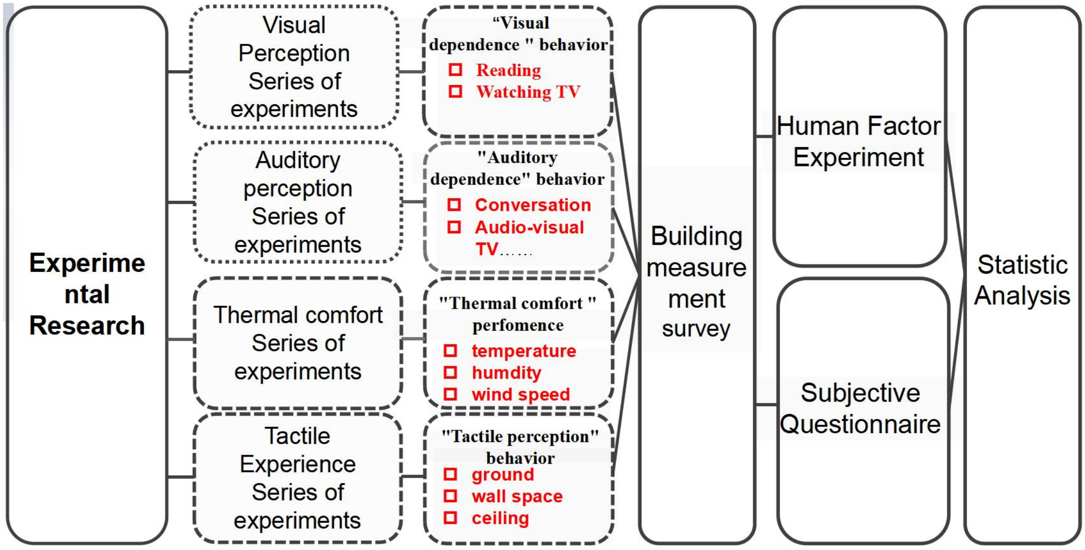


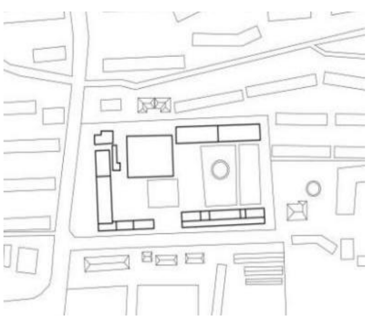
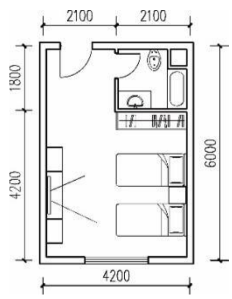
Fig. 3- 3 Research on the status quo of elderly care buildings

3.4.1 Object selection

Combined with the definition types of nursing homes in the existing specifications, as well as the existing form and use of Shenyang nursing homes. In this paper, the scope of nursing homes will be defined as those established and put into use before 2018. Including nursing homes, apartments for the elderly and so on.

Many nursing homes in Shenyang have small area and few beds, the nursing homes with large area and many nursing homes are selected for research, so as to ensure the number of elderly people in the research, comprehensively understand their needs, and facilitate the finding of more practical problems to be solved, and finally to improve the quality of life of the elderly. In addition, the author also went to the largest nursing home in northern Liaoning -- Qinchunyuan Nursing Home in Kaiyuan City (Bed 2000) for research. This nursing home has about 1800 residents, which can meet the research needs.

3.4.2 Summary of research objects

General plan of Qinchunyuan	Unit layout of Qinchunyuan	Qinchunyuan has a total of 5 buildings, including a hospital and 4 residential buildings. The apartment type is mainly twin rooms, which are equipped with toilets, wardrobes, tables and chairs and other furniture. The newly built buildings have leisure areas and open kitchens,
		

<table>
<tr><td></td><td></td><td>while the old multi-room buildings have relatively poor configuration.</td></tr>
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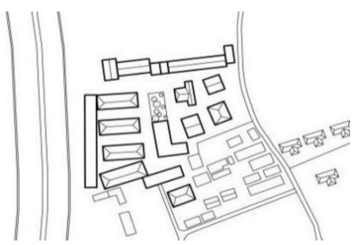
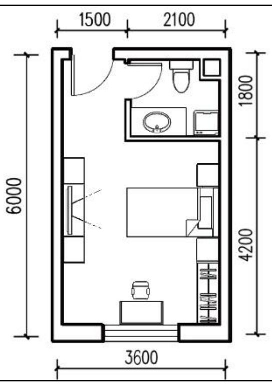
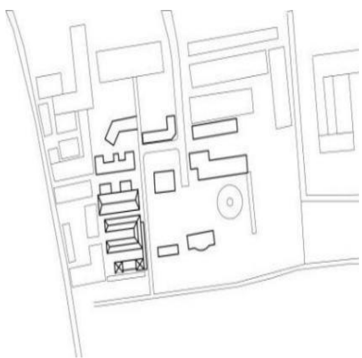
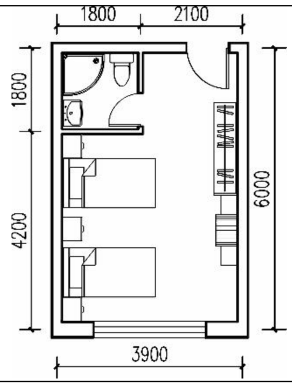
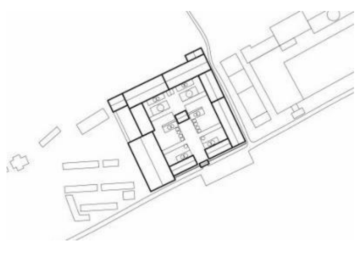
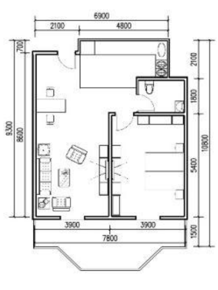
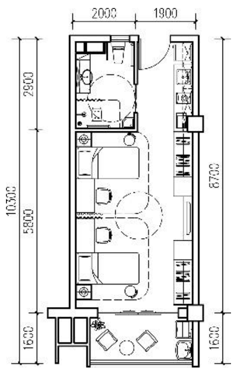
<table>
<tr><td colspan="4">Qinchunyuan Nursing Home, Kaiyuan City</td></tr>
<tr><td>Time of establishment</td><td>2002</td><td>Geographical location</td><td>Kaiyuan City, Tieling City, Liaoning Province</td></tr>
<tr><td>Nature</td><td>Private</td><td>Type</td><td>Nursing Home</td></tr>
<tr><td>Number of beds</td><td>2000</td><td>Number of building floors</td><td>8 buildings
6-storey, 2-storey, 7-storey</td></tr>
<tr><td>Total area</td><td>50000m^2</td><td>Floor area</td><td>100000m^2</td></tr>
<tr><td>Room type</td><td>Single room, twin room, dormitory room</td><td>Number of staff</td><td>187</td></tr>
<tr><td>Receiving object</td><td colspan="3">Self-care elderly, device-helping elderly, the elderly who need complete care, the elderly who need special care</td></tr>
</table>

<table>
<tr><td>General Plan of Tianzhu Mountain Nursing Home</td><td>Unit layout of Tianzhu Mountain Nursing Home</td><td rowspan="2">Tianzhu Mountain Nursing Home is located in Dongling District, Shenyang. It has 15 buildings, including“一”shaped, L-shaped and single-family villas, which can meet the needs of the self-care, assistance and care of the elderly.</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">Tianzhu Mountain Nursing Home (Source： Author's drawing)</td></tr>
</table>

<table>
<tr><td>Time of establishment</td><td>2014</td><td>Geographical location
Geographical location</td><td>Dongling Road, Dongling District, Shenyang City</td></tr>
<tr><td>Nature</td><td>Private</td><td>Type</td><td>Nursing home</td></tr>
<tr><td>Number of beds</td><td>620</td><td>Number of building floors</td><td>5 4-storey villas +1 2-storey building +5 4-storey buildings</td></tr>
<tr><td>Total area</td><td>9800m^2</td><td>Floor area</td><td>19000m^2</td></tr>
<tr><td>Room type</td><td>Twin room,</td><td>Number of staff</td><td>80</td></tr>
</table>

<table>
<tr><td></td><td>three-person room,
four-person room</td><td></td><td></td></tr>
<tr><td>Receiving object</td><td colspan="3">Self-care elderly, device-helping elderly, the elderly who need complete care, the elderly who need special care</td></tr>
<tr><td>General Plan of Xanadu</td><td colspan="2">Unit layout of Xanadu</td><td rowspan="2">Xanadu Nursing Home has 8 buildings, 5 residential buildings, and 3 public buildings to meet the needs of self-care, assistance, and care of the elderly. Outdoor activity field is large, planted a lot of trees, cloth fitness equipment, specially for the elderly exercise.</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td colspan="4">Xanadu Nursing Home</td></tr>
<tr><td>Time of establishment</td><td>1998</td><td>Geographical location</td><td>South of Dongling Bridge, Dongling District, Shenyang City</td></tr>
<tr><td>Nature</td><td>Private</td><td>Type</td><td>Nursing home</td></tr>
<tr><td>Number of beds</td><td>500</td><td>Number of building floors</td><td>4-storey +3-storey +1-storey</td></tr>
<tr><td>Total area</td><td>22000m^2</td><td>Floor area</td><td>68000m^2</td></tr>
<tr><td>Room type</td><td>Twin room,
three-person room,
four-person room</td><td>Number of staff</td><td>39</td></tr>
<tr><td>Receiving object</td><td colspan="3">Self-care, semi-self-care, disabled elderly</td></tr>
<tr><td>General Plan of Gaoshoufu</td><td colspan="2">Unit layout of Gaoshoufu</td><td rowspan="2">Gaoshoufu Nursing Home backs on Tianzhu Mountain, adjacent to Jinglao Road in the south. The architectural pattern is “回” shaped. It has an independent large restaurant and a large recreational multi-function hall.</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Gaoshoufu Nursing Apartment</td></tr>
<tr><td>Time of establishment</td><td>2013</td><td>Geographical location</td><td>Dongling East Street, Dongling District, Shenyang City</td></tr>
<tr><td>Nature</td><td>Private</td><td>Type</td><td>Nursing home</td></tr>
<tr><td>Number of beds</td><td>449</td><td>Number of building floors</td><td>2-storey</td></tr>
<tr><td>Total area</td><td>7400m^2</td><td>Floor area</td><td>12000m^2</td></tr>
</table>

Room type	Twin room, three-person room, four-person room	Number of staff	37
Receiving object	Self-care, semi-self-care, disabled elderly		

General plan of Boai Nursing Home	Unit layout of Boai Nursing Home	
		The area of Boai Nursing Home is small, the main building is divided into two buildings, one building is a “T” shaped layout, the other building is a “一” shaped layout , the interior has a small courtyard landscape and activity venue for the elderly to carry out recreational activities.

Boai Nursing Home			
Time of establishment	2005	Geographical location	Chengde Road, Shenhe District, Shenyang City
Nature	Private	Type	Nursing home
Number of beds	150	Number of building floors	3-storey
Total area	1700m^2	Floor area	1200m^2
Room type	Twin room, three-person room, four-person room	Number of staff	27
Receiving object	Self-care, semi-self-care, disabled elderly		

Table 3- 4 Summary of research objects

Reference

[1] China Mental Health Association, China Employment Training Technology Guidance Center. Psychological counselor (Basic knowledge) : National Publishing House, 2015

[2] Fan Lu."The Avant-Garde "without Avant-Garde"- A Study on Adolf Loos and His Modernity Conception" The Architect .01(2006):63-72.

[3] Jin Bing Hua et al,eds. Great Dictionary of Philosophy (Revised Edition).Shanghai: Shanghai Dictionary Publishing House, 2001;1140.

[4] China Mental Health Association, China Employment Training Technical Guidance Center. Psychological Consultant (Basic Knowledge) : National Publishing House, 2015.

[5] Wu N, Jiang H, Yang G.Emotion Recognition Based on Physiological Signals.2012,7366: 311-320.

[6] Picard R W,Vyzas E,Healey J,"Toward Machine Emotional Intelligence:Analysis of Affective Physiological State".IEEE Transactions on Pattern Analysis and Machine Intelligence,(2001),23(10):1175-1191.

[7] Xie Jing , Fang Ping , Jiang Yuan. Advances in Emotion Measuring Methods[J]. Journal of Psychological Science,2011，34(2): 488-493.

Chapter 4

4. STUDY ON THE CORRELATION BETWEEN VISUAL COMFORT AND SPACE

CHAPTER FOUR: STUDY ON THE CORRELATION BETWEEN VISUAL COMFORT AND SPACE

4.1 The relationship between visual dependence behavior and space

4.1.1 Relationship between visual ability of the elderly and architectural space

(1) Visual sensitivity and spatial brightness requirements

With the increasing of age, the visual acuity of the elderly will decrease correspondingly. As a result, the elderly cannot see many small things clearly, which will cause a lot of inconvenience to their daily activities such as reading books and newspapers, threading needles and so on. In addition, visual acuity can be divided into static and dynamic ones. Dynamic ones decline more obviously than static ones, so the effect of observing dynamic moving objects will be worse for the elderly. With the increasing of age, visual acuity continues to decline. The elderly fall easily because they can’t see objects clearly. More spacious windows are needed to improve indoor illumination to meet the visual needs of the elderly.

(2) The relationship between visual space perception and spatial change

As mentioned above, the space perception of the elderly is weakened, and it is difficult for them to detect many small things. Especially in the turning place of indoor space, such as the floor junction of bedroom and bathroom, the floor junction of living room and kitchen, the corner of the wall and other places with spatial variation. The elderly cannot judge the spatial relationship accurately or distinguish the relative relationship between the front and back of the space, so they will easily fall. Therefore, special signs are needed at the turning point of space to stimulate the eyes of the elderly to remind them to pay attention.

(3) Color recognition and decorative style (spatial details)

In the former chapter, we analyzed a series of changes in the elderly’s eye lens and came to the conclusion that the elderly’s color perception gradually became weakened. We should not use the color which is difficult to distinguish in alarm button related to safety issues. Instead, we should use logo of obvious color. For the wall color, we should use long wavelength color such as orange and other warm colors.

(4) Glare sensitivity and avoidance

Due to astigmatism in the elderly, the contrast of retinal imaging in the elderly’s eyes will be reduced, which will lead to decreased visual function. Moreover, the elderly will suffer from uncomfortable glare when facing direct sunlight outdoors and light from windows indoors, which will make it difficult for them to distinguish specific objects. Therefore, we should pay attention to the illumination of the elderly room. If the light from side to center is too bright, there will be blind glare. Although the elderly need more light to distinguish the space environment, glare should be absolutely avoided in the elderly’s living environment.

4.2 The Effect of Daylight Illumination in Nursing Buildings on Reading Comfort

4.2.1 Introduction

Globally, an increasing number of people are aging; consequently, the quality of life of elderly persons has become the focus of the international community. It is crucial to provide a comfortable lighting environment for elderly persons. Due to visual decline [1], special consideration should be given to the lighting design of their living spaces. Reading is among the most popular leisure activities among elderly persons [2][5] However, with age, the ciliary muscle loses its ability to contract and the pupil size decreases, resulting in presbyopia [6]. There is insufficient light intake for narrow pupils. Hence, elderly persons often need higher illumination to make up for the decline in visual ability. Studies have shown that illumination considerably influences the reading ability of elderly persons with low vision [7]. As the world's population ages, many countries and institutions have studied the illumination standard of reading for elderly persons and recommended specific values and ranges. However, lighting design standards in different countries do not have an agreed illumination value required for reading. The Architectural Lighting Design Standard of China [8] stipulates that, typically, reading lighting in the bedroom should be 300 lx. American National Standards Institute (ANSI) lighting standards [9] stipulate that reading lighting in the bedroom is 750 lx. The Lighting Handbook of Japan [10] stipulates that reading lighting in the bedroom is 600–1500 lx. Some scholars have conducted studies on the illumination preferred by seniors in terms of reading. Robert G. Davis conducted an experiment on the visual preference of elderly persons when reading under 1076, 107.6, and 10.76 illuminations. Results indicate that the favored illumination of elders was 1076 lx [11]. Zhang and Ma investigated the visual executive power and subjective comfort of elderly persons when reading under 50, 300, and 1000 lx. The results showed that elderly persons had the best visual executive power and relatively good subjective comfort when reading under 1000 lx [12]. The standards and research listed above were set or carried out under the assumption of artificial lighting. According to the living habits of the elderly persons, it is normal for them to read in daylight in front of windows. In the context of carbon peaking and carbon neutrality, it is also encouraged to make full use of daylight in daily activities. However, no detailed regulations apply to daylight illumination in the lighting design standards according to indoor activities of elderly persons in China, Japan, or the United States.

Illumination is a common parameter for evaluating the quality of daylight environment, and lighting evaluation methods such as DF, DA, and UDI all use illumination as the basic parameter. Illumination has an important supporting role for human visual function, and is not only the most important photometric indicator for elderly persons to complete reading tasks, but also one of the important indicators for evaluating the comfort and health associated with the lighting environment. Furthermore, elderly persons, as a special social group, have a certain dependence on daylight [13]. Physiologically, daylight can regulate the secretion of melatonin in their bodies and promote the absorption of calcium ions. Psychologically, daylight can reduce the risk of depression in elderly persons. Although they have different needs for daylight, they are highly satisfied with activities performed in a daylight environment [14]. As such, it is of great significance to focus on the impact of daylight illumination on the reading behavior of elderly persons in nursing buildings.

The main purpose of this study was to investigate daylight illumination of comfortable reading for elderly persons. “Comfort” is a state of relaxation and peace without physiological pressure, which is related to the overall state of a person. The full range of factors, both mental and physical, can be described as being involved in the state. Traditionally, subjective questionnaire surveys are commonly used in comfort-related research, such as human perceived comfort experience and comfort evaluation. This paper refers to the methods used in international research on emotions. Based on the view that “comfort” includes not only physical sensations, but also psychological factors [15], the combination of a physiological index measurement and a subjective questionnaire survey was used to analyze state arousal level and visual comfort in the reading of elderly persons. The effect of different levels of daylight illumination on reading by elderly persons was then explored.

4.2.2. Materials and Methods

4.2.2.1. Research Subjects

Elderly persons living in senior care institutions were the research subjects of this study. The enrolled subjects met the following requirements: self-care elderly people aged 60–89, graduated from primary school or above, with normal naked or corrected vision, no color blindness, cognitive impairment, or Alzheimer’s disease, and reading behavior at least twice a week. A total of 30 seniors were enrolled, 15 men and 15 women.

4.2.2.2. Reading Materials

To reduce the impact of different reading materials, fonts, and other factors on the physiology and psychology of elderly persons, the length of each reading activity was controlled; also, the reading material was provided by our research group. The newspaper was selected as the experimental reading material (**Fig. 4-1**). The background color of the newspaper was light gray and white. The font color was black, and font size was the 12 pt. for Han Chinese characters. Eight paragraphs from eight issues of the newspaper were randomly selected. The layout of each paragraph was the same with 100 words each. The reading time of each paragraph was controlled at approximately 5 min, and each paragraph was in the same position of the newspaper. The content of the material was serial articles. Simple and understandable emotional stories were selected to eliminate personal preferences of elderly persons and reduce the impact of article content on their cognitive and emotional states.

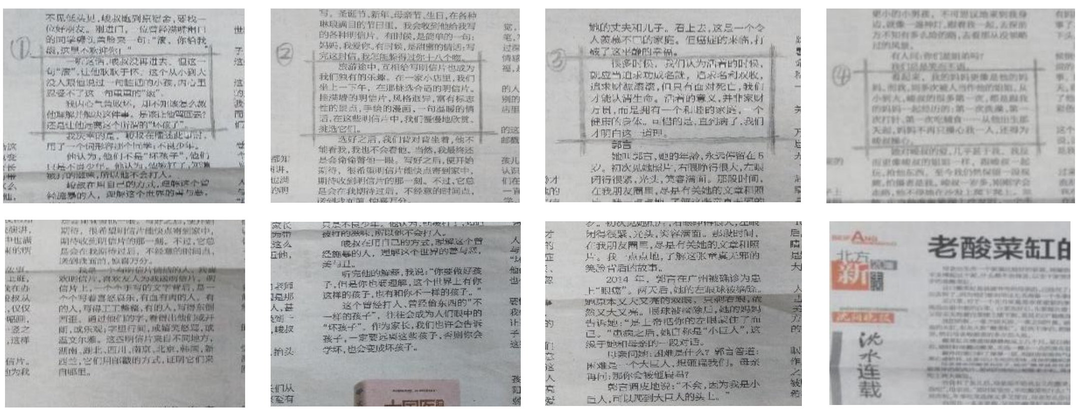


Fig. 4-1 Reading materials.

4.2.2.3. Daylight Illumination Measurement

This study was based on the residential building of an elderly care institution in Dongling District, Shenyang, China. The building was established in 2014, with four floors and 12 households on each floor (**Fig. 4- 2**). All dormitories are single rooms, with a size of 3.6 × 6 m. These dorms include bedrooms, a leisure area, and independent bathrooms. The walls and ceilings in the room are painted white, and the floor is made of brown wood. The window in the room has a size of 2 × 1.8 m and is a height of 1 m from the ground, and faces south.

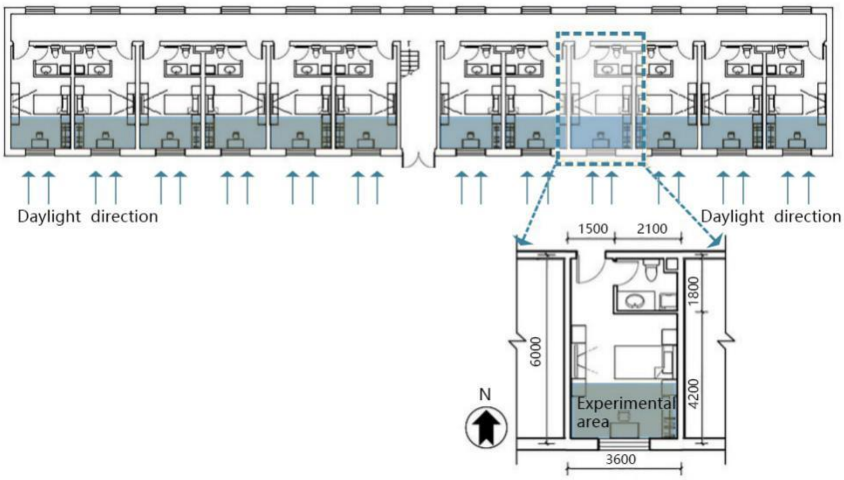


Fig. 4- 2 Floor orientation and room layout.

The elderly persons read experimental materials on the desk under the window. The desk is 0.75 m high, and the chair is 0.42 m high. After a survey of 30 elderly persons, their one-day activities were summarized in Table 4- 1, and experimental time was finally determined. The illumination was measured between 8:00 and 10:00 every morning. Combined with the Architectural Lighting Design Standard of China, the illumination range of the experiment was set as 300–1000 lx. Prior to the start of the experiment, the elderly persons were free to change the illumination using the curtains. A TES-1330A illumination meter (TES Electrical Electronic Corp.) was used to measure the illumination before the elderly persons started reading. Electrodermal activity (EDA) data were received in real time using a laptop placed on the table at the rear left of the subject (Fig. 4- 3).

Table 4- 1 The general situation of nursing homes.

Timetable	5:00-6:00	6:00-8:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	16:00-18:00	18:00-21:00	21:00-05:00
Bed room	B	I	A		K		L, E	D	K
Dining room		L		L					
Chess room			J			H			
Reading room									
Outdoor	F					G		N	
Foyer				M					

Types of activity: A. Reading books and newspapers; B. Getting up; C. Using computer; D. Watching TV; E. Doing housework; F. Fitness; G. Walking; H. Playing mahjong; I. Raising flowers; J. Play chess; K. Sleeping; L. Eating; M. Chatting; N. Dancing P. Others.

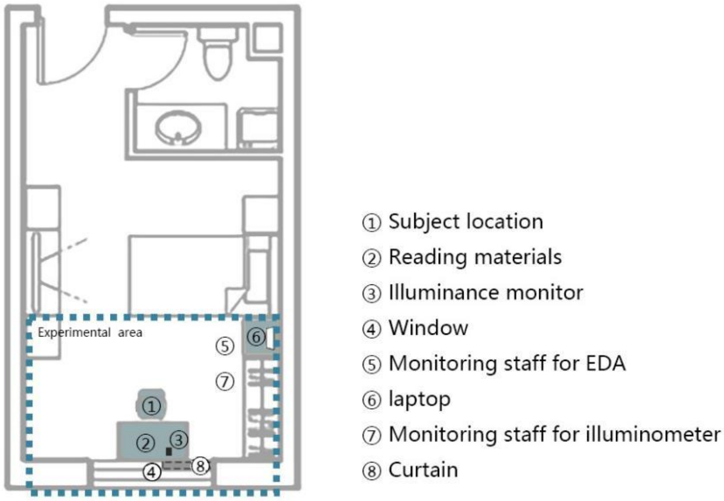


Fig. 4-3 Experimental area plan.

The final illumination value was determined using the mean value of the illumination at the midpoint of each side of the reading material and the intersection of the diagonal (Fig. 4-4). To reduce the fluctuation in daylight illumination, reading material with fewer words was first chosen in order to minimize the reading duration. Based on the experience during the pre-experiment, the elderly persons are not sensitive to changes in illumination within 50 lx. Thus, when the experiment was carried out, the illumination meter was placed close to the top of the reading material, and data that did not change beyond 50 lx throughout were adopted. A staff member stood at the left rear of the elderly persons and observed the illuminance meter's value on the table throughout the process to control the illumination change during the experiment (Fig. 4-5) in order to avoid the problem of glare or uneven illumination during the experiment, which may have caused discomfort to the elderly persons. Before the experiment, the elderly persons could slightly adjust the position of the curtain, chair, and reading materials according to the actual situation (Fig. 4-5). At the end of the experiment, elderly persons were asked if they encountered glare or excessive fluctuations in their visual field brightness. Data collected when this occurred were eliminated. The measurements were performed over 20 weeks from September 2017 to March 2018, and 217 valid data points were obtained.

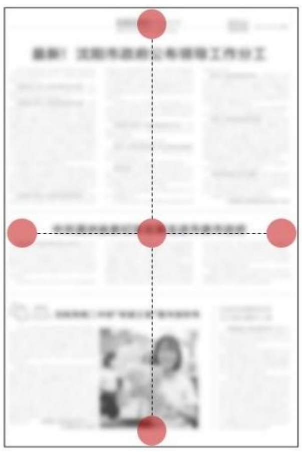


Fig. 4-4 The selected points of the illumination value.

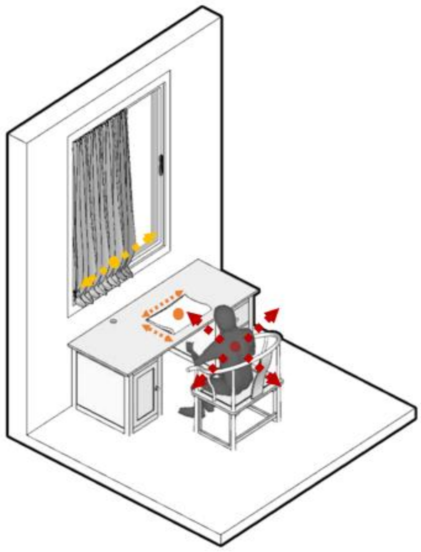


Fig. 4- 5 Adjustable position.

4.2.2.4. Visual Comfort Level Measurement

(1) Measurement of Skin Conductance

When an individual engages in cognitive activities or is exposed to particular emotional stimuli, areas of the brain such as the anterior cingulate gyrus and the amygdala act, resulting in a sympathetic nervous system reaction [16]. The more excited the sympathetic nervous system becomes, the more stimulated the sweat glands become. In addition, the sweat glands secrete sweat to the skin surface through pores in the skin. When a balance between positive and negative ions in the secretion occurs, the skin conductance (SC) changes. Changes in SC thus indicate the activity level of specific areas of the brain during reading tasks, notably crucial cognitive and emotional activities. According to research, the neural systems of emotion and cognition are closely interwoven, and both positive and negative emotions play a role in learning and remembering [17]. Thus, it can be seen that the shift in SC indicates the state arousal level of the elderly persons during reading. However, it is possible that a well-lit environment facilitates the arousal or that the arousal compensates for the annoyance produced by a poor light environment. This was investigated further with the subjective questionnaire. The mean of the time-domain characteristics of the SC can reflect the average level of electrodermal activity in the statistical period [18]. The greater the absolute value of the mean change rate in different periods, the higher the state arousal degree.

An electrodermal activity (EDA) wireless physiological sensor (KingFar International Inc. Beijing, China) was used to collect and monitor the data of the SC indicators. Data storage and analysis were performed with a human–machine environment synchronization experimental platform (Ergo LAB). During reading, the elderly persons needed to wear the EDA wireless physiological sensor on the palm via an electrode so that the original physiological signal could be collected and transmitted to the Ergo LAB experimental platform in real time (**Fig. 4- 6**). The experimental platform has built-in filtering methods such as Smooth, Guass, and Hann, which can extract SC index data from the collected original signal and analyze the mean of SC time-domain characteristics in the corresponding time window.

(a) Human–machine environment synchronization experiment platform (b)EDA modules (c)Physiological sensing kit (d)Wearing instruments

Fig. 4- 6 Instruments.

(2) Subjective Questionnaire

This research established two evaluation methods: a subjective comfort questionnaire and electrodermal activity measurement. The questionnaire was designed for the subjective visual comfort of elderly persons when reading at different illumination levels. The question was “What is your visual comfort level when reading at this illumination level?”. The 5-point Likert scale method was adopted, in which five evaluation scales, from very uncomfortable to very comfortable, were used (Fig. 4- 7). There is no academic consensus on the concept of “visual comfort,” and there are two widely used methods of evaluating visual comfort: One of them is the “no annoyance method”, which states that no discomfort is considered comfortable. In other words, no physiological pain or irritation is considered to be visual comfort. Another is the “well-being method”, which is based on subjective happiness and satisfaction [19]. In this study, “visual comfort” was defined as a state in which the reading task could be accomplished without physical or psychological stress by combining these two ways.

At the end of reading, the persons enrolled in this study were asked whether they had fully seen and understood the reading materials. The data from the cases when they could not fully see and understand the reading materials were excluded. All respondents were informed of the purpose of the study and how the data would be used before filling out the questionnaire. According to the requirements of local legislation and institutions, this study did not require ethical review and approval. A total of 240 questionnaires were distributed, and 217 valid questionnaires were returned, with a recovery rate of 90%.

Q: What is your visual comfort level when reading at this illumination level?

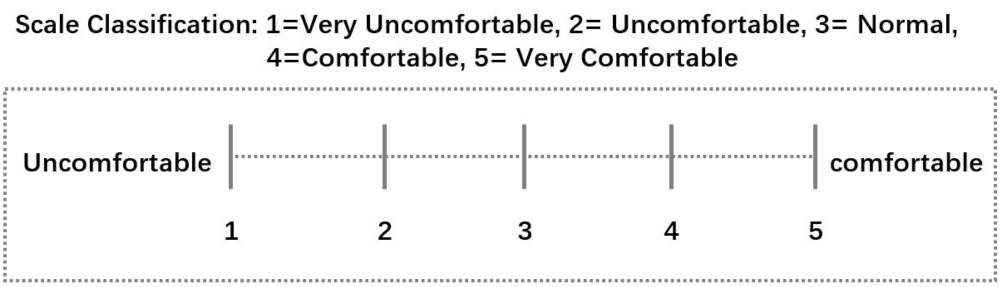


Fig. 4- 7 Subjective psychological evaluation scale.

4.2.2.5. Experimental Process

Before the experiment, the physiological signal baseline of the elderly persons was collected for 5 min in a daylight environment with approximately 300 lx illumination and uniform light. The mean value of the SC time-domain characteristics during this period was considered the baseline value. The collection site was on a chair next to a desk in the elderly person's own bedroom. The posture was a natural sitting posture, and the ambient illumination was adjusted using the curtains. The baseline only needed to be collected once, and there was no need to repeat it before every illumination.

After the baseline was determined, the participants could adjust their comfortable reading posture by themselves or adjust the illumination of the surrounding daylight by adjusting the curtains. After 3–5 min adjustment time, reading could start. The illumination value was randomly set in each experiment, in order to reduce the impact of the previous illumination value on the elderly persons; time was also left for them to make adjustments after each change in illumination. Throughout the reading process, the elderly persons wore physiological sensors. Ergo LAB human-machine experimental software marked the physiological data in real time at the beginning and end of reading. The recording stopped after the elderly persons finished their reading. Subsequently, the elderly persons began to complete the subjective questionnaire. The staff asked the elderly persons whether they experienced any discomfort such as glare during reading, and whether they fully saw and understood the content of the reading materials. The entire measurement process is illustrated in the figure below (Fig. 4- 8).

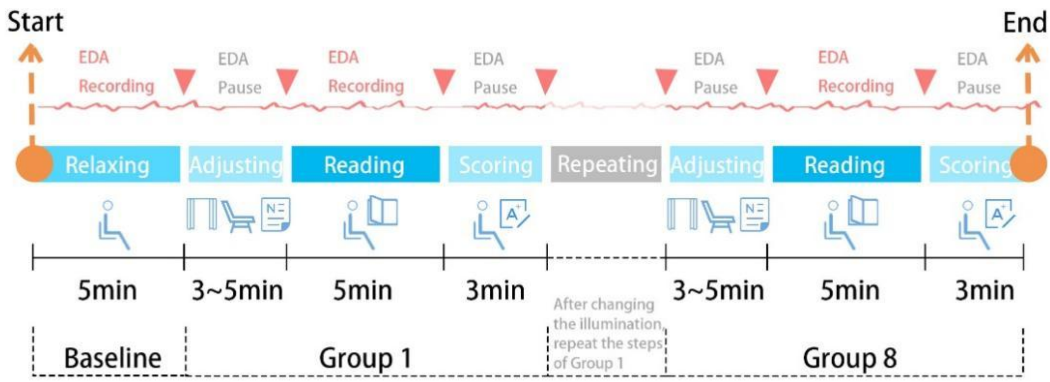


Fig. 4- 8 Experimental process.

4.2.3. Results

4.2.3.1 Daylight Illumination Measurement Results

A total of 217 illumination data points ranging from 300 to 1000 lx were used; this is the daylight illumination range that is acceptable for the elderly person to read. The questionnaire data and physiological data measured under different illumination levels were grouped according to the distribution of illumination data. The illumination difference corresponding to each group of data did not exceed 100 lx. Eight groups were recognized, i.e., "300 lx," "400 lx," "500 lx," "600 lx," "700 lx," "800 lx," "900 lx," and "1000 lx," with 25 to 30 valid data points under each group (Table 4- 2).

Table 4- 2 Illumination data summary.

Data Summary	
Illumination range	300 – 1000 lx
The total number of data	217
The number of data group	8
The number of valid data under each group	25 – 30

4.2.3.2. Influence of Daylight Illumination on Visual Comfort

(1) Data Preprocessing

Analysis of Covariance

The level of basic electrodermal activity is related to personality characteristics. Individuals who have a higher basic electrodermal activity tend to be more introverted, nervous, and emotionally unstable. In contrast, individuals with a lower basic level are found to be more cheerful and outgoing, and have a more balanced mentality and better psychological adaptation. The time-domain mean of SC of each elderly person under different illumination was plotted on a scatterplot. According to this scatterplot (Fig. 4-9), although the change in the electrodermal activity level of each elderly person was relatively small under different illumination conditions, a large difference in its values between different subjects was observed. This difference may originate from different physiques and cannot be artificially controlled. Covariance analysis was used to explore whether the individual's basic electrodermal activity level would affect the analysis of the SC time-domain characteristic mean under different illumination levels, and to clarify whether the SC time-domain mean values measured by different subjects could be directly compared.

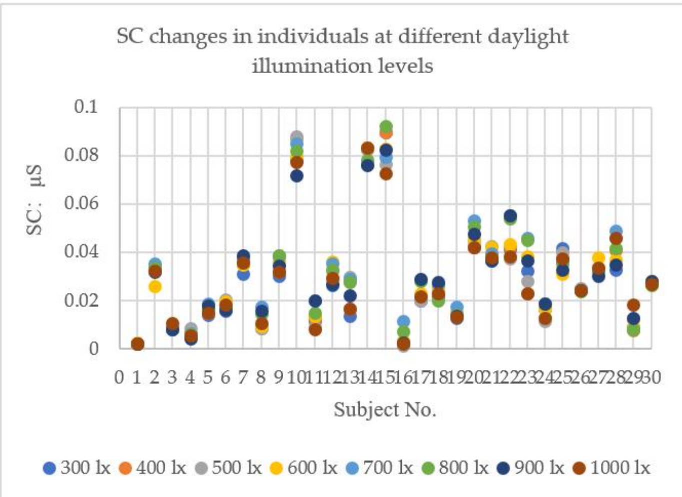


Fig. 4- 9 SC changes in individuals at different daylight illumination levels.

In this study, the SC time-domain characteristic mean values (hereinafter referred to as the baseline value) of the elderly persons during the baseline period was the covariate. The illumination was the independent variable, and the SC time-domain characteristic mean (hereinafter referred to as the SC mean value) under different illumination was the dependent variable. The statistical results of covariance are shown in the table below. The between-subjects effects test shows the baseline value of covariate p (Sig.) = 0.000 < 0.01 (Table 4- 3). Hence, it can be considered that an interactive relationship existed between the SC mean value of the dependent variable and the baseline value of the covariate, indicating that a person's initial electrodermal activity level did affect the electrodermal activity level under different illumination conditions.

Table 4- 3 Between-subjects effects test.

Dependent Variable: SC Time-Domain Mean Values					
Source	**Type III Sum of Squares**	**Degrees Of Freedom**	**Mean Square**	**F**	**p (Sig.)**
Modified model	1033.506 a	8	129.188	525.045	0.000
Intercept Distance	9.049	1	9.049	36.775	0.000
Baseline	1028.447	1	1028.447	4179.796	0.000
Illumination	5.060	7	0.723	2.938	0.006
error	56.838	231	0.246		
Total	3256.463	240			
Total after correction	1090.344	239			

a. R^2 = .948 (After adjustment R^2 = .946)

After deducting the effect of covariate baseline on the experiment, p (Sig.) had a value of 0.006 < 0.05 (Table 4- 4), showing that the illumination of the independent variable still had a significant effect on the SC mean value of the dependent variable.

Table 4- 4 Univariate tests.

Dependent Variable: SC Time-Domain Mean Values					
	Sum of Squares	**Degrees Of Freedom**	**Mean Square**	**F**	**p (Sig.)**
Contrast	5.060	7	0.723	2.938	0.006
error	56.838	231	0.246		

SC Time-Domain Mean Value Normalization

To eliminate the influence of each elderly person's initial electrodermal activity level, it was necessary to perform data normalization. The specific operation of normalization involves subtracting the SC mean value of an elderly person's reading under different illumination conditions from the baseline value, and dividing the result by the baseline value. The change rate Δk obtained is the normalized result. The Δk value indicates the state arousal level. A high Δk indicates high state arousal, whereas a low value indicates low state arousal. The equation below shows the normalization process, where Δk denotes the normalized change rate of the SC. $\overline{X}_{emotion}$ refers to the SC mean value under a certain illumination, and $\overline{x}_{calm}$ represents the baseline value. The formula is as follows [20]:

(2) State Arousal

$$\Delta k = \frac{\overline{x}_{emotion} - \overline{x}_{calm}}{\overline{x}_{calm}}$$

Correlation Analysis

The variance homogeneity analysis of Δk data revealed a significance p = 0.000 < 0.05; thus, it was impossible to use the parametric test. Therefore, the nonparametric Kaplan–Meier (KM) analysis was performed to test the difference between each group of data. The obtained significance was $p = 0.006 < 0.05$, indicating a significant difference. As such, the data could be further analyzed. The illumination and Δk values did not satisfy the normal distribution; thus, Spearman correlation analysis was performed. The results show that the correlation coefficient was 0.108 > 0.01 (Table 4- 5), revealing a significant correlation.

Table 4- 5 Spearman correlation coefficient of illumination and Δk.

			Illuminance	**Δ k**
Spearman Rho	Illumination	Correlation coefficient	1.000	0.108
		Significance (2-tailed)	.	0.097
		Number of cases	217	240
	Δ K	Correlation coefficient	0.108	1.000
		Significance (2-talied	0.097	.
		Number of cases	217	240

Cumulative Analysis

First, analysis of variance (ANOVA) was performed on Δk under each group of illumination to test whether there was significant difference in state arousal under different illumination conditions. A variance homogeneity test revealed that p (Sig.) = 0.460 > 0.05; thus, ANOVA could be continued. The results are shown in the table below. p (Sig.) = 0 < 0.01 indicated a significant difference in state arousal under different illumination conditions (Table 4- 6).

Table 4- 6 ANOVA analysis results.

Δ k					
	Sum of Squares	**Degrees of Freedom**	**Mean Square**	**F**	**p (Sig.)**
Between groups	51.523	7	7.360	6.203	0.000
Within group	242.047	204	1.187		
total	293.570	211			

The Δk value can indicate the arousal degree. The greater the value, the greater the arousal, whereas the smaller the value, the smaller the arousal degree. By accumulating the Δk value under each group of illuminations, the trend of arousal under different illumination conditions can be determined (Fig. 4- 10). For 600–900 lx, the state arousal degree was the largest. Under other illumination values, the state arousal degree was small (Table 4- 7). However, the positive or negative state of each group remained unknown. Thus, further analysis in combination with the results of subjective questionnaire was required.

Table 4- 7 Cumulative Δk value result.

Illumination (lx)	300	400	500	600	700	800	900	1000
Cumulative Δ k	1.93	3.06	3.51	5.34	7.66	6.85	7.18	2.04

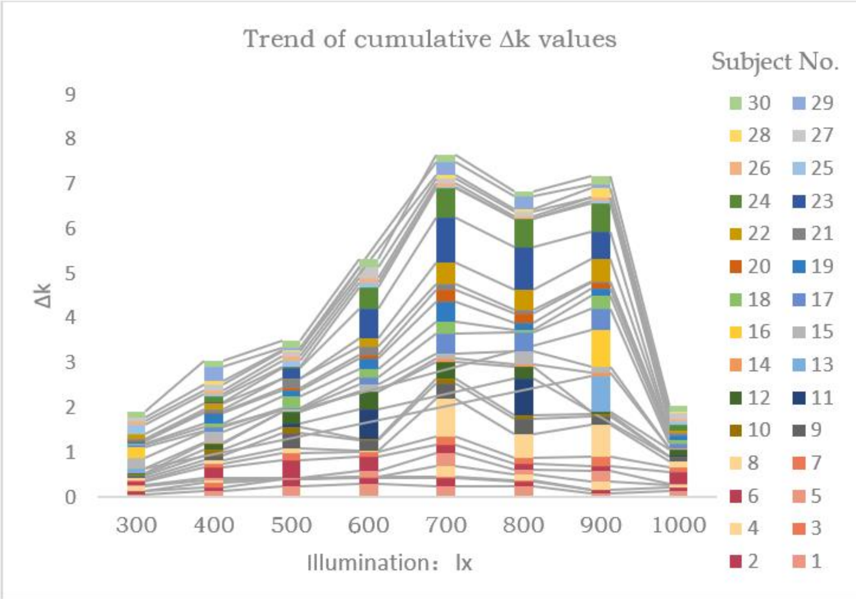


Fig. 4- 10 Trend of cumulative Δk value.

(3) Visual Comfort

Correlation Analysis

The score data of visual comfort questionnaire were analyzed by variance homogeneity, and the significance was $p = 0.387 > 0.05$. Hence, one-way ANOVA was performed, and the significance determined was $p = 0.000 < 0.05$, indicating a significant difference; thus, in-depth analysis could be conducted. The illumination value and comfort score did not meet the normal distribution; therefore, the Spearman correlation analysis was performed. The results show that the correlation coefficient was 0.312 > 0.01, revealing a significant correlation (Table 4- 8).

Table 4- 8 Spearman correlation coefficient of illumination and visual comfort score.

			Questionnaire Score	Illuminance
Spearman Rho	Questionnaire score	Correlation coefficient	1.000	0.312
		Significance (2-tailed)	.	0.000
		Number of cases	240	240
	Illumination	Correlation coefficient	0.312	1.000
		Significance (2-tailed)	0.000	.
		Number of cases	240	240

Descriptive Analysis

The scores of visual comfort questionnaire of each group were counted, and the proportion of “Very Uncomfortable”, “Uncomfortable”, “Normal”, “Comfortable”, and “Very Comfortable” in each group was counted. From the questionnaire scores, it was found that (Fig. 4- 11):

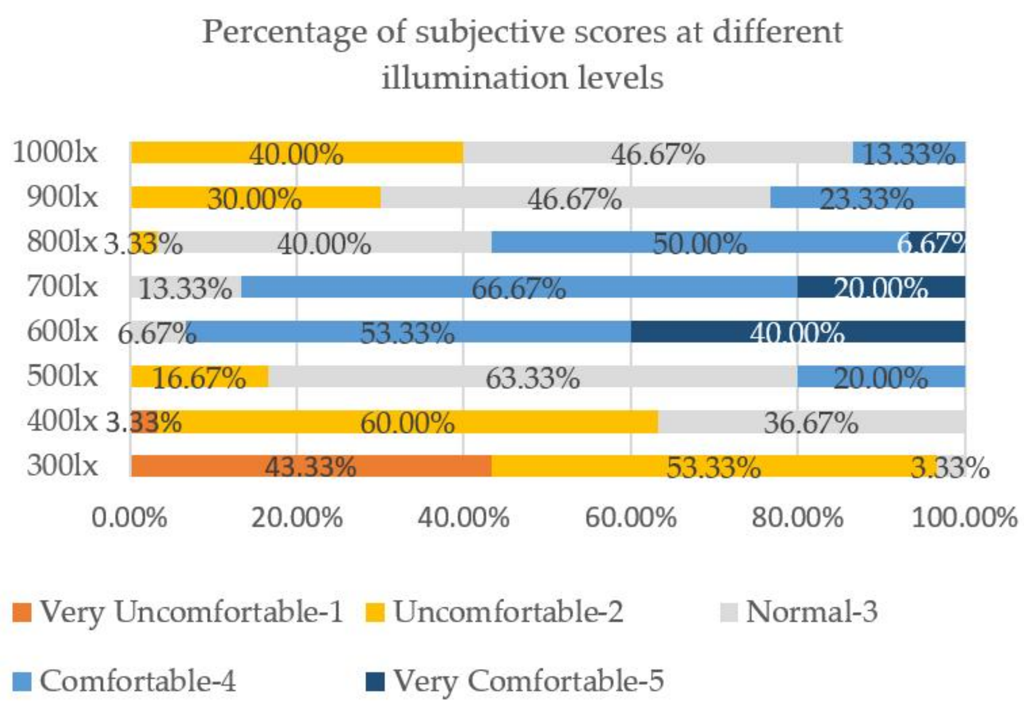


Fig. 4- 11 Percentage of subjective scores at different illumination levels.

1.When the illumination was 300 and 400 lx, the proportion of “Comfortable” and “Very Uncomfortable” below 3 points was very high, reaching 96.66% and 63.33%, respectively. At 500 lx, the proportion of “Normal” had the highest proportion, reaching 63.33%.

2.At 600 and 700 lx, the proportion of “Comfortable” and “Very Comfortable” more than 3 points was very high, accounting for 93.33% and 86.67%, respectively. At 800 lx, the proportion over 3 points still exceeded half, accounting for 56.67%. The proportion of “Normal” of 3 points also reached 40%, and the proportion of less than 3 points was only 3.33%.

3.At 900 lx, the proportion of “Uncomfortable” and “Very Uncomfortable” below 3 points was 30%. The largest proportion is 3 points for "Normal"., accounting for 46.67%. At 1000 lx, the proportion of “Uncomfortable” and “Very Uncomfortable” below 3 points was 40%, close to the proportion of “Normal” (46.67%).

Based on the above situation, it can be preliminarily concluded that 300 and 400 lx resulted in negative visual perception for most elderly persons, who were unable to read without physical or psychological stress. With the increase in illumination, the visual perception tended to be positive at 500 lx. At 600 and 700 lx, positive feedback was obtained from most elderly persons, and their feelings were biased towards comfort. When the illumination was 800 lx, the opinions began to diverge. Although the number of elderly persons who had normal feelings increased, more elderly persons felt comfort. At 900 lx, the number of elderly persons who considered they had normal feelings were in the majority, at nearly half. At 1000 lx, the number of the elderly persons who considered they had normal feelings was similar to that who were uncomfortable, but a small proportion of elderly persons felt comfortable.

By averaging the visual comfort scores under each group of illumination values, the general trend of visual comfort could be obtained (Table 4- 9). The range of discomfort fell within 0–3 points. From the average value, 300, 400, and 1000 lx can be considered as negative discomfort in the range of less than 3 points. The scores under 900 and 500 lx were close to 3 points, which can be judged as normal. The scores under 600, 700, and 800 lx were in the range of more than 3 points, which can be considered as positive comfort.

Table 4- 9 Average value of the visual comfort score.

Illuminatio (lx)	300	400	500	600	700	800	900	1000
Average score	1.6	2.36	3.04	4.36	4.07	3.6	2.9	2.69

4.2.3.3 Daylight Illumination Threshold Analysis

The average score of the visual comfort questionnaire of each group was compared with the accumulated Δk value. The comparison diagram is show in Fig. 4- 12.

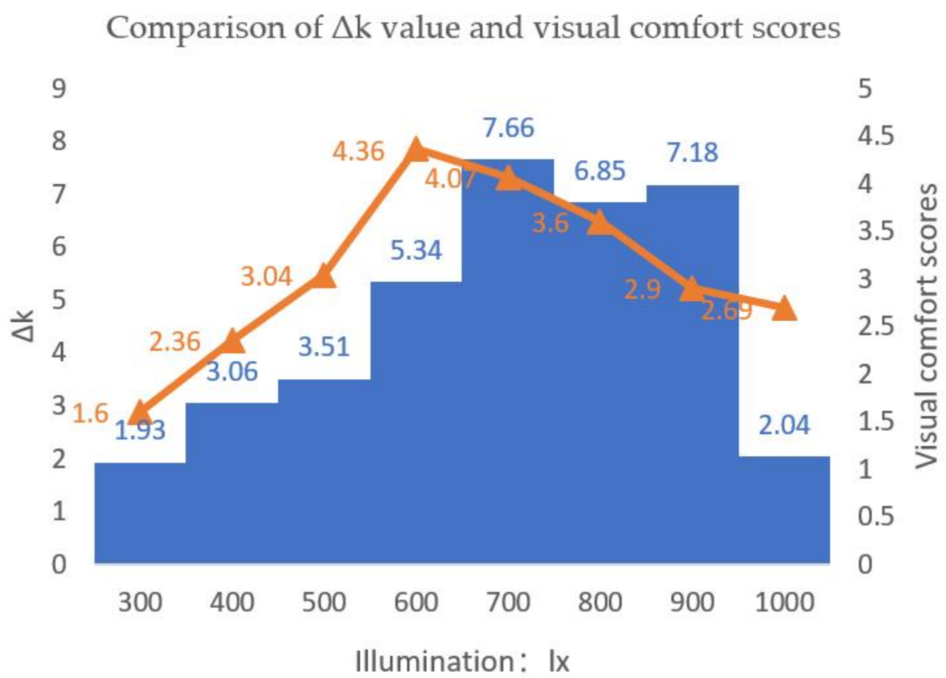


Fig. 4- 12 Comparison diagram of Δk and visual comfort scores.

Δk indicates state arousal level, and the visual comfort score indicates the trend of "Comfort" (>3 points), "Normal" (3.1> n > 2.9), and "Uncomfortable" (<3 points), which can be further divided into detail according to the level of 1–5 points (Table 4- 10). According to the results of the subjective questionnaire, at 300–400 lx, the subjective visual comfort score was below 3, indicating discomfort. State arousal was also low, making it harder for the elderly persons to engage. When the illumination was increased to 500 lx, the situation improved, and most of the elderly persons were able to complete the reading task more easily. At the same time, the elderly persons' states of arousal rose during this procedure. At 600 lx, the subjective visual comfort score reached a maximum of 4.36 points, which was classified as "Very comfortable." This indicated that the elderly persons could read without feeling stressed, and their arousal level had improved slightly. When the light level was increased to 700 and 800 lx, the subjective comfort score decreased, but both scores were greater than 3 and still fell into the "comfort" category. At these illumination levels, the elderly persons were under greater pressure to complete the reading task than at 600 lx. Their state arousal was higher, which was a positive outcome. At 900 lx, the subjective visual comfort score remained at 3, despite the fact that state arousal remained high. Subjective visual comfort fell below a score of 3 at 1000 lx, and was classified as "uncomfortable", with a considerable decline in state arousal.

Table 4- 10 Ranking of scores of the visual comfort questionnaire.

Trend of Visual Feeling	Uncomfortable (n < 3 points)			Normal (3.1 > n > 2.9)		Comfortable (n > 3 points)		
Illumination (lx)	300	400	1000	900	500	800	600	700
Scores of visual comfort (n)	1.6	2.36	2.69	2.9	3.04	3.6	4.36	4.07
Arousal Level (Δ k)	1.93	3.06	2.04	7.18	3.51	6.85	5.34	7.66

4.2.4 Discussion and Conclusions

4.2.4.1 Discussion

Based on the analysis of the experimental data, a trend can be noticed. When daylight illumination was set at 300–500 lx, subjective visual comfort scores rose in tandem with state arousal, showing that the elderly persons were gradually becoming more active and engaged. At an illumination level of 600–800 lx, the subjective visual comfort score dropped from its maximum point but remained in the "comfort" category, while state arousal levels continued to rise. Based on the elderly persons' subjective assessments, when the illumination was between 600 and 800 lx, the condition of state arousal was positive. It can be seen that physiological and psychological activity improved the elderly person's subjective perception. The levels of both 700 and the 600 lx had a subjective visual comfort score of 4 or more; 700 lx may be preferable since it resulted in a higher level of state arousal.

However, this did not necessarily apply to the 900 and 500 lx levels, which were both rated 3 out of 5 as "normal." According to the proportion of subjective visual comfort scores, more than half of the elderly persons assessed 500 lx as "normal." At 900 lx, several subjects experienced trouble adjusting the uniformity of light in their field of view, and more glare cases were reported. Some subjects also reported preferring the higher illumination of 900 lx, which helped them see more clearly. As a result, high state arousal can be both a positive and a negative outcome. In terms of consistency of evaluation, the 500 lx level is superior to that of 900 lx.

4.2.4.2 Conclusions

It can be seen from the experimental data that the peak of subjective visual comfort score appeared at 600 lx, and the peak of state arousal level appeared at 700 lx. The reason for this peak gap can be analyzed from the changes of the two indicators. When the daylight illumination was low (300 lx), as the illumination increased, the elderly persons invested more energy, and the visual comfort also improved. However, when the illumination was increased to 800 lx, the elderly persons felt a certain pressure when reading, and the increase in state arousal then offset a part of this pressure. When the illumination was higher than 1000 lx, the elderly persons appeared to have low state arousal, and the visual comfort was also greatly reduced.

Within the context of this experiment, the most comfortable illumination range for the elderly persons to read in daylight was 600–800 lx, and 700 lx was optimal. This level was higher than the illumination of 300 lx recommended for reading under artificial lighting in the Architectural Lighting Design Standard of China. This showed that, due to the dependence of the elderly persons on daylight, their demand for daylight illumination was higher than that under constant artificial lighting. This conclusion was also confirmed by a study in UK, in which individuals tolerated significantly higher levels of daylight illumination than CIBSE's typical artificial lighting recommendations unless there was glare or direct sunlight [21].

The main conclusions can be summarized as follows:

1.At daylight illumination of 300–500 lx, subjective visual comfort rose, in addition to state arousal, a process in which the elderly persons became progressively more engaged.

2.At daylight illumination of 600–800 lx, subjective comfort decreased from its highest point, but remained in the "comfort" category, while state arousal continued to increase.

3. At daylight illumination of 800 lx, the active state of the elderly compensated for some of the stress caused by the light environment.

4. At daylight illumination of 900 lx, although the subjective visual comfort rating was close to "normal", the comments were polarized and it was difficult to determine whether the increase in state arousal was due to positive or negative factors.

5. When the lighting was dim, the elderly persons had low state arousal and found it harder to engage in reading tasks. As the degree of illumination rose, so did the arousal level, and the body state of the elderly gradually became more active. When the illumination level exceeded a specific threshold, however, the arousal level dropped dramatically.

6. The most comfortable reading illumination level for the elderly persons was between 600 and 800 lx, with 700 lx providing the best performance. The ranking of the visual comfort levels of the daily illuminance values under reading behavior is shown in Fig. 4- 13.

Fig. 4- 13 Schematic of illumination value and comfort level.

This experiment was chosen to take place in Shenyang, a city in China's harsh cold area, which is located at high latitudes. Long winters, low solar azimuths, and short daylight hours characterize cities in high latitudes. The elderly persons who live here are restricted to indoors and prefer the more daylight is brought indoors because they are psychologically closer to it. However, in cities located at low latitudes with high levels of daylight radiation (e.g., Guangdong), the issues to consider are quite different. On sunny days, low latitudes are characterized by intense daylight radiation, whereas cloudy situations result in insufficient daylight hours. Although it is critical to bring in as much daylight as possible, too much direct light may generate glare and diminish the comfort of the light environment. The elderly persons in various climatic zones may have different adaptations to daylight, and additional research in various regions is needed.

In this research, extraneous light environment indicators such as glare [22] and illumination uniformity [23] were controlled for, although these two indications are also crucial for evaluating the quality of the light environment. At the same time, the primary purpose of the light environment indicators is to inform the architects' lighting design strategy. The physiology, psychology, and behavior of the elderly persons are affected by design considerations such as building orientation, room sizes, window sizes and parameters, frames and position, types of glazing, transmission characteristics of glazing, cleanliness of glazing, and interior room surfaces [24][25]. The comfort of the daylight environment is a systematic "human-behavior-environment" problem, which is better suited to multifactorial research with the use of appropriate algorithms. Before that, however, experiments are needed to clarify the specific relationships between the different factors. The best design strategy based on daylight performance indicators may be discovered using enough experimental sample data and a multi-objective algorithm [26].

4.2.5 Limitation

First, the set illumination range was 300–1000 lx in the experiments. This was based on the recommended value of reading illumination under artificial lighting in the Architectural Lighting Design Standard of China and the pre-judgment of the actual situation in the pre-experiment. However, there were also cases where it exceeded 1000 lx or was less than 300 lx in the experiments. Since elderly persons with normal vision and reading habits were selected in this experiment, only in certain cases did elderly persons with low sensitivity to light believe that illumination higher than 1000 lx was more comfortable, or those with relatively better vision and high tolerance of daylight illumination considered that daylight below 300 lx was acceptable. It can be seen that the acceptance of daylight illumination was also different for the elderly persons with different physiological and psychological states. This research focused on a certain category of elderly persons and was not representative of a broad group of elderly persons. In addition, this experiment set the time from 8:00–10:00 in the morning according to the reading habits of the elderly persons. Table 1 summarizes the activities of the elderly persons in one day, among which watching TV, playing cards, playing chess, eating, and chatting were the activities enjoyed by the elderly in other periods; these activities were also not covered in this research. Finally, the site selected for this article was a rectangular room facing south, which was relatively simple. The daylight features of other rooms were different from those facing the south direction and would behave differently over time. In addition, there were complex geometries, which needed to be specifically analyzed according to the movement tracking of the elderly persons' activities. These questions all need to be further explored in the future.

4.3 Distance between watching TV and space

4.3.1 Experiment Principle and method

Through the investigation, it is found that watching TV is also one of the activities often carried out by the elderly in the living space, but there are some problems. Due to the influence of distance and layout, the elderly often have some difficulty in watching TV, and the quality of watching TV is not very high. The aim of this experiment is to study the distance at which elderly people can clearly watch television， that is visual distance, which makes them feel more comfortable watching TV.

4.3.1.1 Experiment content

1) Experimental behavior: This experiment is mainly to study the visual comfort of the elderly watching TV, an important behavior. According to the previous investigation, the elderly mainly watch TV in the bed after dinner before going to bed. Generally, they sit at the end of the bed, facing the TV, and then watch TV programs.

2) The purpose of the experiment: This experiment is mainly to study the influence of distance on the visual comfort of the elderly when watching TV, in order to study an optimal distance to watch TV. Therefore, the elderly can achieve the best visual comfort, that is, can easily capture the TV picture and see the content clearly.

3) Experimental basic value: First, consult the basic data and determine the basic data -- the distance from the end of the bed to the TV. Since most TVs are wall-mounted and relatively thin, the distance from the opposite wall to the TV screen is basically the same as the horizontal distance from the end of the bed to the eyes of the elderly, so the visual distance of the TV can be understood as the distance from the end of the bed to the wall where the TV is located. According to the code of Architectural Design Standards for Care Facilities for the Elderly, the distance from the end of the bed to the TV cabinet opposite should not be less than 105cm in clear width, considering the need to leave room for wheelchair rotation [27]. The minimum width of the TV cabinet is 50cm, so the distance from the end of the bed to the TV, is 1.55m, which is rounded to 1.6m. According to the preliminary experiment, it is found that the visual comfort of the elderly watching TV is not significantly changed according to the distance variation within 30cm, so 30cm is selected as the interval distance for watching TV. According to the previous investigation, it is found that the maximum distance from the wall to the bed in the nursing home is 2.8m, so the final data is 1.6m, 1.9m, 2.2m, 2.5m, 2.8m, a total of 5 sets of data.

Experimental subjects: Considering that the elderly subjects' own conditions (such as age, education background, income and occupation) will become the experimental variables, affecting the scientific nature of the experiment and the accuracy of the data. The selected elderly should aged between 60 and 89 years old and graduate from primary school or above, so as to ensure that the elderly can understand the newspaper they read in the later experiment. In addition, the elderly should have normal naked eyes or corrected vision, no color blindness, and be able to see clearly and have normal intellectual comprehension during the reading experiment. There are 30 people, 15 men and 15 women. The 30 people refer to these people whose experimental data is valid, that is, 30 valid data are needed, and the number of elderly people participating in the experiment should be larger than 30. Although elderly people are screened, physiological data of some elderly people still cannot be used, mainly because everyone has different physical conditions. There are individual differences.

4.3.1.2 Experimental methods

Experimental materials: Before the experiment, the experiment video was prepared in advance. In order to avoid the psychological changes of the elderly caused by the video content, movies and TV series were not selected. Finally, neutral weather forecast videos frequently watched by the elderly were selected, and extreme weather conditions such as storm and rainstorm were excluded from the content selection, so as to avoid the psychological discomfort and worry of the elderly. The weather forecast video was prepared in advance before the experiment. After editing, the beginning and end were removed, and each video was controlled to be 2 minutes. A total of 5 videos were selected (Fig. 4- 14). The copy is put into the U disk for the experiment. Because this experiment only studies visual comfort, in order to avoid the interference of sound to the elderly, the sound of the video was eliminated and only the playback of the picture content is kept.

Fig. 4- 14 Weather forecast video

2) Experimental principle: The ErgoLAB human-machine environment synchronization platform technology is used to carry out the human factor experiment. Physiological sensors are worn on the elderly, the position of the TV is fixed, the distance size prepared in advance is marked on the ground, and the corresponding physiological indexes of the subjects are obtained by moving them to watch movies and television works in different positions. After the experiment, the experimental data are analyzed and the experimental results are obtained. Then the influence of TV distance on visual comfort of the elderly is studied.

3) Experimental instruments: TV (size: 75cm × 45cm), computer (record physiological indicators), measuring tape, EDA wireless leather sensor.

4.3.1.3 Experimental process

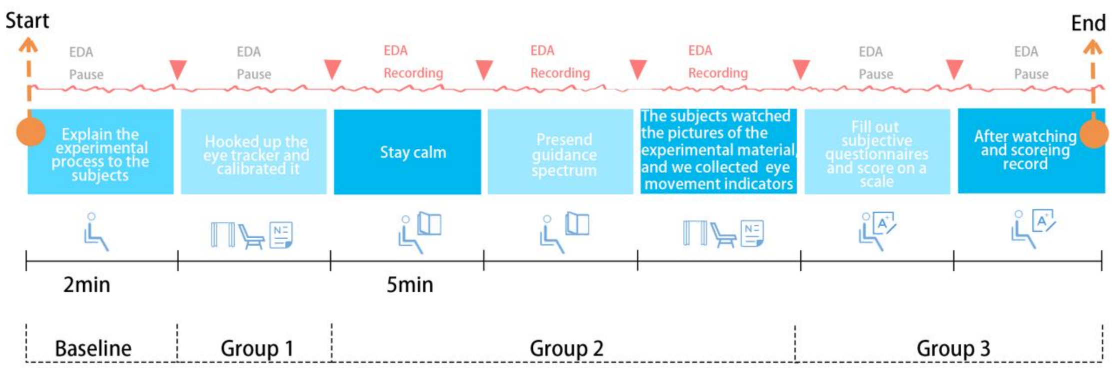


Fig. 4- 15 Experimental program diagram (Source: Draw by the author)

This TV watching distance experiment is mainly divided into two stages, which are as follows:

A: Using EDA wireless electrodermal sensor to measure the elderly's electrodermal response index, which is an objective experimental measurement。B: After the objective experimental test, a subjective questionnaire was conducted to score the satisfaction of viewing distance. From 18:00 to 20:00 in the evening, the experiment was conducted on the bed in the bedroom, as shown in Fig. 4- 15.

1) explained the experimental principle and the experimental process to the elderly participants in the experiment, so that the elderly could understand the purpose and operation of the experiment, so as to facilitate experiment, and then let the subjects breathe calmly and relax their mood.

2) The subjects were asked to sit on a well-prepared chair in the living space (Fig. 4- 16). Since the elderly need to be moved behind, the beds were moved in advance to leave room for the chairs to move back and forth. The U disk with the weather forecast video was inserted into the TV jack and adjusted to the video playing page, so that the elderly could keep the sitting position of watching TV in daily life. The watching TV distance was marked on the ground to facilitate the elderly to move during the experiment.

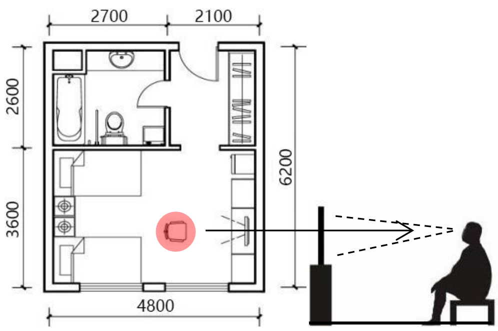


Fig. 4- 16 Laboratory site (Source: Draw by the author)

3) The palms of the subjects were cleaned with alcohol-containing clean cotton, dried to keep dry, and then the electrodes were installed on the contact button of the EDA wireless electrodermal sensor, and then the elderly were put on the instrument. The elderly were asked to close their eyes and sit quietly for 5 minutes without thinking or speaking. The baseline was collected by keeping their breathing calm and mood stable.

4) During the experiment, the position of each elderly person was randomly changed, which was selected in the middle of 1.6m, 1.9m, 2.2m, 2.5m and 2.8m to ensure that the distance order of each elderly person was different. A video of weather forecast with noise elimination was watched at each position, and the corresponding video of weather forecast at each distance was different. To prevent the elderly from being tired due to repeated video content, after the video is played, the experiments in the next position should be carried out randomly until all the experiments in the 5 distances are completed. Marks should be made at the beginning and end of each distance to facilitate subsequent data analysis. Note should be made on the order of the distance each elderly person watches TV. In accordance with this method, 30 old people were asked to complete the experiment in turn. In the process of watching the video, the instrument recorded the data

throughout the whole process. The position distance of each old person watching the video was all random, so as to reduce errors as much as possible, avoid contingency, and ensure the accuracy and scientific data.

5) In the experiment, it is necessary to conduct a subjective questionnaire survey on the elderly, and score the distance satisfaction corresponding to watching each weather forecast video. By combining with the physiological index data, the optimal viewing distance can be obtained by summarizing and analyzing.

4.3.2 Results

4.3.2.1 Indicators of electrodermal response index

(1) Graph of subjects' indexes

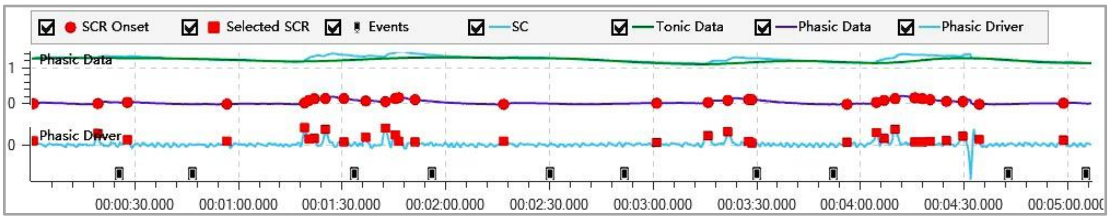


Fig. 4- 17 Physiological Indicators Curve of Subjects (Source: Software output)

Fig. 4- 17 Physiological index graph of the subjects is the EDA electrodermal response index, which can be seen to have ups and downs. With the corresponding distance between the subjects when watching TV changes each time, the elderly will have different visual feelings, and the index will naturally change accordingly. The upper part of the Fig. 4- 17 is the index change curve, the first row is SC and Tonic Data index, the second row is Phasic Data index. The analysis of this experiment needs to use the mean index in the time domain analysis of EDA, which represents the average value of Tonic Data, Phasic Data and SCsignal after the decomposition of skin electrical signal. The black button below is marking, starting one button and ending one button. The middle part of the two groups of marking is the time of moving the elderly to change their distance from TV. The TV distance before the experiment is the baseline time. 5 groups of distance curves of effective data of 30 complete participants in this experiment are shown in the appendix. The curves of selected individual indicators are listed here as explanations.

(2) Basic information and experimental data

Due to the individual differences of sympathetic feedback in the elderly people, the EDA results of the elderly subjects were statistically analyzed by using the change rate of EDA, which equals to (measured value minus baseline value)/baseline value. The distribution of the EDA change rate in the elderly subjects was more obvious at different distances, the closer the distance, the smaller the range of EDA change rate, and the farther the distance, the larger the range of EDA change rate (Fig. 4- 18).

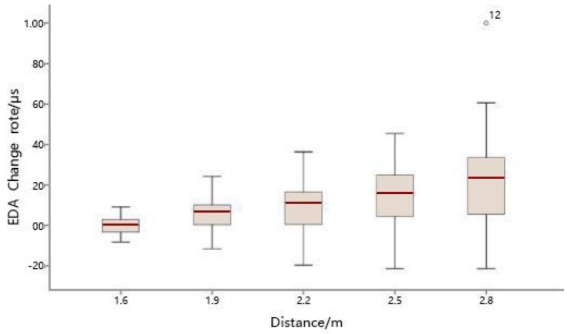


Fig. 4- 18 The distribution EDA rates of the elder at different distances

One-way repeated ANOVA was performed on the EDA results to investigate whether there was a significant difference between the EDA data of subjects with repeated measurements for different distances. The data were tested for the EDA change rate , and the data met normal distribution, Shapro-Wilk significance was greater than 0.05, the homogeneity test of variance significance was 0.168>0.05, and the data homogeneity test of variance was passed. One-way repeated ANOVA was performed, in which the Mauchly's test of sphericity significance was less than 0.05 and failed the Mauchly's test of sphericity. the Mauchly W value was 0.025, which required correction process. When the Mauchly W was less than 0.75, the Greenhouse Geisse method was used for the correction, and the corrected variance statistic F was 11.495, the df was 1.485 and 43.057, the significance was 0.00<0.05, theη2 was 0.284. The subjects had statistically significant differences in the data of the EDA change rate at different distances, the mean value of the EDA change rate estimated by the univariate repeated variance at different distances is shown in Fig. 4-19.

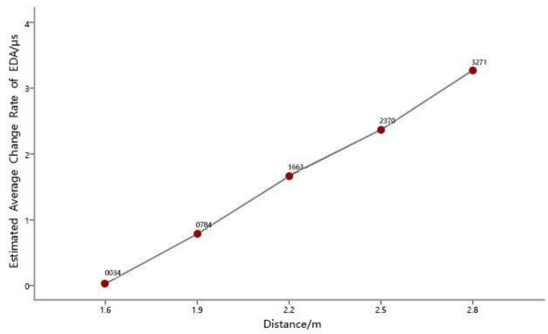


Fig. 4-19 Estimate the average EDA change rate at different distances

The Bonferroni method was used to do pairwise comparison of EDA data measured repeatedly at different distances, the mean differences were significant at the 0.05 level, and the results are shown in Table 4- 11. From the table, it can be concluded that there were significant differences between 1.6 meters and 2.5 meters, 1.6 meters and 2.8 meters, 1.9 meters and 2.8 meters, and 2.2 meters and 2.8 meters, while no significant differences were found between the other distances.

Table 4- 11 Paired comparison of the EDA at different distances

Distance Correlation Value	Mean difference	Standard Error	Significance	95% Confidence Interval	
				Lower Limit	Upper Limit

1.6/2.5	-0.307	0.09	0.02	-0.582	-0.033
1.6/2.8	-0.410	0.109	0.008	-0.743	-0.077
1.9/2.8	-0.342	0.102	0.023	-0.653	-0.031
2.2/2.8	-0.213	0.066	0.03	-0.414	-0.013

4.3.2.2 Subjective questionnaire survey

The results of the subjective evaluation in visual comfort of the elderly people at different distances are shown in Fig. 4-20. As can be seen, the data on subjective ratings of elderly people are more evenly distributed at different distances. The evaluation of the comfort level at 1.9 meters and 2.2 meters are the most concentrated, which are more comfortable and moderately comfortable respectively. While 1.6 meters, 2.5 meters and 2.8 meters have relatively small dispersion in the evaluation data distribution, and the data characteristics are more obvious. The median and upper quartile of the comfort evaluation results at 1.6 meters were very comfortable, the median of the comfort evaluation results at 2.5 meters and 2.8 meters were both less comfortable, but the overall evaluation at 2.8 meters was lower than that at 2.5 meters, between them were very uncomfortable and less comfortable.

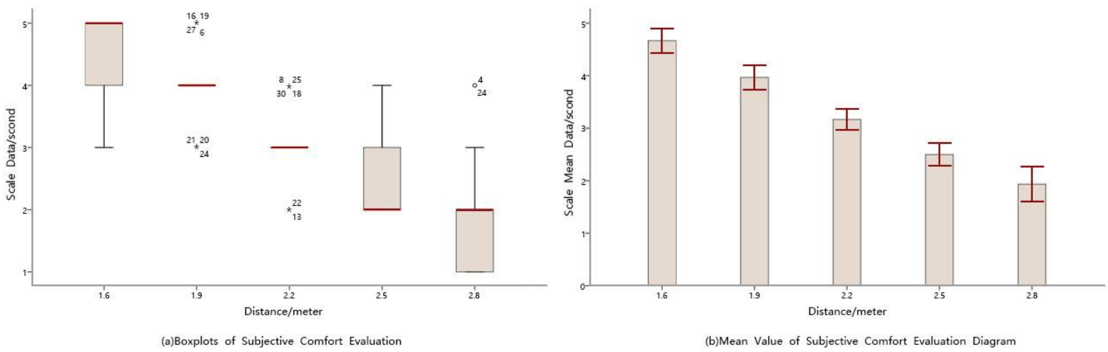


Fig. 4-20 The Subjective comforts evaluation of the elder at different distances

One-way ANOVA was performed on the subjective evaluation results to investigate whether there were significant differences in subjects' subjective comfort perceptions of different distances. Before analyzing the variance, the data were tested for normal distribution and homogeneity test of variance. Results show that Kolmogorov-Smirnov test and Shapro-Wilk test significance are less than 0.05, which do not satisfy the normal distribution. The homogeneity test of variance significance is 0.033 less than 0.05, then the homogeneity test of variance is not passed. Therefore, a non-parametric test was applied for the analysis of variance, the Jonckheere-Terpstra test was used, the results indicated that the subjective comfort perception of the subjects for different distances were statistically different, the significant is less than 0.05. In the final pairwise comparison of the subjective perception of each distance to each other were significantly different, the greater the distance, the lower the subjective perception evaluation.

4.3.3.3 Analysis and Conclusion

It was found that the distance had significant differences on the subjective perception of elderly people's TV watching behavior, their comfort level changed with the distance, the closer the distance, the higher the comfort level of elderly people, and the further the distance, the lower the comfort evaluation, with an average decreasing trend. The EDA results at different distances also showed significant differences in the physiological feedback of the elderly people, which corresponded to the subjective questionnaire, the farther the distance the greater the fluctuation of physiological feedback. In the later multiple comparisons, the EDA feedback was significantly higher at 2.8 meters than at 2.2 meters, 1.9 meters, and 1.6 meters, while the feedback was also significantly higher at 2.5 meters than 1.6 meters. This indicates that the sympathetic nerve was abnormally excited at a distance of 2.8 meters in elderly people, the emotional arousal is higher than that at other distances, resulting in greater changes in the electrical conductivity of sweat glands on the skin surface.The subjects had higher emotions of nervousness, happiness and panic, combining with the results of the subjective comfort evaluation scale, it can be inferred that the watching distance of 2.8 meters was negative emotion and uncomfortable for the elderly people compared to other distances. Similarly, the discomfort at 2.5 meters was stronger than that at 1.6 meters, there was no significant difference between other distances. The distance differences with physiological differences were found to be 0.6 meters, 0.9 meters and 1.2 meters. Constructing the comparison of different distances, the subjective comfort responses of different distance had otherness, but there was no significant difference in the physiological comfort of the elderly people with the distance difference value within 0.3 meters, with the distance difference value above 0.9 meters, the physiological comfort of the elderly people had large differences.There was a significant difference between the distance and the subjective evaluation of the elderly people as well as the physiological feedback data, which is the farther the distance, the stronger the discomfort of the elderly people.The elderly people have no difference in physiological comfort level for distance changes within 0.3 meters, while have significant physiological and subjective discomfort for distances of 0.9 meters and 1.2 meters.

4.4 Interior space color preference recognition

4.4.1 Color recognition preference measure experiment

According to the previous research, the old people think color is very important in the living space. Among the 112 old people surveyed, 16% of them think it is normal, 47% of them think it is not very satisfied, and 18% of them think it is very unsatisfied, because they think the color of the house is too monotonous. In addition, among the factors affecting visual comfort, 83% of the elderly think color is an important factor for visual comfort. However, there are some problems in the use of colors at present. In the previous construction of houses, the color design was not paid attention to, resulting in too monotonous colors. It is hoped that this experiment can study the color preferred by the elderly and create a warm and comfortable living space environment for the elderly.

4.4.1.1 Experimental content

1) Experimental purpose: This experiment is mainly to study the color factor as an important factor of visual comfort of living space. This experiment mainly involves the color preference and psychological feeling, and has no clear relationship with specific living space behavior.Through the collection of eye movement physiological indicators, combined with subjective questionnaire scoring, through the analysis of the specific color corresponding to the physiological response, so as to get the elderly's favorite color ranking.In the future, the principle can be followed and used in the residential space design of nursing homes, so that the elderly can enjoy their old age in a living space full of vitality.

2) Experimental subjects: Experimental subjects: Considering the subjects of elderly people oneself circumstance (e.g., age, education, income, occupation) will be the experimental variables, affect the scientific nature of the experiment, there is no guarantee that the accuracy of the data, so in the choice of the elderly, the selection in the middle of the 70-89 - year - old age, degree of primary school and above, in addition to ensure the normal order of the naked eye or vision correction, Self-care elderly who can clearly see the experimental materials displayed by the computer, have no color blindness, and have normal intellectual comprehension.Number of 30 people, men and women each 15 people, this 30 people refers to the experimental data is valid, namely need 30 valid data, number of elderly people in the trials will be greater than the number of the 30, although has carried on the screen to the elderly, but the physiological data of some old people are still unable to use, mainly because each person's physical condition is not the same, There are individual differences.The elderly participants were informed and consented to the experiment,Compliance with Ethical Standards.

4.4.1.2 Experimental Methods

1) The experimental material, this study USES the Color of the material, is through the system to determine the Color samples, sample system, is the concept of in People's Daily behavior, in terms of colour feels, their psychological equidistant scale for Color space order, Color of sample is known as Color order system (Color order system).It is a system of Color samples (also known as Color cards) composed of many things, organized regularly according to the degree of adjacencies of the three basic attributes of colors.Common international standard color system contains the following: the Munsell Ostwald (Munsell color system), Germany (Ostwald) color

system, the international lighting members in this paper(Li Guoguo 2016) [28],we study the living space of color mainly reference to Munsell color system, choose the color of the main types in a lot of color card, select the main hue of the color card: Red, yellow, green, blue, purple, in addition to two intermediate colors: red, yellow, green and blue, and finally add the elderly living space in furniture and floor more commonly used brown, as well as the non-color gray.The final color card selection is shown in Fig. 4-21. This experiment mainly studies the color hue to the elderly's preference, so the saturation and brightness are unified and fixed, that is, only the color hue is studied.

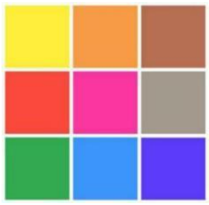


Fig. 4-21 Color card pattern (Photo credit: author's drawing)

2) Experimental principle: By referring to Munsell's color system, red, yellow, green, blue, purple, red-yellow, green-blue, and common brown and gray are selected.The images were imported into the software, and the eye movement index was collected by a remote sensing eye tracker placed at the front of the screen. Each image was viewed for 10 seconds, and then played randomly after shuffling the order.The most comfortable color was obtained by analyzing the total fixation duration, pupil diameter and subjective questionnaire.

3) Experimental instruments: the computer ran physiological software to display color pictures and store physiological indicators, and Tobii Pro X3-120 eye tracker.

4.4.1.3 Experimental process

(1) Explain the experimental principle and process to the elderly participants in the experiment (Fig. 4-22), so that the elderly can understand the purpose and operation of the experiment, so as to facilitate the smooth progress of the experiment, and then let the subjects calm down and relax.

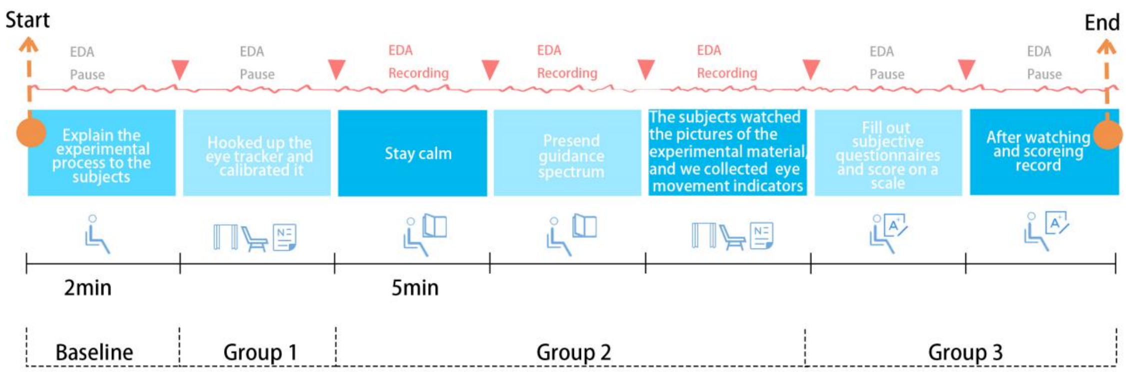


Fig. 4-22 Experimental program diagram (Photo credit: author's drawing)

(2) To prepare computer, connect the remote sensing type eye movement instrument installation, the participants to sit in front of a computer screen in place, keep watching computer posture is usually, before the formal experiment need to open the computer, run the eye movement instrument software, then let the old calibration, mainly to see whether the old people's eyes is

suitable for participation in the experiment, if the eyes have serious astigmatism or lesions, The eye tracker will not be able to capture the eye, that is, there is no data, then the elderly are not suitable to participate in the experiment.

(3) Everything ready to do a good job and after the calibration, explain to the subjects instructions: "please keep the line of sight of you the whole on the computer screen, don't leave the scope, otherwise can't catch your eye, eye movement apparatus under the computer will play each color pictures, please you think the color used in your living space, please watch carefully, Focus on their favorite color, after the experiment needs you to liking the color grade evaluation ", click the start button, the color of the old man sit to watch the computer random broadcast images, presents the material of eye movement instrument to capture all the eye at the same time, record the eye movement index, were shown after all the materials, the last one page marked with the words "" the experiment ended, thank you for your cooperate slides, Indicate that the whole experiment has been completed, a total of 9 color pictures, each 10s, a total of 95 seconds, and then the eye tracker to stop recording, click the finish button, data automatic saving.

(4) According to this method, 30 elderly people were asked to complete the experiment in turn, as shown in Fig. 4- 23. During the process of looking at the color pictures, the instrument recorded the data throughout the whole process, and the color pictures looked at by each elderly person were all random, so as to reduce the error as much as possible, avoid the accident, and ensure the accuracy and scientificness of the data.

Fig. 4- 23 Experimental subjects (photo credit: author photo)

4.4.2 Results

4.4.2.1Total fixation duration

The physiological feedback data collected by the eye tracker device were mainly in pupil diameter and fixation duration, with pupil diameter data concentrated in the range of 2.68-3.18 millimeters, with the median fluctuating around 2.95 millimeters, fixation duration data distribution was concentrated in the range of 0.92-3.46 seconds, with the median fluctuating around 2.02 seconds (Fig. 4-24).

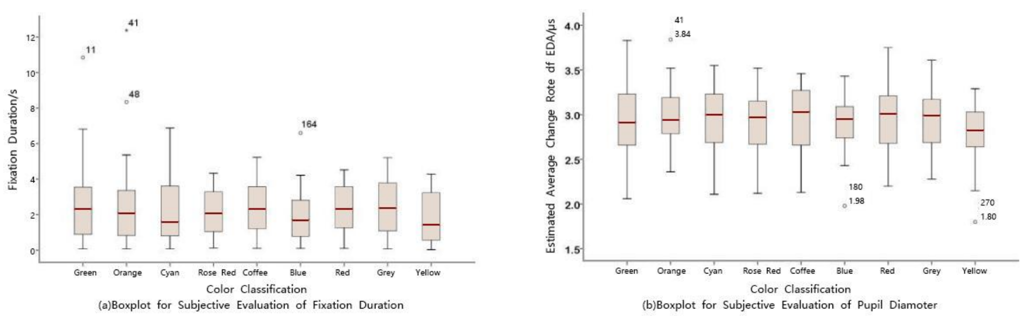


Fig. 4-24 The distribution Visual physiological index of the elder in different colors

It can be seen from Fig. 4-25 that both pupil diameter and fixation duration have a small number of single-factor outliers, which are due to individual differences in physical function of the elderly people, so they were screened. A multivariate ANOVA was performed on pupil diameter and fixation duration, the data were hypothesis tested: the screened data obeyed a normal distribution, and the scatterplot found a linear relationship between the dependent variables, no multivariate outliers were found for Mahalanobis distance. The Pearson's correlation coefficient between pupil diameter and fixation duration was 0.597, with a moderate correlation between the two dependent variables and no multicollinearity (correlation coefficient was less than 0.9, significance was less than 0.05). Box's M test showed that the covariance matrix of variance was equal (significance was 0.847>0.001), and the Levene's variance of pupil diameter and fixation duration in all groups with different colors was homogeneous (significance was greater than 0.05). The mean values of pupil diameter and fixation duration for different colors are shown in Fig. 4-25. There was no statistical difference between groups of oculomotor physiological indices at each color level, with a variance statistic of 0.501, significant greater than 0.05, a Wilks' Lambda multivariate statistic of 0.964, with$\eta 2$ = 0.018.

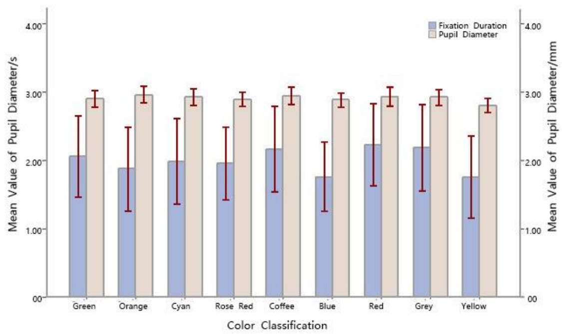


Fig. 4-25 The mean pupil diameter and gaze length of examines in different colors

4.4.2.2 Subjective questionnaire survey

The distribution of subjective evaluation data in visual color preferences of the elderly people is shown in.

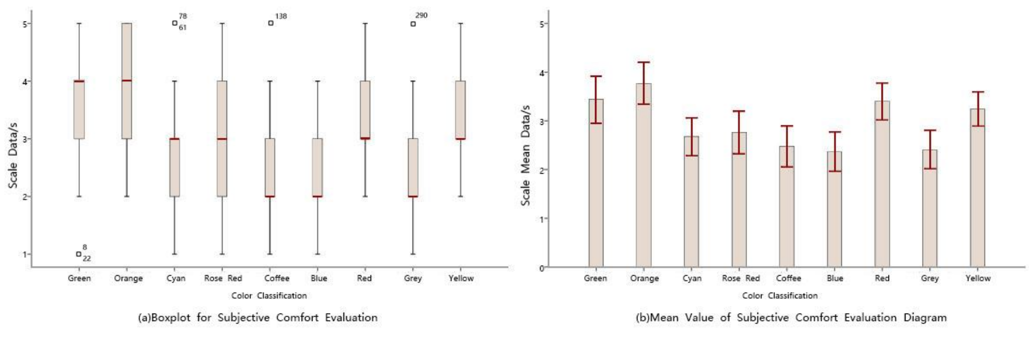


Fig. 4-26**. The distribution of subjective evaluation data in visual color preferences of the elderly people**

It can be seen that the distribution of subjective evaluation data of different colors is more uniform. The distribution of green, red and yellow is more consistent and mainly concentrated between moderate like and more like, and the distribution of orange and rose red data is more discrete, while the distribution of other colors is concentrated between less like and moderate like.

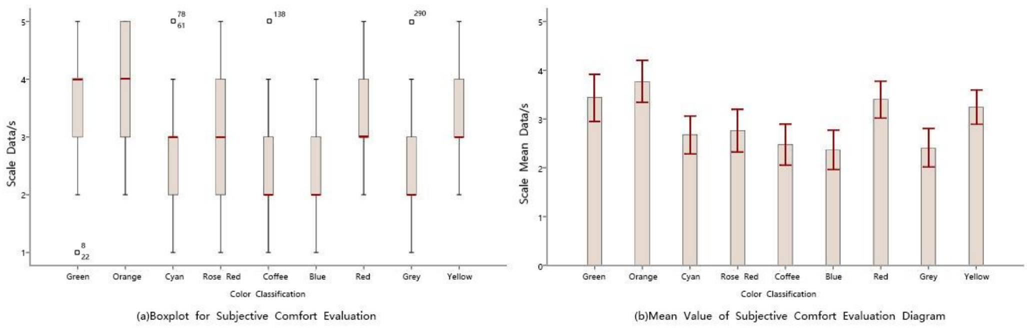


Fig. 4-26 The Subjective comforts evaluation of the elderly person in different colors

One-way ANOVA was conducted on the subjective evaluation results to investigate whether there was a significant difference in the subjective comfort perception of the subjects for different colors. The data were tested for normal distribution and the homogeneity test of variance, in which the Shapro-Wilk test $p < 0.05$, which did not satisfy the normal distribution, and the homogeneity test of variance $p = 0.559 > 0.05$, which satisfied the homogeneity test of variance. Welch's variance test was used, and the results showed that the subjective comfort perception of the subjects was statistically different by color.

4.4.3 Analysis and Conclusion

The experiment showed that there were significant differences in subjective responses to color preferences of elderly people, multiple comparisons on subjective evaluations of each color showed that the differences in color preferences were concentrated on orange, green, red, and yellow. Among which, orange has a higher preference and number of differences with other colors, green has the same preference as red and the same number of differences with other colors, yellow has an average preference and mainly has differences with coffee, blue and gray. However, the results of oculomotor physiological data showed no statistical difference in color preference among the elderly people and no significant association with the results of the subjective scale, but the literature [29][30] indicates that color should have significant differences on fixation duration and pupil diameter. The reasons are as follows: (i) The fixation duration should reflect the attention degree of the subject's attention to the material, so as to reflect the preference degree of the interest zone. Due to the changes of turbidity and yellowing of the lens in the eye, the elderly people's ability to perceive color will be greatly affected, so they pay less attention to color and only focus on the experimental materials. (ii)Pupil diameter is an indicator of subjects' attention to information, which can be used to predict emotional changes under different color stimuli, but it is closely related to fatigue [31]. Continuous stimulation will increase the impact of viewing fatigue on pupil diameter, thereby reducing the sensitivity of pupil diameter to color preference [32]. (iii) Subjects were selected by the reason of their regions and number limitations on people, insufficient data sample size, and individual limitations resulting in insignificant data analysis. Therefore, the experimental results leading to no significant differences in subjects' oculomotor physiological data for color.

There were no statistical differences in the oculomotor physiological data of the elderly people by color, but there were significant differences in their subjective evaluations, with stronger preferences for orange, green, red, and yellow than for other colors.

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Chapter 5

5. EXPERIMENTAL STUDY ON AUDITORY COMFORT AND SPATIAL CORRELATION

CHAPTER FIVE: EXPERIMENTAL STUDY ON AUDITORY COMFORT AND SPATIAL CORRELATION

5.1 Relationship between auditory comfort and space

5.1.1 Investigation and analysis of the virtual condition of acoustic environment

(1) Sound source investigation

By visiting and investigating the above four nursing homes, the researchers summarized the sound sources in the living space, and extracted the main sound sources on this basis.

Table 5- 1 Living space sound source information table (Source: Author's drawing)

Type	1	2	3	4	5	6
Interior of living space	TV sound	Semi-conductor sound	Telephone sound	Human speech	Sound of moving tables and chairs	Mechanical sound

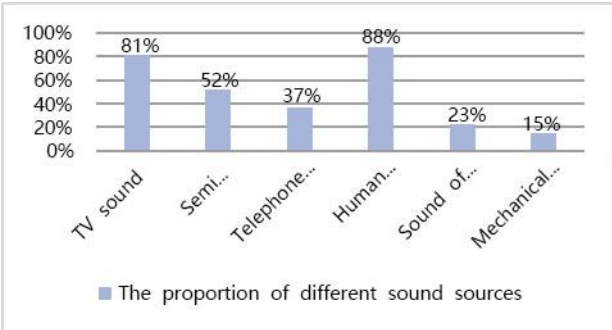


Fig. 5-1 The proportion of different sound sources in the living space of nursing homes (Source: Author's drawing)

According to the basic research of various nursing homes, the sound sources of living space mainly include TV sound, semiconductor sound, telephone sound, human speech, mechanical sound, and external environmental sound. Fig. 5-1 shows the proportion of the elderly who thought they could hear the sound frequently compared with the total number of the elderly people who participated in the research. Among them, 81% of the elderly thought they could often hear the sound of television. 52% of the elderly could often hear the sound of semiconductor. 37% of the elderly could often hear the sound of telephone. 88% of the elderly could often participate in and hear the sound of conversation. 23% of the elderly thought they could hear the sound of moving tables and chairs, and 15% of the elderly thought they could hear the mechanical sounds such as refrigerator. It can be concluded from the summary of Fig. 5-1 that the main sound source of the living space of the nursing home is the sound of television, the sound of conversation, and the sound of semiconductor.

(2) Auditory behavior survey

This research is mainly based on the daily behaviors of the elderly and takes the elderly as the research object to solve practical problems. The main task is to study the daily behaviors of the elderly, the time and the place of activities, to summarize all the behaviors related to hearing in space, and then to screen out the main behaviors related to hearing. Further detailed research is carried out on these behaviors. According to the visit and research in the nursing home, the time behavior of the elderly in a day is summarized, as shown in Fig. 5-2.

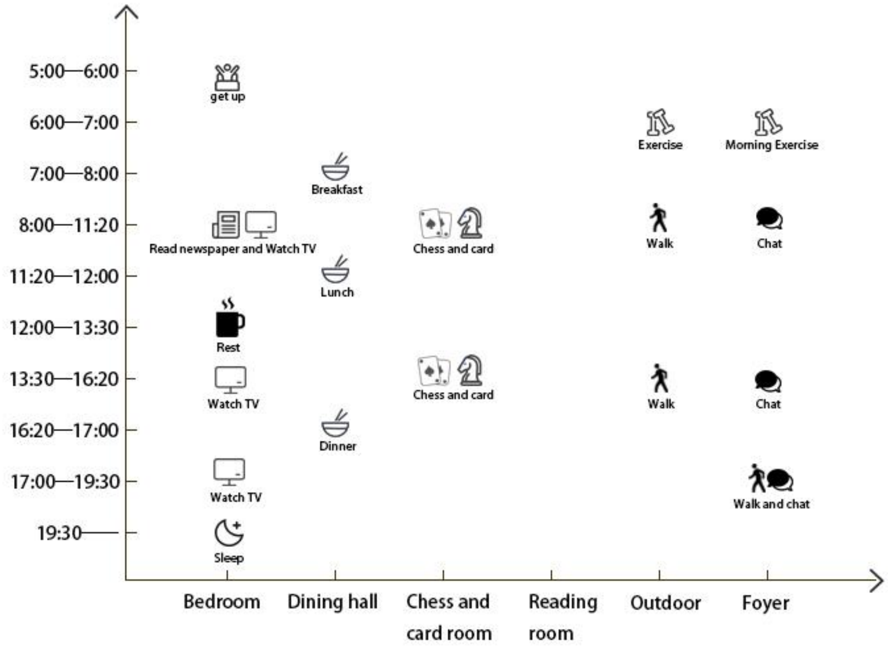


Fig. 5-2 Time behavior table for the elderly in nursing homes (Source: Author' s drawing)

Through the above Fig. 5-2, the main behaviors related to hearing of the elderly in the living space are summarized:

① Watching TV: Watching TV in the living space had become one of the main activities of the elderly. The time was mainly from dinner to bed, and most of the elderly sat on their beds to watch TV. Most of the elderly with serious hearing degradation would choose to increase the volume of TV when watching TV to ensure the clarity of the sound of TV. Some elderly people chose to move closer to the TV to ensure the clarity of the sound, so the distance between the bed and the TV was directly related to the clarity of the sound of the elderly.

② Conversation: In the twin room, the two elderly people often took chat as one of the recreational activities during their leisure time. They sometimes chatted while sitting on the seat. However, it is found in the survey that there was no seat in the living space of some nursing homes, so the elderly usually chatted with their partners on their own beds. Therefore, the distance between the two beds in a twin room also directly affected the clarity of language communication.

(3) Summary of questionnaire survey

A total of four nursing homes were investigated. 200 questionnaires were distributed and 173 valid questionnaires were collected. The questionnaires mainly included a preliminary understanding of the basic information of the elderly, such as age, gender, education background, occupation, etc. In addition, we also got a detailed understanding of the elderly' s hearing status, living status and the impact of hearing changes on their life. The research results are summarized as follows:

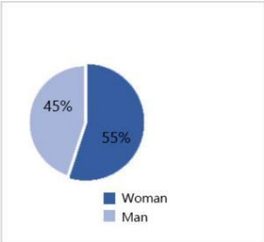


Fig. 5-3 Gender ratio of elderly respondents (Source: Author' s drawing)

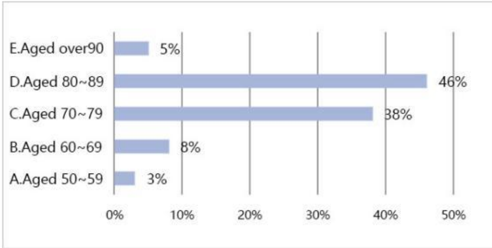


Fig. 5-4 Age ratio of elderly respondents (Source: Author' s drawing)

There were 95 women in this survey, accounting for 55%. There were 78 men, accounting for 45%. From the perspective of gender distribution, the proportion of women were slightly higher than men. In terms of age distribution, the vast majority of elderly people were between 70 and 89 years old, accounting for 84% of the total. The elderly aged 50-59 and over 90 accounted for the least, accounting for only 8% of the total. Therefore, in general, the proportion of elderly women in nursing homes are slightly higher than men, and the age distribution is mostly between 70 and 89 years old.

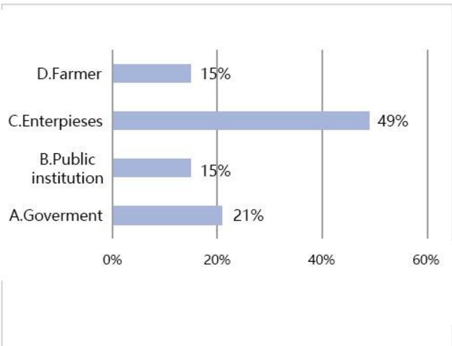


Fig. 5-5 Occupation of elderly respondents (Source: Author' s drawing)

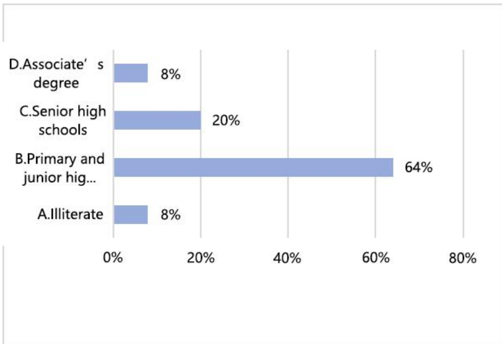


Fig. 5-6 Educational background of elderly respondents (Source: Author' s drawing)

In this survey, the elderly mainly worked in enterprises, accounting for 49%, nearly half of the proportion. The elderly who worked in government units accounted for 21%. The elderly who worked in public institutions and who were farmers accounted for 15% respectively. According to the survey on the educational level of the elderly, 64% of the elderly graduated from primary and junior high schools, and 20% from senior high schools. The remaining 8 % were illiterate and 8 % had an associate's degree.

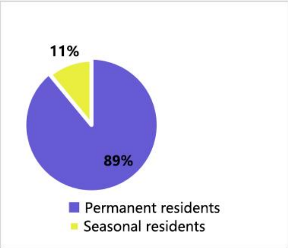


Fig. 5-7 Occupation of elderly respondents (Source: Author's drawing)

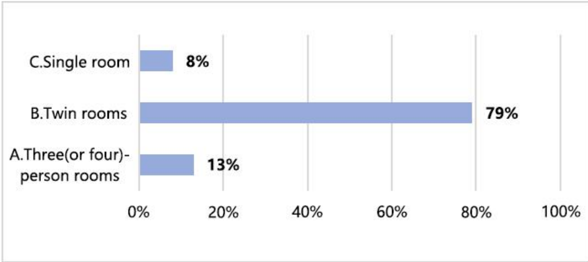


Fig. 5-8 Occupation of elderly respondents (Source: Author's drawing)

In the survey on the living status and living type of the elderly, 89% were permanent residents, and the remaining 11% were seasonal residents. 79% of the elderly lived in twin rooms, and 13% lived in three(or four)-person rooms. The remaining 8% of the elderly lived in single rooms. In twin rooms, same-sex partners accounted for the highest proportion.

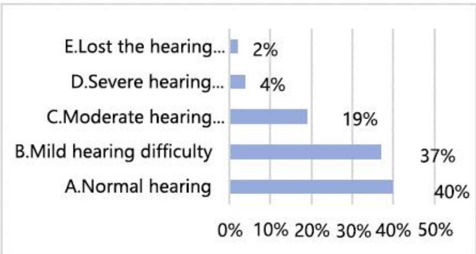


Fig. 5-9 Distribution of hearing level in the elderly (Source: Author's drawing)

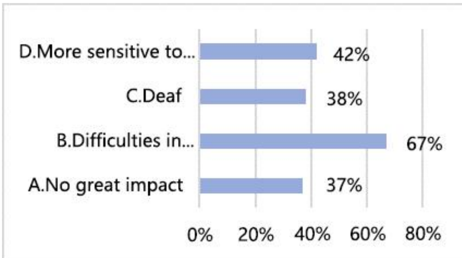


Fig. 5-10 The effect of hearing change on the elderly (Source: Author's drawing)

In this survey, there were 69 elderly people with normal hearing, accounting for 40%. 64 elderly people with mild hearing difficulty, accounting for 37%. 33 elderly people with moderate hearing difficulties, accounting for 19%.7 elderly people with severe hearing difficulty, accounting for 4%. 3 elderly people who had lost the hearing completely, accounting for 2%. From the impact of hearing changes on the life of the elderly, 37% of the elderly thought that there was no great impact, and most of them were the elderly with normal hearing level. 67% of the elderly thought that sometimes there were difficulties in hearing, such as they could not hear each other's voices clearly, which would affect the communication. 38% of the elderly thought that sometimes they were deaf, such as they could not hear the sound of the telephone and so on. 42% of the elderly thought that they became more sensitive to sound, such as they were easy to be disturbed by noise during rest and sleep, resulting in difficulty in falling asleep.

Reverberation time is one of the important acoustic indicators that affect the clarity of language[1], and is also a key factor to evaluate the acoustics design of dining space in nursing homes[2]. There are two measurement methods for the quality of reverberation design of dining space in nursing homes, objective measurement method and subjective questionnaire method[3]. As objective measurement method requires the cooperation of various acoustic instruments. It will also consume a lot of manpower and material resources, and require relatively high debugging accuracy of instruments, so any negligence may seriously affect the accuracy of measurement results. Therefore, based on the above factors, we adopted the form of subjective questionnaire in the field investigation to understand the length of reverberation time in the dining space of the nursing homes, so as to infer the quality of the acoustic environment in the dining space of the nursing homes. As for the question setting of reverberation time questionnaire, since reverberation time is an exclusive disciplinary term[4], we cannot exclude the possibility that some subjects may have difficulty in understanding reverberation time which requires the author to explain one by one. Therefore, in order to improve efficiency, the author decided to replace this term with its synonym after referring to other similar articles[5][6][7][8][9]. As for the problem setting of reverberation time, we used the word echo as a substitute, which has been repeatedly discussed in previous studies. We used the two words with the opposite meanings “strong” and “weak” in the five scales.

5.1.2 Auditory comfort and spatial correlation

5.1.2.1 Problems are Raised

In the investigation of living space, it is found that the main sound sources are television sound and conversation sound, and the accompanying problems are as follows:

① The sound of the TV is too loud, which affects other elderly people

In the process of investigation, it is found that the elderly liked to watch TV in their spare time, and they often watched TV in their own beds, as shown in Table 4-8 . Some nursing homes had poor living space layout. The TV was far away from the bed. In order to “hear” the content of the TV clearly, the elderly had to raise the volume, which would cause serious interference to other elderly people and affect their work and rest. Especially the elderly with hearing impairment would increase the volume largely in order to hear the content of the TV. This behavior would bring great interference to the elderly in other rooms especially in summer, when most of the room would open the doors and windows in order to ensure the indoor coolness.

② Unclear communication

In addition to watching TV, elderly people spent their leisure time chatting with others. According to statistics, 33% of elderly people chatted on chairs, and 67% chose to sit or lie on beds to chat with their partners in another bed, as shown in Fig. 5-12. The reason was that there was no proper space to talk and the elderly thought they would feel more comfortable while sitting or lying on beds. However, in the process of investigation, it is found that the distance between seats and beds in some living spaces was too far, which would affect the language clarity of communication between two or more people. In addition, too close distance would affect the privacy of the elderly’s psychological perception.

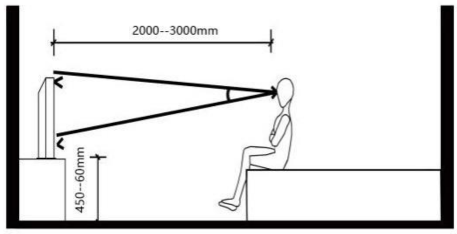


Fig. 5- 11 Living space old people watching TV behavior (Source: Author' s drawing)

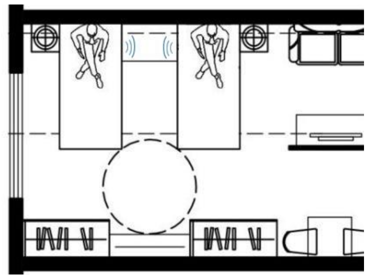


Fig. 5- 12 Talking behavior of the elderly in residential space (Source: Author' s drawing)

5.1.2.2 Extraction of auditory comfort elements

Based on the summary the main factors affecting auditory comfort are loudness, reverberation time, direct sound and reflected sound, and background noise sound pressure level. In this chapter, the main factors affecting auditory comfort are extracted based on the actual problems of space in the actual research.

① Loudness influence analysis

We should solve the problems found in the living space during the investigation. Firstly, in terms of loudness, we should ensure that the elderly can "hear clearly", so the TV audio should has a certain loudness. But the loudness of the TV audio should be ensured within the decibel level range that does not affect other people's daily life. Therefore, under the premise that the TV audio has a certain loudness, the loudness of the sound that can be heard by the human ear is the key. The distance that the sound signal spreads in space, that is, the distance between the listener and the TV, becomes an important factor that affects the listener's reception of the TV signal.

② Other factors influence analysis

Second, in terms of reverberation time, it can be seen through subjective questionnaires survey that most of the elderly did not have obvious sense of echo in the living space, so the reverberation time in the living space is not a factor that interferes with the subjective auditory comfort of the elderly. Third, in the aspect of direct sound, the sound source is sent from the TV to the receiver to receive the signal content, which will also be affected by the distance of the listener.

5.1.2.3 Auditory comfort standards

According to the field survey, it is found that the elderly in the nursing homes mainly watch TV and talk in the living space. Compared with other indoor environments such as dining space and activity space, the indoor environment of the living space is relatively quiet. Therefore, for the behavior of watching TV, the relationship between human ear and TV decides the subjective hearing comfort of the elderly. Similarly, for the behavior of conversation in living space, the relationship between two or more people decides the subjective auditory comfort of the elderly. In a relatively quiet space, the conversation between human ear and television or more people can be divided into two categories: "hear clearly" and "audible". "hear clearly" includes "audible", but we should also ensure that the information of the sound source can be accurately received, rather than just the sound. To sum up, for the living space, the standard to ensure the auditory comfort of the elderly is to be able to “hear clearly” the sound source information.

5.1.2.4 The relationship between auditory comfort and space is proposed

Based on the above analysis and the problems found in the survey, it is confirmed that the distance between the listener and the sound source[10], namely “hearing distance”, will affect the auditory comfort of the sound source receiver. Therefore, it can be proposed that the distance between the listener and the sound source, namely “hearing distance”, is the main factor affecting the auditory comfort of the elderly in the living space. So we’re not going to do the check here. In order to study the relationship between “hearing distance” and auditory comfort, the background noise sound pressure level is taken as a non-interfering factor, that is, we choose the time when the outdoor noise is less in winter, and the interior building is not noised , and the audio decibel of the television is also controlled within the permissible range of the national regulations on noise.

5.1.3 Summary

Firstly, this chapter is about the effects of the hearing change characteristics of the elderly and hearing problems, in order to give a basic understanding of the characteristics of hearing aging of the elderly.

Secondly, through literature research, it is found that there is a necessary relationship between auditory comfort and language clarity. we know the relevant factors affecting auditory comfort, which lays the foundation for the following research work.

Finally, through field visits to nursing homes in many places, the sound sources in the living space and dining space are summarized, and the main sound sources and the main behaviors related to auditory comfort are extracted. Through questionnaire survey, we have a preliminary understanding of the basic information of the users of the nursing home. On this basis, systematic statistical analysis is made on the hearing condition of the elderly, the influence of hearing decline on life, living status, dining style and subjective evaluation of the auditory comfort of the space. On the basis of these, we summarize the problems existing in the nursing home space in terms of auditory comfort and further extract the key factors affecting auditory comfort. Then the relationship between auditory comfort and space existence is proposed.

5.2 The clarity of language and spatial layout

5.2.1 Introduction

Based on the summary of factors affecting auditory comfort in Section 5.1, the main factors affecting auditory comfort are loudness, reverberation time, direct sound and reflected sound, and background noise sound pressure level. In this chapter, the main factors affecting auditory comfort are extracted based on the actual problems of space in the actual research.

We should solve the problems found in the living space during the investigation. Firstly, in terms of loudness, we should ensure that the elderly can “hear clearly”, so the TV audio should has a certain loudness. But the loudness of the TV audio should be ensured within the decibel level range that does not affect other people’s daily life. Therefore, under the premise that the TV audio has a certain loudness, the loudness of the sound that can be heard by the human ear is the key. The distance that the sound signal spreads in space, that is, the distance between the listener and the TV, becomes an important factor that affects the listener’s reception of the TV signal.

Second, in terms of reverberation time, it can be seen through subjective questionnaires survey that most of the elderly did not have obvious sense of echo in the living space, so the reverberation time in the living space is not a factor that interferes with the subjective auditory comfort of the elderly. Third, in the aspect of direct sound, the sound source is sent from the TV to the receiver to receive the signal content, which will also be affected by the distance of the listener.

This chapter is an experiment on studying the relationship between hearing distance and auditory comfort in living space of nursing home. The “hearing distance” of living space can be summarized into two categories according to the previous research. For the elderly watching TV, “hearing distance” is the distance between human eyes and the TV interface. For the elderly chatting with each other, the hearing distance is the clear distance between two beds in a twin room. Therefore, this chapter is divided into two experiments. The selection of “hearing distance” for different experimental contents is determined by the researcher according to the basic theoretical knowledge of architecture. The subjects were classified according to their listening level, and the experiments were carried out respectively. In addition, before the experiment, we set the premise that the experiment is a twin room in the nursing home. The independent variables and dependent variables of the experiment were also determined to prevent the interference of other factors. The fixed variables were also needed to be determined in the experiment, the same experiment should be conducted in the same experimental room to prevent the interference of visual factors. The experiment subjects closed eyes. Under the premise that the prerequisite of the experiment has been ensured, the experiment is expected to adopt the physiological feedback measurement index method, according to the change rate of subjects in different situations combined with the subjective questionnaire, to determine the “hearing distance” under the auditory comfort of the elderly.

5.2.2 Experimental methods

5.2.2.1 Experimental conditions

(1) Research site

In this section, pure random sampling method was adopted for random sampling of the above four nursing homes, and finally Qinchunyuan Nursing Home in Kaiyuan City (hereafter refferred as “Qinchunyuan”) was selected as the object of in-depth study. Qinchunyuan has sufficient personnel, complete space facilities and 2,000 beds. It can be seen from Table 5-2 that Qinchunyuan is an oversized elderly care building. The research object of this paper is also the nursing homes with large facilities, which meets the conditions for further research. Therefore, Qinchunyuan was selected as the final research object. In addition, in order to avoid the interference of external sound environment on the indoor, winter is the best time for the survey. At this time, the windows are closed, and during the experiment, the door is guaranteed to be closed, which can better reduce the interference of external noise on indoor measurement data.

Table 5-2 Classification of the building grade of the old-age facilities (Source: Author’s drawing)

	Nursing home for the elderly（bed）	Nursing Home（bed）	Day care center for the elderly（person）
Small size	≤100	≤150	≤40
Medium size	101-250	151-300	41-100
Big size	251-350	301-500	-
Over-sized	＞350	＞500	-

(2) Spatial type sampling

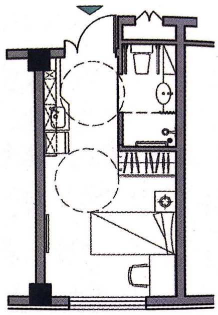
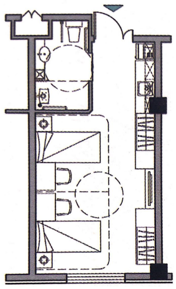
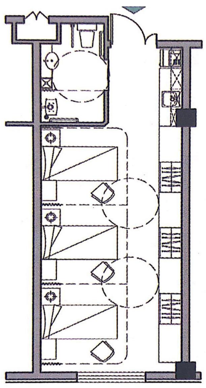
In the second chapter, non-random sampling method was adopted to conduct preliminary field research on the status quo of the nursing home classical space. In this chapter, the auditory comfort of the living space of the nursing home was further studied and discussed in detail. It is expected to adopt non-random sampling method, that is, the sample selected by researchers after a series of conditions screening and under certain conditions.

① Room type selection

The living space of nursing homes can be divided into three types: single room, twin room and dormitory room. Based on the characteristics of the three types of rooms and the psychological perspective of users, the three types of rooms were studied and summarized, as shown in Table 5-3. Finally, on the basis of analyzing the characteristics of each type, the researchers decide to choose the twin room with the highest universal applicability as the object of study of space type.

Table 5-3 Characteristics and diagrams of different types of rooms (Source: Author’s drawing)

Type	Plane diagram	Characteristics

Single room		①Psychologically, some elderly people prefer to live in a space full of privacy and do not like to live with strangers, or they worry about that their habits and other aspects are different from others, so they prefer a single room. ②In terms of physical health, some elderly people worry that living with other elderly people, their normal life and physical health will be affected by their diseases. ③ Some single rooms will have a separate living area, so the price of single rooms are generally of higher price.
Twin room		①Psychologically, some elderly people do not like lonely environment, so they prefer to have "partners" around them to chat with them and take care of each other. ② Some elderly couples in nursing homes usually choose twin rooms. ③Compared with single rooms, the price of twin rooms is moderate, so more elderly people are more inclined to choose twin rooms.
Dormitory room		①The biggest difference between dormitory rooms and single rooms(or twin rooms) is that there are more elderly people living together in dormitory rooms. Generally, dormitory rooms are three or four occupants rooms, so the elderly who like lively environment, and are not afraid of being disturbed to choose dormitory rooms. ②Another biggest difference between dormitory rooms and single rooms(or twin rooms) is that the price is more affordable. ③Some elderly people have to temporarily live in dormitory rooms because the single rooms and twin rooms are full when they enter the nursing home, so they have to wait for an extra room.

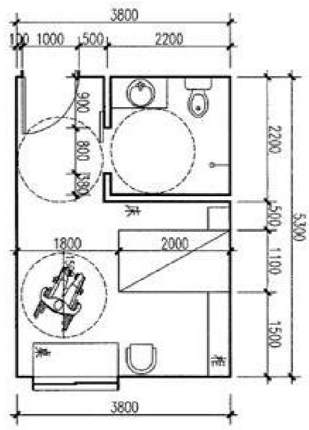
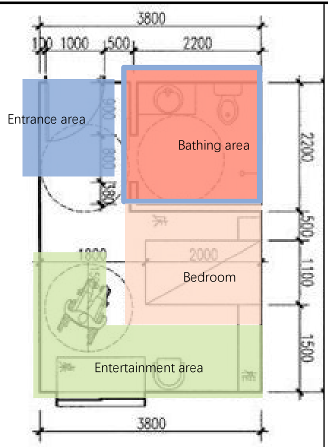
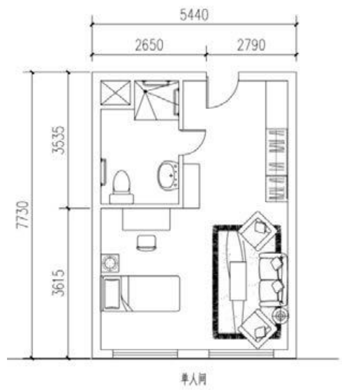
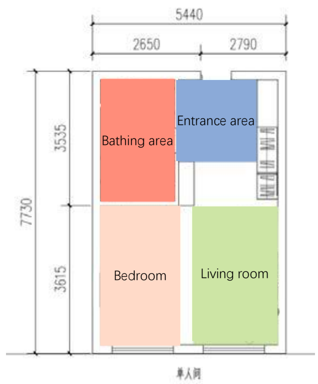
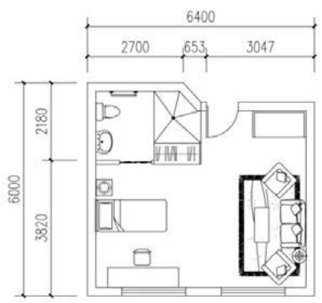
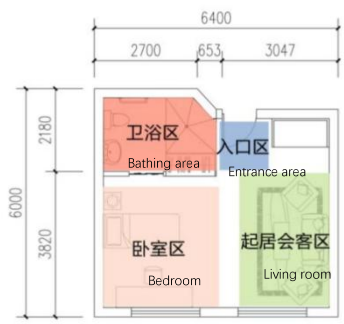
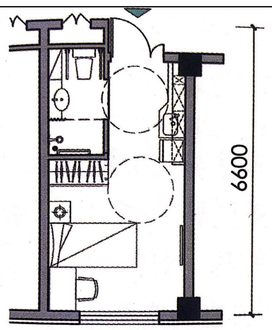
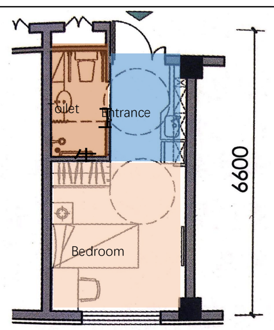
② The interior layout of the room

The elderly living buildings generally contain functional space: living room, bedroom, toilet, kitchen, dining room and so on. For the nursing home, its living space generally includes: bedroom and toilet, as well as a certain storage space. Some also have kitchen, balcony, living room and other spaces. The following table summarizes the basic layout of common living spaces such as single room, twin room and dormitory room, as shown in Table 5-4.

Table 5-4 Classification of different types of room interior layout (Source: Author's drawing)

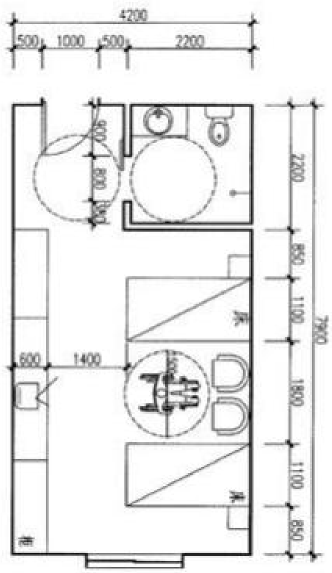
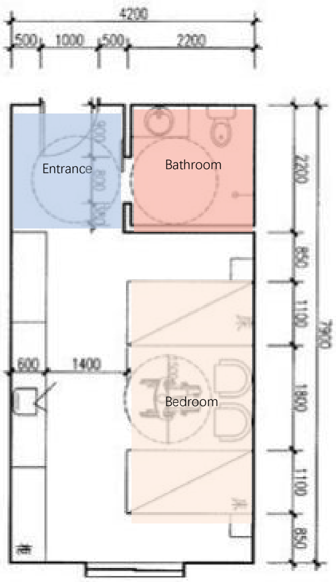
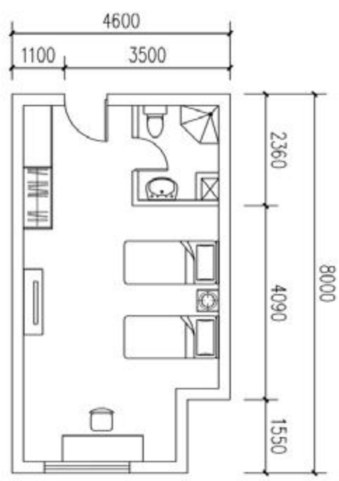
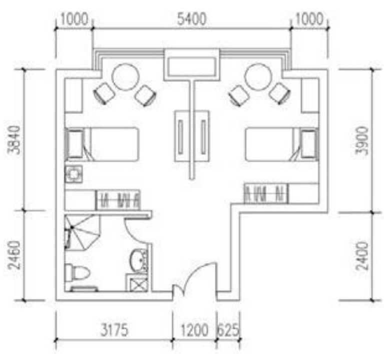
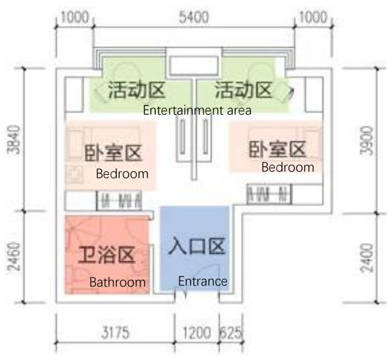
a. Common plane diagram of single room

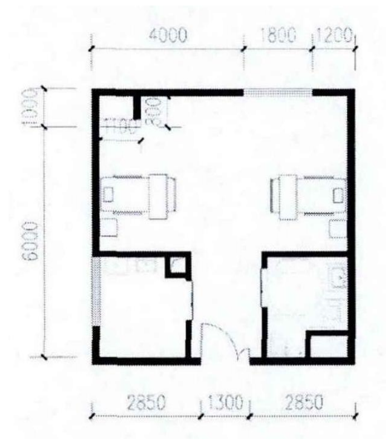
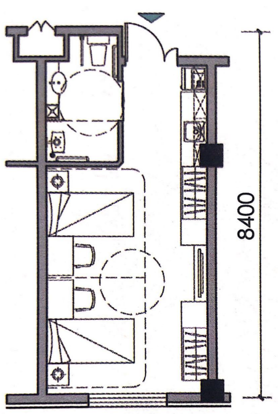
Plane diagram of single room	Functional area distribution	Characteristics

		1. The routine layout of each area of the living room is suitable for the elderly who can take care of themselves and the elderly in wheelchairs. 2. Small and wide room saves cost. 3.Economical room's function setting is relatively simple, and independent living room and special reception area are not set.
		1. The routine layout of each area of the living room is for the elderly who can take care of themselves. 2. The living room is set in the southeast direction with wide space, which can better meet the elderly's need of rest and reception activities. 3. The toilet door is open outside to ensure safety.
		1. The bedroom area is arranged close to the bathroom and the entrance, which is suitable for the elderly people who need complete care. The distance between the living room and the toilet, as well as the distance between the living room and entrance are reduced to reserve the activity area to meet the daily needs of the elderly. 2. Large south window can meet the sunshine needs of nursing elderly people.
		1. The space has with simple function composition including bedroom, toilet and entrance area, but can meet the basic requirements. 2. The most economical room type with short depth and wide surface also saves space

b. A common plan for a double room

Plane diagram of twin room	Functional area distribution	Characteristics

		1. The most common twin room layout is suitable for the elderly who need care and the device-helping elderly people who can take care of each other. 2. Bedrooms are adjacent to beds, so privacy measures should be paid attention to. 3. The activity area is arranged with desk or table, which can facilitate the elderly to eat in the room.
		1. The most common twin roomlayout is suitable for the elderly who need care and the device-helping elderly people who can take care of each other; 2. Bedrooms are adjacent to beds, so privacy measures should be paid attention to. 3. The activity area is arranged with desk or table, which can facilitate the elderly to eat in the room.
		1.Bedroom partition which is suitable for fully self-care elderly can ensure the privacy of the elderly. 2. Two separate and independent activity areas can be arranged according to the different living habits of the elderly.

<table>
<tr>
<td>
</td>
<td>
</td>
<td>1.There is a certain distance between the two beds, which is suitable for the fully self-care elderly and they have certain private areas.
2.The disadvantage is that the TV is not set or the TV's position is not ideal. The elderly on the west side can hardly receive the sun when they are in bed.
3. A kitchen is set up, generally in the rooms near the exterior wall of the building.</td>
</tr>
<tr>
<td>
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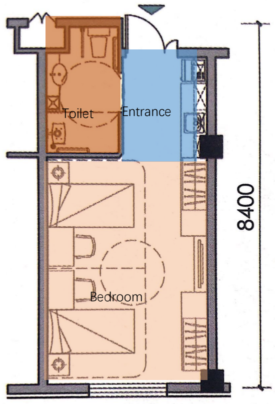
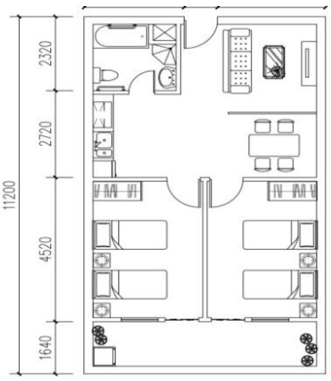
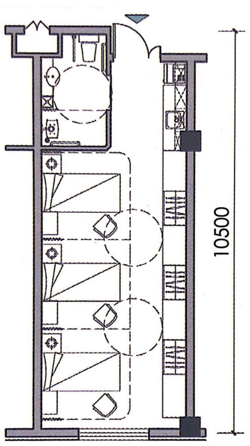
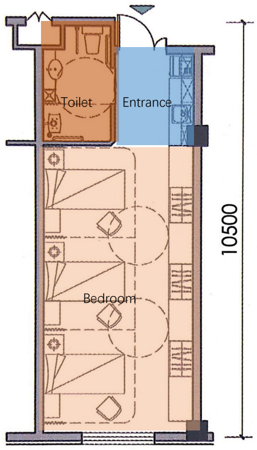
<td>
</td>
<td>1. The space is simple, but it has a wide range of applicability. It can be used as a single room with large area and complete functions, or as a standard twin room.</td>
</tr>
</table>

c. Three, four people rooms commonly used plane diagram

<table>
<tr>
<th>Plane diagram of dormitory room</th>
<th>Functional area distribution</th>
<th>Characteristics</th>
</tr>
<tr>
<td>
</td>
<td>
</td>
<td>1. Two independent bedroom areas, which can accommodate couples and relatives.
2. A small and complete family atmosphere is formed by arranging the living reception area, dining area and kitchen meal preparation area.
3. The wide balcony is not only conducive to the elderly basking in the sun, but also a communication space for chatting.</td>
</tr>
</table>

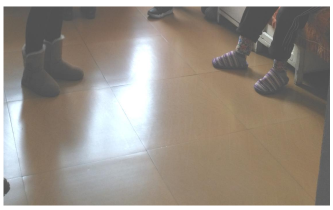
		The room type that can be arranged as a three-person room or an elderly couple's room with dinner function.

After the above summary, the common internal arrangement of single room, twin room and dormitory room is shown in the table above. The layout of the twin room is divided into three types: a rectangular form type with two parallel rooms, a square type with two beds and L-type with two beds and a block between the two beds. Based on the investigation and interview, it is found that most of the rooms with two beds in parallel layout are rectangular, which can better represent the characteristics of twin rooms in the living space of nursing homes in cold regions. Therefore, the interior layout of twin rooms is arranged in a rectangular form with two beds in parallel.

③ Others

In terms of decoration materials for living space: through investigation and interview, it is found that most decoration materials for living space of nursing homes are not sound-absorbing materials in consideration of economy and universal applicability. The mainly used interface is floor or floor tile. The wall material is paint, some nursing homes will paste wallpaper material on the wall in order to create rich spatial experience for the elderly. The ceiling is usually painted with common non-sound absorbing materials, as shown in Table 5- 5. Therefore, the decorative materials of living space selected in this experiment are also non-acoustic materials.

Table 5- 5 The current status of the Materials for each Interface in the Residential Space (Source: Author's drawing)

Main interface	Status chart	
Ground		

Wall		
Ceiling		

(3) Research time

According to the behavior schedule of the survey, the elderly generally got up between 5:00 and 6:00 in the morning, some of them chose to do morning exercise between 6:00 and 7:00, and had breakfast between 7:00 and 8:00. Therefore, some of the elderly in these three periods had fixed arrangements in time and were not in the room when they did morning exercise. Therefore, the research time was selected between 8:00 and 11:00 in the morning; At noon, the lunch time of Qinchunyuan was between 11:20 and 12:00. After lunch, the elderly would choose to take a lunch break from 12:00 to 13:30, and the dinner time was from 16:20 to 17:00, so the survey time in the afternoon is between 13:30 and 16:00.

(4) Questionnaire scale selection

As for the subjective satisfaction evaluation of the living space of nursing homes, it is impossible to adopt relevant acoustic measuring instruments like physiological feedback measurement. Therefore, to obtain the subjective comfort index of the elderly in each situation in the living space, it is necessary to adopt the relevant measurement method of sociology and psychology: using the scale to measure the subjective index. The scale is a measuring tool with structural intensity sequence, in which all statements or items are arranged in a certain structural sequence to reflect the different degrees of the concept or attitude of measurement. In the survey, the more common scales include the Bogedas Social Distance Scale, the Semantic Difference Scale and the Richter Scale.

A.Bogedas Social Distance Scale[11]: It focuses on a multi-layered and detailed dissection of a question such as: Do you like listening to music? Do you like the music in the dining space? Do you like music playing in the dining space of the nursing home? Therefore, the survey of the sound in the dining space will be very lengthy, and considering that the elderly users of the space will have a little difficulty in understanding it, it is not conducive to the extraction of results.

B. Semantic Difference Scale[12]: Also known as semantic differentiation scale, it is used to study the different meanings of concepts to different people. This scale was originally used in studies by the American psychologist C. Osgood and others. The Semantic Difference Scale divides adjectives into seven levels, so each adjective is more finely divided. In previous studies, such as Kang (2003)'s study on the cross-culture of soundscape in urban open space and Tai Huixin (2004)' s subjective evaluation of soundscape research in urban residential areas, this table is mainly applied to the judgment of subjective judgement of sound, and the seven levels have high requirements on the accuracy description of adjectives. In this paper, it is also considered that the surveyed population is the elderly, whose understanding ability declines to varying degrees with the increase of age, so the semantic difference scale is not suitable for this survey.

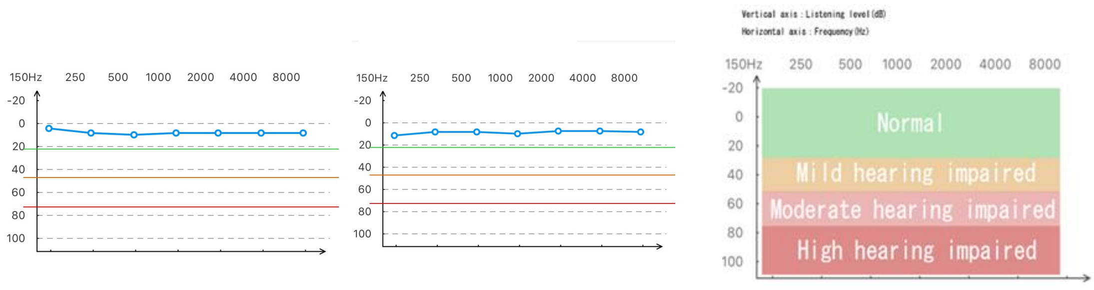
C. Richter Scale[13]: This is the most common type of scale. It was modified by Richter, an American social psychologist, in 1932 on the basis of the original sum-sum scale. Similar to the semantic difference scale, this scale is also composed of a group of adjectives. But it is composed of five levels, which are respectively recorded as 1-5 points. The scoring is to distinguish the intensity between each level. Finally, the total score of each survey participants on this issue reflects the intensity of the survey participant's attitude towards this issue. Compared with semantic difference scale, this scale is easier to be understood by the elderly. Therefore, to sum up, Richter Scale is selected in subjective satisfaction evaluation of living space in this chapter.

(5) Design of subjective evaluation of auditory comfort in living space

Along with aging, all aspects of the elderly's physical functions are declining. In order to enable the elderly to accurately select their subjective feelings about the acoustic environment of the living space of the nursing home under the current situation through the questionnaire, we chose the adjectives which were closer to everyday language, making it sound easy for the elderly to understand when we set questions. The researchers hope that in different situations (i.e., different distances), the elderly can give subjective scores to the same decibel sound source they hear. The score of 1 is the worst, and the score of 5 is the best. 5 points for very comfortable, 4 points for comfortable, 3 points for general, 2 points for uncomfortable, and 1 point for particularly uncomfortable. Here, the elderly can give subjective scores according to the sound source feeling they hear in different situations.

5.2.2.2 The selection of subjects

Along with aging, the elderly have varying degrees of hearing impairment. According to the hearing impairment classification standard of the World Health Organization (WHO-1997) in Chapter II[14], it can be seen that when the degree of hearing impairment is moderate, hearing aids should be used. Therefore, the research objects in this paper were divided into two groups, namely normal hearing group and mild hearing impairment group (Hereinafter referred to as hearing impaired group). The elderly that need to use hearing aids were not the research object of this paper. Here audiometry software was used to determine the hearing level of the elderly. The interface is shown in Fig. 5- 13. In addition, considering that the subjects' own conditions (age, educational background, income and occupation) will affect the experiment and become the experimental variable, we selected the self-care elderly who were between 60 and 80 years old, evenly distributed among low, medium and high levels of education, and have normal intellectual comprehension. They were divided into two groups, namely normal hearing group and mild hearing impaired group, and there were 30 people in each group, namely 15 men and 15 women.



(a) Left ear test results interface

(b) Right ear test results interface

(c) Listening level assisted reading interface

Fig. 5- 13 Test listening level interface (Source: Author's drawing)

5.2.3 Methods

The experimental part of the living space is mainly on the degree of emotional stress response shown by the elderly in different experimental situations[15]. The degree of emotional stimulation combined with the subjective questionnaire is used to determine the comfort level of the subjects. The experimental space in this chapter is the living space. The elderly have enough private space to calm down to cooperate with the experimental simulation. Time is sufficient, and the behavior is reasonable, so the experimental conditions of using physiological feedback technology are satisfied. Therefore, based on the above situation, the experimental method in this chapter is expected to be the physiological feedback measurement index method[16]. This method can record the physiological responses of the elderly to different situations more directly.

5.2.3.1 Experimental design of TV sound comfort and space distance

(1) Experimental materials:

Three one-minute audio clips were selected. In order to reduce the emotional impact on the elderly, the audio content was neutral, so that the elderly could only pay attention to the influence of audio distance on sound clarity. The independent variable of this experiment is the distance between the subjects and the audio, so the audio volume should be fixed. Based on the data survey, it is known that the volume of the TV is between 50-70dB, and the decibel value exceeding 60dB belongs to the category of noise. Moreover, the decibel value of the living space during the day is not allowed to exceed 55dB, so the audio volume is controlled at 50-55 dB.

Distance limitation: For the passage space formed between the bed tail and the TV in the nursing home, the standard stipulates that it is not less than 1050mm. The thickness of the TV cabinet is 500-700mm, so the minimum distance between the bed tail and the TV is 1550mm, and in this experiment it is rounded to 1600mm. In the previous research, it was found that some living spaces will be extended to 3000mm because of the operating table around the TV and bed. Therefore, 3000mm is taken as the upper limit of the change value in this experiment. Therefore, in this experiment, the distance between 1600-3000mm is divided into a section with a 300mm interval, and six sections are 1.6m, 1.9m, 2.2m, 2.5m and 2.8m.

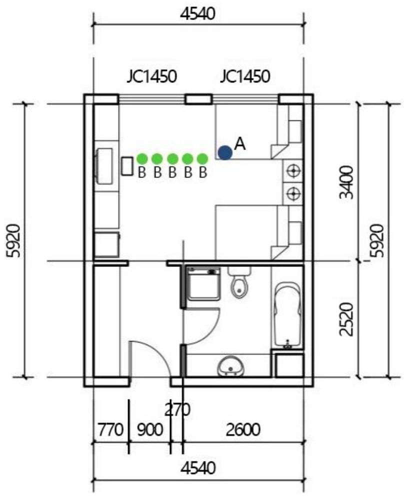


Fig. 5- 14 Survey point distribution map

(2) Experimental principle, instruments and variables

① Experimental principle:

A mobile sensor is used to provide real-time visual recording of the subject's physiological data. The analysis of this physiological information with other visible behavioral data allows for the direct detection and quantification of subconscious perceptions and feelings that are difficult to perceive intuitively, such as stress levels, happiness or not.

This experimental method, different from the traditional subjective questionnaire form, adopts ErgoLAB human-machine environment synchronous platform technology to conduct human factor experiment. Through quantitative research method, wearable physiological module is used to collect physiological indicators, and then analyze the changes of the sympathetic nerve of the elderly under specific environment and activity state, and finally analyze the elderly's stress ability or emotional changes and other information.

We mainly used ErgoLAB PPG and ErgoLAB EDA to study the comfort and space distance of the elderly while watching TV. In the process of the elderly participating in the experiment, physiological indicators are collected. This experimental method is more scientific and rational.

② Experimental instruments: audio clips, measuring tape, PPG, EDA

③ Experimental independent variables: the distance between the subject and the sound source. Experimental dependent variable: physiological index of subjects. Fixed variable: sound pressure level

(3) Experimental process

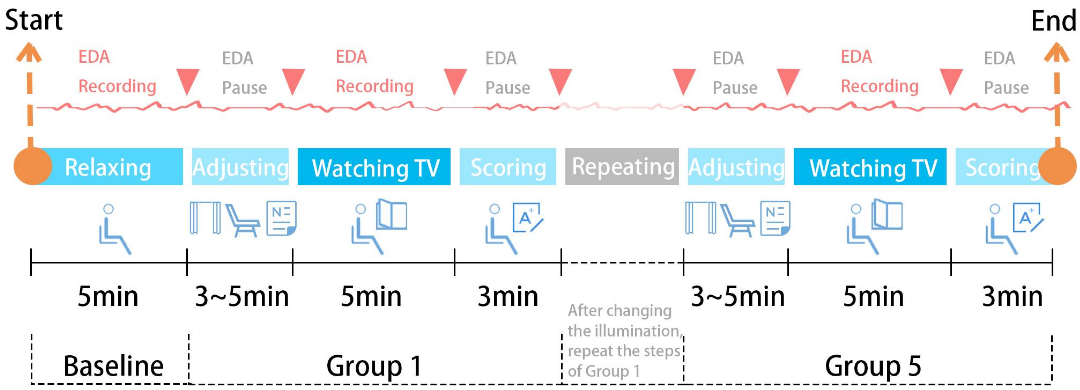


Fig. 5-15 Experimental process of TV sound comfort

① Introduced the experiment process to the subjects, let the subjects relax and concentrate on the audio.

② The subjects were in position and kept the usual posture of watching TV.

③ Cleaned palms and wore instruments. First, the subjects sat quietly for 5 minutes in a no-audio environment to maintain a stable mood and collected the baseline level of the subjects.

④ In order to eliminate the interference of reverberation caused by different furniture materials and positions in the room, the experiment was fixed in the same room, and the subjects were invited to the room one by one for the experiment, so as to minimize the external interference factors. The five distances of 1.6m, 1.9m, 2.2m, 2.5m and 2.8m were randomly allocated and the audio was played. Due to the large number of segments, in order to prevent the repeated presentation of the same audio segment from interfering with the psychology of the elderly, this experiment selected three neutral audio segments with the same time for random playback, and noted the corresponding distance value of physiological indicators in each segment to avoid confusion. After listening to a piece of audio, marking and recording were carried out. After recording, the next distance was moved randomly. After the subjects were stabilized, the next piece of audio was played and physiological indicators were recorded.

⑤ After all the 5 groups of experiments were finished, the elderly would be asked to score the subjective questionnaire, score the audio quality evaluation corresponding to each distance, and then make a summary analysis.

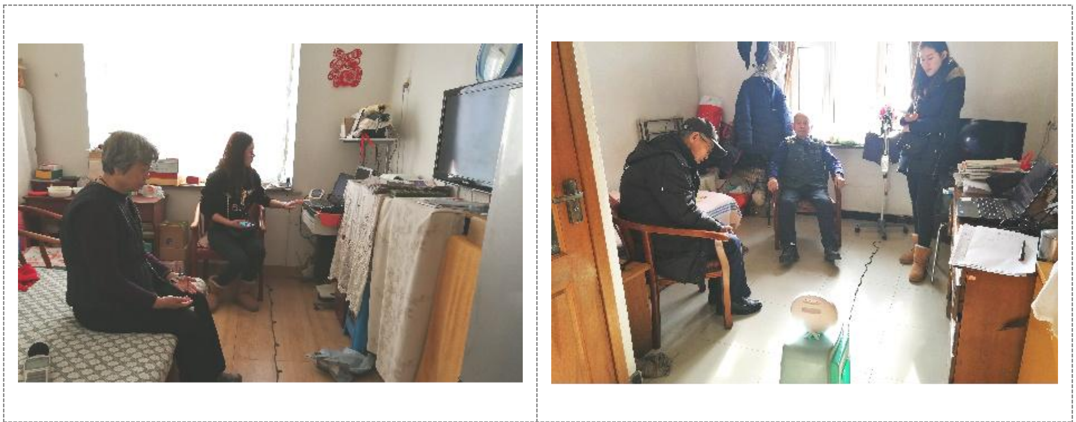


Fig. 5- 16 Experimental scene picture

5.2.3.2 Experimental design of conversational sound comfort and space distance in living space

(1) Experimental content

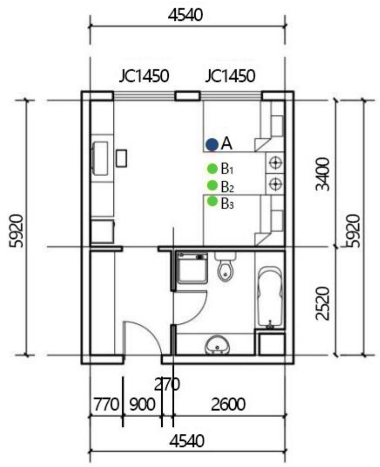
Experimental objective: Through the experimental study on the distance between single beds in the living space, to explore the distance between beds when the elderly talk on each other's beds, the elderly can reach the most comfortable state of hearing.

The experimental principles and instruments of this experiment are the same as those of the previous experiment, so this section will not expand.

(2) Experimental materials:

a. The audio content of this experiment is the same as that of the previous experiment, which is also divided into three audio segments. The difference lies in the decibels of the audio. Since the audio of this experiment is to imitate the voice of the elderly in daily speaking, before selecting the decibels of the audio, we recorded the decibels of 30 elderly people in the process of random chatting, and took the average value as 40dB to imitate the decibels of the elderly people in daily speaking.

b. Distance limitation: The nursing home design code requires that the distance between two beds should be no less than 0.85m. According to the previous research and data review, the depth of the living space in economic and commonly used nursing home is 6m. Taking the toilet, bed, wardrobe, and aisle out, the remaining distance between the beds is at most 1.55m. Therefore, three interval distances (0.9m, 1.2m and 1.5m) were selected between 0.85 and 1.55.



I

Fig. 5- 17 Survey point distribution map

(3) Experimental process

①Introduced the experiment process to the subjects, let them relax and concentrate on the audio of each paragraph.

② The subjects were in position and kept lying flat.

③ Cleaned palms and wore instruments. First, the subjects sat quietly for 5 minutes in a no-audio environment to maintain a stable mood and the baseline levels of the subjects were collected .

④ In order to eliminate the interference of different materials and positions of furniture in the room on reverberation, the experiment was also fixed in the same room, and the subjects were invited to the room one by one for the experiment to minimize the external interference factors. The three distances of 0.9m, 1.2m and 1.5m were randomly allocated and the audio was played. Due to the large number of segments, in order to prevent the repeated presentation of the same audio segment from interfering with the psychology of the elderly, this experiment selected three neutral audio segments with the same time for random playback, and noted the corresponding distance value of physiological indicators in each segment to avoid confusion. After listening to a piece of audio, marking and recording were carried out. After recording, the next distance was moved randomly. After the subjects were stabilized, the next piece of audio was played and physiological indicators were recorded.

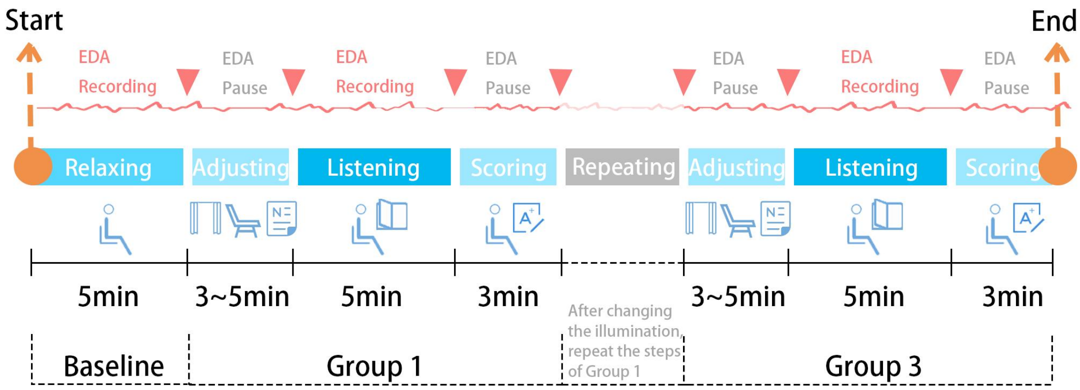


Fig. 5-18 Experimental process of conversational sound comfort

After all the three groups of experiments were finished, the old people were asked to score the subjective questionnaire, to score the audio quality evaluation corresponding to each distance, and then make a summary analysis.

5.2.4 Result

5.2.4.1 Comfort analysis of listening to TV

(1) Electrical skin response index

Due to the individual factors of the elderly such as easy sweating, allergy, and psychological resistance during the test, the data collected from physiological signals will be lost and abnormal, so the number of valid subjects with invalid data excluded was 30. The initial data were processed in ErgoLab software by different categories of segments and denoised to obtain the dermatographic data. Due to the individual differences of sympathetic feedback in the elderly, the data need to be processed, and the rate of change of electrodermal is used for statistics and analysis, i.e., the rate of change of electrodermal = (measured value - baseline value)/baseline value.

①Statistics of data results for the good hearing group

The data of electrical skin response index of the good hearing group subjects are shown in Fig. 5-19 shows. The EDA responses of the elderly varied at different distances, and most of them had significant differences in response to changes in distance. Therefore, the specific data statistical analysis using the rate of skin electrical change analysis including the baseline can accurately reflect the changes of physiological parameters under listening to TV sound.

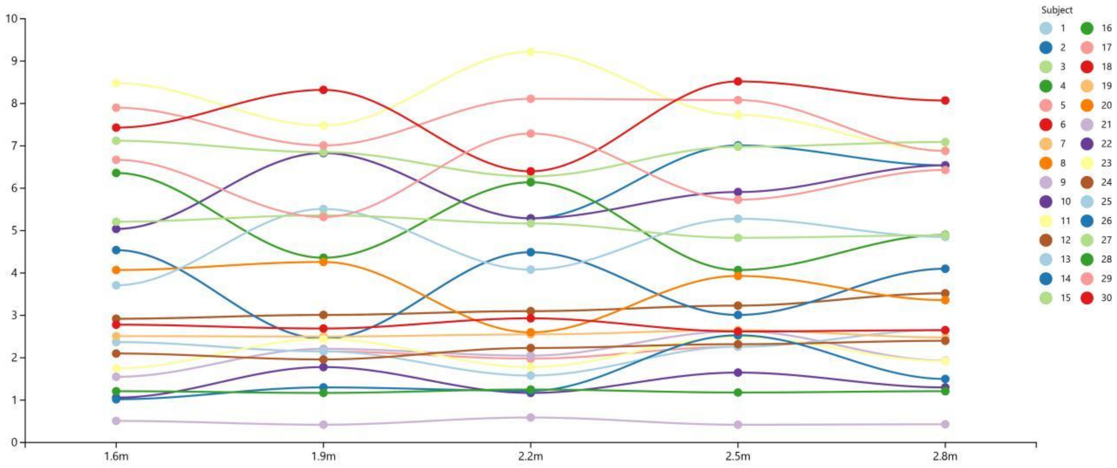


Fig. 5-19 Basic information and results of electrodermic data of group A (good hearing)

The distribution of electrodermal variation rate data in the elderly subjects at different distances is more obvious, and the electrodermal variation of the elderly within the same distance has a large data distribution difference. It can be seen that the distribution of electrodermal variation rate is more concentrated at 1.5m, and the distribution of data changes from 1.9m to 1.9m is more and more significant (see Fig. 5-20).

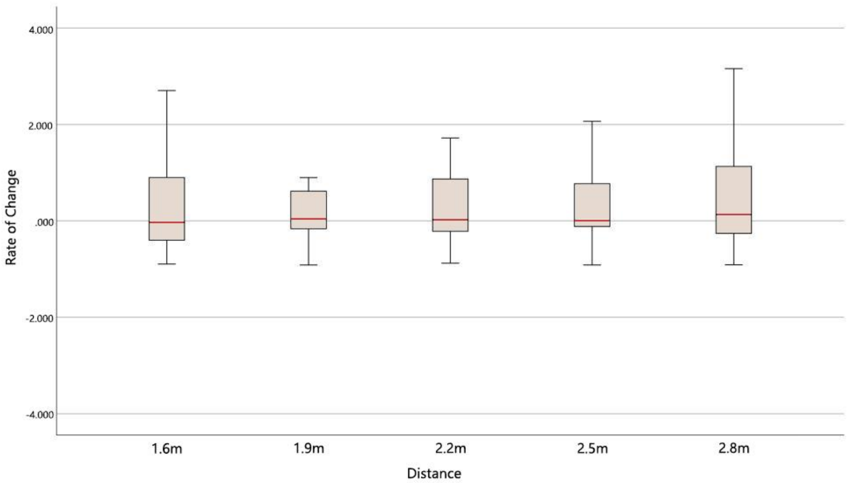


Fig. 5-20 Distribution of electrodermal change rate of elderly people with different distances in listening to TV sound comfort (good hearing)

One-way repeated ANOVA was performed on the dermatographic results to find whether there was a significant difference between the dermatographic data measured repeatedly for subjects at different distances. The rate of change of tare data was tested and the data satisfied normal distribution with Shapro-Wilk $p>0.05$; the chi-square test p was $0.248>0.05$ and the data chi-square test was passed. One-way repeated ANOVA was performed, and the variance covariance matrix of the dependent variable was not equal by Mauchly's spherical hypothesis test, $\chi2(9) = 59.81$, $p < 0.001$, corrected by Greenhouse & Geisser method $\varepsilon = 0.547$. The data of the rate of change of the skin electricity of subjects in the good hearing group listening to TV sound at different distances did not The mean values of the one-way repeated variance electrodermal rate of change at different distances are shown in Fig. 5-21.

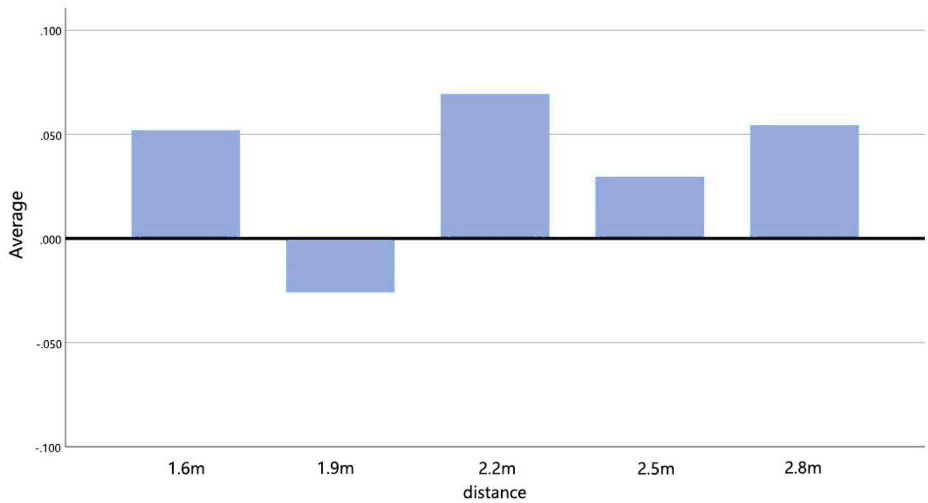


Fig. 5-21 Mean values of electrodermal change rate of listening to TV sound at different distances in the good hearing group

② Statistics of data results for the hearing impaired group

The data of electrical skin response index of subjects in the hearing impaired group are shown in Fig. 5-22 shown. The EDA responses of the elderly varied greatly at different distances. Among them, the degree of variation was too large for subject 25, which was analyzed and considered to be due to the elderly's mis-touching during the use of the dermal electrical apparatus. Therefore, the data analysis excluded the data related to subject 25 to ensure the feasibility of data analysis.

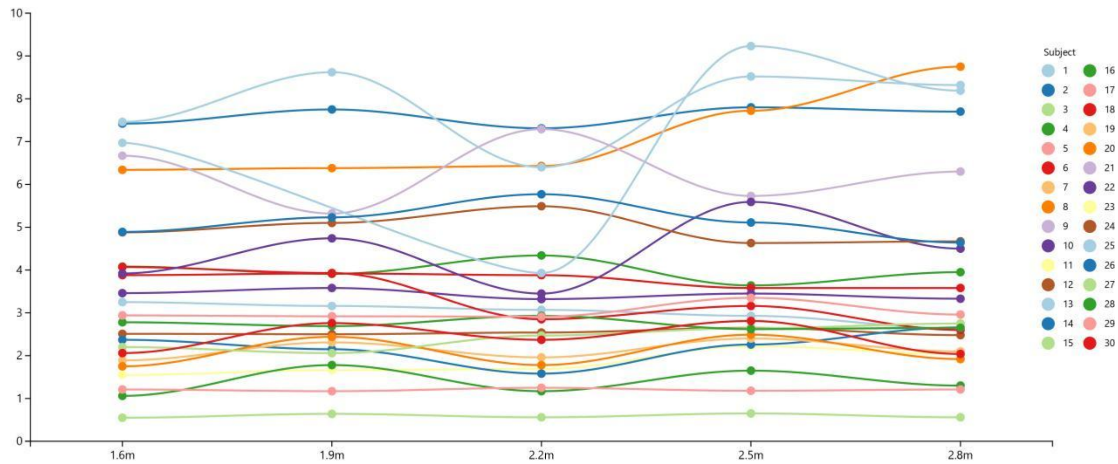


Fig. 5-22 Basic information and results of electrodermic data of group B (hearing impairment)

The distribution of electrodermal variation rate data was relatively concentrated among the elderly subjects at different distances, and there was little difference in the electrodermal variation rate among the elderly within the same distance, and the variation rate was within ±1. The distribution of the data at different distances was also uniform, and the data were distributed around the change rate of 0 (see Fig. 5-23).

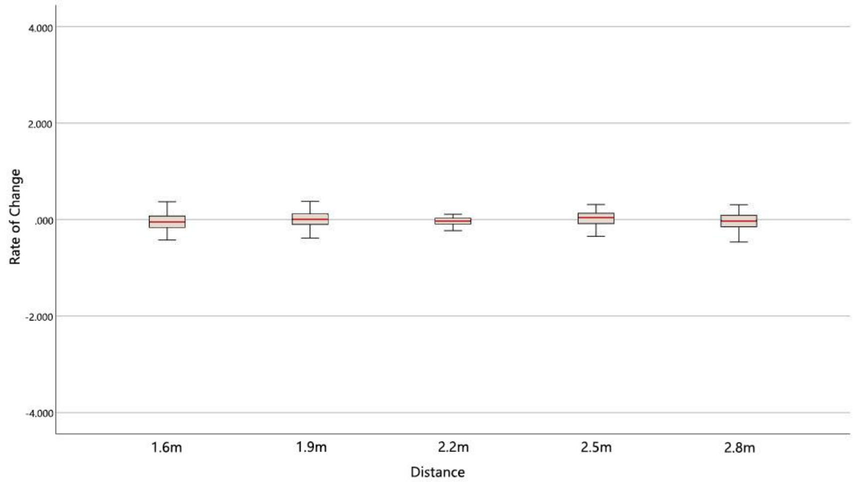


Fig. 5-23 Distribution of electrodermal change rate (hearing impairment) in elderly people with different distances in listening to TV sound comfort

One-way repeated ANOVA was performed on the dermatographic results to find out whether there were significant differences in the dermatographic data measured repeatedly for subjects at different distances. The rate of change of tare data was tested and the data satisfied normal distribution with Shapro-Wilk $p>0.05$; the chi-square test p was $0.098>0.05$, and the data chi-square test was passed. One-way repeated ANOVA was performed and the variance covariance matrix of the dependent variable was not equal by Mauchly's spherical hypothesis test, $\chi2(9) = 78.505$, $p < 0.001$, corrected by Greenhouse & Geisser method $\varepsilon = 0.441$. as shown in Fig. 5-24, the rate of change of the electrical skin at 1.6m, 1.9m, 2.2m, 2.5m, and 2.8m for the subjects was 0.012 (±0.054), 0.085 (±0.070), -0.011 (±0.044), 0.104 (±0.053), and 0.046 (±0.059), respectively. The difference in the electrodermal rate of change data for listening to TV sound at different distances in the hearing impaired group was not statistically significant, corrected F(1.762, 51.109)=2.172, P=0.13.

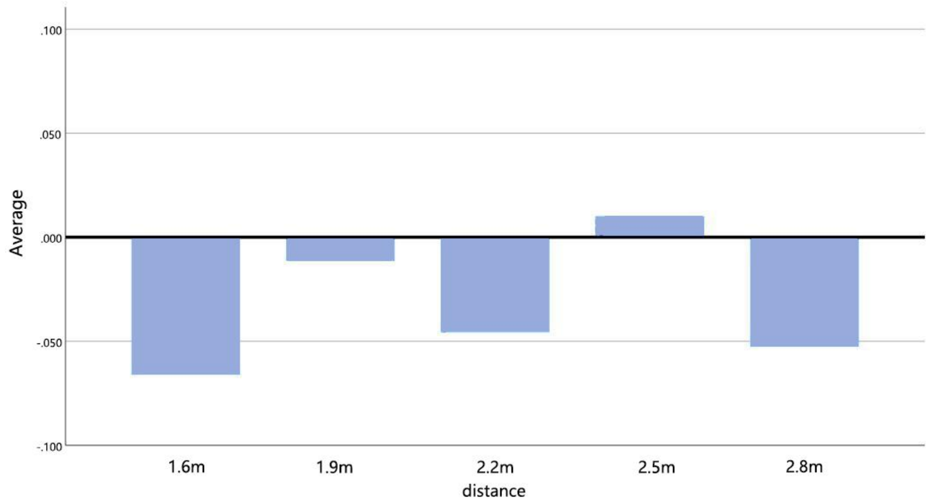


Fig. 5-24 Mean value of electrodermal change rate of listening to TV sound at different distances in the hearing impaired group

(2)**Analysis of subjective questionnaire survey results**

① Subjective psychological satisfaction evaluation of subjects in the good listening group

Last section is the experimental measurement of the changes of the physiological indicators of the subjects under each group of distance. Through calculation and statistics, it can be known that the psychological impact of the several groups of distance on the subjects fluctuates greatly. However, whether the fluctuation is caused by the comfort fluctuation or the discomfort fluctuation can not be specified in the previous section. Therefore, the subjective questionnaire should be used to explain it. Fig. 5- 25 is a columnar statistical table for the satisfaction evaluation of the subjective psychological feelings of group A, namely the group with good listening ability. It can be seen from the table that the ranking of the satisfaction of the five distances is 1.6m > 2.8m > 1.9m >2.5m > 2.2m. It can be seen that in the five distances, the three groups with the highest subjective satisfaction are 1.6m, 2.8m and 1.9m, and the worst is 2.2m.

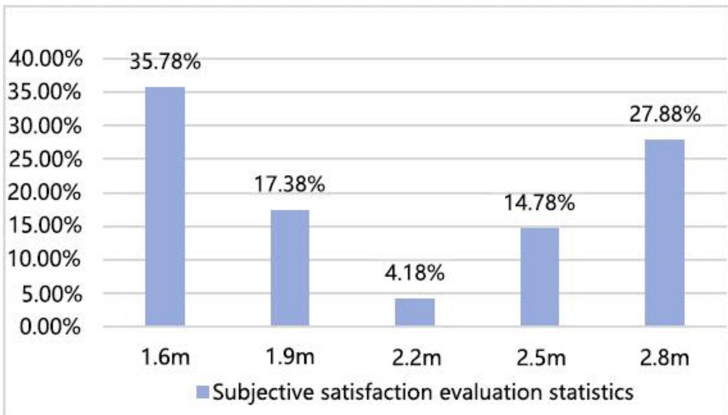


Fig. 5- 25 Subjective satisfaction evaluation statistics under different distance of group A (good hearing) (Source: Author's drawing)

②Subjective psychological satisfaction evaluation of the hearing impaired group

Fig. 5- 26 is a columnar statistical table for the satisfaction evaluation of the subjective psychological feelings of group B, namely the hearing impaired group. It can be seen from the table that the satisfaction ranking of the five distances is 1.6m > 1.9m > 2.2m > 2.5m>2.8m. It can be seen that the three groups with the highest satisfaction among the six distances are 1.6m, 1.9m and 2.2m, and the worst is 2.8m.

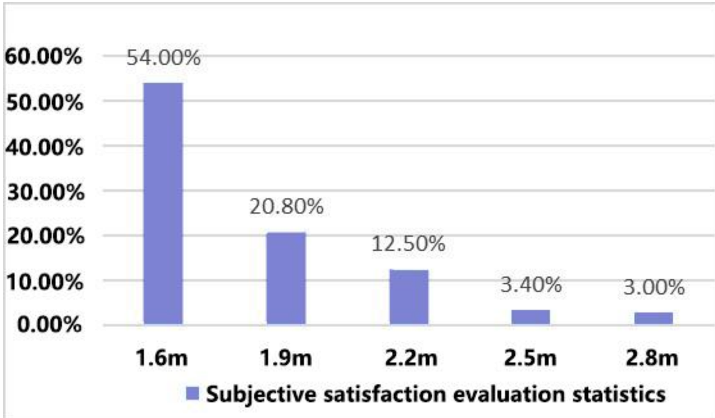
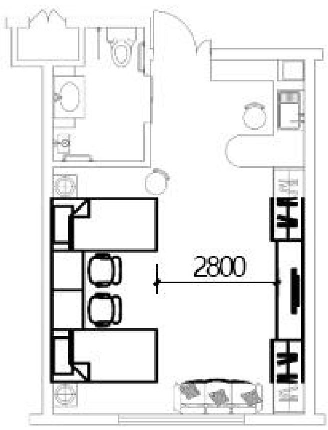


Fig. 5- 26 Subjective satisfaction evaluation statistics at different distances of group B (hearing impairment) (Source: Author's drawing)

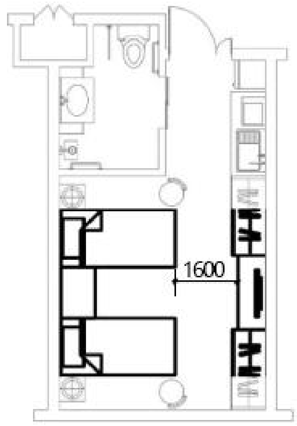
(3) Comprehensive evaluation and analysis

Based on the objective physiological index measurement and subjective psychological satisfaction evaluation of each subject, it can be concluded that for group A, that is, the group with good hearing, the physiological index fluctuates the most at the distance of 2.8m, and the reason for the big fluctuation is the comfort fluctuation. The possible reason is that the elderly in group A belong to the category of good hearing, and the close distance will make them feel too loud. Therefore, this kind of elderly people prefer a slightly distant distance, which will make the elderly with good hearing feel more comfortable. Therefore, when designing the living space of nursing homes, the choice of this size should be given priority as far as possible.

For group B, that is, the hearing impaired group, the elderly have a great physiological fluctuation in the 1.6m, and the reason for the big fluctuation is the comfort fluctuation. This may be because the elderly in group B belong to the category of hearing impaired, and close distance will make the elderly with hearing impaired hear the sound more clearly, so they prefer a slightly closer distance. This will make older people with hearing impairment feel more comfortable. Therefore, when designing the distance between the elderly living space and the TV, the closer size should be considered first.



a.Good hearing



b.Impaired hearing

Fig. 5- 27 Comfortable distance between watching TV and hearing in living space (Source: Author's drawing)

5.2.4.2 Comfort analysis of alternating sound

(1) Electrical skin response index

The electrical skin response index for AC comfort in the elderly was selected as in the previous section, and the rate of change of skin electricity was used for statistics and analysis. The valid subjects were 30, and the initial data were denoised in ErgoLab software by different categories of segments.

①Statistics of data results for the good hearing group

The data of electrical skin response index of subjects in the good hearing group are shown in Fig. 5-28. The EDA responses of the elderly did not vary significantly at different distances. The only ones with excessive degree of variation were subject 21 and subject 6, which after analysis was thought to be due to the fact that the elderly were involved in communication that had a greater impact on the individual during the experiment. However, since it is more common to involve a greater impact on the individual during the actual communication process but does not reflect the true comfort situation, the statistical analysis concluded that the treatment should be removed.

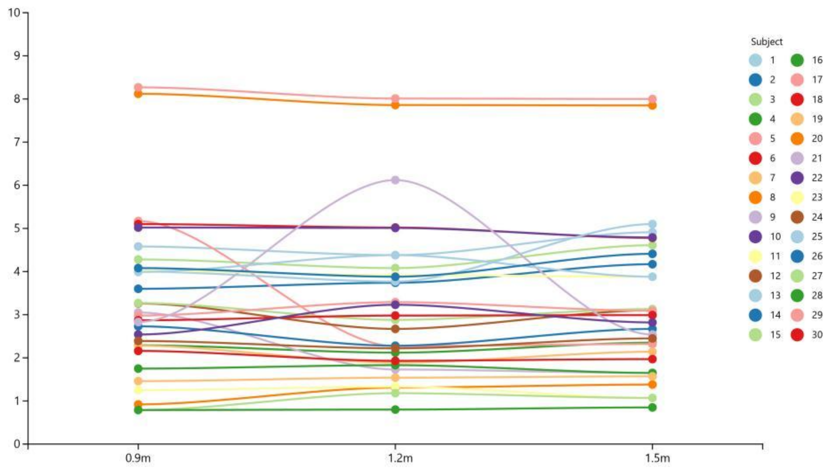


Fig. 5-28 Basic information and results of electrodermic data of group A (good hearing)

The distribution of electrodermal variation rate data was more general among the subject elderly at different distances, and the distribution of electrodermal variation among the elderly within the same distance did not differ much (see Fig. 5-29).

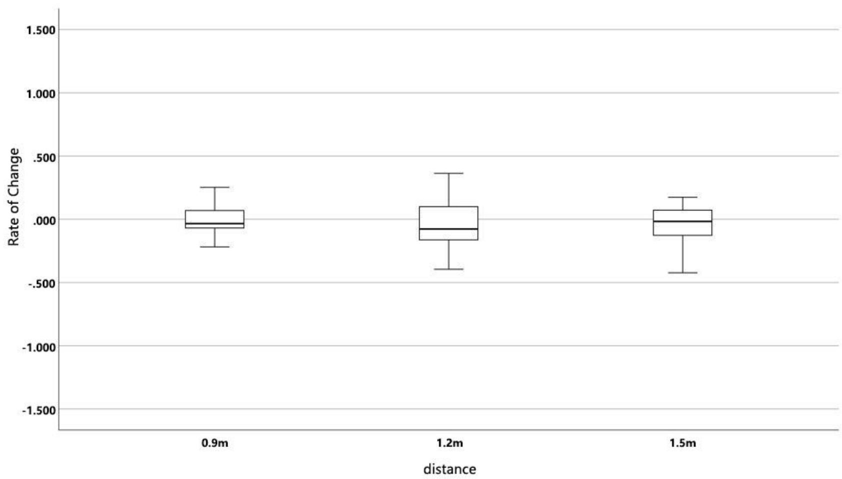


Fig. 5-29 Distribution of the rate of change of electrical skin of elderly people at different distances in AC sound comfort (good hearing)

One-way repeated ANOVA was performed on the dermatographic results to find whether there was a significant difference between the dermatographic data measured repeatedly for subjects at different distances. The rate of change of tare data was tested and the data satisfied normal distribution with Shapro-Wilk $p>0.05$; the chi-square test p was $0.08>0.05$ and the data chi-square test was passed. One-way repeated ANOVA was performed and the variance covariance matrix of the dependent variables were equal by Mauchly's spherical hypothesis test, $\chi2(2)=5.545$, $p=0.063$. The data of the rate of change of electrodermal change of AC sound at different distances for subjects in the good hearing group were not statistically different, corrected $F(2, 46)=1.532$, $p=0.227$. One-way repeated The mean values of the variance skin electrical rate of change are shown in Fig. 5-30.

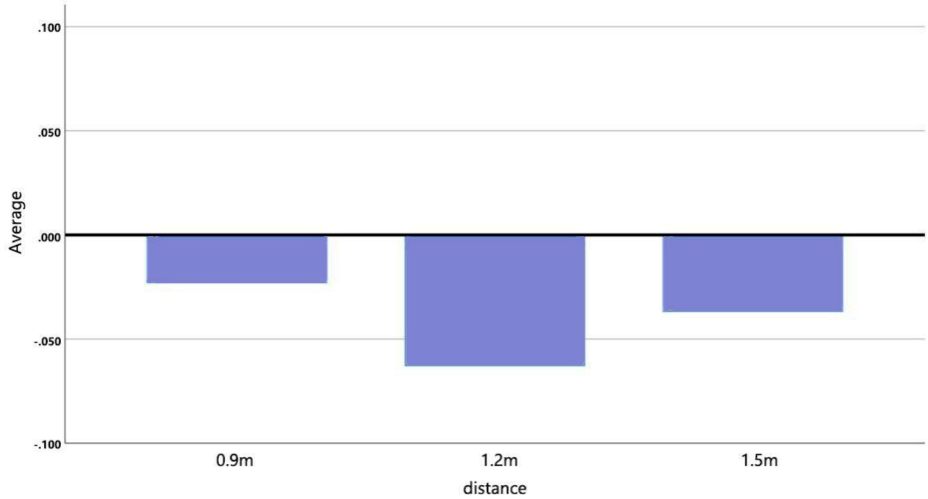


Fig. 5-30 The mean value of the rate of change of the electrical skin of AC sound at different distances in the good hearing group

②Statistics of data results for the hearing impaired group

The data of electrical skin response index of subjects in the hearing impaired group are shown inFig. 5-31 shown. The differences in EDA responses at different distances in the elderly were general. Most elderly people have significant response differences to the change of distance, and the rate of change of skin electric of specific data statistical analysis can reflect the change of physiological parameters under AC sound.

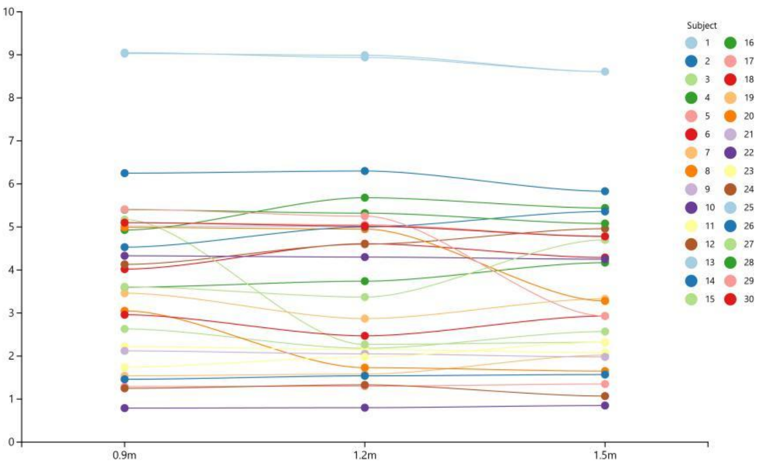


Fig. 5-31 Basic information and results of electrodermic data of group B (hearing impairment)

The distribution of electrodermal variation rate data in the elderly subjects at different distances had some differences, and the difference in the electrodermal variation rate of the elderly at the same distance varied more at 0.9m and 1.5m, but not much at 1.2m (see Fig. 5-32).

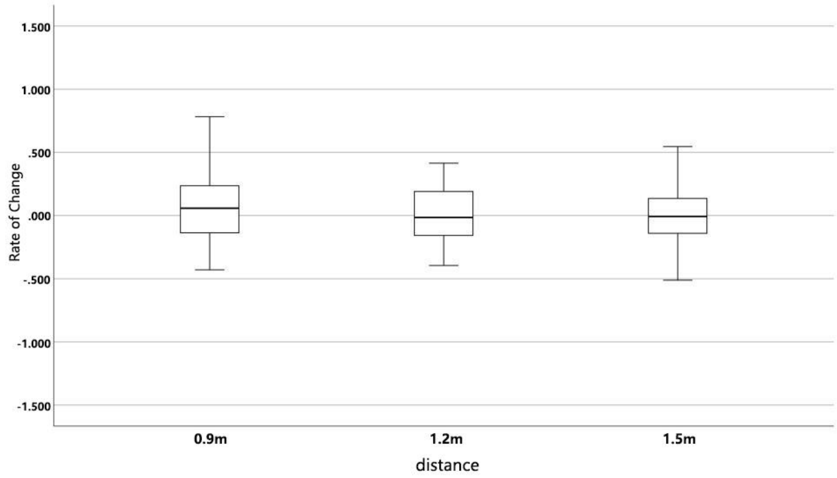


Fig. 5-32 Distribution of electrical skin change rate of elderly people at different distances in AC sound comfort (hearing impairment)

One-way repeated ANOVA was performed on the dermatographic results to find whether there was a significant difference between the dermatographic data measured repeatedly for subjects at different distances. The rate of change of tare data was tested and the data satisfied normal distribution with Shapro-Wilk $p>0.05$; the chi-square test p was $0.110>0.05$ and the data chi-square test was passed. One-way repeated ANOVA was performed, and the variance covariance matrix of the dependent variable was not equal by Mauchly's spherical hypothesis test, $\chi2(2)=7.003$, $p=0.03$, corrected for $\varepsilon=0.861$ using the Huynh-Feldt method. as shown in Fig. 5-33 , the rate of change of electrical skin at 0.9m, 1.2m, and 1.5m for the subjects was 0.053 (±0.048), 0.003 (±0.042), and -0.005 (±0.038), respectively. The difference in the rate of electrodermal change data for AC sound at different distances in the hearing-impaired group was not statistically significant, corrected $F(1.722, 49.949)=1.155$, $P=0.322$.

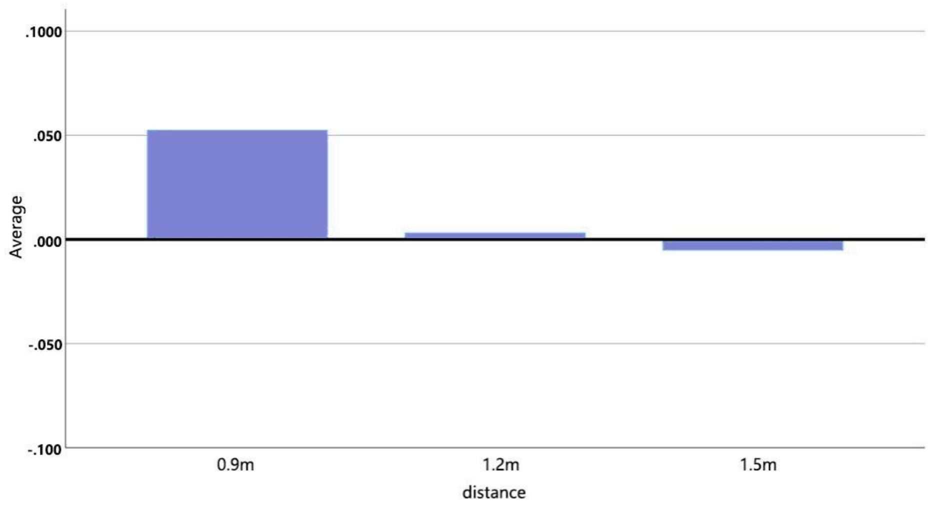


Fig. 5-33 Mean values of the rate of change of the electrical skin at different distances of AC sound in the hearing impaired group

(2)Analysis of subjective questionnaire survey results

①Subjective psychological satisfaction evaluation of subjects in the good listening group

Fig. 5-34 is A columnar statistical table for the satisfaction evaluation of the subjective psychological feelings of group A, namely the group with good hearing. It can be seen from the table that the satisfaction ranking of the three distances is 1.5m >1.2m >0.9m. It can be seen that among the three distances, the subjects are most satisfied with 1.5m and 1.2m, and least satisfied with 0.9m.

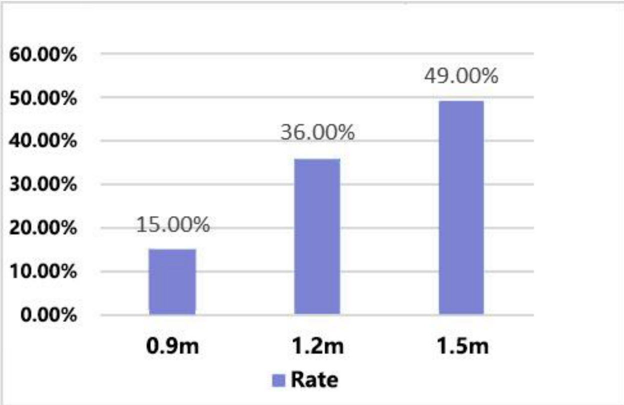


Fig. 5-34 Subjective satisfaction evaluation statistics at different distances of group A (good hearing) (Source: Author's drawing)

②Subjective psychological satisfaction evaluation of the hearing impaired group

Fig. 5-35 is a columnar statistical table for the satisfaction evaluation of the subjective psychological feelings of group B, namely the hearing impaired group. It can be seen from the table that the satisfaction ranking of the three distances is 0.9m > 1.2m =1.5m. The subjects are most satisfied with 0.9m.

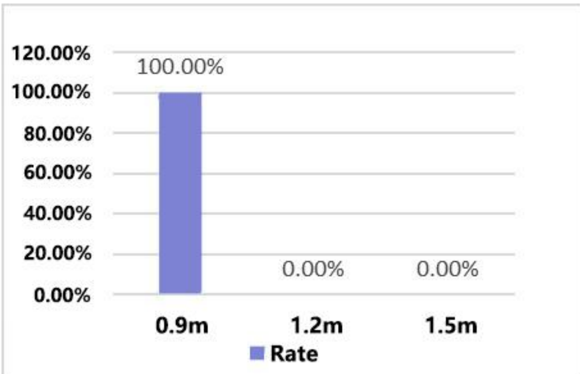


Fig. 5-35 Subjective satisfaction evaluation statistics at different distances of group B (hearing impairment) (Source: Author's drawing)

(3) Comprehensive evaluation and analysis

Based on the objective physiological index measurement and subjective psychological satisfaction evaluation of all subjects, the physiological index of 0.9m and 1.5m fluctuated greatly among the elderly with good hearing in group A. Subjectively the most popular was 1.5m and 1.2m, while the least popular was 0.9m. Therefore, when designing the distance between bed and bed in the living space for elderly people with good hearing, the best conversation distance is 1.5m and the least comfortable one is 0.9m. This maybe because elderly people with good hearing may wish to have some private space between them when talking with their partners in bed, and do not want to be too close to each other. They prefer a slightly longer distance.

For group B, that is, the elderly with hearing impairment have a large physiological fluctuation of 0.9m. The reason for the large fluctuation is comfort fluctuation according to the subjective psychological questionnaire. The possible reason is that when the elderly have hearing impairment, they prefer a slightly closer distance when talking, which can make them hear more clearly.

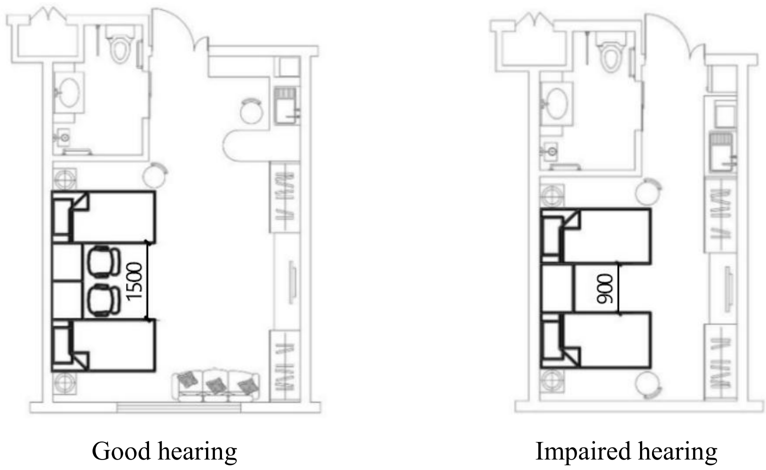


Fig. 5- 36 Comfortable distance of conversation sound in living space (Source: Author's drawing)

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Chapter 6

6. RESEARCH ON THE CORRELATION BETWEEN THERMAL COMFORT AND SPACE

CHAPTER SIX: RESEARCH ON THE CORRELATION BETWEEN THERMAL COMFORT AND SPACE

6.1 Measurement and analysis of objective data of thermal environment

This section is mainly about the environmental parameters in the living space of nursing homes in Shenyang area. selects Five nursing homes of different plane types were selected from all nursing homes in Shenyang, which are Tianzhu Mountain Nursing Home, Qinchunyuan Nursing Home, Xanadu Nursing Home, Gaoshoufu Nursing Home and Boai Nursing Home. A large number of measured environmental parameters are needed for the investigation of the living space of nursing home to lay the foundation for subsequent research. The measured environmental parameters mainly include temperature, humidity and wind speed, and then the parameters were combined with subjective questionnaire and human factor experiment to judge the degree of thermal comfort of the elderly in the living space.

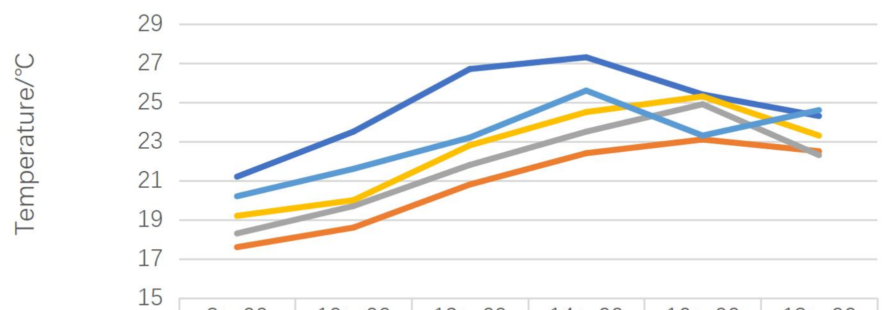
The measurements were carried out in relatively harsh environment so as to truly reflect the reaction of the elderly to thermal comfort. The temperature was measured mainly in the coldest and hottest time. The humidity was measured in the driest and the wettest time. The wind speed was measured when the wind was strongest.

6.1.1 Temperature measurement and analysis of living space

6.1.1.1 Temperature measurement and analysis in the coldest season

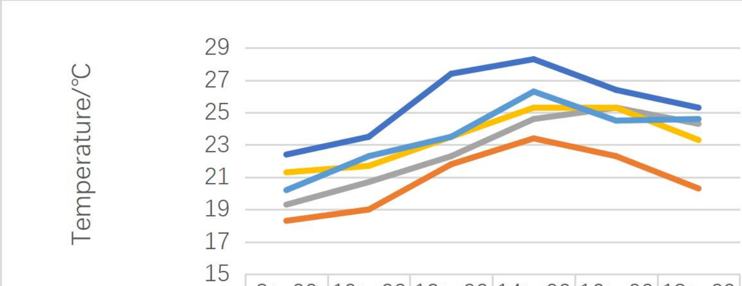
The coldest season was selected for measurement, and the measured time is from 8:00 to 18:00 on December 20th to 22nd, 2017. The actual temperatures of the five nursing homes under natural conditions were measured, and the measured locations were selected as the center position of the rooms in the two ends of the living space and the room in the middle of the living space.

The temperature of the living space in the process of actual measurement is selected for analysis. The selected natural conditions are only geothermal heating without the influence of other factors. The doors and windows are closed, and there is no natural ventilation.



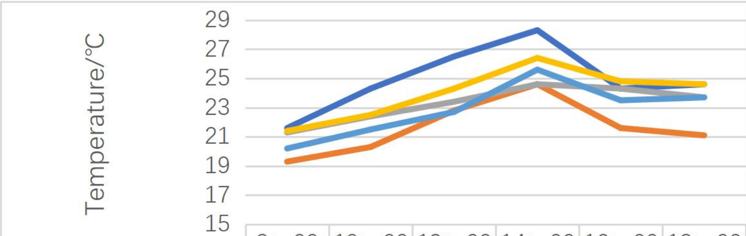
	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	21.2	23.5	26.7	27.3	25.4	24.3
Tianzhu	17.6	18.6	20.8	22.4	23.1	22.5
Shiwaitaoyuan	18.3	19.7	21.8	23.5	24.9	22.3
Gaoshoufu	19.2	20	22.8	24.5	25.3	23.3
Boai	20.2	21.6	23.2	25.6	23.3	24.6

Fig. 6- 1 The temperature of nursing home was measured on Dec 20 (Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	22.4	23.5	27.4	28.3	26.4	25.3
Tianzhushan	18.3	19	21.8	23.4	22.3	20.3
Shiwaitaoyuan	19.3	20.7	22.3	24.6	25.3	24.3
Gaoshoufu	21.3	21.7	23.5	25.3	25.3	23.3
Boai	20.2	22.3	23.5	26.3	24.5	24.6

Fig. 6- 2 The temperature of nursing home was measured on Dec 21 (Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	21.6	24.3	26.5	28.3	24.3	24.6
Tianzhushan	19.3	20.3	22.8	24.6	21.6	21.1
Shiwaitaoyuan	21.3	22.4	23.4	24.6	24.3	23.7
Gaoshoufu	21.4	22.5	24.3	26.4	24.8	24.6
Boai	20.2	21.5	22.7	25.6	23.5	23.7

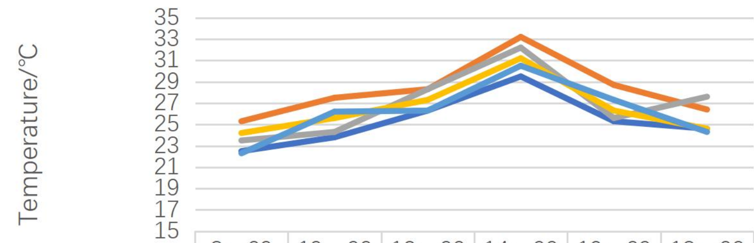
Fig. 6- 3 The temperature of nursing home was measured on Dec 22 (Source: Author's drawing)

As can be seen from the figure above, living space is greatly affected by climate in the coldest season. The nursing homes are greatly affected. Some nursing homes cannot meet the national standards. Generally speaking, there are some differences in the living space of different nursing homes[1]. At the same time, even in the case of using floor heating, the living space still cannot reach the comfortable temperature of the elderly. As can be seen from the figure, the highest temperature does not reach 28°C, which is the hottest time. At most of the other time, the living space temperature is still relatively low. In the coldest season, Qinchunyuan Nursing Home did a good job in temperature comfort. Tianzhu Mountain Nursing Home has the worst thermal comfortableness.

6.1.1.2 Temperature measurement and analysis in the hottest season

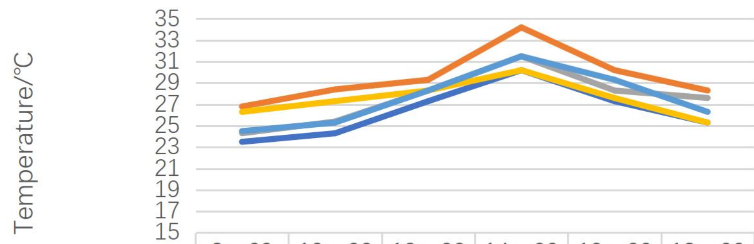
The hottest season was selected for measurement, and the measured time was from 8:00 to 18:00 on August 3rd to 5th, 2018. The actual temperature of the nursing home under natural conditions is measured. The locations of measurement were selected as the center position of the rooms in the two ends of the living space and the room in the middle of the living space.

The temperature of the living space in the process of actual measurement is selected for analysis. The selected natural conditions are not affected by technical facilities (air conditioning, fans). The doors and windows are open in most cases, and there is natural ventilation.



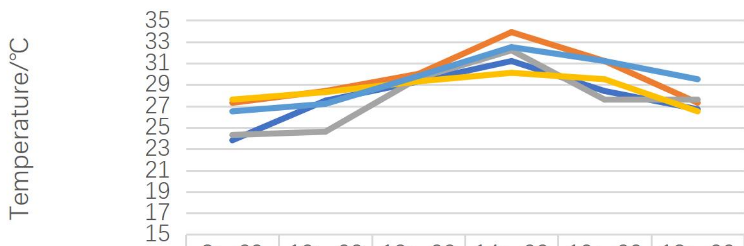
	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	22.5	23.8	26.3	29.5	25.3	24.6
Tianzhushan	25.3	27.5	28.3	33.2	28.7	26.4
Shiwaitaoyuan	23.5	24.3	28.3	32.2	25.6	27.6
Gaoshoufu	24.2	25.6	27.3	31.2	26.3	24.6
Boai	22.3	26.2	26.3	30.5	27.3	24.3

Fig. 6- 4 The temperature of nursing home was measured on Aug 3 (Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	23.5	24.3	27.3	30.2	27.3	25.3
Tianzhushan	26.8	28.4	29.3	34.2	30.2	28.3
Shiwaitaoyuan	24.3	25.4	28.3	31.5	28.3	27.6
Gaoshoufu	26.3	27.3	28.3	30.2	27.6	25.3
Boai	24.5	25.3	28.3	31.5	29.3	26.3

Fig. 6- 5 The temperature of nursing home was measured on Aug 4 (Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	23.8	27.5	29.3	31.2	28.4	26.7
Tianzhushan	27.3	28.4	30	33.9	31.2	27.3
Shiwaitaoyuan	24.3	24.6	29.6	32.2	27.6	27.6
Gaoshoufu	27.6	28.3	29.3	30.1	29.5	26.5
Boai	26.5	27.2	29.8	32.5	31.2	29.5

Fig. 6- 6 The temperature of n nursing home was measured on Aug 5 (Source: Author's drawing)

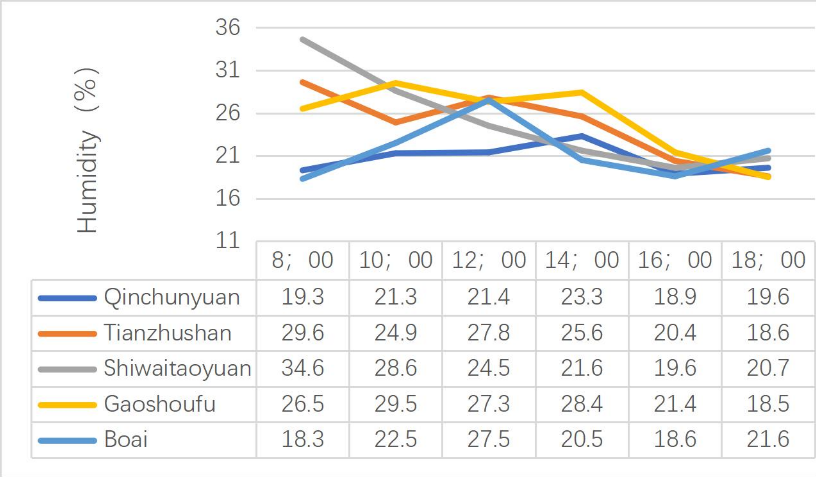
As can be seen from the figure above, in the hottest season, the living paces of the five nursing homes are affected by different external climates, and there are still some differences in their living space. However, due to the continuous rise of temperature in recent years, the temperature inside the whole living space is relatively high in the process of measurement, but it is cooler in the morning and evening. From the time point of view, the temperature from 10:00 to 16:00 is basically 28℃, and the highest temperature has exceeded 33℃. From the overall trend, in the hottest season, Tianzhu Mountain Nursing Home doesn't do well in the heat insulation. Gaoshoufu Nursing Home does better in the heat insulation.

6.1.2 Humidity analysis and measurement of the living space

6.1.2.1 Measurement and analysis of humidity in the driest season

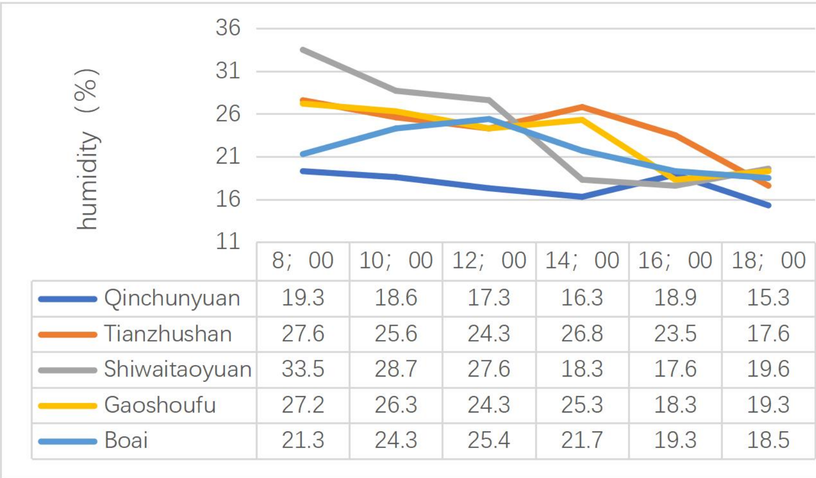
Due to the geographical location of Shenyang, the humidity in winter is generally low. The driest time was selected for measurement in the five nursing homes, and the measured time was from 8:00 to 18:00 on December 20 to 22, 2017.The locations of measurement were selected as the center position of the rooms in the two ends of the living space and the room in the middle of the living space.

The humidity of living space in the process of actual measurement is selected for analysis. The selected natural conditions are only geothermal heating without the influence of other factors. The doors and windows are closed, and there is no natural ventilation.



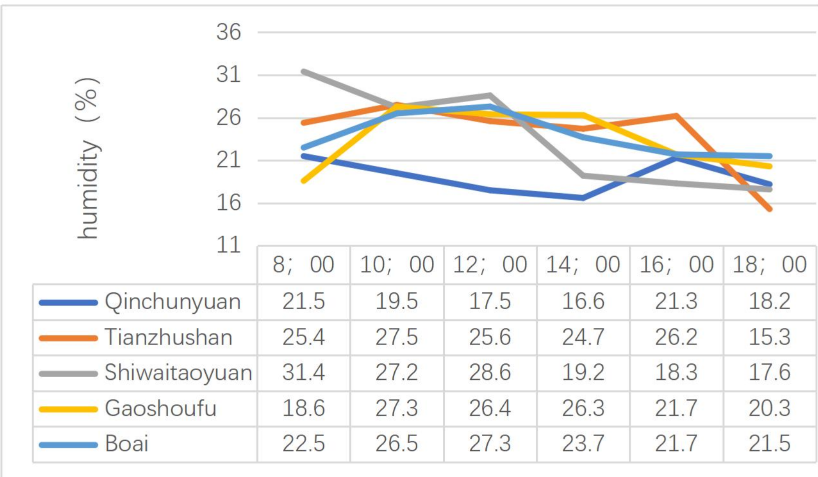
	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	19.3	21.3	21.4	23.3	18.9	19.6
Tianzhushan	29.6	24.9	27.8	25.6	20.4	18.6
Shiwaitaoyuan	34.6	28.6	24.5	21.6	19.6	20.7
Gaoshoufu	26.5	29.5	27.3	28.4	21.4	18.5
Boai	18.3	22.5	27.5	20.5	18.6	21.6

Fig. 6- 7 The humidity of nursing home was measured on Dec 20 (Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	19.3	18.6	17.3	16.3	18.9	15.3
Tianzhushan	27.6	25.6	24.3	26.8	23.5	17.6
Shiwaitaoyuan	33.5	28.7	27.6	18.3	17.6	19.6
Gaoshoufu	27.2	26.3	24.3	25.3	18.3	19.3
Boai	21.3	24.3	25.4	21.7	19.3	18.5

Fig. 6- 8 The humidity of nursing home was measured on Dec 21 (Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	21.5	19.5	17.5	16.6	21.3	18.2
Tianzhushan	25.4	27.5	25.6	24.7	26.2	15.3
Shiwaitaoyuan	31.4	27.2	28.6	19.2	18.3	17.6
Gaoshoufu	18.6	27.3	26.4	26.3	21.7	20.3
Boai	22.5	26.5	27.3	23.7	21.7	21.5

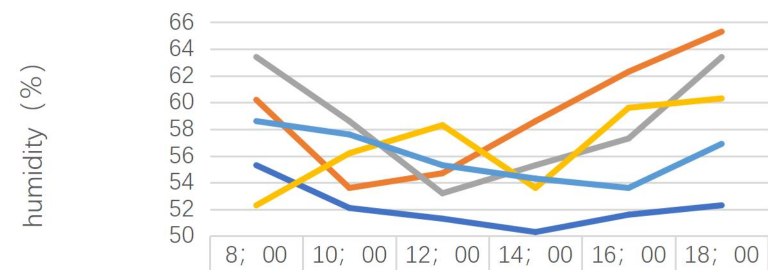
Fig. 6- 9 The humidity of nursing home was measured on Dec 22 (Source: Author's drawing)

As can be seen from the figure above, the living space is greatly affected by climate in the driest season. Due to the high temperature of the living space under the influence of heating equipment, the humidity of the living space is relatively low. However, the general trend can be seen from the fluctuation of the graph. In winter, the humidity inside the living space in Shenyang generally cannot reach the standard. As can be seen from the figure, the humidity is basically around 25%, and the highest is 31%. From the overall trend, the humidity of Qinchunyuan Nursing Home is the lowest, and that of Xanadu Nursing Home is the highest.

6.1.2.2 Humidity measurement and analysis in the wettest season

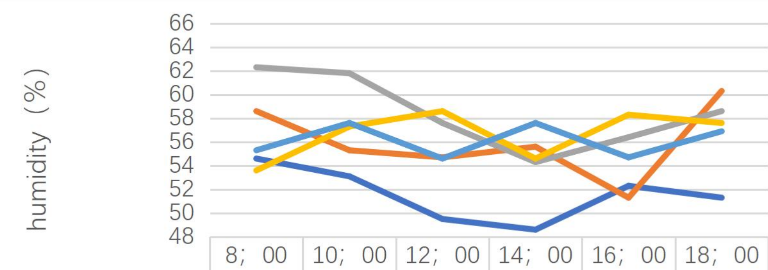
The wettest season was selected for measurement, and the measured time was from 8:00 to 18:00 on August 3rd to 5th, 2018. The locations of measurement were selected as the center position of the rooms in the two ends of the living space and the room in the middle of the living space.

The humidity of living space in the process of actual measurement is selected for analysis. The selected natural conditions are not affected by technical facilities (air conditioning, fans). The doors and windows are open in most cases, and there is natural ventilation.



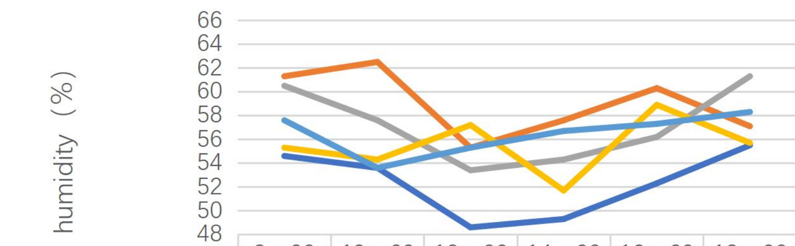
	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	55.3	52.1	51.3	50.3	51.6	52.3
Tianzhushan	60.2	53.6	54.7	58.6	62.3	65.3
Shiwaitaoyuan	63.4	58.6	53.2	55.3	57.3	63.4
Gaoshoufu	52.3	56.2	58.3	53.6	59.6	60.3
Boai	58.6	57.6	55.3	54.3	53.6	56.9

Fig. 6- 10 The humidity of nursing home was measured on Aug 3(Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	54.6	53.1	49.5	48.6	52.3	51.3
Tianzhushan	58.6	55.3	54.7	55.6	51.3	60.3
Shiwaitaoyuan	62.3	61.8	57.6	54.3	56.4	58.6
Gaoshoufu	53.6	57.3	58.6	54.6	58.3	57.6
Boai	55.3	57.6	54.6	57.6	54.7	56.9

Fig. 6- 11 The humidity of nursing home was measured on Aug 4(Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	54.6	53.6	48.6	49.3	52.3	55.5
Tianzhushan	61.3	62.5	55.3	57.6	60.3	57.1
Shiwaitaoyuan	60.5	57.6	53.4	54.3	56.2	61.3
Gaoshoufu	55.3	54.3	57.2	51.7	58.9	55.7
Boai	57.6	53.6	55.3	56.7	57.3	58.3

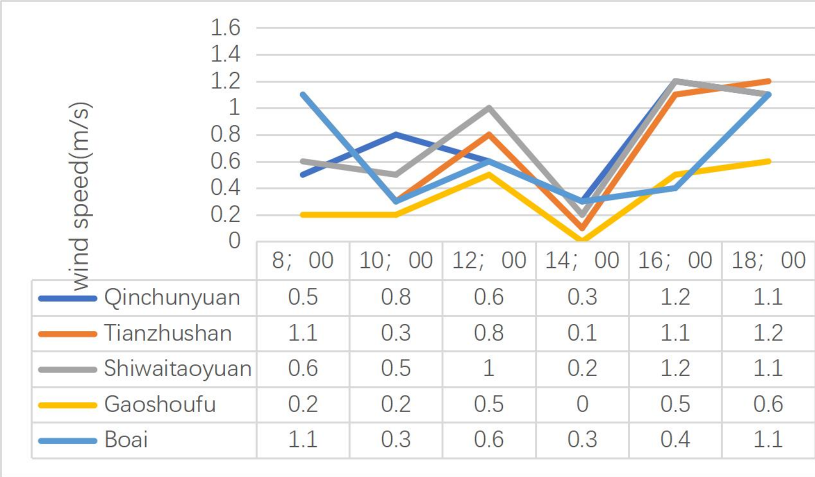
Fig. 6- 12 The humidity of nursing home was measured on Aug 5(Source: Author's drawing)

As can be seen from the figure above, in the wettest season, the living space of the five nursing homes are affected by different external climates, and there are still some differences in their living space. In the process of actual measurement, it is found that in the morning and evening, the humidity of the living space is higher than 60%, but the majority of the overall humidity is still in 50%-60%. It can be concluded that in the wettest season, 50%-60% of the comfortable humidity of the elderly can be satisfied under natural conditions. However, the humidity of Qinchunyuan Nursing Home is lower than that of other nursing homes.

6.1.3 Measurement and analysis of wind speed in living space

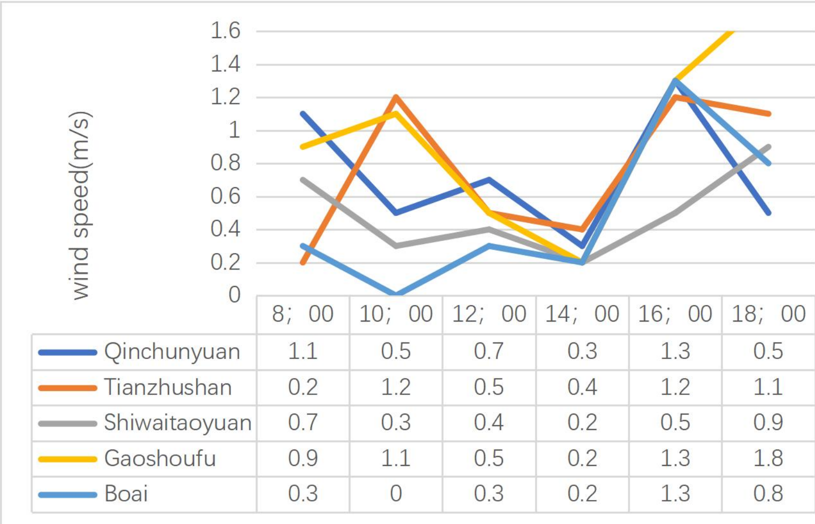
Through the investigation of nursing homes in Shenyang, it is found that in winter, all nursing homes basically do not open their windows, and the windows of some nursing homes have gaps due to the aging and sinking of the outer protective structure. The elderly usually plug the windows to prevent the cold wind from blowing into the living space. Therefore, the research on wind comfort should be conducted in April when the wind speed is relatively high.

The season with the highest wind speed was selected for measurement, and the measured time was from 8:00 to 18:00 on April 5 to 7, 2018. The actual wind speeds of the living space of five nursing homes under natural conditions were measured. The locations of measurement were selected as the center position of the rooms in the two ends of the living space and the room in the middle of the living space.



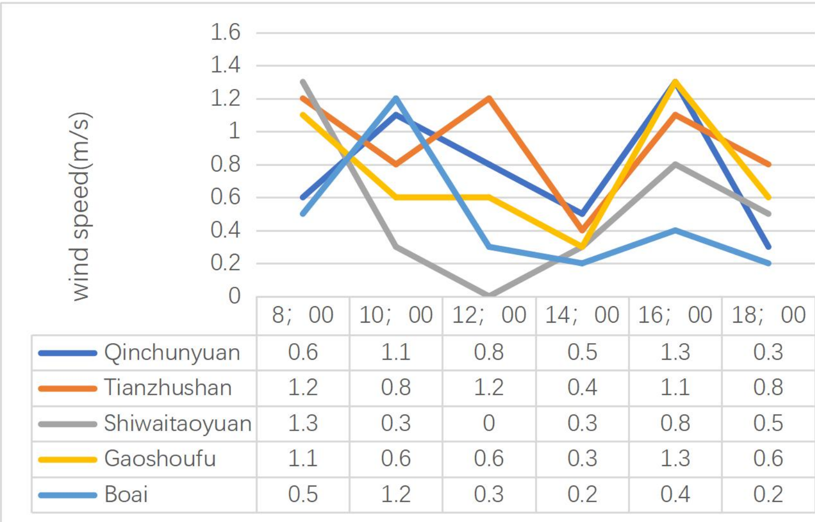
	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	0.5	0.8	0.6	0.3	1.2	1.1
Tianzhushan	1.1	0.3	0.8	0.1	1.1	1.2
Shiwaitaoyuan	0.6	0.5	1	0.2	1.2	1.1
Gaoshoufu	0.2	0.2	0.5	0	0.5	0.6
Boai	1.1	0.3	0.6	0.3	0.4	1.1

Fig. 6- 13 The wind speed of nursing home was measured on Apr. 5(Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	1.1	0.5	0.7	0.3	1.3	0.5
Tianzhushan	0.2	1.2	0.5	0.4	1.2	1.1
Shiwaitaoyuan	0.7	0.3	0.4	0.2	0.5	0.9
Gaoshoufu	0.9	1.1	0.5	0.2	1.3	1.8
Boai	0.3	0	0.3	0.2	1.3	0.8

Fig. 6- 14 The wind speed of nursing home was measured on Apr 6(Source: Author's drawing)



	8；00	10；00	12；00	14；00	16；00	18；00
Qinchunyuan	0.6	1.1	0.8	0.5	1.3	0.3
Tianzhushan	1.2	0.8	1.2	0.4	1.1	0.8
Shiwaitaoyuan	1.3	0.3	0	0.3	0.8	0.5
Gaoshoufu	1.1	0.6	0.6	0.3	1.3	0.6
Boai	0.5	1.2	0.3	0.2	0.4	0.2

Fig. 6- 15 The wind speed of nursing home was measured on Apr 7(Source: Author's drawing)

As can be seen from the figure above, in the season with the highest wind speed, the living space of the five buildings are affected by different external climate, and there are some differences in the living space. In the process of actual measurement, it is found that although there are certain changes, from the line chart, the wind speed in one day does not change with time. From the point of view of wind speed, some wind speeds exceed the comfort wind speed of the elderly 0m/s -0.4m /s measured above. From the point of view of the overall average wind speed. The wind comfort of the elderly in Tianzhu Mountain Nursing Home will be affected more.

6.2 Subjective Questionnaire Survey

6.2.1 Survey results

6.2.1.1 Subjective survey results

In this survey of five nursing homes, all the elderly surveyed are self-care elderly, in good physical condition and without other diseases. At the same time, they can clearly express their personal views and have a certain understanding of the nursing homes. Finally, the results of the survey and analysis are as follows:

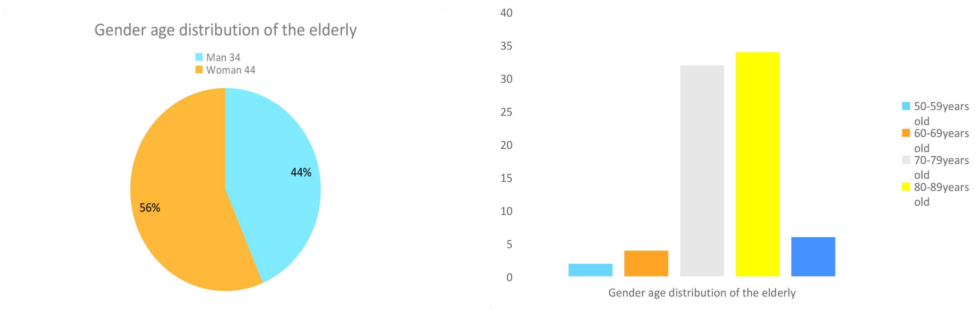


Fig. 6- 16 Gender age distribution of the elderly (Source: Author's drawing)

In this survey, women accounted for a large proportion of 44 people, accounting for 56%. The number of men is 34, accounting for 44%. From the perspective of age distribution, most people are between 70 and 90 years old, accounting for 84% of the total number of the elderly surveyed. 2 people are between 50 and 59 years old, 6 people between 60 and 69 years old, 30 people between 70 and 79 years old, 36 people between 80 and 89 years old, and 4 people above 90 years old. The average life expectancy of women is 77.37 years, which is higher than that of men (72.38 years).

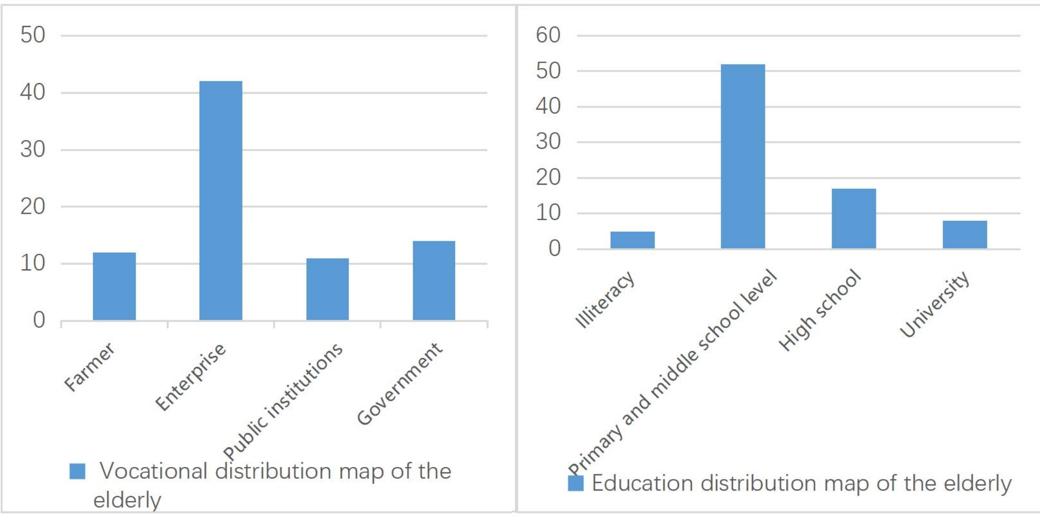


Fig. 6- 17 Vocational education distribution map of the elderly (Source: Author's drawing)

In this survey, the elderly mainly worked in enterprises. 43 of them worked in enterprise, 16 in government, 12 in public institutions and 13 are farmers. In terms of the education level of the elderly, most of them are at the primary and middle school level, which is still relatively low, accounting for 65% of the total number of people surveyed. This also adds some difficulty to the research.

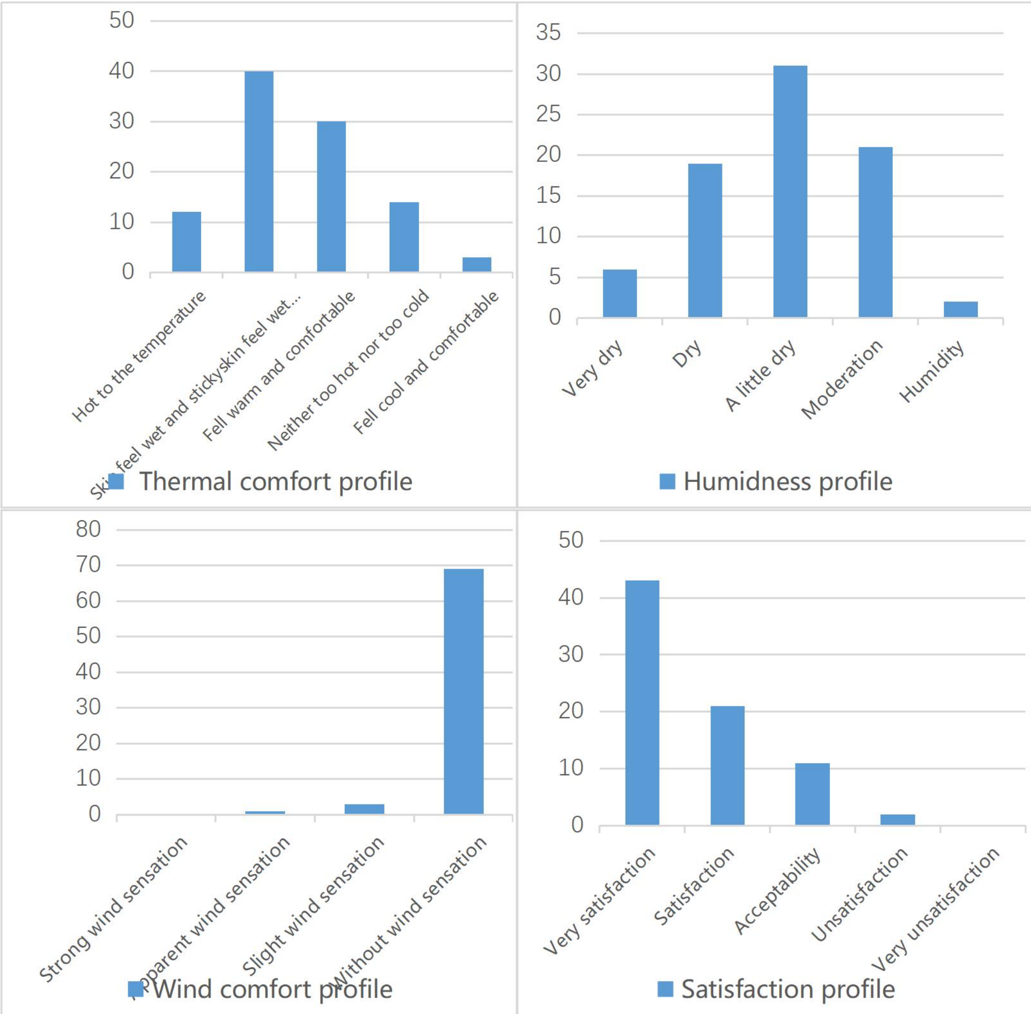


Fig. 6- 18Thermal comfort profile (Source: Author's drawing)

This survey is mainly about the satisfaction of the elderly on temperature, humidity, wind speed and overall environment in winter. According to the results of the survey, most of the elderly feel hot to the temperature at that time, and their skin feel wet and sticky. Only a few elderly people feel cold. From the perspective of humidity comfort, most of the elderly feel a little dry to the humidity at that time, only a small part of the elderly feel a little wet. From the perspective of wind comfort, it is found that all the elderly in nursing homes in Shenyang have the habit of plugging the windows, so they feel no wind. Finally, they are relatively satisfied with the overall environment. However, considering their previous life experience, their satisfaction with this environment is only psychological satisfaction, not physiological satisfaction, and further scientific experiments are needed to verify this fact.

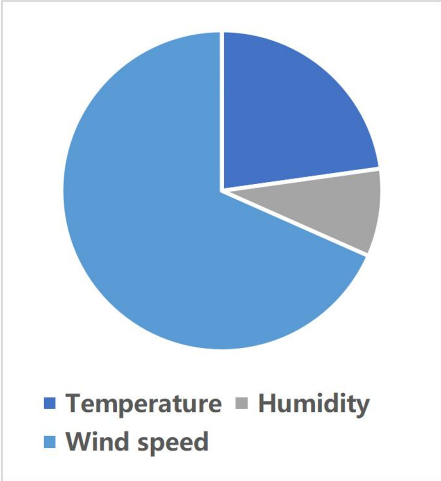


Fig. 6- 19 Index sensation distribution diagram (Source: Author's drawing)

According to the questionnaire on the three indexes of the elderly, the elderly have higher requirements for temperature comfort than other indexes, and lower requirements for humidity and wind speed, which is also in line with the characteristics of weakened body function of the elderly.

6.2.1.2 Comfort range acceptable to the elderly

Based on the analysis of the comfort results of the investigation in the existing living space, the comfortable environment to the elderly in winter and summer is as follows:

Table 6- 1 Comfort range acceptable to the elderly(Source: Author's drawing)

	Winter	Summer
Temperature	22℃-27℃	24℃-28℃
Humidity	25%-50%	50%-59%
Wind speed	None	0m/s-0.4m/s

6.3 Human factor experiment

6.3.1 Human factor experiment of comfortable ambient temperature

6.3.1.1Comfortable ambient temperature in winter

(1)Experiment content

The research method of human factor experiment was adopted to measure the most comfortable temperature range in winter for the elderly in the nursing home in Shenyang area.

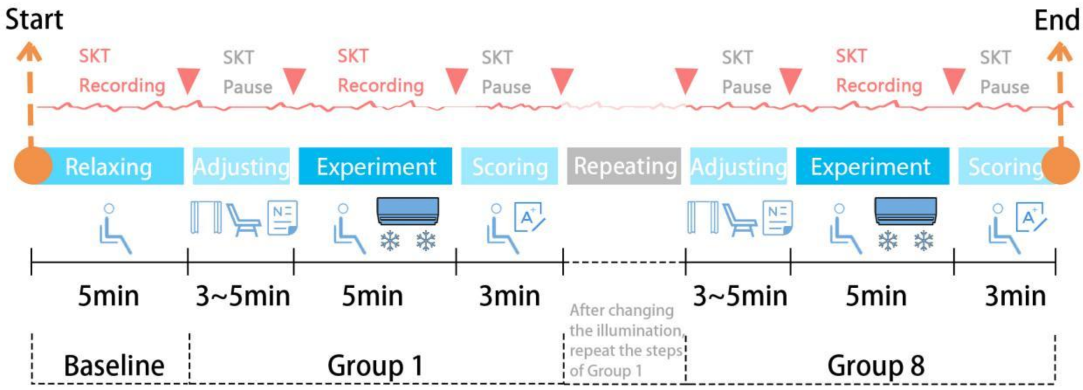


Fig. 6- 20 SKT Experimental process (Source: Author's drawing)

(2)Experimental process

In order to obtain scientific and effective physiological data fragments, the elderly should take a rest and sit quietly before accepting the experiment. Strenuous exercise is not allowed.

For this experiment, subjects are required to dress the same(All the elderly wear cotton underwear, sweater and vest , a pair of cotton underwear and a pair of trousers, and cotton sneakers), and at the same time, there is no sound and no video interference, so as to reduce the influence of other external factors on the experimental results. The subjects wore the SKT experimental equipment in Ergolab human-machine ring synchronization experiment and sat still for 5 minutes to record the breathing conditions at that time. Meanwhile, the ambient humidity of the subjects was ensured to be 25%-50%, so as to achieve a single variable. The ambient temperature around the elderly was changed by electric heater. The temperature change from 19℃ to 28℃, with every 1℃ as an interval, which was recorded. Meanwhile, the elderly were asked about their comfort and satisfaction with the current temperature.

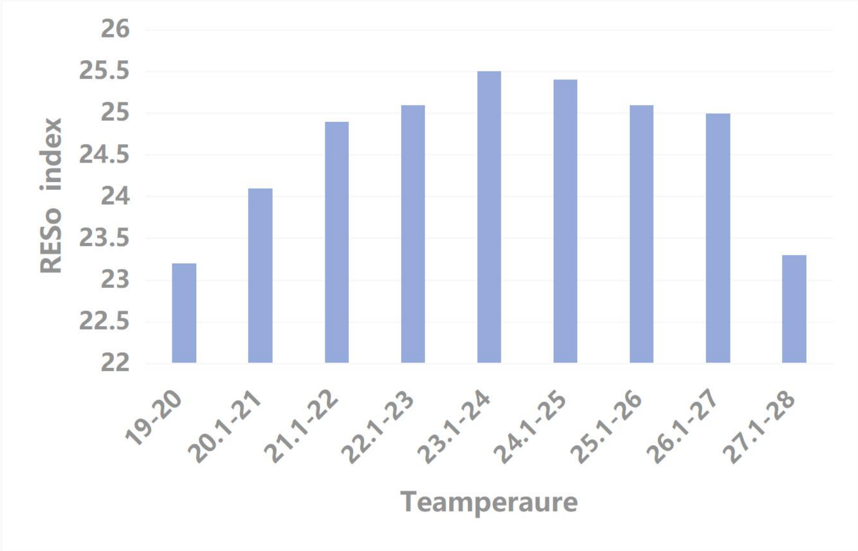


Fig. 6- 21 RESP analyses the best winter comfort temperature (Source: Author's drawing)

(3) Experimental results

Through the measurement of physiological indexes of the elderly and the analysis of the comfort temperature through subjective conversation, the measured results are shown in Fig 6-21. When the RESP value is above 25, the elderly are more comfortable. Therefore, the comfortable temperature of the elderly in winter is 22℃-27℃.

6.3.1.2 Comfortable ambient temperature in summer

(1)Experiment content

The research method of human factor experiment was adopted to measure the most comfortable temperature range in summer of the elderly in the nursing home in Shenyang area.

(2)Experimental process

In order to obtain scientific and effective physiological data fragments, the elderly should take a rest and sit quietly before accepting the experiment. Strenuous exercise is not allowed.

For this experiment, subjects were required to dress the same (All the elderly wore short sleeves, a pair of trousers, and sneakers), and at the same time, there is no sound and no video interference, so as to reduce the influence of other external factors on the experimental results. The subjects wore the SKT experimental equipment in Ergolab human-machine ring synchronization experiment and sat still for 5 minutes to record the breathing conditions at that time. Meanwhile, the ambient humidity of the subjects was ensured to be 40%-60% and the wind speed to be 0m/s-0.4m/s, so as to achieve a single variable. The ambient temperature around the elderly was changed by electric heater. The temperature change from 23℃ to 30℃, with every 1℃ as an interval, which was recorded. Meanwhile, the elderly were asked about their comfort and satisfaction with the current temperature.

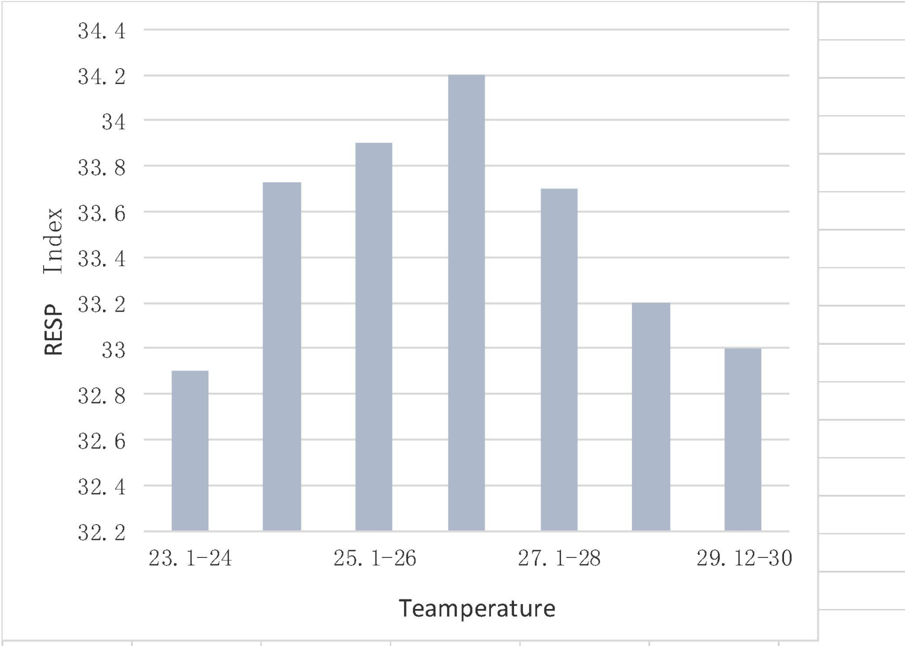


Fig. 6- 22 RESP analyses the most comfortable temperature in summer(Source: Author's drawing)

(3) Experimental results

Through the measurement of physiological indexes of the elderly and the analysis of the comfort temperature through subjective conversation, the measured results are shown in Fig 6-22. When the RESP value is above 33.6, the elderly are more comfortable. Therefore, the comfortable temperature of the elderly in winter is 24℃-28℃.

6.3.2 Human factor experiment of comfortable humidity

6.3.2.1 Comfortable ambient humidity in winter

(1)Experimental content

The research method of human factor experiment was adopted to measure the most comfortable humidity range in winter for the elderly in the nursing home in Shenyang.

(2)Experimental process

In order to obtain scientific and effective physiological data fragments, the elderly should take a rest and sit quietly before accepting the experiment. Strenuous exercise is not allowed.

For this experiment, subjects were required to dress the same, and there was no sound and no video interference, so as to reduce the influence of other external factors on the experimental results. The subjects wore the SKT experimental equipment in Ergolab human-machine ring synchronization experiment and sat still for 5 minutes to record the breathing conditions at that time. Meanwhile, the ambient temperature of the subjects was ensured to be 22℃-27℃, the wind speed to be 0m/s, so as to achieve a single variable. The humidifier was used to change the ambient humidity around the elderly. The humidity change was increased from 13% to 29%, with 2% as an interval, which was recorded. At the same time, the elderly were asked about their comfort and satisfaction with the current humidity.

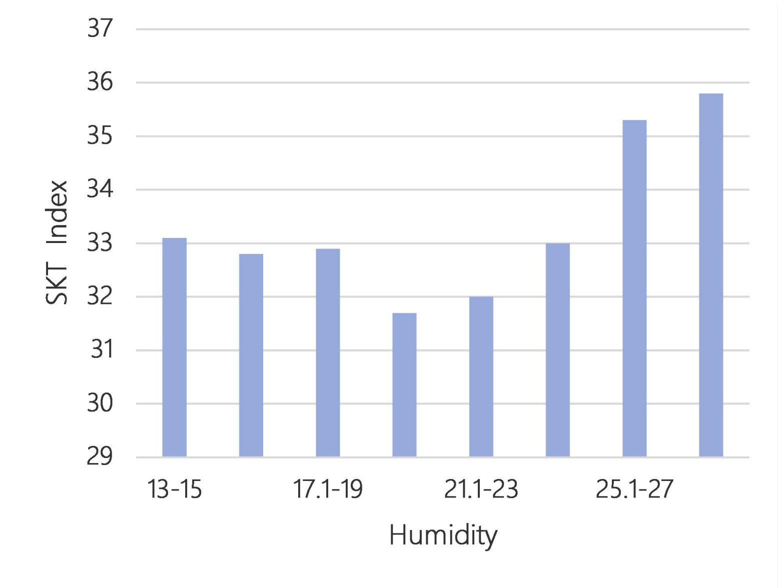


Fig. 6- 23 SKT analyzes the most comfortable humidity in winter (Source: Author's drawing)

(3) Experimental results

Through the measurement of physiological indexes of the elderly and the analysis of comfortable humidity by subjective conversation, the measured results are shown in Fig 6-23. When the SKT value is above 35, the elderly are more comfortable. Due to the climate in Shenyang, indoor humidity in winter is difficult to reach a higher level. The comfortable humidity for the elderly in winter is 25%-50%.

6.3.2.2 Comfortable ambient humidity in summer

(1)The experiment content

The research method of human factor experiment was adopted to measure the most comfortable humidity in summer of the elderly in the nursing home in Shenyang.

(2) Experimental process

For this experiment, subjects were required to dress the same, and there was no sound and no video interference, so as to reduce the influence of other external factors on the Experimental results. The subjects wore the SKT experimental equipment in Ergolab human-machine ring synchronization experiment and sat still for 5 minutes to record the breathing conditions at that time. Meanwhile, the ambient temperature of the subjects was ensured to be 25℃-28℃, so as to achieve a single variable. The humidifier was used to change the ambient humidity around the elderly. The humidity change was increased from 51% to 65%, with 2% as an interval, which was recorded. At the same time, the elderly were asked about their comfort and satisfaction with the current humidity.

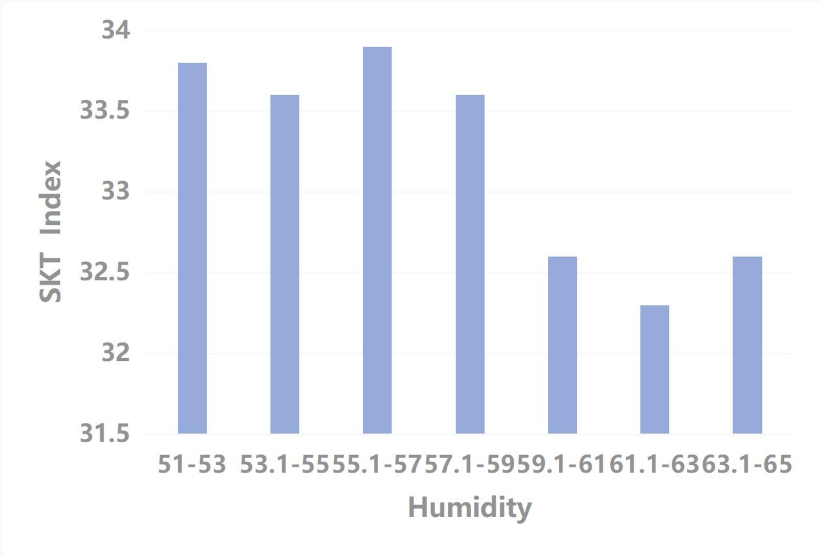


Fig. 6- 24 SKT analyzes the most comfortable humidity in summer (Source: Author’s drawing)

(3) Experimental results

Through the measurement of physiological indicators of the elderly and the analysis of the comfortable humidity through subjective conversation, the measured results are shown in Fig 6-24. When the SKT value is above 33.5, the elderly are more comfortable. Therefore, the comfortable humidity of the elderly in summer is 50%-59%.

6.3.3 Human factor experiment of comfortable wind speed

6.3.3.1 Comfortable ambient wind speed in winter

In winter, the elderly in the nursing homes in Shenyang have the habit of pasting the windows and plugging the window seams. They basically do not open the windows, so there will be no wind in the living space. Meanwhile, the person in charge of the nursing homes does not allow the elderly to use electric fans in winter. Therefore, the winter wind comfort wasn’t considered.

6.3.3.2 Comfortable ambient wind speed in summer

(1)Experiment content

The research method of human factor experiment was used to measure the most comfortable wind speed range in summer for the elderly in the nursing homes in Shenyang area.

(2) Experimental process

For this experiment, subjects were required to dress the same, and there was no sound and no video interference, so as to reduce the influence of other external factors on the experimental results. The subjects wore the SKT experimental equipment in Ergolab human-machine ring synchronization experiment and sat still for 5 minutes to record the breathing conditions at that time. Meanwhile, the ambient temperature of the subjects was ensured to be 25℃-28℃ and the humidity to be 50%-59%, so as to achieve a single variable. The ambient wind speed around the elderly was changed by electric fans, and the change of wind speed increased from 0m/s to 1.4m/s, with every 0.2m/s as an interval, which was recorded. Meanwhile, the elderly were asked about their comfort and satisfaction with the current wind speed.

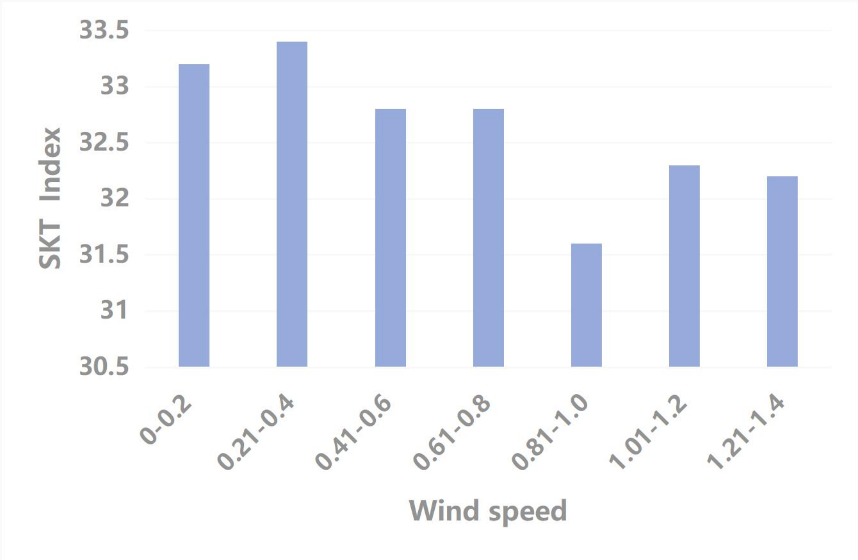


Fig. 6- 25 SKT analyzes the most comfortable wind speed in summer (Source: Author's drawing)

(3) Experimental results

Through the measurement of physiological indexes of the elderly and the analysis of the comfortable humidity through subjective conversation, the measured results are shown in Fig 6-25. When the SKT value is above 33, the elderly are relatively comfortable. Therefore, the comfortable humidity of the elderly in summer is 0m/ S-0.4m /s.

6.3.4 Statistical analysis of thermal comfort physiological data

Physiological signal data of temperature and humidity were imported into SPSS for statistical data analysis,in order to obtain Patterns of influence of objective data of the thermal environment on physiological data of the elderly. Physiological data measurements were performed as before, using respiratory RESP and skin temperature SKT, see Fig. 6-26 and Fig. 6-27. Box line plot responses of the data collection, subject 25 and subject 10 showed abnormal values, and the cause of the analysis was the inaccuracy of the equipment measurement data due to mis-touching by the elderly during the instrument use, so the abnormal values were excluded. Because of the time frame of the instrument measurements and the problem of individual differences in the raw data, RES used root mean square amplitude for data analysis and SKT used mean skin temperature to respond to the basic physiological conditions of the elderly.

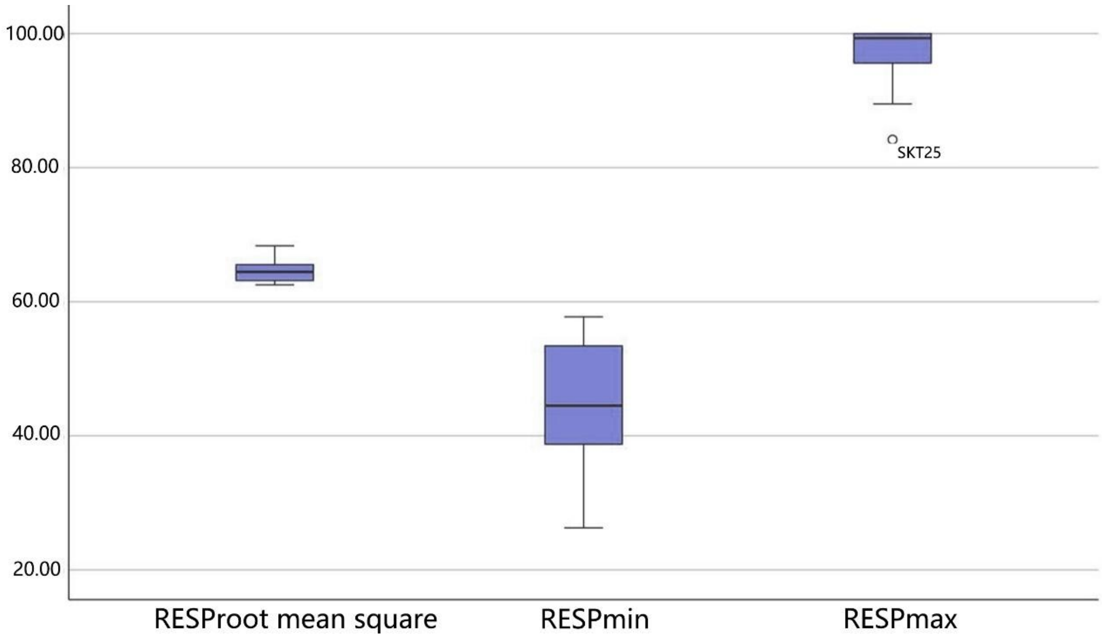


Fig. 6-26 Distribution of respiratory RESP data(Source: Author's drawing)

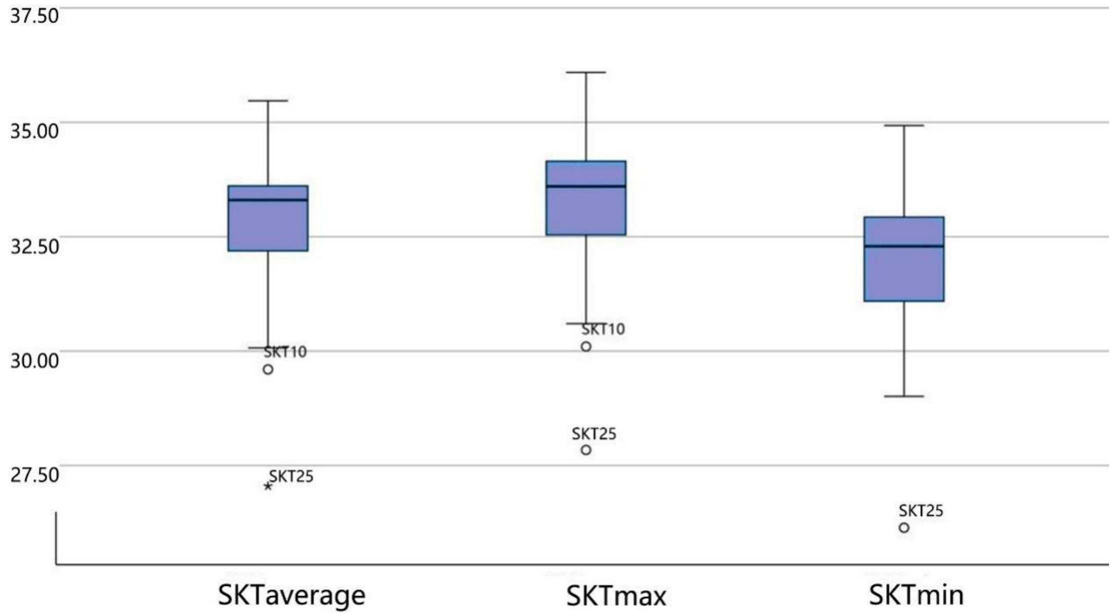


Fig. 6-27 Distribution of skin temperature SKT data(Source: Author's drawing)

The temperature setting in the thermal environment changes the ambient temperature around the elderly person by means of an electric heater, and the temperature change increases from 19°C to 28°C. The humidity setting in the thermal environment is changed by a humidifier to change the ambient humidity around the elderly, and the humidity changes from 10% to 29%.

The correlation between temperature and humidity on the physiological indicators of the elderly was analyzed separately to determine the association between them. The sample sizes of temperature, humidity, RESP root mean square amplitude and SKT mean temperature data were less than 50, and the Shapiro-Wilk test results were used to determine the normality of the data, and the data all satisfied normal distribution with Shapro-Wilk p>0.05. Pearson correlation was used to construct the correlation coefficient matrix, and since temperature and humidity were considered separately during the data collection process The physiological effects of temperature and humidity were considered separately during data collection, so the correlation test of temperature and humidity was not considered, see Table 6-2 and Table 6-3 .

Table 6- 2 Correlation test between temperature and physiological data(Source: Author's drawing)

	Temperature	SKT average temperature	RESP root mean square amplitude
Temperature	1	0.293	0.006
SKT average	0.293	1	.387*
RESP root mean square amplitude	0.006	.387*	1

Table 6- 3 Correlation test between humidity and physiological data(Source: Author's drawing)

	Humidity	SKT average temperature	RESP root mean square amplitude
Humidity	1	0.078	0.25
SKT average	0.078	1	.387*
RESP root mean square amplitude	0.25	.387*	1

From the above table, it can be seen that there is no relevant effect of temperature and humidity on both SKT mean temperature and RESP root mean square amplitude. That is, changes in temperature do not affect SKT and RESP, and changes in humidity do not affect SKT and RESP.

6.4 Summary of this chapter

This chapter is mainly the analysis and summary of the research. In order to accurately and comprehensively understand the reality of thermal comfort of nursing home buildings, this chapter conducts a detailed investigation on the living space of Shenyang Tianzhu Mountain Nursing Home, Kaiyuan Qinchunyuan Nursing Home, Dongling District Xanadu Nursing Home, Dongling District Gaoshoufu Nursing Home and Shenhe District Boai Nursing Home.The investigation include the measured physical data of temperature, humidity and wind speed.The satisfaction survey of the elderly on the comfort level of local temperature, humidity and wind speed was also conducted, so as to obtain a more comprehensive, accurate and scientific change rule and characteristics of thermal comfort. Through Data measurement and subjective questionnaire survey, this paper analyzes the problems existing in the thermal comfort of the elderly in the living space of nursing homes in Shenyang area.

According to the research content of this chapter, it can be summarized as follows:

In terms of temperature value, the living space of several elderly care buildings that have been surveyed shows low temperature, so the design of the thermal environment of living space mainly needs the improvement of the indoor temperature. According to the field survey, the reasons for the low temperature of the living space may be as follows: (1) The buildings of nursing homes are mostly located in mountainous areas, where the ambient temperature is low. The living space is greatly affected by the outdoor environment. (2) Nowadays the buildings of nursing homes are old, and some buildings are reconstructed from original buildings. The windows are in disrepair, and many windows have been deformed, which cannot meet the thermal insulation needs of the elderly. Some exterior wall structures have no thermal insulation bricks, but are just ordinary brick and concrete structures, with poor thermal insulation capacity. Therefore, it is important to consider the seal structure and exterior protected structure of windows in living space, so as to protect the temperature of the living space. (3) The spatial shape of the internal space of the building is also very important. Especially in the vertical spatial structure, the clear height of the living space directly affects the lighting inside the space. Since the living space of the nursing homes in Shenyang is in the lower floor, the lighting time is relatively short, except at noon. The temperature of the living space without direct sunlight will drop significantly. At the same time, the orientation of the windows also affects the lighting condition of the living space. The indoor temperature of some east-west oriented buildings is significantly lower than that in south-north oriented buildings.

In terms of humidity value, the average humidity value measured in the living space of the five buildings is below 25%, which is far from 25%~59% which is the comfortable humidity value for human body. Although some people still say that the humidity is moderate in the subjective questionnaire survey, the comfortableness is closely related to the regional differences and population differences. The low humidity value cannot be ignored. Therefore, the thermal comfort design of living space also needs great improvement of the indoor humidity. The main reason for the low humidity in the living space is the cold and dry natural climate in Shenyang in winter. Secondly, the nursing homes mostly use heating system in winter, which will also lead to the decrease of humidity in the living space. In view of this situation, we can first start from the natural environment outside the living space. More green plants and water landscape should be adopted to improve indoor and outdoor humidity. In addition, in the design of outdoor space, attention should be paid to not destroying the natural water system, and we should try to make use of the surrounding conditions to improve humidity as far as possible. In the selection of maintenance structure and paving material, we should choose the material that can store moisture and that can prevent condensation. At the same time, some potted plants can be placed inside the living space, and some fish can be raised inside the living space. The water evaporation in the aquarium can be used to improve the indoor humidity.

In terms of ventilation, the survey of the five nursing home buildings shows that most of the elderly have no obvious feelings about indoor ventilation in the subjective questionnaire. At the same time, because the elderly in the nursing homes like to plug the windows in winter, and use some foam and transparent tape to seal the air leaks in the windows, there is basically no wind in the room. The feeling of this aspect is one of the weakest among the three items of temperature, humidity and wind speed. Because the nursing homes mainly rely on the heating, which can easily cause indoor air pollution when the temperature is passively raised and the window is not opened for ventilation. This article mainly hopes that in the aspect of the indoor and outdoor air exchange, some advanced and reasonable ventilation equipment and ventilation structures can be used to keep the indoor air fresh and improve the thermal comfort of the living space.

Later, based on the survey results of this chapter, the corresponding designs will be carried on, so as to improve the thermal comfort of the elderly in the living space of nursing homes.

Reference

[1] Wang Shou Yi, And Wang Yun Xuan. "Survey on the Winter Thermal Comfort of the Buildings for the Aged in Cold Regions." Urbanism and Architecture 16.23(2019):3

Chapter 7

7. TACTILE SENSE AND SPACE MATERIALS

CHAPTER SEVEN: TACTILE SENSE AND SPACE MATERIALS

7.1 Characteristics of Tactile Behavior in the Elderly and the Current Application of Materials in Living Spaces

7.1.1 Characteristics of Tactile Behavior in the Elderly in Living Spaces

7.1.1.1 Physiological Characteristics of Tactile Perception in the Elderly

As people age, their sense of touch gradually weakens.Researcher Zoble (1938) conducted tests on the sensitive touch thresholds of the eyes and surrounding areas for participants ranging from 20 to 80 years old. The results indicated that tactile perception remains relatively unchanged before the age of 55, but after the age of 55, tactile perception sharply declines. Cosh (1958) tested the vibration perception threshold (the number of vibrations at which the stimulus is perceived) and similarly confirmed the dulled tactile perception in the elderly. The study found that fingers, which are frequently used for tactile tasks, have a faster response compared to the less-used thumb on the foot, which exhibits dulled tactile perception. The specific physiological characteristics of tactile perception are as follows[1]:

(1) Decreased environmental sensitivity

Due to physiological reasons, the response ability of the elderly to external stimuli is weakened, the reaction time is prolonged, the agility is correspondingly decreased, and the stability and coordination are poor.Therefore, elderly people place great importance on their personal safety in their daily lives. For example, falls are the leading cause of injury and death among older adults, and almost everyone has been involved in an accident in which an elderly person has suffered a fall injury.As a result, many older people pay more attention to the safety and comfort of the flooring materials in their living spaces when making choices.

(2) Decreased temperature sensitivity

Temperature receptors for thermal perception are located in cold spots and hot spots on the skin, which are distributed unevenly across different parts of the body. There are more cold spots on the nose, cheeks, and forearms, and fewer on the thighs, with more on the back of the hand than on the palm. In each area, the number of cold spots is several times or even more than thirty times that of stable spots. Facial skin is the most sensitive to temperature perception, while the lower limbs are less sensitive.

(3) Decreased pain sensitivity

Research has shown that pain thresholds increase with age, leading to higher levels of pain stimuli needed to elicit pain sensations as individuals grow older. This indicates that the pain sensitivity of the elderly tends to dull with age. There are also gender differences in the decline of pain sensitivity in the elderly, with females exhibiting more significant reductions[2].

(4) Weakened localization sensitivity

As older people age, not only does the sensitivity of their skin sensations decline, but their ability to localize tactile stimuli also significantly weakens. If people are asked to close their eyes and report which part of their body is being touched, it is found that young people can accurately report the location, whether it is a single point or simultaneous touching at two points. However, older people, similar to 3-6-year-old children, can only perceive one of the two touched locations, indicating a noticeable decline in the tactile localization ability of the elderly compared to young people.

7.1.1.2 Psychological Characteristics of Tactile Perception in the Elderly

Tactile perception is an effective way for humans to understand the external environment by physically interacting with materials and perceiving their characteristics. Material properties have certain effects on both physiological and psychological aspects of individuals, and people tend to select suitable materials based on their own genuine experiences and sensations. Throughout history, people have shown a preference for warm and soft materials, psychologically exhibiting a willingness to accept them. On the other hand, people tend to resist hard and cold materials, as these align with their genuine tactile experiences and feedback.

(1) Focus on a sense of security

Due to physiological reasons, older people have reduced reaction capabilities to external stimuli, longer response times, decreased agility, instability, and poor coordination. As a result, older adults place great emphasis on their own safety in daily life. For example, falls are the leading cause of injuries and deaths among the elderly in our country. Almost everyone has encountered accidental incidents where older people around them have fallen and suffered injuries. Therefore, many older adults prioritize the safety and comfort of materials used in their living spaces, particularly for flooring materials.

(2) Nostalgic mindset

Due to accumulated life experiences and material possessions over many years, most older adults possess a sense of nostalgia. Therefore, it is not advisable to use excessively modern materials, such as hard, cold, and highly reflective materials in their living spaces. The materials should ensure a comfortable and familiar tactile sensation to evoke a sense of nostalgia.

(3) Emphasis on a cozy feeling

Currently, many elderly facilities have living spaces that resemble hospitals or dormitories, which fail to provide a sense of care in the daily lives of older people. Therefore, in the living spaces of older adults, it is beneficial to use natural materials and incorporate soft materials to soften the space, allowing older individuals to relax and enhance the overall warmth and coziness of the environment.

7.1.1.3 Characteristics of Tactile Behavior in the Elderly

Tactile perception abilities vary among individuals, and people of different ages have different perceptual abilities and behavioral characteristics. The elderly population encompasses individuals who range from being able to take care of themselves to requiring assistance from handrails, crutches, wheelchairs, or even caregivers, depending on their level and nature of physical health[3]. Based on the different degrees and nature of their physical health, older adults can be roughly divided into three groups[4]: the first group consists of relatively young seniors with overall good physical health who can independently perform daily activities, and their tactile behavior characteristics are similar to those in middle age; the second group consists of older adults with age-related diseases and limited mobility due to various physical reasons, and they have higher requirements for tactile perception in their environment; the third group consists of very elderly individuals with poor health and inability to perform self-care, requiring assistance from caregivers[5].

In this study, the focus is on older adults who are capable of self-care. The research examines the tactile behavior characteristics and living habits of older adults in their living spaces, including the following aspects:(Table 7-1)

(1) Behavioral characteristics of older adults in living spaces

As the physical functions of older adults decline, their behavioral characteristics exhibit certain patterns. Different behavioral characteristics have different tactile requirements for materials. Tactile behaviors closely related to older adults in their living spaces include walking behavior, hand contact behavior, sitting behavior, and getting up behavior. Walking characteristics: During the walking process, independent older adults have a slightly reduced leg lift height, while assisted older adults require support from handrails, canes, walkers, or wheelchairs, and their walking is slow and cautious. It is important to pay attention to handling floor height differences in living spaces and strive to maintain a level floor surface.

(a) Hand contact behavior: During the process of touching materials, older adults show a clear preference for materials that are gentle, natural, and have a soft texture, such as wood and cotton.

(b) Sitting behavior: Prolonged sitting postures are not conducive to relaxation of the elderly's spine. Therefore, older adults are not accustomed to sitting for long periods of time and require support for their back when sitting. Furniture such as beds, sofas, and chairs need to have a certain level of hardness to prevent the body from sinking and causing discomfort.

(c) Getting up behavior: Independent older adults have no major difficulties in the process of getting up and can complete the action with minimal support. Assisted older adults require assistance through the use of supportive handrails, such as armrests on chairs or handrails beside toilet seats in bathrooms.

Table 7- 1 Tactile behavior and characteristics of the elderly

Tactile behavior	Characteristics of tactile behavior
Hand contact	There is a noticeable preference for materials that have a gentle, natural texture and are soft and smooth in terms of touch
Sitting and lying down	Sitting and lying down are commonly accompanied by behaviors such as sitting, leaning, reclining, and supporting oneself
Getting up	Independent elderly individuals may require slight support when getting up, while assisting an elderly person in getting up may involve leveraging armrests for assistance

(2) Dressing Characteristics of the Elderly in Living Spaces

In the living spaces of older adults, comfortable flooring materials play a crucial role in achieving a comfortable living environment. It is necessary to select flooring materials that provide comfort to older individuals. When walking on the floor and subjectively evaluating its comfort, the footwear worn by older adults can significantly impact their perception of comfort. In this study, a survey was conducted on the footwear worn by older adults in different seasons. The survey was conducted in January and August 2016, and the specific results are shown in Fig. 7-1.

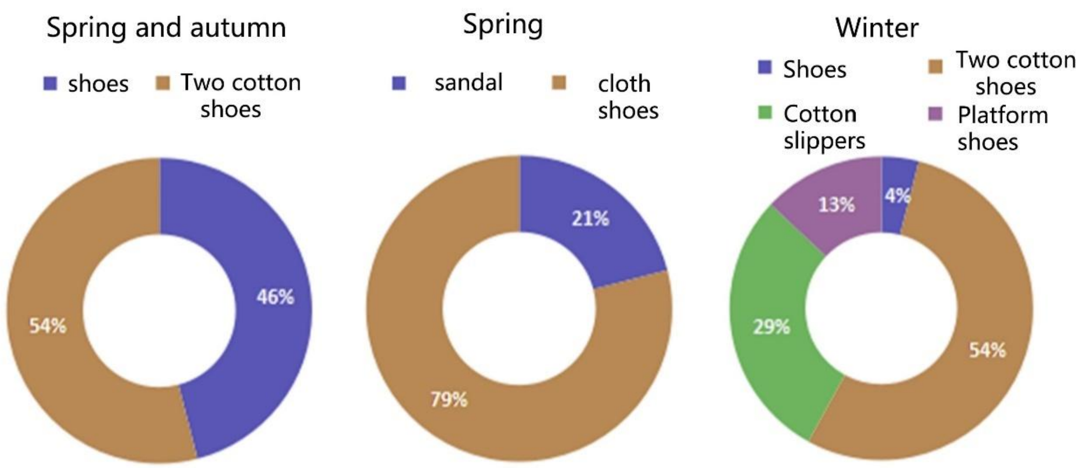


Fig. 7-1 The wearing characteristics of the elderly living space in different seasons

According to the results, it can be observed that in spring and autumn, the primary footwear choices are single shoes and canvas shoes. In summer, the main choice is cloth shoes. In winter, the dominant options are canvas shoes and cotton slippers. The soles of the shoes are predominantly made of rubber, with a moderate thickness.

7.1.2 Investigation on the use of living space materials in elderly apartments

7.1.2.1 Overall Survey

In the preliminary stages of this study, field visits and research were conducted in elderly facilities and large building material markets in areas such as Shenyang and Beijing, including locations such as Shenyang Tiexi Jiulu Furniture City and Shenyang Changqing Decoration City. The survey aimed to investigate the current usage of decorative materials in living spaces for older adults. The specific usage situation is shown in Table 7-2.

Table 7- 2 Apartments for the elderly living space decorative material usage

	Shenyang Wucai Sunshine City	Shenyang Happy Elders' Gathering	Shenyang Songpu Caring	Shenyang Elderly Care Service Cente	Beijing Ainong Nursing Home	Beijing Jinsong Senior Living Community	Beijing Qianhe Senior Apartments
Categories	Decoration materials (walls, floors)						
Ceramic tiles	√	√	√	√	√	√	√
Flooring	√	√	–	√	√	√	–
Carpet	–	√	–	–	–	–	–
Wallpaper	√	√	–	√	√	–	–
Paint	√	√	√	√	√	√	√

Categories	Furniture and Decorative Materials					
Solid wood	−	√	−	−	−	−	−
Particle board	√	√	√	√	√	√	√
Bamboo and rattan	−	√	−	−	−	−	−
Fabric	√	√	√	√	√	√	√
Plastic	√	√	√	√	√	√	√
Rubber	−	−	−	−	−	−	−
Leather	−	−	−	√	√	√	−
Ceramic	√	√	√	√	√	√	√
Glass	√	−	√	√	−	−	−
Stone	√	−	√	√	√	√	√
Meta	√	−	√	√	√	√	√

In addition, a questionnaire survey was conducted to investigate the usage of decorative materials in elderly apartment living spaces. The results of the survey are shown in Fig. 7-2.

According to the survey results, tiles and floors are often used in residential Spaces.Ceramic tiles are commonly used for walls and floors in bathrooms and kitchens. When it comes to carpet selection, the elderly consider factors such as safety, comfort, and ease of maintenance. Small carpet pieces are preferred, and their usage proportion is relatively small. In terms of furniture materials, solid wood has a lower usage rate due to its expensive price, and engineered wood is primarily used. Additionally, with the increasing demand for green and low-carbon lifestyles, there is a growing trend of using bamboo and rattan furniture. Fabric materials have a relatively large proportion in residential spaces, adding a warm feeling. Plastic and rubber are often used in areas that come into contact with hands, such as armrests and handles on the sides of seats. Leather materials are commonly used in sofas, chairs, and upholstered furniture. Ceramic is widely used as sanitary ware material[ ]. Glass is typically used in decorative cabinets and bookshelves as cabinet doors or partitions. Stone is commonly applied to window sills, skirting boards, and kitchen countertops. Metal materials are used for furniture assembly parts and decorative components.

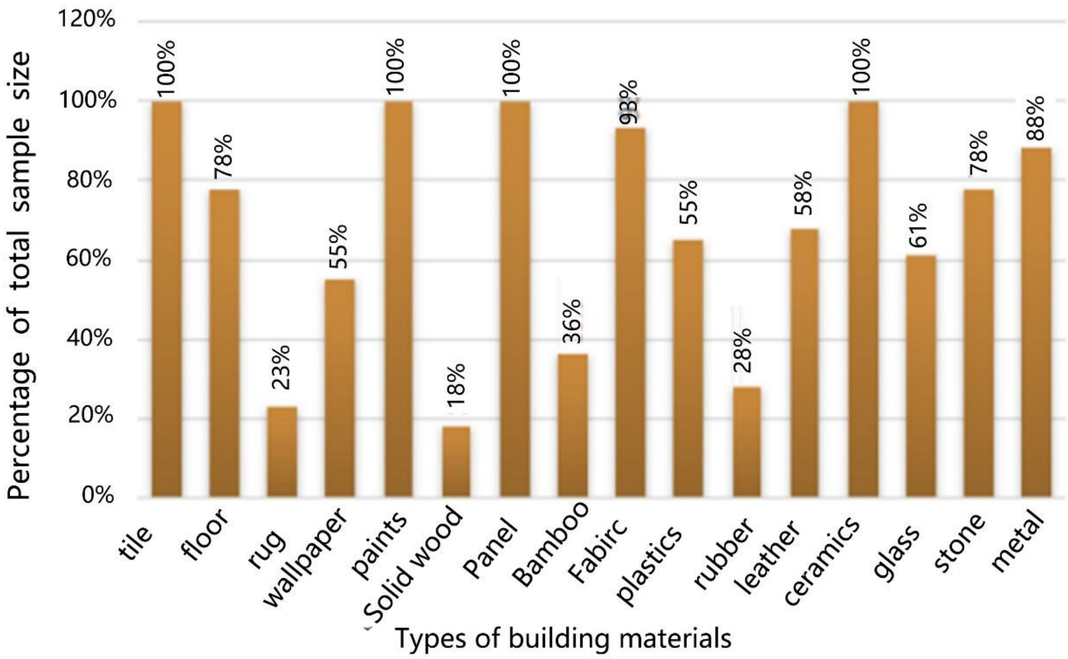


Fig. 7-2 Apartments for the elderly living space decorative material usage

7.1.2.2 Wucayangguang City Elderly Apartment and Care Service Center

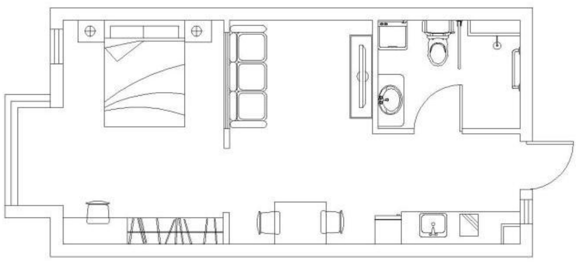
(1) Project Overview

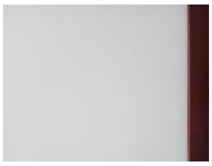
The design of the residential units in the retirement apartments adopts a single-household living plan. On one hand, it emphasizes the feeling of freedom and independence similar to living at home, and on the other hand, it incorporates age-friendly designs into the living context. The 60-square-meter south-facing unit in Wucayangguang City Elderly Apartment is chosen as the research object, with a specific area of 61.78 square meters.

(2) Current Application of Materials in Living Spaces

The application of materials in the living spaces is shown in Table 7-3.

Table 7-3 The use of building materials in the living space of the Aged Apartment

floor plan				
Materials	Plastic flooring	Glazed tiles	Latex paint	Embossed wallpaper
Application Locations	Bedroom and living room flooring	Kitchen walls; bathroom walls and floors	Interior walls other than bathrooms and kitchens	TV background wall

picture				
Materials	Glass	Metal	Wood	Stone
Application Locations	Partition walls	Sanitary and kitchen hardware	Furniture, doors, door frames, window frames	Window sills, countertop
picture				
Materials	Plastic	Blackout fabric	Ceramic	
Application Locations	Handrails, skirting boards, windows	Curtains	Sanitary fixtures	
picture				

7.1.2.3 Happiness Elderly Apartment at Elderly Care Hub

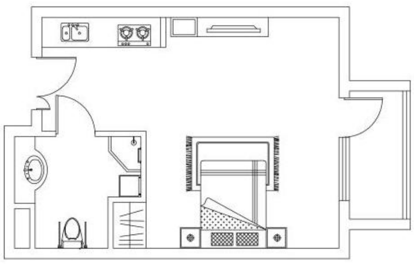
(1) Project Overview

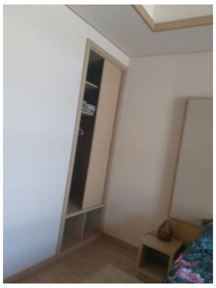
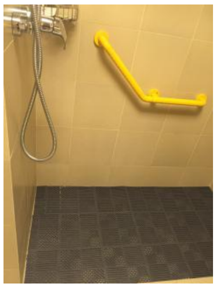
The unique dragon-shaped retirement and rehabilitation apartment complex, known as Happiness Elderly Apartment, offers six types of units ranging from one-bedroom apartments to deluxe suites (designated as A to G). The rooms are furnished with high-quality standards and equipped with facilities tailored to the needs of the elderly, ensuring convenience in their daily lives. For this study, a detailed investigation was conducted on the A-type one-bedroom unit, which has a room area of 54 sqm.

(2) Current Application of Materials in Living Spaces

The application of materials in the living spaces is shown in Table 7-4.

Table 7- 4 The use of building materials for residential apartments in the elderly

floor plan				
Materials	Solid wood composite flooring	Matte glazed tiles	Mosaic	Modular carpet
Applicatio	Bedroom	Entrance hall floor,	Kitchen walls	Beside the bed

n Locations		bathroom walls and floors		
picture				
Materials	Hemp wallpaper	Latex paint	Plastic	Wood
Application Locations	Interior wall surface	Bedroom wall surface	Plastic carpet, handrails in the shower area	Furniture, skirting boards, doors, door frames
picture				
Materials	Hemp	Cotton	Ceramic	
Application Locations	Bed headboard upholster	Curtains	Sanitary fixtures	
picture				

7.1.2.4 Songpu Boai Care Center

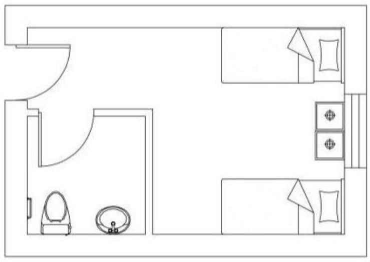
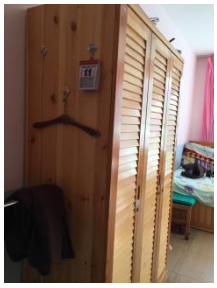
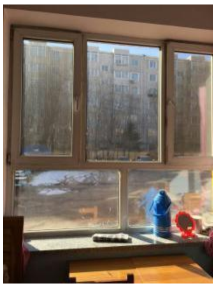
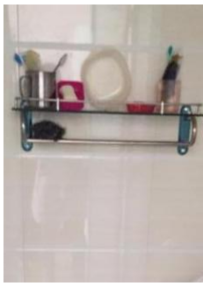
(1) Project Overview

The project site is located at No. 49 Beidaying East Street, Da Dong District, with the street (Beidaying East Street) on the west side and facing the Wutong Xinyuan residential area. The north and east sides are military land. A detailed investigation was conducted on the south-facing double room in the care center, with a room area of 21.6 sqm.

(2) Current Application of Materials in Living Spaces

The application of materials in the living spaces is shown in Table 7-5.

Table 7- 5 The use of building materials in maintenance center

floor plan				
Materials	Matte glazed tiles	Glazed tiles	Latex paint	Wood
Application Locations	Bedroom and bathroom flooring	Bathroom wall surfaces	Bedroom wall surfaces	Furniture
picture				
Materials	Stone	Plastic	Metal	Glass
Application Locations	Window sills, skirting boards	Handrails, door and window frames	Bathroom hardware	Folding doors
picture				
Materials	Sheer fabric	Ceramic		
Application Locations	Curtains	Sanitary fixtures		
picture				

7.1.3 Classification and Tactile Characteristics of Decorative and Furniture Materials

Materials in living spaces can generally be classified into two categories: foundational hard materials and later-stage soft decorative materials. The former primarily focuses on surface treatments of the three major interfaces: ceiling, walls, and floors, from a spatial perspective. The latter extends to the level of indoor furniture and decorative items[6].

7.1.3.1 Flooring Materials

Flooring materials commonly used in living spaces can be categorized into three types: tiles, flooring, and carpets.

(1) Tiles

Tiles are commonly used as decorative materials for flooring. They have a solid texture, are water-resistant, and easy to clean, making them highly favored.

Common types of ceramic tiles and their tactile characteristics can be found in Table 7-6.

Table 7- 6 The commonly used tile types and tactile characteristics

Material Names	Production Process	Tactile Characteristics
Glazed Ceramic Tile	Glazed ceramic tiles are produced through firing porcelain clay. They have a smooth surface and are typically not very slip-resistant. The backside of the tile is gray-white, with a dense texture and high strength. They have a low water absorption rate. These tiles are widely used	Smooth surface, moderate slip resistance
Matte Glazed Tile	Matte glazed tiles are created by polishing the surface of glazed tiles. They have an irregular texture and are relatively rough	Irregular texture, relatively rough
Full Body Tile	Full body tiles are made by crushing hard granite clay material and then pressing it under high pressure. They have a rough surface, do not have glaze, and possess inherent slip resistance. The material and color on both sides are consistent, and they have good wear resistance	Rough surface, inherent slip resistance, good wear resistance
Mosaic Tile	Mosaic tiles are composed of multiple small pieces of tiles. They are made from high-quality clay using a semi-dry pressing method. They have good slip resistance and come in two types: with glaze and without glaze	Small individual pieces assembled into larger tiles, good slip resistance

(2) Flooring

Flooring materials can be classified into different types based on their materials: solid wood flooring, solid wood composite flooring, laminate flooring, bamboo flooring, cork flooring, and vinyl flooring. Among them, vinyl flooring includes varieties such as vinyl sheet flooring, commonly known as linoleum, and PVC plastic flooring.

The common types of tiles and their tactile characteristics can be found in Table 7-7.

Table 7- 7 The types and characteristics of common floor touch

Material Names	Production Process	Tactile Characteristics
Solid Wood Flooring	A floor covering material formed by natural wood after drying and processing	Comfortable to the touch, good insulation, not easily conductive, cool in summer and warm in winter, resistant to condensation, good slip resistance, gentle impact and resistance to the human body, natural. Achieves the comfortable feel of solid wood flooring
Solid Wood Composite Flooring	Thin slices of wood are cut from the wood, several layers or multiple layers are cross-laminated and bonded together. The base layer is treated for insect and moisture resistance, and multiple thicknesses of wood veneer are attached. After lacquering and coating, it becomes the finished product	Has a certain hardness, slightly firm to the touch, available in various types such as glossy, embossed, or textured
Laminate Flooring	Made by laminating impregnated paper overlay layer with hard fiberboard or high-density fiberboard as the base material. The surface is coated with wear-resistant materials such as melamine and aluminum trioxide	Elastic, relieves foot pressure, hard texture, smooth and non-slip, regulates room temperature, warm in winter and cool in summer
Bamboo Wood Flooring	Uses high-quality bamboo, carefully selected. It undergoes processing steps such as milling, bleaching, sulfurization, dehydration, insect prevention, and preservation, and is then bonded under high temperature and pressure	Elastic, relieves foot pressure, hard texture, smooth and non-slip, helps regulate room temperature, keeping warm in winter and cool in summer.
Cork Flooring	Raw material comes from the bark of cork oak trees. It can have no coverings or be treated with coatings or veneers	Comfortable to the touch, gentle, flexible, resistant to compression, and provides excellent cushioning.
Vinyl Flooring	Produced using the calendering method, with a main ingredient of paste-like PVC resin. The base material is mineral fiber paper and glass fiber felt. It can be embossed, printed, and foamed	Soft, good elasticity
PVC Plastic	Mainly made from polyvinyl chloride (PVC) and copolymers, with fillers,	Soft texture, strong resistance to impact,

Flooring	plasticizers, stabilizers, colorants, and other additives. It is formed through processes such as coating, calendering, extrusion, or compression on a continuous sheet substrate	excellent elastic recovery, becomes slightly slippery when wet, good slip resistance

(3) Carpet

The common types of carpets and their tactile characteristics can be found in Table 7-8:

Table 7- 8 The types and characteristics of common floor touch

Classification method	Carpet Name	Tactile Characteristics
Classification by Pile Type	Loop Pile Carpet	Yarn height is even, moderate hardness, resistant to foot traffic, good durability, excellent resistance to pile flattening, strong elasticity
	Multi-Level Loop Carpet	Yarn height is uneven, with irregular variations in surface height
	Cut Pile Carpet	Portions of the loops are cut, creating a plush surface
	Shag Carpet	Yarn length is the same, without loop pile, lower durability and elasticity

7.1.3.2 Wall Materials

(1) Wallpaper

There is a wide variety of wallpapers available, and the popular types of wallpapers currently in use are listed in the table below. Among them, the common types of wallpapers and their characteristics in elderly living spaces can be found in Table 7-9:

Table 7- 9 The types and characteristics of wallpaper

Material Names	Production Process	Tactile Characteristics
Paper-based Wallpaper	The base layer is made of paper, and the surface layer undergoes color printing and embossing. It is then compounded with the paper base for installation	Not easily cleaned, less production
Textile Wallpaper	Made by weaving fibers such as silk, wool, cotton, and linen	Good texture, soft, comfortable
Natural Material Wallpaper	Made from natural plants such as grass, hemp, wood, and leaves	No static electricity, strong three-dimensional effect
	The base material is paper, which is	Divided into regular wallpaper and

Plastic Wallpaper	coated with PVC resin in a paste form. It is then printed and embossed	foamed wallpaper, with strong elasticity in foamed wallpaper

(2) The types of wall tiles in elderly living spaces are similar to those used for flooring. Please refer to Table 2.6 for more details.

(3) Paint

Paint coating refers to the application of various coatings on the surfaces of wood, metal furniture components, and buildings, forming a protective film that adheres to the object's surface. Paints contain various additives, and the resulting thin film on the surface can have a certain texture, such as a hammered, wrinkled, or orange-peel texture. Interior wall paints are mostly water-based and emulsion paints, with latex paint being the most common. The latex paint has fine texture, is not easy to powder, and has good recoating performance.

7.1.3.3 Furniture and Decorative Materials

(1) Furniture Materials

Tactile sensations can be used to judge the texture and surface characteristics of materials. Different surface characteristics can produce different tactile experiences. Furniture design and the use of furniture materials are closely related, as comfortable tactile materials can enhance the overall furniture experience[7]. Table 7-10 lists common furniture materials and their tactile properties.

Table 7- 10 The commonly used furniture material types and tactile characteristics

Material Name	Tactile Characteristics	Application Range
Natural Wood	Slow heat conduction, gentle touch, warm in winter and cool in summer	Traditional furniture materials, such as dining tables and chairs
Engineered Wood	Comfortable feel, second only to natural wood	Substitutes for solid wood as the main material for furniture
Rattan	Naturally warm, good elasticity, lightweight and easy to move	Rattan furniture, such as rattan sofas, rattan rocking chairs, etc
Metal	Tough texture, cold, hard, heavy	Components and decorative parts of furniture, commonly used in kitchens and bathrooms
Glass	High hardness, relatively cold	Decorative cabinet doors, partitions, coffee tables, etc
Plastic	Lacks the warm and comfortable feel of natural materials	Such as shower chairs, small tables, etc

(2) Decorative Materials

Decorative materials are also crucial considerations in elderly living spaces, as different materials offer varying degrees of tactile comfort and serve different purposes. Based on their application locations, decorative materials can be categorized into three types: curtains, sofas, and bedding. Common types of decorative materials and their tactile characteristics can be found in

Table 7-11. It should be noted that bedding materials primarily include cotton and silk, and these are not repeated in the table[8].

Table 7- 11 The commonly used jewelry material types and tactile characteristics

Types of Decorative Materials	Material Types	Tactile Characteristics
Curtains	Fabric	Moderate softness
	Velvet	Soft, comfortable
	Chiffon	Cool, lightweight
	Silk	Comfortable, luxurious, high strength, good elasticity
	Cotton	Comfortable touch, less static electricity
	Linen	Coarse and smooth touch
Sofa	Textile	Moderate softness
	Leather	Soft, smooth, elastic

7.1.4 Summary:

This chapter is divided into two main parts. The first part analyzes the tactile perceptual characteristics of elderly individuals from the perspectives of psychological features, physiological features, and behavioral habits. The second part consists of on-site research and analysis, which involves conducting surveys at various elderly care institutions and large-scale decorative material markets in Shenyang and Beijing. The research findings are summarized accordingly. Lastly, based on the usage areas, the commonly used materials in the living spaces of the elderly are classified into three categories. The classification is further subdivided, and the tactile characteristics of the materials are summarized, providing a reference for the selection of experimental samples in subsequent chapters.

7.2 Subjective evaluation of tactile comfort of living space materials for the elderly

When a person's skin comes into contact with a material, the physical characteristics of the material stimulate the sensory receptors in the surface layer of the skin, resulting in tactile sensations. In residential spaces, materials such as flooring, walls, furniture, and decorations frequently come into contact with individuals[9]. The different tactile properties of these materials can elicit varying degrees of preference, aversion, and comfort for the individuals, such as the comfortable sensation of wooden flooring or the gentle touch of wooden handrails. In this chapter, we will evaluate the subjective perception of tactile comfort in materials used in elderly living spaces and analyze the results.

7.2.1 Construction of a Subjective Evaluation System for Tactile Comfort in Materials

Subjective evaluation and objective evaluation are commonly used methods in comfort evaluation. Subjective evaluation, also known as sensory evaluation, expresses subjective perceptions through quantitative data, descriptive language, vocabulary, and other forms. The main factors influencing sensory evaluation include sample characteristics, evaluation environment, test participants, evaluation methods, and evaluation criteria. The general process of subjective evaluation involves: (1) clarifying the evaluation objectives and methods; (2) selecting trained test participants, elderly individuals to be tested, and material samples; (3) allowing the elderly participants to experience the materials through touch in a suitable environment; (4) conducting the experiment following the established procedure, where the elderly participants provide corresponding evaluations based on their real sensations and make evaluation choices using questionnaires; (5) organizing and analyzing the evaluation results to draw conclusions.

7.2.1.1 Determination of Subjective Evaluation Methods and Indicators

(1) Determination of Subjective Evaluation Methods

We often use these methods for subjective evaluation analysis, as follows:

①Paired comparison method: This method involves comparing only two test samples at a time and describing the degree of difference between the two samples. For example, the comfort level of touch sensation for two samples can be divided into multiple levels (3, 5, 7), such as "Excellent," "good," "somewhat good," "average," "somewhat poor," "poor," "very poor," and so on. Its advantages include accurate evaluation results as samples are compared pairwise, and it allows for detailed assessment of differences. However, the method can be time and labor-consuming when comparing multiple materials.

②Ranking method: This method involves multiple participants ranking the material samples based on tactile comfort, and the total rank sum of each sample is calculated to evaluate the superiority or inferiority of the tactile sensations.

③Semantic differential (SD) method: This method involves identifying opposite concepts, such as smoothness and roughness, softness and hardness, and placing them at the two ends of an SD evaluation axis, dividing it into 5-7 evaluation scales corresponding to 5 scores (e.g., -2, -1, 0, 1, 2). The SD method can provide scores for a specific comfort indicator but cannot determine the corresponding comfort level of the scores[10].

④Scoring method: This method determines the scores for each evaluated characteristic according to the established evaluation system criteria and calculates the total scores for each evaluated option based on certain rules. The total score serves as the scale to measure the superiority or inferiority of the samples.

Considering the characteristics of the analysis of tactile comfort superiority and inferiority in building materials, which involves a large number of material samples with small differences among samples of the same category, the final subjective experimental evaluation adopted the scoring method.

7.2.1.2 Establishment of Subjective Evaluation Indicators

The selection of subjective evaluation indicators for material tactile comfort is crucial to the entire evaluation system, and it is necessary to scientifically concretize the evaluation concepts. In this study, the relevant research status was first summarized, and preliminary evaluation indicators were proposed. Subsequently, these indicators were screened and determined through the use of expert questionnaires[11].

The selection of evaluation indicators should follow the following principles: 1) scientificity, 2) systematicity, 3) simplicity, 4) representativeness, and 5) independence. Based on relevant research on materials in residential spaces, it is known that researchers often evaluate materials based on their economic viability, practicality, and environmental regulation. There is relatively limited research specifically focusing on the evaluation of material tactile comfort, especially for the elderly population. In Chen Guangsheng's study "Rough Set Reduction and Fuzzy Evaluation of Comfort Attributes of Wood Materials" (2011), warmth, roughness, and hardness were selected as evaluation indicators for tactile comfort in wooden materials. After indicator selection and attribute reduction, roughness was identified as the specific tactile indicator. The results showed that decorated materials had comfort membership degrees above 0.9, indicating excellent performance compared to untreated materials. In the book "Production Technology of Wood Flooring" (2014) by Wang Chuangui, bamboo-wood flooring and solid wood flooring were compared from the perspective of softness and hardness. It was found that bamboo-wood flooring had higher strength and hardness but was less comfortable to the feet compared to solid wood flooring. In a study by Mitsuru Masuda (Japan) on walking comfort, the relationship between "softness," "warmth," "impact," "walking sensation," and physical quantities was analyzed in experiments on floor materials. It was concluded that walking sensation is a comprehensive result of hardness, slipperiness, and warmth. In the paper "Analysis of Carpet Compression Performance and Thickness Recovery Performance" (2016) by He Yumei, the structural performance, compression performance, and thickness recovery performance of seven carpets made from wool fibers (Wo), polypropylene fibers (PP), and cationic cellulose fibers (PAC) were analyzed[12]. The study also examined the raw materials, yarn density, and the number of tufts per unit area of different carpet products. The key factors influencing the softness and comfort performance of carpets were found to be the recovery performance after compression, and an increase in yarn density and tuft density had a positive impact on carpet thickness, pile quality, and recovery performance. Furthermore, when individuals come into contact with the surface of building materials, the texture and unevenness of the material surface have a significant impact. Based on the selection of tactile comfort indicators in the relevant literature mentioned above, this study initially proposed indicators related to tactile comfort and ultimately determined the following three-level indicators and their descriptive terms through expert questionnaires: warmth, softness/hardness, roughness/smoothness, concavity/convexity, and resilience. The questionnaire and results are presented in Table 7-12, and the explanations of the indicators are provided in Table 7-13.

Table 7- 12 Description of material tactile comfort index

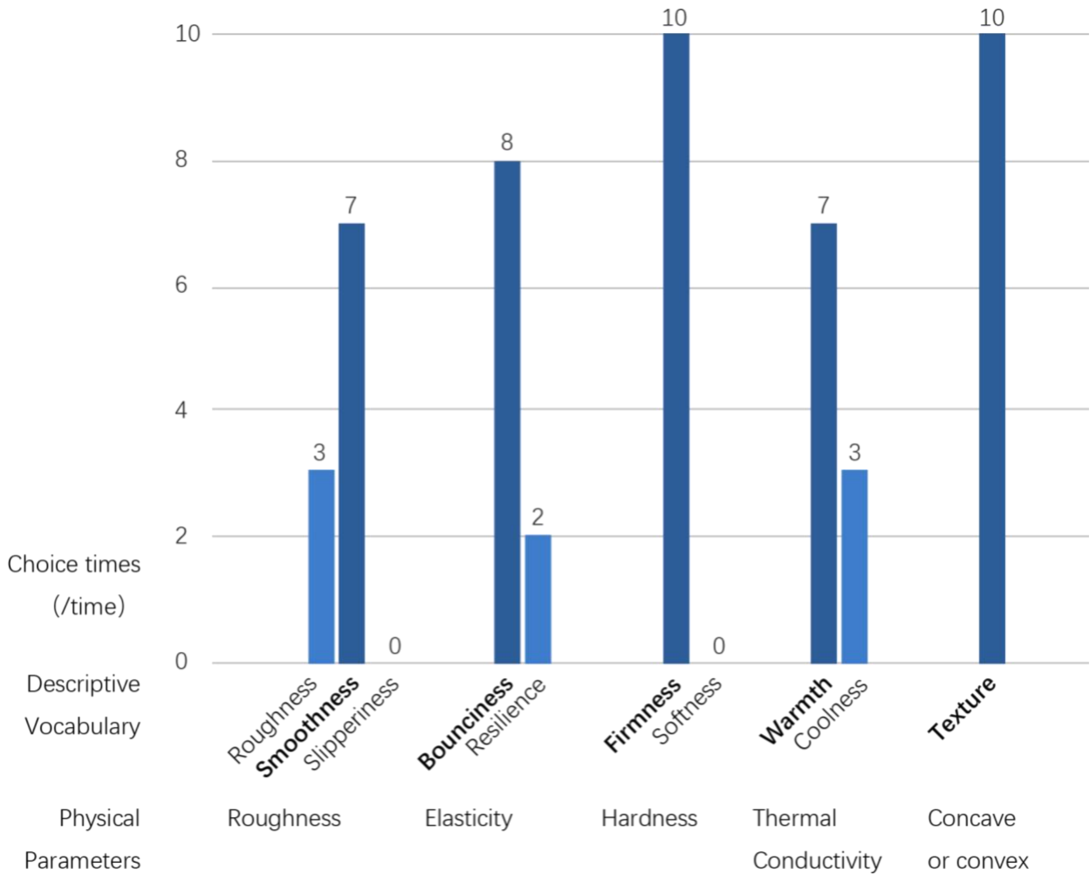


Table 7- 13 Subjective evaluation index of tactile comfort of materials

Evaluation Criteria	Criterion Explanation:
Warmth	Refers to the sensation of warmth or coldness experienced when in contact with a material due to the temperature difference between the body and the material
Firmness	Refers to the perceived resistance or impact load experienced when in contact with a material
Smoothness	Refers to the perception of roughness and the sensory stimulation produced by friction when in contact with a material
Texture	Refers to the tactile sensation caused by variations in height on the surface of a material
Bounciness	Refers to the perception of cushioning and rebound effects experienced when in contact with a material

7.2.1.3 Determination of AHP Evaluation Indicator Weights

(1) Introduction to AHP Software

In this section, the Yaahp Analytic Hierarchy Process (AHP) software is used. Yaahp (Yet Another AHP) is a simple and compact AHP application software that provides functions for ranking weight calculations and exporting data. The software is designed to be flexible, convenient, and fast for AHP applications. Users do not need to have a deep understanding of the specific details of the AHP calculation steps. With basic knowledge of the AHP, they can use the AHP for research and decision-making on relevant issues[13]. The software interface is shown in Fig. 7-3.

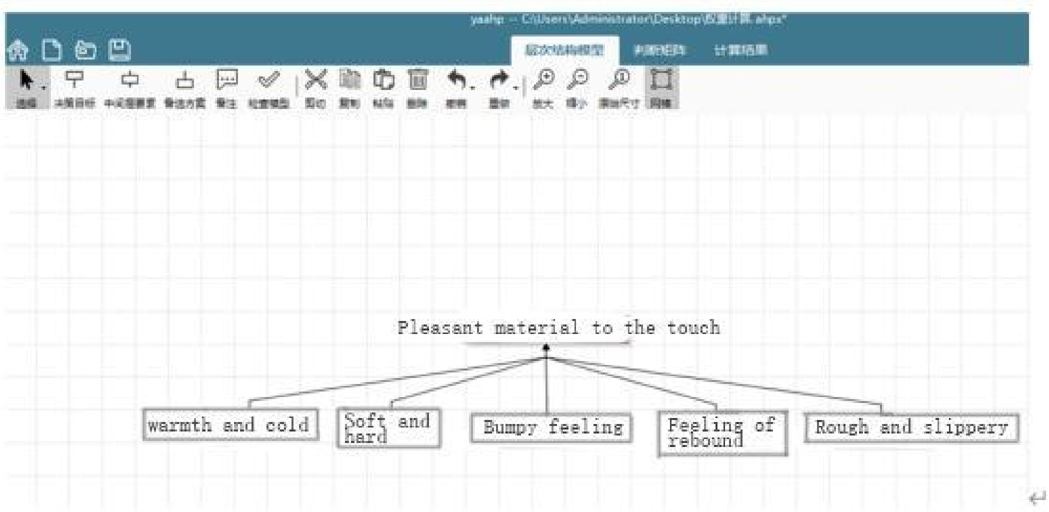


Fig. 7-3 Software hierarchy model interface

Fig. 7-4 Scale and consistency of judgment matrix

In the Yaahp software, the Analytic Hierarchy Process (AHP) model construction module is used to construct a hierarchical structure model for the problem or objective at hand. It includes three levels: the decision objective, intermediate factors, and alternative options. In the judgment matrix module, the judgment matrix is filled out using the "1-9" scale method, as shown in Fig. 7-4. The scale bar on the upper right side of the software is used to fill in the judgment matrix. In the figure, "Equally important" corresponds to 1, and the values increase upwards from 2 to 9, and decrease downwards from 1/2 to 1/9. After filling out the matrix, the software automatically calculates the consistency index of the judgment matrix. If the consistency index does not meet the requirements, the corresponding judgment matrix needs to be adjusted until the requirements are met. Finally, in the calculation results module, the software displays the results of the option level calculations. By clicking "Display detailed data," the weight calculation results for each criterion level indicator and the consistency index of each judgment matrix can be viewed. If needed, the software can also export the calculation data for user reference.

(2) Construction of the Analytic Hierarchy Process Model

①Model Construction

Based on the principles of the Analytic Hierarchy Process, the hierarchical analysis model for evaluating the subjective perception of material tactile comfort is constructed, as shown in Fig. 7-5.

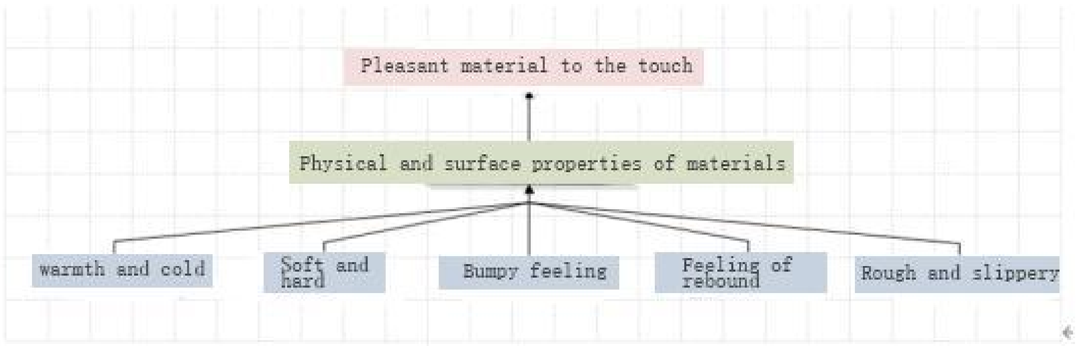


Fig. 7-5 Material tactile comfort subjective evaluation hierarchical structure model

②Constructing the Judgment Matrix

In the Analytic Hierarchy Process, the judgment matrix is the most basic information and plays an important role in calculating relativity. The elements in the judgment matrix, denoted as aij, represent the ratio of the relative importance between element i and element j, subject to the following conditions:

$$a_{ij}=1/a_{ji} \quad i \neq j \quad j=1, 2, ..., n$$
$$a_{ij}=1 \quad i=j \quad j=1, 2, ..., n$$
$$a_{ij}>0 \quad i \neq j \quad j=1, 2, ..., n$$

In this study, a judgment matrix was constructed based on multiple interviews, questionnaires, and weighting result corrections conducted with 10 experts from the fields of materials science, medicine, psychology, and architecture, as well as 20 elderly participants selected from the sample. The questionnaire can be found in Fig. 7-6, and the complete questionnaire is available in the appendix.

Haptic comfort of building materials - AHP analytic hierarchy questionnaire A1

Please compare the importance of indicators that affect the tactile comfort of flooring materials according to subject expertise or your own real feelings, and check the corresponding position in the table, all are single-choice questions.

Options:

A Extremely important B Strongly important C Obviously important

D Slightly more important E Equally important F Slightly unimportant

G Obviously unimportant H Particularly unimportant I Extremely unimportant

Question:

1 Do you think that for the tactile comfort of flooring materials, the feeling of cold and warm is relative to the feeling of soft and hard:__________

Fig. 7-6 Material tactile comfort -AHP hierarchical analysis questionnaire

During the judgment process, strict adherence to the relevant criteria and analytical steps of the Analytic Hierarchy Process (AHP) was followed. The 1-9 scale, as shown in Table 7-14, was utilized.

Table 7- 14 Analytic hierarchy process

judgment scale	definition
1	ai and aj are equally important.
3	ai is slightly more important than aj.
5	ai is noticeably more important than aj.
7	ai is significantly more important than aj.
9	ai is extremely more important than aj.
2、4、6、8	It is somewhere in between the two scales of judgment mentioned above.

Due to the different ways and body parts through which materials come into contact with individuals, there are varying emphases and requirements for material tactile comfort evaluation. Therefore, two sets of judgment matrices were constructed in this study. The first set is the judgment matrix A1, which focuses on the tactile comfort of floor materials primarily in contact with the feet. The second set is the judgment matrix A2, which focuses on the tactile comfort of wall materials and furniture accessories primarily in contact with the hands. The judgment matrices were constructed based on the evaluations provided by experts and the tested elderly individuals. The results of the judgment matrices are shown in Table 7-15-Table 7-18.

1)Judgment matrix A1

Table 7- 15 Judgment matrix A1-B

A1	B
B	1

Table 7- 16 Judgment matrix B-C

B	C1	C2	C3	C4	C5
C1	1	1/2	1/5	1/3	3
C2	2	1	1/4	1/2	2
C3	5	4	1	2	6
C4	3	2	1/2	1	4
C5	1/3	1/2	1/6	1/4	1

2)Judgment Matrix A2

Table 7- 17 Judgment matrix A2-B

A2	B
B	1

Table 7- 18 Judgment matrix B-C

B	C1	C2	C3	C4	C5
C1	1	1/3	1/5	1/3	5
C2	3	1	1/6	1/4	2
C3	5	6	1	2	6
C4	3	4	1/2	1	5
C5	1/5	1/2	1/6	1/5	1

7.2.1.4 Index Hierarchy Ranking and Consistency Test

(1) Principle of Consistency Test

When answering questions, due to the complexity of the object and the diversity of human understanding, it is not necessary to ensure the consistency of the judgment matrix when constructing it. This may lead to decision-making errors and deviations in hierarchy ranking. When the deviation from consistency in the judgment matrix is too large, the reliability of this approximate estimation becomes questionable. This requires checking the consistency of the judgment matrix[ ]. The steps are as follows:

For the judgment matrix A, the i-th component Wi of its eigenvector W is given by

$$W_{\mathrm{i}} = (\prod_{i=1}^{n} a_{ij})^{1/n}, i = 1,2,....,n;$$

$$W = (W_{1,} W_{2,} W_{3,} ..., W_{\mathrm{n}})^{T}$$

$$令 W'_{\mathrm{i}} = W_{i} / \sum_{i=1}^{n} W_{i}$$

$$W' = (W'_{1}, W'_{2,} ..., W'_{n})^{T}$$

$$AW' = \lambda W'$$

This allows us to determine the maximum eigenvalue λmax' of the judgment matrix.

thereinto $$\lambda = \begin{bmatrix} \lambda_1 & & 0 \\ & & \\ 0 & & \lambda_n \end{bmatrix}$$

Calculating the eigenvalues and eigenvectors of the judgment matrix is a summary of the hierarchical ranking problem. Specifically, for the judgment matrix A, we solve the equation AW' = λmaxW', where λmax is the largest eigenvalue of A, and W' is the normalized eigenvector corresponding to λmax.

To verify whether the judgment matrix is consistent, the consistency index must be calculated: CI = (λmax - n) / (n - 1).

When CI = 0, the judgment matrix is exactly the same. The larger the CI, the more inconsistent the judgment matrix. Generally, consistency is represented by the ratio CR of CI to the average random consistency index RI: CR = CI / RI. The corresponding RI values for different matrix orders can be found in Table 7-19. When CR < 0.1, the consistency of rankings is very satisfactory.

Table 7- 19 The corresponding values of different order matrix RI

Order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

(2) Index Hierarchy Ranking and Consistency Check

① Single-ranking and Consistency Check

Based on the judgment matrix, for a certain factor in the previous level, it is necessary to calculate the weights of all factors related to it in this level and perform consistency checks on each matrix. The weight values and consistency of each judgment matrix are shown in Table 7-20-Table 7-21. According to the calculation results, all CR values are less than 0.1, indicating that the ranking results have satisfactory consistency.

Table 7- 20 Hierarchical single ordering and consistency checking -A1

judgment matrix	a1	a2	a3	a4	a5	CI	RI	CR	consistency Inspection
A1-B	1					0	0		satisfy
B-C	0.100	0.135	0.457	0.250	0.058	0.033	1.12	0.029	satisfy

Table 7- 21 Hierarchical single ordering and consistency checking -A2

judgment matrix	a1	a2	a3	a4	a5	CI	RI	CR	consistency Inspection
A2-B	1					0	0		satisfy
B-C	0.439	0.066	0.276	0.174	0.045	0.051	1.12	0.045	satisfy

② Overall Hierarchy Ranking Results

1)A1 matrix hierarchy total sort results

Table 7- 22 A1 matrix hierarchy total ordering results

C	B（1）	weight value	sort
C1	0.100	0.100	4
C2	0.135	0.135	3
C3	0.457	0.457	1
C4	0.250	0.250	2
C5	0.058	0.058	5

According to Table 7-22, the weight ranking of evaluation indicators for materials in contact with the feet, which refers to the tactile comfort of residential floor materials, is as follows: C3 Roughness-Smoothness > C4 Unevenness-Smoothness > C2 Softness-Hardness > C1 Warmth-Coolness > C5 Resilience.

2)A2 matrix hierarchy total sort result

Table 7- 23 A2 matrix hierarchy total ordering results

C	B（1）	weight value	sort
C1	0.439	0.439	1
C2	0.066	0.066	4
C3	0.276	0.276	2
C4	0.174	0.174	3
C5	0.045	0.045	5

According to Table 7-23, the weight ranking of evaluation indicators for materials in contact with the hands, which refers to the tactile comfort of materials primarily found in walls, furniture, and decorations in residential spaces, is as follows: C1 Warmth-Coolness > C3 Roughness-Smoothness > C4 Unevenness-Smoothness > C2 Softness-Hardness > C5 Resilience.

7.2.2 Experimental Design for Subjective Evaluation of Material Tactile Comfort

7.2.2.1 Selection of Experimental Testers and Samples

(1) Selection of Experimental Testers

Due to the constraints of experimental time and conditions, a total of 80 elderly individuals were selected to subjectively evaluate the sample materials. Taking into consideration factors such as the age distribution and physical condition of the participants, elderly individuals between the ages of 60 and 74 with good physical conditions and self-care abilities were chosen as the research subjects. The average age of the participants was 70.4 years, including 37 male testers and 43 female testers, with a roughly balanced gender ratio. The distribution of testers' ages and the number of participants are shown in Fig. 7-7 Population distribution of 60-74year old self-care type.

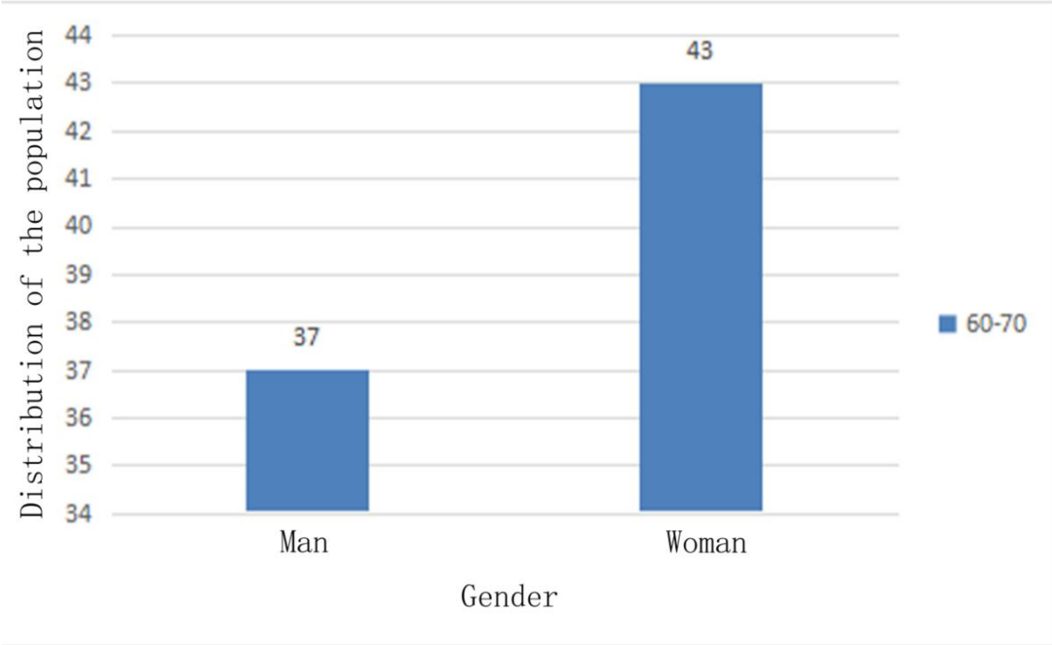


Fig. 7-7 Population distribution of 60-74year old self-care type

Before conducting the experimental tests, the participants were instructed to avoid vigorous exercise and ensure that they were in a calm emotional state. All participants were provided with detailed explanations of the purpose and requirements of the experiment. The meaning of the subjective evaluation indicators and the questionnaire items were also explained to ensure better understanding and cooperation from the participants. The participants were strictly instructed to follow the guidelines provided by the experimenters during the experiment. After collecting the questionnaires, a thorough analysis was conducted. Samples with incomplete data collection were excluded from the analysis. Finally, the subjective evaluation results from 72 participants were considered as valid data samples for further analysis.

(2) Selection of Experimental Samples

In the subjective evaluation experiment of material tactile comfort, the rational selection of samples plays a crucial role in determining the results. The selection of experimental samples should adhere to the following basic principles: ①Comprehensiveness: The samples should include a wide range of commonly used building materials in residential spaces. ②Representativeness: There should be significant differences in physical attributes or surface characteristics among different samples. ③Irrelevance: Control should be exercised over irrelevant variables of the samples, such as size, shape, and color.

Based on the composition of common materials in the living spaces of the elderly as discussed in section 2.3, and considering the different physical attributes and surface characteristics of the materials, a selection of 13 common flooring materials, 8 wall materials, and 13 furniture and decorative materials was made. Please refer to Table 7-23 for detailed information.

7.2.2.2 Experimental Methods and Procedures

(1) Experimental Methods

The main approach of this experiment is to have the elderly participants come into contact with different material samples and record their subjective ratings of tactile comfort for each sample. These ratings will serve as the data source for subsequent subjective evaluation analysis.

① Selection of Experimental Environment and Control of Irrelevant Variables

Due to limitations in experimental conditions, it was not possible to test all elderly participants in the same environment. Therefore, when conducting the experiment in individual environments, it was ensured that the temperature, humidity, and atmosphere were comfortable and quiet. Before the actual experiment, each elderly participant was given 15 minutes to adapt to the experimental environment before experiencing the tactile sensation of the material samples. Additionally, since the experiment focuses primarily on material tactile comfort, it is important to avoid factors such as color and shape of the material samples that may influence the elderly participants. Therefore, the selection of material samples primarily consisted of flat surfaces, and during the tactile experience, the elderly participants were instructed to look straight ahead to minimize the influence of visual factors on the evaluation results.

② Contact Time and Contact Method

Prior to the formal subjective evaluation experiment, a pilot study was conducted to identify any shortcomings and make necessary improvements. Ten independent elderly individuals were selected for the pilot study, and the time required for them to go through the process of contacting the material samples, experiencing the sensations, and completing the subjective ratings of tactile comfort was recorded. Based on this, a rough range of contact time was determined to be between 60 seconds and 90 seconds. Furthermore, based on the investigation results of elderly individuals' tactile behavior characteristics regarding footwear, it was found that the majority of elderly individuals in residential spaces wear slippers or shoes with rubber soles of moderate thickness. Therefore, for the experiment, rubber-soled slippers of the same style but different sizes were provided for the elderly participants to wear, as shown in Fig. 7-8.

Fig. 7-8 Rubber soled slippers for testing

③ Design of Subjective Rating Questionnaire

The selected material samples will be grouped and numbered according to the method of contact. Elderly participants will be asked to rate the vertical comfort level of each material sample based on the evaluation criteria. Additionally, considering the decreased tactile perception ability in the elderly and feedback received during the pilot study indicating that some elderly individuals found it difficult to accurately judge scores on a 7-point scale, a 5-point scale will be used for the subjective evaluation. The highest score is 5 points, the lowest score is 1 point, and the score interval is 1 point. The descriptive words or phrases are symmetric, and the perceived comfort level increases from left to right. The evaluation questionnaire can be found in the appendix.

(2) Experimental Procedure

Fig. 7-9 Material tactile comfort test phase 1

Stage 1: First, the testers are asked to wear rubber-soled slippers and sit quietly on a comfortable chair for 15 minutes. After 15 minutes, the testers maintain a standing position with relaxed muscles, and the material samples are sequentially arranged for them to experience. The testers simultaneously stand on the samples and perform actions such as standing, rubbing, sliding, and stepping, while keeping their eyes forward. The duration of the experience is between 60 to 90 seconds. After the experience, each tester is given a 1-minute rest. They then provide subjective ratings for the comfort of the tactile indicators based on their actual sensations, using the evaluation questionnaire provided in the appendix. This process is repeated for each sample, following the numbering of the materials(Fig. 7-9).

Stage 2: The testers are instructed to sit quietly and rest for 15 minutes. After 15 minutes, the testers maintain a natural sitting posture with relaxed muscles and a calm state. Material samples are sequentially arranged on the tabletop for the testers to experience. The testers sit on a chair and use their hands to touch, slide, and press the material samples, while keeping their eyes forward. The duration of the experience is between 60 to 90 seconds. After the experience, each tester is given a 1-minute rest. During this time, they provide subjective ratings for the comfort of the tactile indicators based on their actual sensations, following the evaluation questionnaire provided in the appendix. This process is repeated for each sample, following the numbering of the materials.

Fig. 7-10 Material comfort test stage two

Due to the relatively large number of samples and to avoid the influence of physical fatigue on the collection of physiological indicators in older adults, different participants have different orders of contact with the materials. Half of the participants start with Stage 2, while the other half start with Stage 1. The final results are processed by taking the average(Fig. 7-10).

7.2.2.3 Statistical Methods

(1) Significance Analysis of Subjective Evaluation Indicators

Although the subjective evaluation indicators of material tactile comfort in this study were derived based on extensive literature review, summarizing existing research, and expert interviews, it is still necessary to verify the significance of the selected subjective sensory evaluation indicators. Thus, ANOVA is used to analyze various subjective evaluation indicators.

(2) Analysis of the Validity of Subjective Evaluation Results

Subjective evaluation of material tactile comfort is influenced by individuals' personal preferences, emotions, and social environment, which leads to individual differences in the evaluation of tactile comfort for building materials. These differences raise questions about the stability and reliability of the data. Therefore, it is necessary to validate the subjective evaluation results.

The Kendall's coefficient of concordance test is a nonparametric test method for testing multiple paired samples. It assesses the ranks of the groups and uses the coefficient of concordance to determine their level of agreement. The null hypothesis is H0: The evaluators have inconsistent judgment criteria. The scores of each sensory indicator for different building materials are treated as paired samples from multiple populations, transforming the problem into a nonparametric test problem for multiple paired samples. However, the analysis of this problem needs further extension. It does not solely analyze whether there are significant differences between sensory ratings, but rather, it continues to assess whether the evaluators have consistent rating criteria on the premise of recognizing the differences. In the Kendall's coefficient of concordance test, the coefficient of concordance is defined as follows:

$$W = \frac{\sum_{i=1}^{n}(R_i - \frac{m(n+1)}{2})^2}{m^2(n^3 - n)/12}$$

Where m is the number of evaluators, n is the number of items being evaluated, and R is the sum of ranks for the i-th item being evaluated. A higher value of the coefficient of concordance indicates greater between-group differences in ranks, indicating significant differences in scores among evaluators and thus indicating more consistent rating criteria among the evaluators.

(3) Analysis of Gender Differences in Material Tactile Comfort Evaluation

To determine whether the selected material tactile comfort evaluation indicators reflect the subjective evaluation of material tactile comfort for the majority of older adults and capture the commonality of subjective touch experiences, it is necessary to further analyze the factors that may influence the evaluation of material tactile comfort by older adults. The specific factors include gender and age. Since the selected older adults are distributed within the age range of 60-74 years and do not form a clear age gradient, this study only analyzes the significance of gender differences. Based on the characteristics of the data, an independent samples t-test is chosen to examine the differences in evaluation indicators between males and females.

The mean values of two independent samples are tested for differences using independent sample t-tests. In the analysis, the two independent samples are male participants and female participants, and the focus is on the differences in evaluation indicators, namely thermal sensation, roughness, softness/hardness, resilience, and unevenness. SPSS software is used for the independent samples t-test analysis. In SPSS, the analysis is performed by selecting Analyze → Compare Means → Independent Samples T-Test → Setting the grouping variable and test variable → Conducting the test. In the test results, based on the homogeneity of variance, different criteria are used to determine the significance. If the sig value is greater than 0.05, it indicates that there is no significant difference in the average values of the two samples for that indicator, whereas if the sig value is less than 0.05, it indicates a significant difference.

7.2.3 Subjective evaluation of material tactile comfort results and analysis

7.2.3.1 Subjective Evaluation Results and Analysis of Flooring Materials

(1) Analysis of Subjective Evaluation Result Validity

①Analyze the significance of Subjective Evaluation Indicators

The results of the ANOVA analysis in SPSS software are shown in Table 7-24. From the significance probabilities in the table, it can be observed that all five evaluation indicators are below the significance level, indicating significance. This means that all five indicators can effectively differentiate between different materials.

Table 7- 24 Subjective evaluation index ANOVA analysis table

source of variance	dependent variable	sum of square	df	mean square	F	prominence
Exposure to different building materials	Warm-Cool Sensation	136.376	12	11.365	103.130	0.000
	Soft-Hard Sensation	355.402	12	29.617	551.789	0.000
	Rough-Smooth Sensation	495.350	12	41.279	156.910	0.000
	Uneven-Smooth Sensation	816.274	12	68.0323	316.832	0.000
	Bounce-Resilience Sensation	168.000	12	14.000	160.767	0.000

② Analysis of Subjective Evaluation Result Validity

The results of Kendall's analysis in SPSS software are shown in Table 7-25. From the data in the table, it can be observed that the progressive significance probabilities are all below the significance level α (0.05), indicating that the subjective evaluation experiment data are valid.

Table 7- 25 Subjective evaluation results Kendall synergy coefficient test table

Evaluation Criteria	N（evaluator）	Kendall's W	Bangla	df	progressive salience
Warm-Cool Sensation	72	0.757	490.65	12	0.000
Soft-Hard Sensation	72	0.989	640.63	12	0.000

Rough-Smooth Sensation	72	0.868	562.70	12	0.000
Uneven-Smooth Sensation	72	0.906	587.11	12	0.000
Bounce-Resilience Sensation	72	0.723	468.19	12	0.000

③ Analysis of Gender Differences

Due to the large number of material samples, partial results of the t-tests are presented below. Table 7-26 shows selected t-test results. In Table 7-26, A11 represents the first evaluation indicator of floor material sample 1, with indicator labels as follows: Cold-Warm Sensation -1, Soft-Hard Sensation -2, Coarse-Smooth Sensation -3, Unevenness Sensation -4, and Rebound Sensation -5.

Table 7- 26 Independent sample T test results of sex factors

codes	t	df	Sig.(2-tailed)
A11	.364	70	.884
A12	.359	70	.421
A13	.309	70	.987
A14	.205	70	.873
A15	1.784	70	.081
A21	2.155	70	.887
A22	-3.799	70	.096
A23	-.688	70	.074
A24	-1.751	70	.083
A25	1.031	70	.061

From the final results, there is no difference in the effect of gender on the 13 ground materials.

(2) Overall Subjective Evaluation Scores

For the selected 54 floor material samples, the comfort ratings for each indicator were calculated based on the completed questionnaires. The mean comfort ratings for each indicator were obtained. These mean ratings were then multiplied by the weights assigned to each indicator in Section 3.1.3: C1 (Cold-Warm Sensation) with a weight of 0.1, C2 (Soft-Hard Sensation) with a weight of 0.135, C3 (Coarse-Smooth Sensation) with a weight of 0.457, C4 (Unevenness Sensation) with a weight of 0.25, and C5 (Rebound Sensation) with a weight of 0.058. Finally, the comfort ratings for each indicator were summed to obtain the overall subjective comfort score for each sample, as shown in Table 7-27.

Table 7- 27 Comprehensive score of tactile comfort of ground material

material code	Material Name	Thermal Sensation 0.100	Softness/ Hardness Sensation 0.135	Roughness/Slipperiness Sensation 0.457	Concavity/Convexity Sensation 0.250	Resilience Sensation 0.058	Total Score
1	Glazed Tile	3	3	4.2	5	3	4.048

2	Matt Glazed Tile	3.2	3	4	4	3	3.727
3	Full Body Tile	3	3	1.8	1.2	3	2.001
4	Long Pile Carpet	4.2	2	3	3	2.2	2.938
5	Short Pile Carpet	4	4	3	3	3.2	3.246
6	Solid Wood Flooring	4.5	4.4	4.2	4.2	4	4.245
7	Engineered Wood Flooring	4.5	4.4	4.2	4.2	3.8	4.234
8	Laminate Flooring	3.2	3	3.8	4.2	3	3.685
9	Cork Flooring	3.2	4	3.8	4.2	4	3.878
10	Bamboo Flooring	3	3	3.8	4.2	3.2	3.677
11	Vinyl Flooring	3.2	3	3	4	3	3.270
12	Plain Patterned Vinyl Flooring	3.7	4.4	4	4.2	3.2	4.027
13	Striped Patterned Vinyl Flooring	3	3	2	1.2	3	2.093

Based on the overall comfort scores for floor materials in Table 7-28, the comfort levels can be categorized into three tiers: ≥4 points, indicating comfortable; 3<n<4 points, indicating moderate comfort; ≤3 points, indicating uncomfortable. The preferred results for the floor materials are as follows:

Table 7- 28 Optimization results of the ground material for the elderly living space

Material category	Subjective scoring	comfort level	material name
ground material	⩾4	comfortable	Solid wood flooring, solid wood composite flooring, glazed tiles, plain vinyl flooring
	3⩽n<4	generally	Cork flooring, matt glazed tiles, laminate flooring, bamboo flooring, floor leather, low-pile carpet
	<3 分	uncomfortable	Plush carpet, striped vinyl flooring, full body tiles

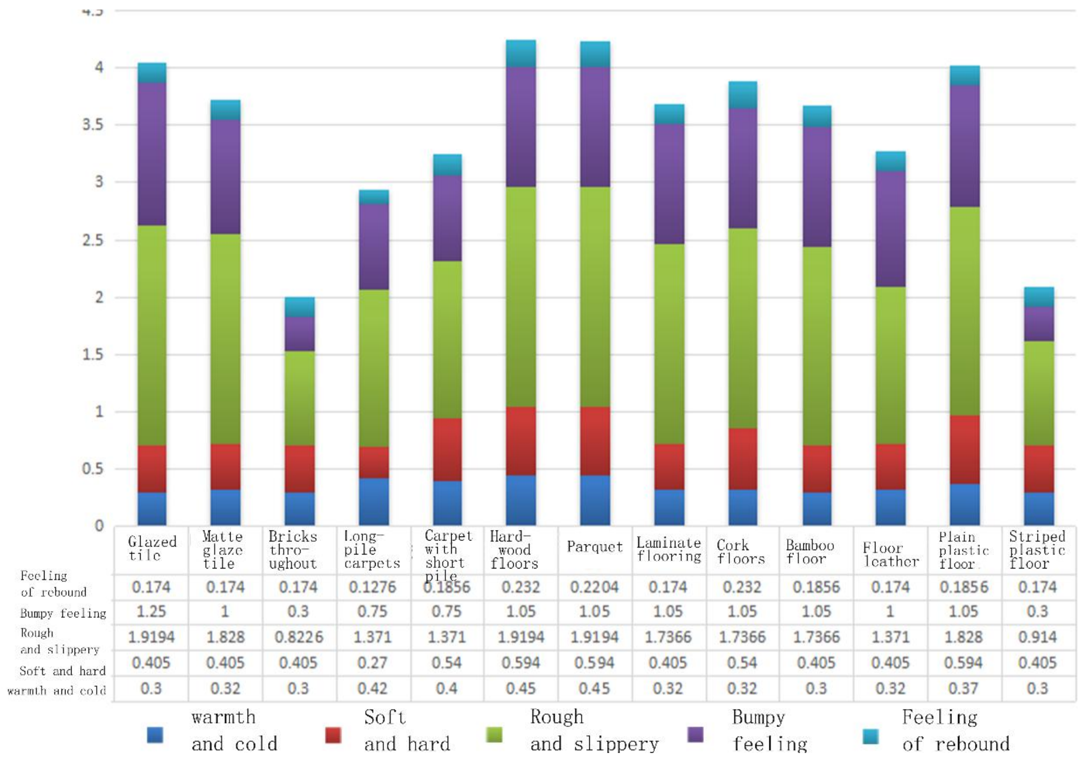


Fig. 7-11 Tactile comfort score of ground material

According to Fig. 7-11, the ranking of floor materials in terms of tactile comfort from high to low is as follows: solid wood flooring > engineered wood flooring > glazed tiles > plain vinyl flooring > cork flooring > matte glazed tiles > laminate flooring > bamboo flooring > linoleum flooring > short-pile carpet > long-pile carpet > striped vinyl flooring > homogeneous tiles.

7.2.3.2 Wall Material Evaluation Results and Analysis

(1) Validity Analysis of Subjective Evaluation Results

① Analyze the significance of Subjective Evaluation Indicators

The results of the ANOVA analysis in the SPSS software are shown in Table 7-29. From the significance probabilities in the table, it can be observed that all five evaluation indicators are lower than the significance level, indicating significance. Therefore, all five indicators can effectively differentiate between different materials.

Table 7- 29 Subjective evaluation index of tactile comfort ANOVA

Variance source	Dependent Variable	sum of square	df	mean square	F	prominence
Exposure to different building materials	Warmth	101.250	7	14.464	170.357	0.000
	Soft and hard feeling	281.250	7	40.179	473.214	0.000
	roughness	353.250	7	50.464	162.097	0.000
	Concave and convex	515.250	7	73.607	520.157	0.000
	Resilience	107.250	7	15.321	180.452	0.000

② Validity Analysis of Subjective Evaluation Results

The results of Kendall's analysis in the SPSS software are shown in Table 7-30. From the data in the table, it can be observed that the progressive significance probabilities are all smaller than the significance level α (0.05), indicating that the subjective evaluation experimental data is valid.

Table 7- 30 Subjective evaluation results Kendall synergy coefficient test table

Evaluation index	N（evaluator）	Kendall's W	Bangla	df	progressive salience
Warmth	72	0.899	339.65	7	0.000
Soft and hard feeling	72	0.485	183.27	7	0.000
roughness	72	0,898	339.48	7	0.000
Concave and convex	72	0.948	358.28	7	0.000
Resilience	72	0.938	344.33	7	0.000

③ Analysis of Gender Differences

Due to the large number of material samples, partial results of the T-tests are listed below. In Table 7-31, B11 represents the first evaluation indicator of wall material sample 1, and the indicator numbers correspond to thermal sensation-1, softness-hardness-2, roughness-smoothness-3, unevenness-4, and resilience-5.

From the final results, it can be concluded that gender does not have a significant impact on the eight types of wall materials.

Table 7- 31 Independent sample T test results of sex factors

codes	t	df	Sig.(2-tailed)
B11	.465	70	.675
B12	.379	70	.322
B13	.309	70	.987
B14	.406	70	.846
B15	2.784	70	.081
B21	2.031	70	.887
B22	-2.199	70	.095
B23	.688	70	.0581
B24	.751	70	.069
B25	1.223	70	.0703

(2) Comprehensive Subjective Evaluation Scores

Data from the filtered 54 wall material tactile comfort evaluation questionnaires were statistically analyzed to obtain the average comfort scores for each indicator of each sample, as shown in Table 7-32. The comfort scores for each indicator were multiplied by the weights of the wall material tactile comfort indicators from section 3.1.3: C1 (thermal sensation) 0.439, C2 (softness-hardness) 0.066, C3 (roughness-smoothness) 0.276, C4 (unevenness) 0.174, and C5 (resilience) 0.045. The scores for each indicator were then summed to obtain the comprehensive tactile comfort score for each sample, as shown in Table 7-32.

Table 7- 32 Comprehensive evaluation of tactile comfort of wall materials

Material serial number	material name	Thermal Sensation 0.439	Softness/ Hardness Sensation 0.066	Roughnes s/Slipperi ness Sensation 0.276	Concavity /Convexit y Sensation 0.174	Resilience Sensation 0.045	Total Score
I	Tabby Smooth Wallpaper	4	3.8	5	5	3	4.392
II	rough wallpaper	4	3.2	2.4	2.8	3	3.252
III	Regular stripes wallpaper	4	3.2	3.2	3.2	3	3.542
IV	glazed tile	3	3	4.8	5	3	3.845
V	Matt glazed tile	3	3	4	3.4	3	3.345
VI	mosaic	3	3	2.8	2	3	2.771
VII	latex paint	3	3	3	3	3	3
VIII	Diatom mud	3	3	2	2	3	2.55

According to the total comfort scores of the material samples in Fig. 7-12, the ranking of tactile comfort of wall materials in residential spaces from high to low is as follows: Plain smooth wallpaper > Glazed tiles > Regular striped wallpaper > Matte glazed tiles > Rough wallpaper > Latex paint > Mosaic > Diatomaceous earth.

Based on the comprehensive comfort scores of wall materials' tactile comfort as shown in Table 7-32, the comfort level of wall materials can be categorized into three levels: ≥4 points, which indicates comfort; 3 < n < 4, which indicates moderate comfort; ≤3 points, which indicates discomfort. The preferred material selection results are presented in Table 7-33:

Table 7- 33 The optimization results of wall materials for the elderly living space

Material category	Subjective scoring	comfort level	material name
wall material	⩾4	comfortable	Tabby Smooth Wallpaper
	3⩽n<4	generally	Glazed tiles, matte glazed tiles, regular striped wallpaper, rough wallpaper, latex paint
	<3 分	uncomfortable	Mosaic, diatom mud

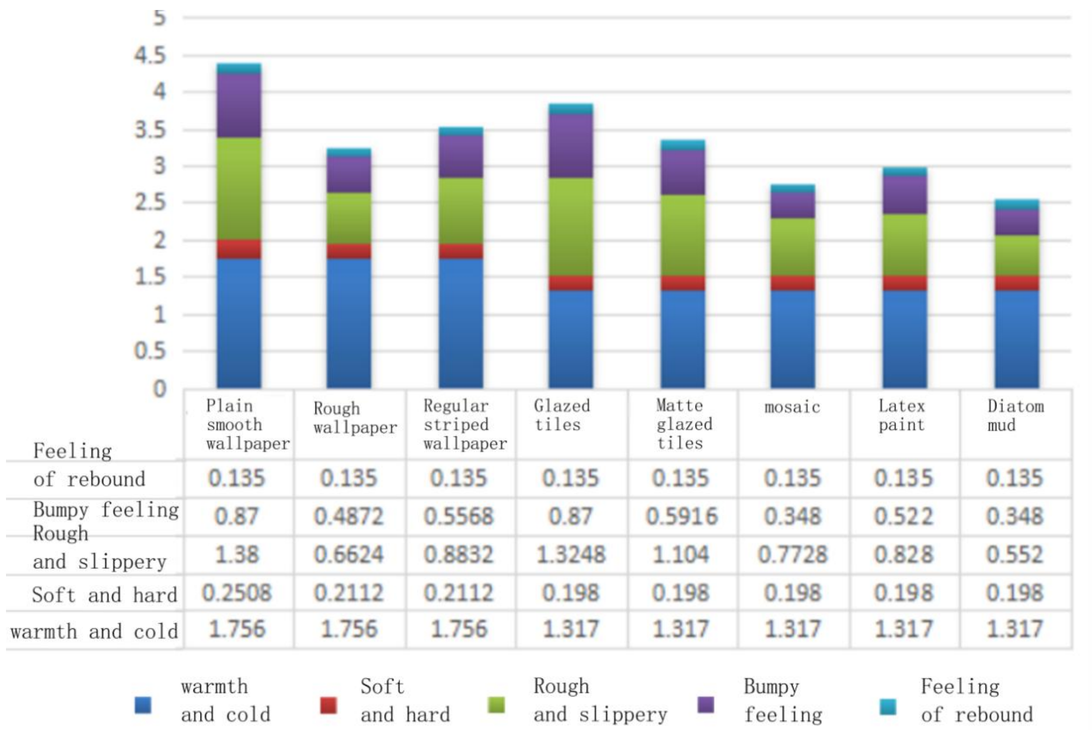


Fig. 7-12 Tactile comfort score of wall material

7.2.3.3 Evaluation Results and Analysis of Furniture and Decorative Materials

(1) Analysis of the Validity of Subjective Evaluation Results

① Analyze the significance of Subjective Evaluation Indicators

The ANOVA analysis results in Table 7-34, obtained using SPSS software, show that the significance probabilities of all five evaluation indicators are below the significance level. This indicates that all five indicators can effectively distinguish between different materials.

Table 7- 34 Subjective evaluation index ANOVA analysis table

source of variance	dependent variable	sum of square	df	mean square	F	prominence
Exposure to different building materials	Warmth	137.5000	11	12.500	132.500	0.000
	Soft and hard feeling	337.500	11	30.682	542.045	0.000
	roughness	481.500	11	43.773	154.664	0.000
	Concave and convex	786.000	11	71.455	344.281	0.000
	Resilience	142.000	11	12.909	136.836	0.000

② Analysis of the Validity of Subjective Evaluation Results

The results of the Kendall's analysis in the SPSS software are shown in Table 7-35. From the data in the table, it can be observed that the p-values for all variables are smaller than the significance level α (0.05). Therefore, the subjective evaluation experimental data is deemed valid.

Table 7- 35 Subjective evaluation results Kendall synergy coefficient test table

Evaluation index	N（evaluator）	Kendall's W	Bangla	df	progressive salience
Warmth	72	0.932	553.62	11	0.000
Soft and hard feeling	72	0.870	517.05	11	0.000
roughness	72	0.938	557,33	11	0.000
Concave and convex	72	0.737	437.80	11	0.000
Resilience	72	0.802	476.16	11	0.000

③ Analysis of Gender Differences

Due to the large number of samples, only a partial list of t-test results is provided below. In Table 7-36, C11 represents the first evaluation criterion of furniture and decorative material sample 1, with criterion labels for warmth-coolness sensation-1, softness-hardness sensation-2, roughness-smoothness sensation-3, concavity-convexity sensation-4, and resilience sensation-5. Based on the final results, it can be concluded that there are no significant differences in the influence of gender on the 13 types of furniture and decorative materials.

Table 7- 36 Independent sample T test results of sex factors

codes	t	df	Sig.(2-tailed)
C11	-.543	70	.677
C12	-.782	70	.722
C13	.343	70	.881
C14	.556	70	.746
C15	1.784	70	.076
C21	0.451	70	.987
C22	-1.187	70	.067
C23	.579	70	.0381
C24	.751	70	.073
C25	1.241	70	.0703

(2) Overall Subjective Evaluation Score

Table 7- 37 Tactile tactile comfort score for furniture and accessories

Material serial number	material name	Thermal Sensation 0.439	Softness/ Hardness Sensation 0.066	Roughnes s/Slipperi ness Sensation 0.276	Concavity /Convexit y Sensation 0.174	Resilience Sensation 0.045	Total Score
A	wood	4	4.2	5	5	4	4.463
B	rattan	3.6	3	3	3	3.8	3.299
C	plastic	3	3	3.6	3.8	3	3.304
D	rubber	3.8	4	4	4	4	3.912

E	ceramics	2	3.2	4.5	4	3	3.162
F	Glass	1.8	3.2	4	4	3	2.936
G	stone	1.6	3	4	4	3	2.835
H	Metal	1.3	3.2	4	4	3	2.717
I	cotton	4.8	5	3.8	4.4	4.2	4.440
J	numb	4	2.4	2	2	3	2.94
K	leather	3.8	3.2	3	3.8	3.2	3.512
L	silk	3	4	4	3.8	3.4	3.499
M	yarn	3.6	3	2	3.3	3	3.040

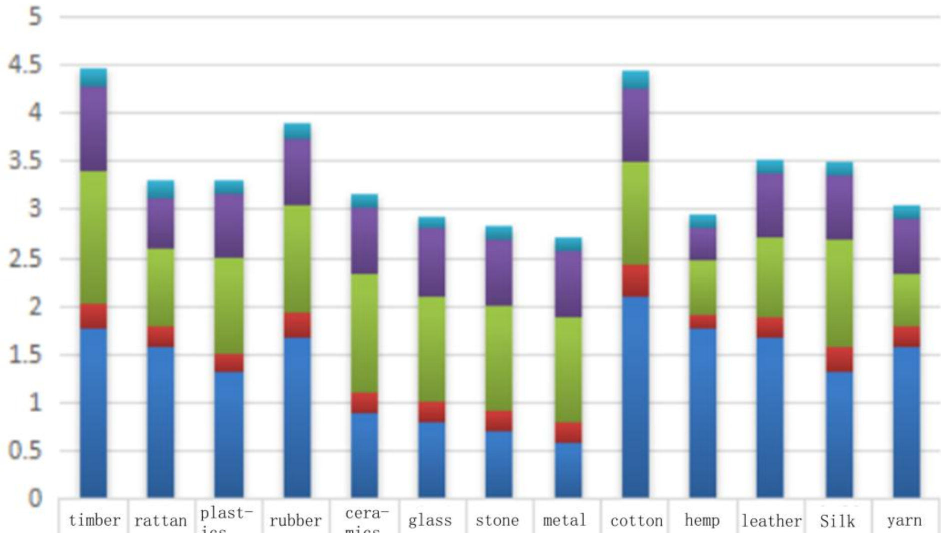
The data from the questionnaire for the tactile comfort rating of the selected 54 furniture and decorative material samples were statistically analyzed. The average comfort rating was calculated for each criterion of each sample. The comfort rating for each criterion was then multiplied by the corresponding weight for tactile comfort indicators of furniture and decorative materials from section 3.1.3, where C1 (warmth-coolness sensation) has a weight of 0.439, C2 (softness-hardness sensation) has a weight of 0.066, C3 (roughness-smoothness sensation) has a weight of 0.276, C4 (concavity-convexity sensation) has a weight of 0.174, and C5 (resilience sensation) has a weight of 0.045. Finally, the comfort ratings for each criterion were summed up to obtain the overall tactile comfort score for each sample, as shown in Table 7-37.

Based on the overall tactile comfort scores for furniture and decorative materials in Table 7-37, the comfort level was divided into three categories: ≥4 points, indicating comfortable; 3<n<4, indicating moderately comfortable; ≤3 points, indicating uncomfortable. The results of the material selection are presented in Table 7-38.

Table 7- 38 The optimization results of wall materials for the elderly living space

Material category	Subjective scoring	comfort level	material name
Furniture and accessories materials	≥4	comfortable	wood, cotton
	3≤n<4	generally	Rubber, leather, silk, plastic, ceramics, rattan, yarn
	<3 分	uncomfortable	Hemp, glass, stone, metal

According to Fig. 7-13, the ranking of tactile comfort for furniture and materials in living spaces, from highest to lowest, is as follows: wood > cotton > rubber > leather > silk > plastic > rattan > ceramic > yarn > hemp > glass > stone > metal.



	timber	rattan	plast-ics	rubber	cera-mics	glass	stone	metal	cotton	hemp	leather	Silk	yarn
Feeling of rebound	0.18	0.171	0.135	0.18	0.135	0.135	0.135	0.135	0.189	0.135	0.144	0.153	0.135
Bumpy feeling	0.87	0.522	0.661	0.696	0.696	0.696	0.696	0.696	0.765	0.348	0.661	0.661	0.574
Rough and slippery	1.38	0.828	0.993	1.104	1.242	1.104	1.104	1.104	1.048	0.552	0.828	1.104	0.552
Soft and hard	0.277	0.198	0.198	0.264	0.211	0.211	0.198	0.211	0.33	0.158	0.211	0.264	0.198
warmth and cold	1.756	1.580	1.317	1.668	0.878	0.790	0.702	0.570	2.107	1.756	1.668	1.317	1.580

Fig. 7-13 Furniture and decoration materials tactile comfort index score

7.2.4 Summary

In this chapter, subjective evaluation methods (scoring method) were employed to quantify the tactile perceptions of different materials among the elderly, ultimately obtaining subjective evaluation results for the tactile comfort of materials in their living spaces.

Evaluation criteria are key factors in the evaluation system. Through literature research and expert questionnaires, five tactile comfort evaluation criteria and their corresponding descriptive words were determined. These criteria include warmth-coolness sensation, softness-hardness sensation, roughness-smoothness sensation, concavity-convexity sensation, and resilience sensation. The criteria were weighted using the Analytic Hierarchy Process (AHP). Since the elderly have different ways of interacting with materials, the weighting results for the criteria differ.

Subjective evaluation experiments were designed, and material samples were selected based on the results of Chapter 2's survey to provide tactile experiences. To reduce the difficulty of evaluation for the elderly, a 5-point scoring method was employed while ensuring the accuracy of the evaluation results. During the experimental process, attention was given to limiting experimental conditions and controlling irrelevant variables.

Finally, scores for each criterion and an overall score for the tactile comfort of the material samples were obtained. Based on these scores, the degree of tactile comfort for materials was classified into three categories, corresponding to different materials.

7.3 Physiological Feedback Validation of Tactile Comfort in Elderly Living Spaces

According to Shahat's "Three-Factor" theory, it can be understood that the environment and the physiological and psychological aspects of individuals are interconnected and mutually influencing. Zhu Jinfu proposed in the book "Medical Psychology" that comfort is not only an objective physiological need but also a subjective experience. It is the perception and psychophysical changes that individuals undergo in response to the external environment and an expression of their attitude towards external stimuli. In this study, considering the physiological and psychological changes experienced by the elderly when interacting with materials, a physiological feedback experiment was conducted to explore the effects of different material surface characteristics on elderly individuals' physiological indicators and the underlying connection between physiology and psychology.

7.3.1 Experimental Design for Physiological Feedback of Tactile Comfort in Materials

7.3.1.1 Experimental Participants and Material Samples

Due to limitations in experiment time and conditions, a total of 30 participants were selected for the physiological feedback validation experiment of tactile comfort. All participants were elderly individuals between the ages of 60 and 74, with an average age of 68.8. Among them, there were 16 male participants and 14 female participants. The age distribution and participant count are shown in Fig. 7-14. All participants were self-sufficient elderly individuals with good physical health, without hypertension, cardiovascular diseases, or other endocrine disorders. Before the experiment, participants were required to have a good night's sleep and have a meal before the test. There should be no vigorous exercise or significant emotional fluctuations prior to the experiment. All participants were thoroughly informed about the purpose and requirements of the experiment, ensuring their full understanding and cooperation. They followed the instructions of the experimenters strictly. No food or beverages containing alcohol or caffeine were allowed during the experiment. After studying and analyzing the experimental data, four samples were eliminated, and the results of the remaining 26 participants were considered as valid samples.

Please refer to section 3.2.1 for details on the experimental material samples.

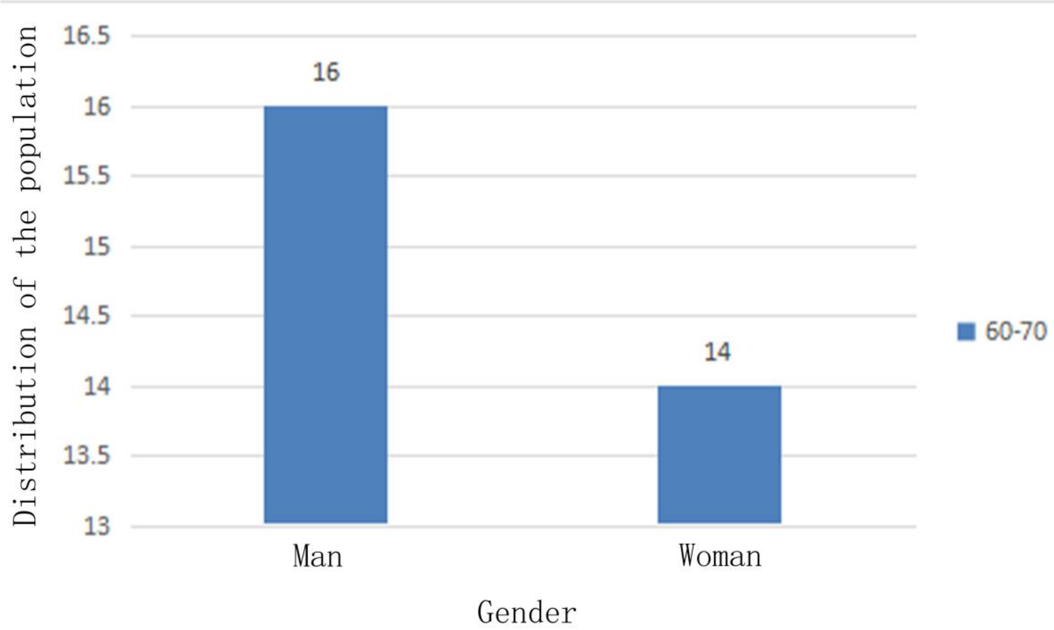


Fig. 7-14 The number of particidants in the test was distributed

7.3.1.2 Measurement Instruments and Accessories

This study utilized the Ergo LAB Human-Machine Environment Synchronization Platform to collect physiological data of the elderly during their activities. This platform captures physiological indicators such as heart rate, electrodermal activity (EDA), and skin temperature (SKT), and further analyzes variables such as heart rate variability (HRV), EDA, and SKT changes. The Ergo LAB platform, developed by Beijing Jinfacompany, is widely used in ergonomics and behavioral studies. It enables synchronous data collection and analysis in various aspects of human-machine-environment interactions. The system has also obtained international certifications in Europe, providing excellent technical support and solutions for human factors engineering research.

The most notable advantage of this platform is its wireless transmission capability, which allows for wearable experiments. It is suitable for real-field research and eliminates the need for participants to wear complex measurement devices, making data collection more convenient. It is currently the only wearable human-machine-environment research platform worldwide. With the Ergo LAB platform, elderly participants can freely experience and perceive tactile sensations while touching or stepping on materials, forgetting any discomfort or inconvenience caused by the measurement devices. Moreover, all wearable devices can simultaneously collect and analyze information, such as simultaneous measurement of brainwaves, electrocardiography, skin temperature, and heart rate[14].

The Ergo LAB Synchronization Platform consists of two parts: the detection part and the analysis part. The detection part serves as the hardware of the platform, while the analysis part represents the software component. The detection part includes wireless physiological signal sensors and signal transmission lines, which adjust the collected signals and ultimately transmit them to a computer for data processing. The analysis processing system is composed of Ergo Lab software, which is responsible for storing, displaying, and processing the collected biological signals. The software system facilitates easy acquisition and analysis of biological signals. Fig. 7-15 shows the Ergo Lab software interface for information acquisition. The detection part and the analysis part work in coordination to achieve data collection, recording, and processing.

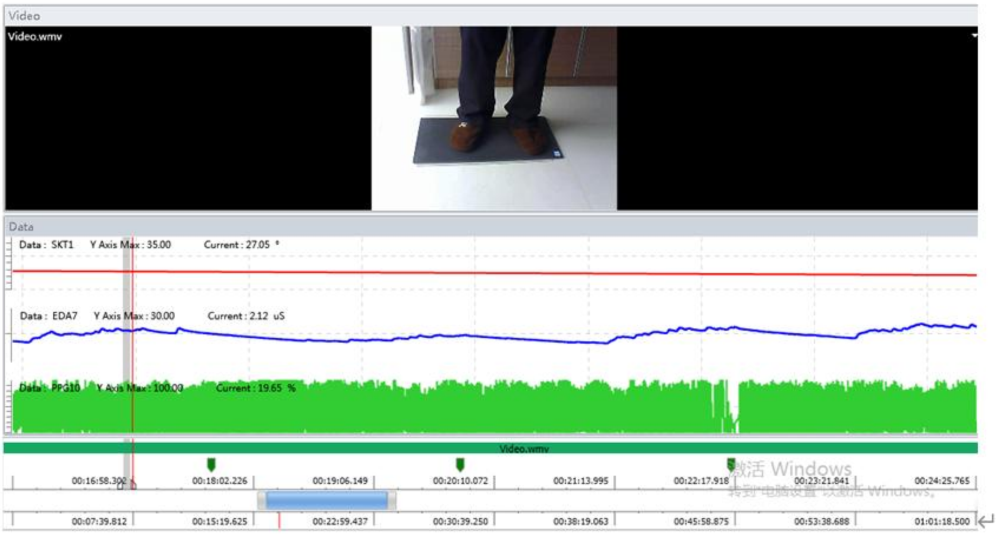


Fig. 7-15 The number of particidants in the test was distributed

In addition to the Ergo LAB photoplethysmography (PPG) and signal receiver, the experiment was equipped with a behavioral camera. The camera was used to capture participants' behavioral information, including movements, postures, motions, and positions during the experiment. In the later stages of the experiment, segments of the waveform data were extracted based on the recorded behavior videos for data analysis. The specific usage of the instruments is described in the experimental procedure. Please refer to Table 7-39 for the main instruments and accessories used in the experiment.

Table 7- 39 Laboratory equipment and spare parts

laboratory apparatus	illustration	effect
Photoplethysmography PPG		Measure human pulse signal
signal receiver		Transfer the collected physiological information of the subjects to the computer

behavior camera		Collecting Behavioral Data of Subjects

Fig. 7-16 Lead method of optical

7.3.1.3 Experimental Method and Procedure

(1) Experimental Method

The experiment was conducted in a room with a temperature of 22 ℃± 1 ℃ and a humidity of 27 ± 2%. Each tester needs to adapt to the experimental environment in the room for a period of time before the experiment to ensure they are accustomed to the experimental environment; The experiment was conducted in a completely quiet environment; The photoelectric capacitance pulse wireless sensor adopts limb lead method, as shown in Fig. 7-16. Firstly, wipe the earlobe of the elderly person clean, and ask the tester to gently rub the earlobe with their fingers to avoid data deviation caused by low earlobe temperature. Secondly, accurately and gently clip the human lead onto the earlobe of the elderly person. Finally, place the optical capacitance pulse wireless sensor in the clothing pocket through a lead wire to avoid random oscillation.

(2) Determination of Experimental Time

Based on relevant studies on the characteristics of physiological changes during hand contact with materials, it is known that significant changes in physiological indicators often occur within 0-30 seconds after material contact. Afterward, the human body system actively regulates itself, and the physiological indicators eventually stabilize at a certain value. Therefore, the 60 seconds after material contact is crucial, and it is important to focus on analyzing the psychological and physiological changes during this period.

Based on the above analysis, considering the experimental conditions and the participants' physical condition, the duration of the tactile experience for each material sample in this study was set at 2 minutes.

(3) Design of Subjective Questionnaire

In addition to collecting physiological feedback data, this experiment also requires collecting participants' subjective evaluations of the tactile comfort indicators for different material samples. The purpose is to provide complementary analysis to the physiological feedback results and further determine the impact of different material characteristics on the participants. Based on the experiment's objectives, this study chose the Semantic Differential (SD) analysis method for subjective evaluation. The same evaluation indicators as in section 3.1.1 were selected, and opposite language descriptors were determined, such as smooth-rough, soft-hard, etc. These descriptors were placed at the two ends of the rating scale in the SD table, with five rating levels corresponding to each scale. The specific layout is shown in Fig. 7-17, and the detailed questionnaire is provided in the appendix.

Subjective Evaluation Questionnaire for Tactile Comfort of Building Materials - Flooring Materials

gender: age: origin: occupation:

Please rate the comfort indicators of the five aspects of the material sample you have just come into contact with according to your real feelings, and fill in the score in the corresponding position of each sample in the form。

Sample name and number / Evaluation indicator score	1	2	3	4	5	6	7	8	9	10	11	12	13
	Glazed tile	Matte glaze tile	Bricks thro-ughout	Long pile carpets	Carpet with short pile	Hard-wood floors	Parquet	Laminate flooring	Cork floors	Bamboo floor	Floor leather	Plain plastic floor	Striped plastic floor
warmth and cold: 1 cold, 2 Colder, 3 So so, 4 Warmer, 5 Warm													

Fig. 7-17 Material tactile comfort subjective evaluation questionnaire

(4) Experimental Procedure

In this study, the experimental procedure is divided into two phases. The detailed process is outlined in Table 7-40.

Phase 1: Firstly, the participant is asked to sit comfortably on a chair and rest for 15 minutes. After 15 minutes, the participant is instructed to stand naturally, relax their muscles, and remain quiet. The wireless photoplethysmography (PPG) sensor is then connected to the participant. Once everything is ready, data collection begins, and physiological signals are continuously recorded for 5 minutes. This data serves as the baseline or reference value. Next, the participant is asked to stand on the sample with both feet and maintain a stationary position for 1 minute. Subsequently, the participant simulates actions such as friction, sliding, and stepping, as they would in normal usage, for 1 minute, while physiological indicators are recorded and displayed on waveforms. After experiencing each material sample, the participant is asked to honestly complete the subjective questionnaire on tactile comfort, providing ratings for the respective indicators of the material samples. This process is repeated for each sample(Fig. 7-18).

Fig. 7-18 Material tactile comfort test

Phase 2: Firstly, the wireless photoplethysmography (PPG) sensor is disconnected from the participant, and the participant is instructed to sit and rest for 15 minutes. After 15 minutes, the participant is asked to sit naturally, relax their muscles, and remain quiet. The PPG sensor is then reconnected to the participant. Once everything is ready, data collection begins, and physiological signals are continuously recorded for 5 minutes to obtain baseline data. Next, the participant is asked to place their hand on the material sample and maintain a stationary position for 1 minute. Subsequently, they are instructed to perform actions such as touching and sliding on the material sample for 1 minute, while physiological indicators are recorded and displayed on waveforms. After experiencing each material sample, the participant is asked to honestly complete the subjective questionnaire on tactile comfort while resting, providing ratings for the respective indicators of the material samples. This process is repeated for each sample(Fig. 7-19).

Fig. 7-19 Material tactile comfort test

Due to the relatively large number of material samples and to avoid the potential impact of physical fatigue on the collection of physiological indicators, the order in which different elderly participants come into contact with the materials was varied in the experiment. Specifically, half of the participants started the experiment from Phase 2, while the other half started from Phase 1. This approach ensures that the effects of fatigue are evenly distributed across the participants. In the end, the results are averaged to obtain a comprehensive outcome.

Table 7- 40 Test process

experimental stage	duration	experiment procedure
	0-15min	Ask the tester to wear the slippers prepared in advance and sit quietly on the chair for 15 minutes to adapt to the environment;
	15-20min	After 5 minutes, connect the photoelectric plethysmometer wireless sensor with the tester, ask the tester to maintain a natural standing

(1)		posture, relax the muscles, and be quiet, collect the ECG data (5 minutes) without touching the material sample, obtain the basic data, and rest for 1 minute;
	21-58min	Place the ground sample material on the non-slip thin mat, ask the tester to stand on the sample with both feet at the same time, stand still for 1 minute, and then start to alternately rub, step on, slide and other actions with both feet for 1 minute, and experience a total of 2 minutes for each sample;
(2)	15min	Take a 1-minute break between samples, and fill in the corresponding subjective questionnaire during the break;
	15-20min	Repeat the above operations until all sample materials are completed;
	21-72min	Disconnect the photoelectric volume pulse wireless sensor from the tester, sit quietly and rest for 15 minutes;

7.3.2 Determination of Physiological Indicators and Analysis Methods

7.3.2.1 Selection of Physiological Indicators and their Physiological Significance

(1) Heart rate variability analysis method determination

Time domain analysis, frequency domain analysis and nonlinear analysis are all subordinate categories of HRV analysis methods. ① Time-domain analysis is widely accepted due to its simplicity, intuitive interpretation of indicators, and is often used to describe the overall magnitude of HRV. It can be used for short-term (e.g., 5 minutes) and long-term (e.g., 24 hours) detection and analysis. ②Frequency-domain analysis describes the distribution of energy in different frequency bands of the complex heart rate fluctuation signal. It separates the effects of various physiological factors and allows for a detailed analysis of the activity levels and balance changes of the sympathetic and parasympathetic nervous systems. ③Nonlinear analysis is an approach that uses nonlinear dynamics to study HRV, and there are many methods available. However, they involve complex mathematical problems.

This experiment uses short-term signals and uses the building materials of the elderly’s living space as independent variables to preliminarily study the overall size of HRV when the elderly are exposed to different building materials. Furthermore, nonlinear analysis requires large sample sizes and long-term studies for validation. Therefore, in this study, the time-domain analysis method was adopted, and the following time-domain indicators were selected: AVHR, AVNN, SDNN, RMSDD, PNN50. These indicators were used to determine the tactile comfort of the materials based on the overall HRV of the elderly. The meanings and roles of the time-domain analysis indicators of HRV are described in Table 7-41.

Table 7- 41 The meaning and function of HRV time domain analysis index

index	unit	Meaning and function
AVNN	ms	Indicates the mean value of all N-N intervals (or cardiac intervals) during the whole recording period, which can reflect the average level of heart rate variability

AVHR	bpm	Indicates the average heart rate value of the ECG signal
SDNN	ms	Indicates the standard deviation of all N-N intervals (or cardiac intervals) during the entire recording, which measures the overall HRV size
RMSSD	ms	Indicates the average value between adjacent RR intervals, which can reflect the size of the fast-changing components of the heart rate and can also be used to measure the role of the parasympathetic nervous system on heart rate regulation
PNN50	%	Represents the percentage of the number of adjacent heartbeats with a difference greater than 50ms in the total number of heartbeats

7.2.3.2 Statistical Methods

In this study, a comparison was made between the physiological indicator data before and after exposure to the material samples. The differences in physiological indicators for different material samples were calculated by taking the difference between the two sets of data.

General Statistical Analysis

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Standard deviation is the most commonly used measure to indicate the degree of dispersion of variable values. The calculation of the sample standard deviation is as follows:

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})^2}$$

In the formula, n represents the sample size, and Xi represents a sample from the population. For two sets of statistical data with the same unit and similar sample means, the one with a larger standard deviation has a greater degree of dispersion, while the one with a smaller standard deviation has a smaller degree of dispersion.

ANOVA (Analysis of Variance) One-Way ANOVA

This experiment meets the basic conditions of independent groups and the comparison of at least three independent groups. Therefore, the one-way analysis of variance method was selected for statistical analysis. In this study, the significance standard was set to 0.05, that is, when $P<0.05$, there is a significant difference between the experimental groups, and when $P>0.05$, there is no significant difference between the experimental groups.

7.3.3 Inspection and analysis of raw material tactile comfort results

7.3.3.1 Results and Analysis of Ground Material Verification

(1) Significance Analysis of Indicators

Intuitive data were obtained through the collection of physiological indicators from elderly participants. Table 7-42 presents the results of one-way ANOVA, demonstrating the significant influence of varying material samples on time-domain indicators of HRV in elderly individuals, as indicated by the significance probabilities. Notably, AVNN, AVHR, and SDNN time-domain indicators all exhibited substantial sensitivity to stimuli from different materials.

Hence, in analyzing the significant influence of ground materials on the time-domain indicators of HRV in elderly individuals, the study utilizes AVNN, AVHR, and SDNN as the foundation.

Table 7- 42 ANOVA analysis of time domain index of ground material

source of variance	dependent variable	sum of square	df	mean square	F	prominence
Exposure to different floor materials	AVNN	22614.243	11	2055.840	2.219	0.032
	AVHR	198.457	11	18.042	2.016	0.045
	SDNN	116.746	11	10.613	2.455	0.022
	RMSDD	276.455	11	25.132	0.162	0.912
	PNN50	116.776	11	10.616	0.410	0.899

(2) Results and Analysis of Indicator Verification

Table 7-43 presents the analysis results of the time-domain indicators in elderly individuals after coming into contact with different ground material samples. Fig. 7-20-Fig. 7-22 show the average line graphs of the differences (relative to the baseline values of physiological indicators before exposure to material samples) in AVNN, AVHR, and SDNN. These graphs reflect the magnitude of the changes in physiological indicators before and after elderly individuals come into contact with material samples.

Table 7- 43 Results of -HRV time domain analysis of different ground materials

serial number	building materials	AVNN/ms	AVHR/time. min^{-1}	SDNN/ms
0	Reference value	811.29	74.75	32.519
1	glazed tile	804.65	75.71	32.15
2	Matt glazed tile	801.56	75.87	32.08
3	Whole body brick	769.62	79.17	29.928
4	plush carpet	778.87	77.85	31.448
5	low pile carpet	780.79	77.43	31.668
6	wooden floor	810.46	75	32.338
7	Parquet	805.17	75.34	32.2
8	Laminate flooring	792.99	76.67	31.838
9	cork floor	802.67	75.75	32.1
10	bamboo floor	798.59	76.5	31.878
11	floor leather	774.5	78.17	30.558
12	Plain vinyl flooring	806.21	75.2	32.2

13	Striped vinyl flooring	762.61	80.67	28.69

According to the average deviation degree of the three physiological indicators from the baseline values, calculated based on the average values of the physiological indicator differences, the impact levels of different material samples on elderly individuals can be ranked as follows (as shown in Fig. 7-23): Solid wood flooring < Plain PVC flooring < Solid wood composite flooring < Cork flooring < Glazed tiles < Matte glazed tiles < Bamboo flooring < Laminate flooring < Short pile carpet < Long pile carpet < Floor leather < Full-body tiles < Striped PVC flooring.

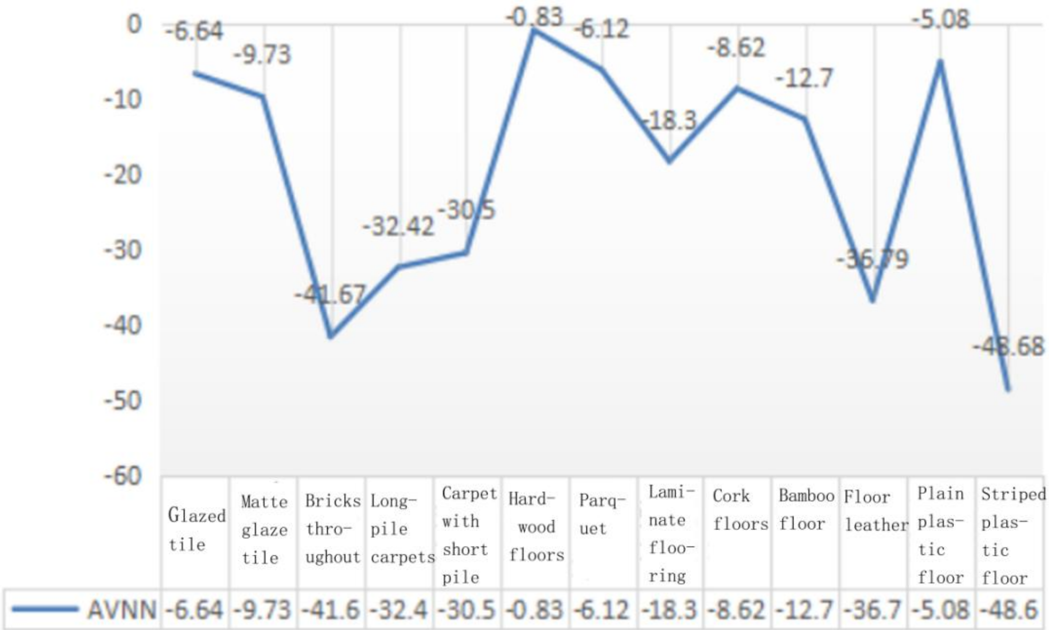


Fig. 7-20 Relative to the state of the material is not touched,the average value of AVNN difference line chart

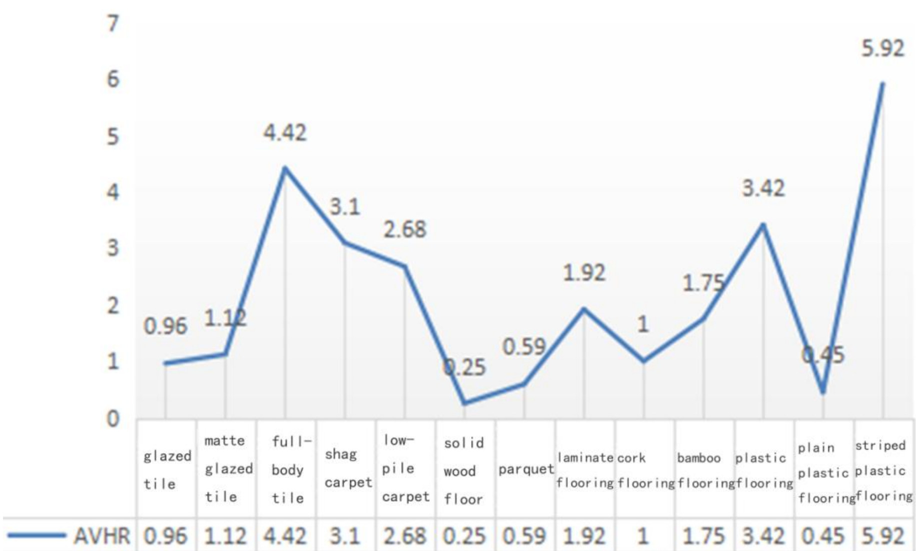


Fig. 7-21 Relative to the state of the material is not touched the average value of AVHR

difference line chart

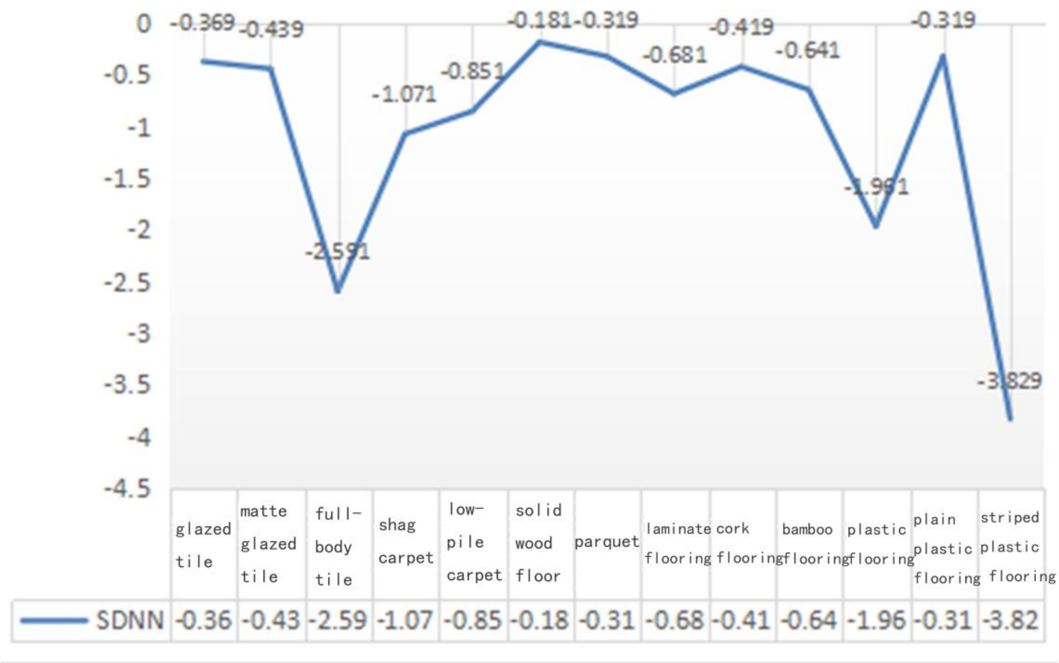


Fig. 7-22 Relative to the state of the material is not touched,the average value of SDNN difference line chart

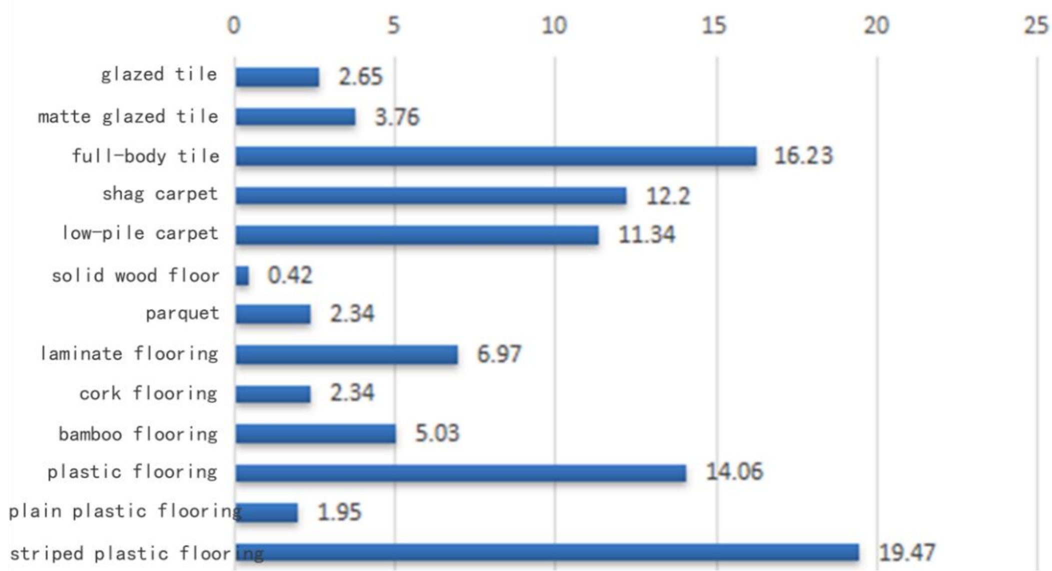


Fig. 7-23 Mean deviation of physiological index under different materials

7.3.3.2 Results and Analysis of Wall Material Verification

(1) Significance Analysis of Indicators

Intuitive data were obtained by collecting physiological indicators from elderly participants. Table 7-44 lists the results of one-way analysis of variance on the impact of different material samples on time domain indicators of HRV in the elderly. The significance probabilities reveal that the time-domain indicators AVNN, AVHR, and SDNN are significantly influenced by stimuli from various materials. Hence, in the analysis of the significant influence of wall materials on the time-domain indicators of HRV in elderly individuals, the study takes AVNN, AVHR, and SDNN as its foundation..

Table 7- 44 Time domain index ANOVA analysis of wall materials

source of variance	dependent variable	sum of square	df	mean square	F	prominence
Exposure to different wall materials	AVNN	12539.667	6	2089.945	2.256	0.033
	AVHR	111.835	6	18.639	2.305	0.020
	SDNN	40.747	6	6.791	3.903	0.007
	RMSDD	195.741	6	32.624	0.492	0.809
	PNN50	95.387	6	15.898	0.827	0.558

(2) Results and Analysis of Indicator Verification

Table 7-45 presents the analysis results of the time-domain indicators in elderly individuals after coming into contact with different wall material samples. Fig. 7-24-Fig. 7-26 show the average line graphs of the differences (relative to the baseline values of physiological indicators before exposure to material samples) in AVNN, AVHR, and SDNN. These graphs reflect the magnitude of the changes in physiological indicators before and after elderly individuals come into contact with material samples.

Based on the average deviation degree of the three physiological indicators from the baseline values, calculated from the average values of the physiological indicator differences, the levels of impact can be ranked as follows (as shown in Fig. 7-27): Pure smooth wallpaper < Regular striped wallpaper < Glazed tiles < Rough wallpaper < Matte glazed tiles < Latex paint < Mosaic < Diatomaceous earth.

Table 7- 45 Results of -HRV time domain analysis of different wall materials

serial number	building materials	AVNN/ms	AVHR/time. min^{-1}	SDNN/ms
0	Reference value	837.87	73	24.39
I	Tabby Smooth Wallpaper	833.57	73.66	23.13
II	rough wallpaper	822.81	75.17	20.8
III	Regular stripes wallpaper	831.65	74.33	22.53
IV	glazed tile	827.15	73.14	24.07
V	Matt glazed tile	818.66	74.67	22.75
VI	mosaic	812.88	75.6	22.46
VII	latex paint	816.12	75.12	22.67
VIII	Diatom mud	810.53	75.73	22.24

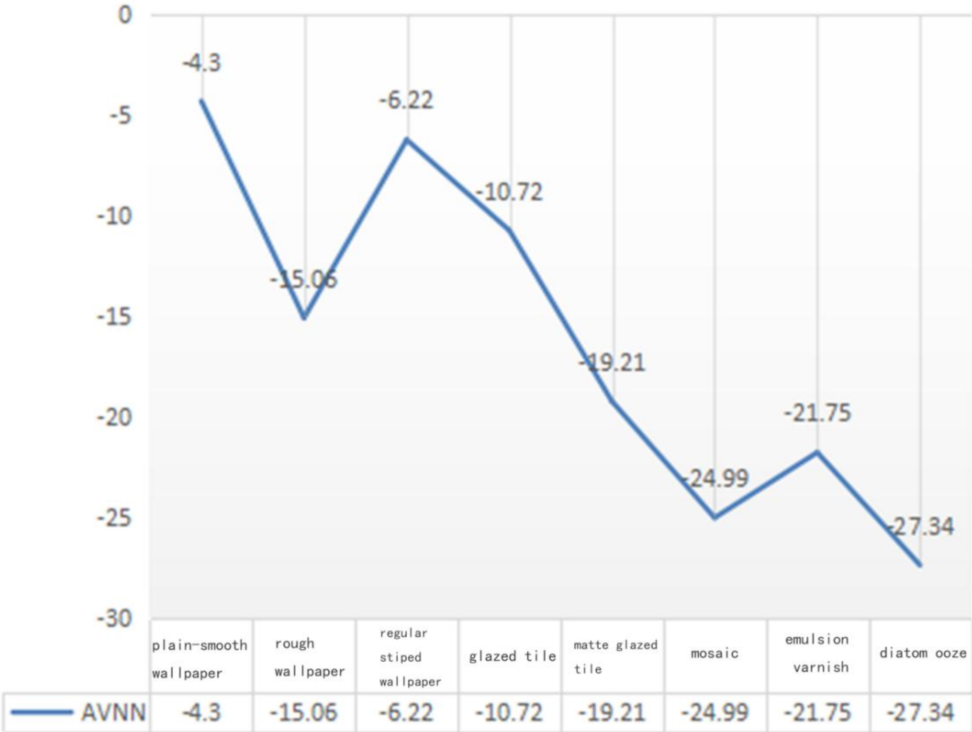


Fig. 7-24 Relative to the state of the building materials the average value of the AVNN difference

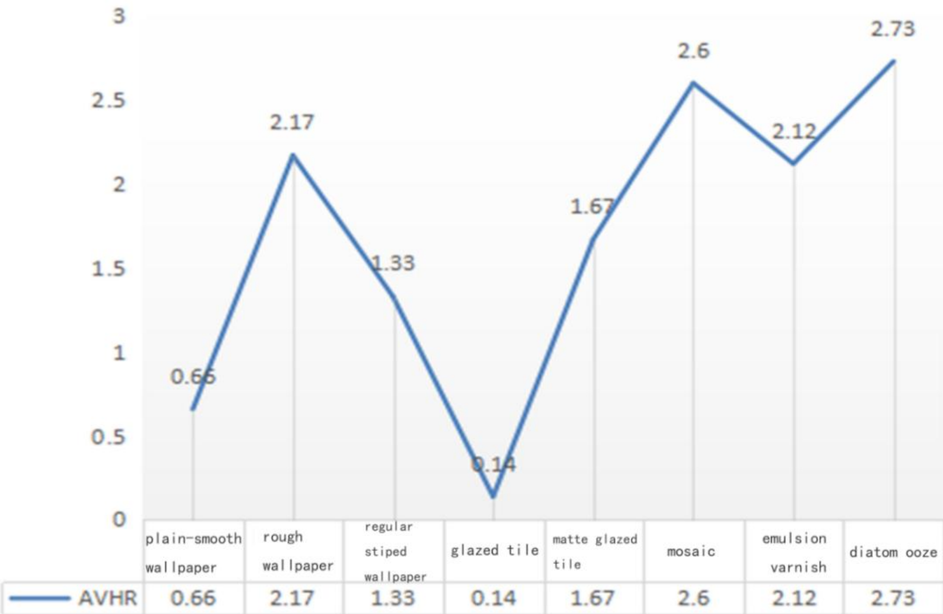


Fig. 7-25 Relative to the state of the building materials,the average value of the AVHR difference

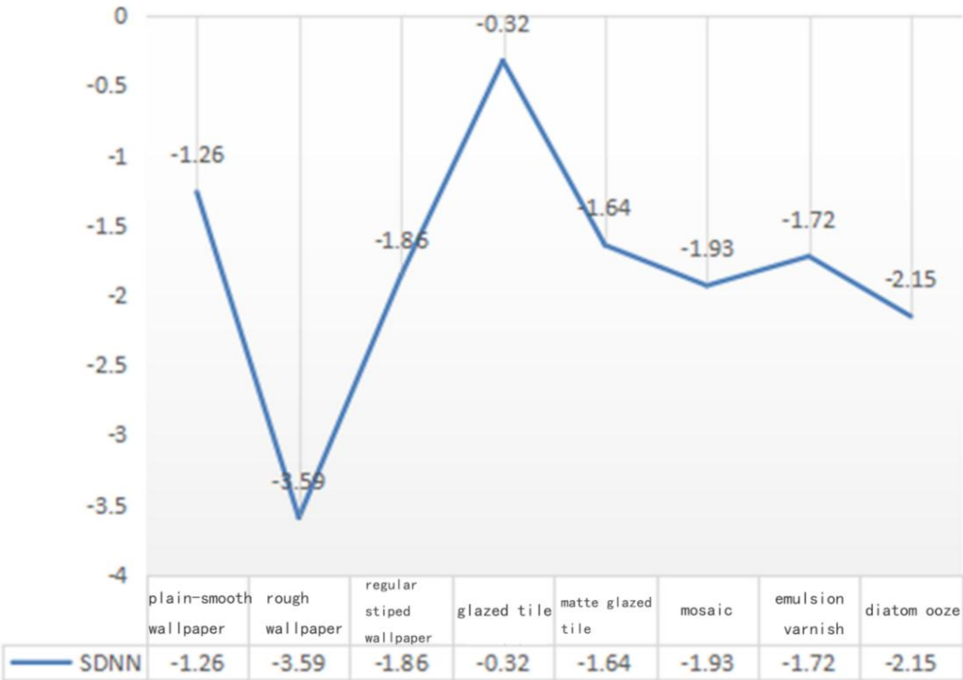


Fig. 7-26 Relative to the state of the building materials,the average value of the SDNN difference

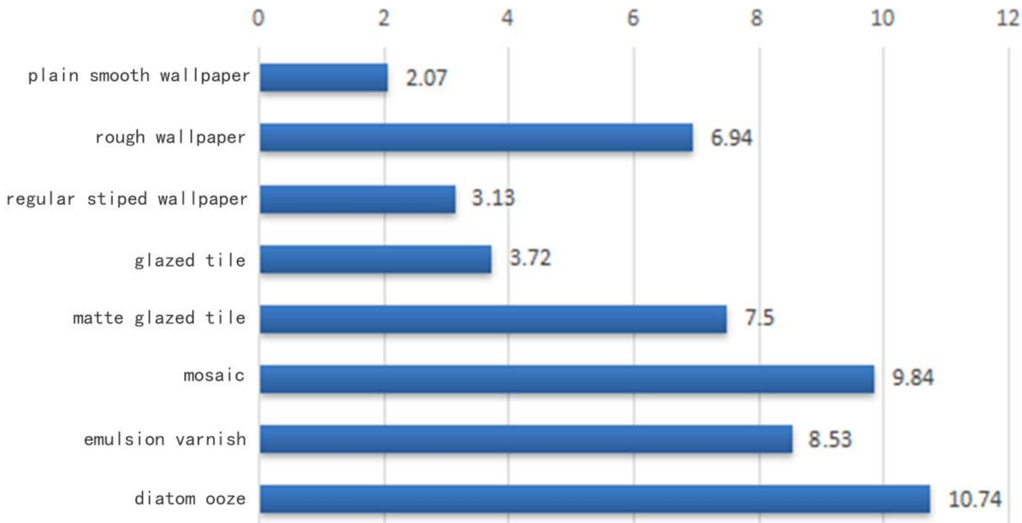


Fig. 7-27 Mean deviation of physiological index under different materials

7.3.3.3 Results and Analysis of Furniture and Decorative Material Verification

(1) Significance Analysis of Indicators

The collection of physiological indicators from elderly participants yielded intuitive data. Table 7-46 displays the results of one-way ANOVA assessing the influence of various material samples on the time-domain indicators of HRV in elderly individuals. The significance probabilities indicate that different material stimuli exert a noteworthy influence on the time-domain indicators AVNN, AVHR, and SDNN. Hence, in examining the substantial influence of furniture and decorative materials on HRV's time domain indicators in the elderly, this study employs AVNN, AVHR, and SDNN as its foundation.

Table 7- 46 Time domain index ANOVA analysis of furniture and accessories

source of variance	dependent variable	sum of square	df	mean square	F	prominence
Exposure to different furniture and accessories materials	AVNN	20009.133	10	2000.913	2.292	0.043
	AVHR	134.682	10	13.468	3.264	0.009
	SDNN	407.109	10	40.711	2.556	0.032
	RMSDD	569.066	10	56.907	0.553	0.844
	PNN50	433.952	10	43.395	1.036	0.426

(2) Results and Analysis of Indicator Verification

Table 7-47 presents the analysis results of the time-domain indicators in elderly individuals after coming into contact with different furniture and decorative material samples. Fig. 7-28-Fig. 7-30 show the average line graphs of the differences (relative to the baseline values of physiological indicators before exposure to material samples) in AVNN, AVHR, and SDNN. These graphs reflect the magnitude of the changes in physiological indicators before and after elderly individuals come into contact with material samples.

Table 7- 47 Analysis results of -HRV time domain index of furniture and decoration materials

serial number	building materials	AVNN/ms	AVHR/time. min^{-1}	SDNN/ms
0	Reference value	837.87	73	24.39
A	wood	828.58	73.72	25.37
B	rattan	825.11	74.07	26.14
C	plastic	824.85	74.14	26.4
D	rubber	850.21	74	26.14
E	ceramics	855.19	74.44	27.8
F	Glass	856.88	74.62	28.24
G	stone	818.06	75	28.54
H	Metal	861.64	75.8	29.56
I	cotton	841.89	73.43	24.47
J	numb	853.5	74.25	27.36
K	leather	826.35	73.98	25.64
L	silk	849.77	73.86	25.64
M	yarn	823.13	74.23	26.51

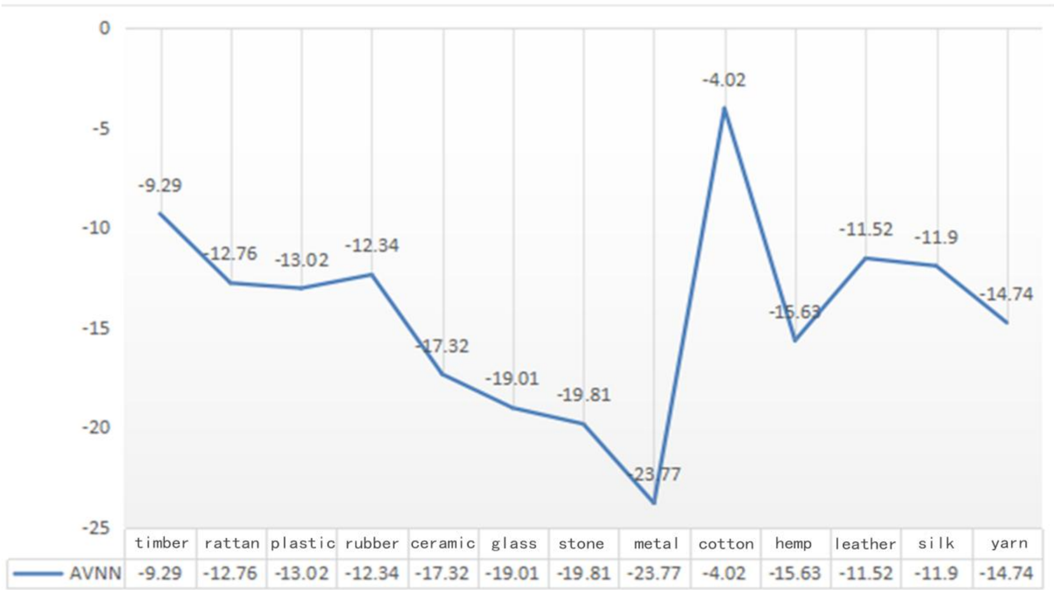


Fig. 7-28 Relative to the state of the material is not touched,the average value of AVNN difference line chart

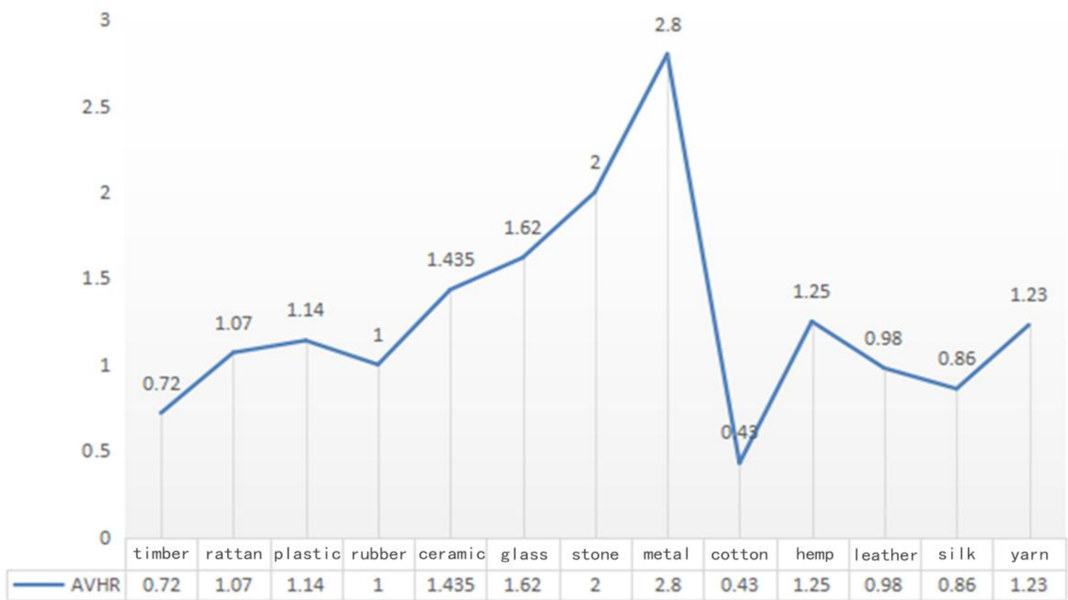


Fig. 7-29 Relative to the state of the material is not touched,the average value of AVHR difference line chart

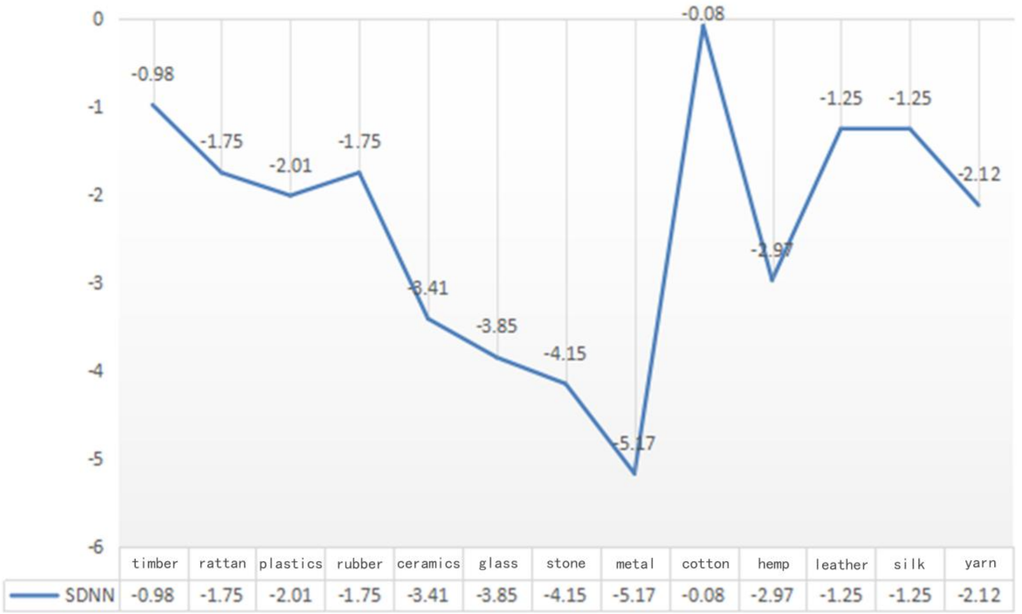


Fig. 7-30 Relative to the state of the material is not touched,the average value of SDNN difference line chart

According to the average deviation values of the physiological indicator differences, as calculated from the data, the ranking of the impact levels of different materials on the three physiological indicators relative to the baseline values can be seen in Fig. 7-31. The order of impact levels is as follows: cotton < wood < silk < leather < rubber < rattan < plastic < yarn < hemp < ceramic < glass < stone < metal.

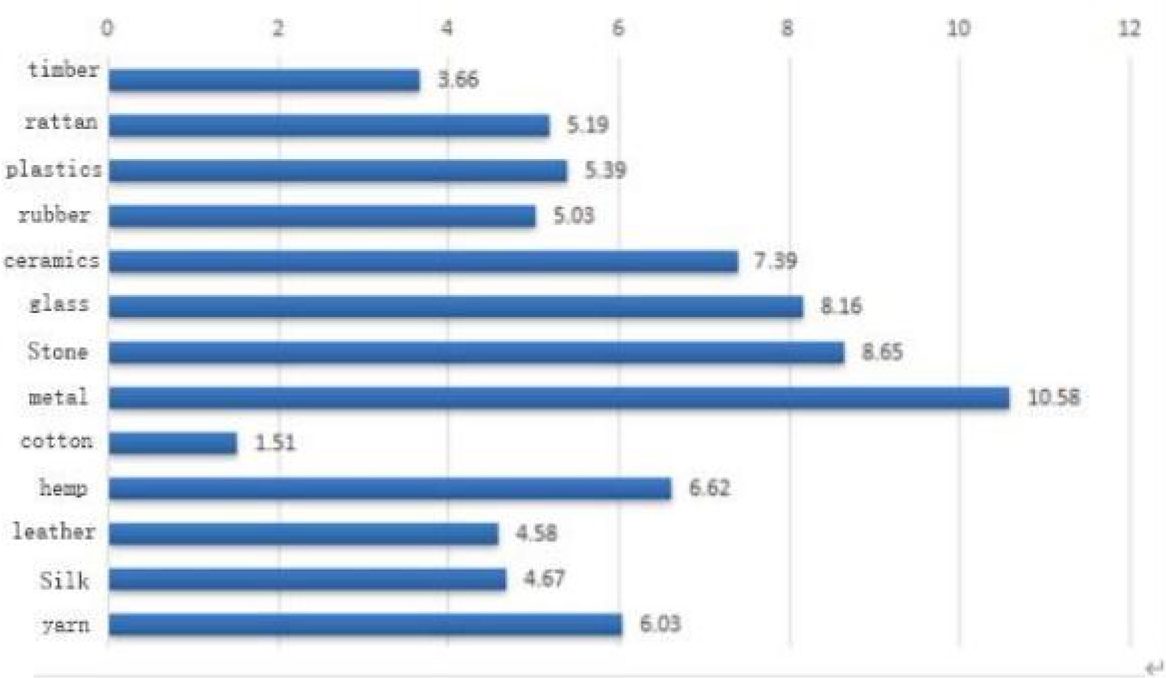


Fig. 7-31 Mean deviation of physiological index under different materials

7.3.4 Summary

An objective evaluation method utilizing physiological feedback experiments was applied in this chapter. Heart rate variability (HRV), which is representative of physiological changes, was selected as the reference index and analyzed using time-domain analysis. Photoplethysmography (PPG) was used to collect physiological index information such as average NN intervals (AVNN), average heart rate (AVHR), and standard deviation of NN intervals (SDNN) to obtain HRV time-domain index results for different materials[15]. One-way analysis of variance (ANOVA) was performed on the data results to determine the effective indices: AVNN, AVHR, and SDNN. Physiological index data of elderly individuals in contact with different materials were collected to compare the degree of deviation of physiological indicators from the baseline state, thus clarifying the extent to which different materials affect the physiology of elderly individuals.

7.4 Comparative Analysis of Subjective and Objective Evaluation Results for Material Tactile Comfort

Currently, for the evaluation of material tactile comfort, there are typically two methods used: subjective evaluation and objective evaluation. In the evaluation process, it is common to choose one method, either subjective or objective, to assess the subjects' experiences. However, this approach can lead to certain issues, such as: (1) Choosing only one evaluation method may result in less persuasive and less reliable outcomes; (2) When evaluating materials, the final choice of evaluation method can be influenced by the evaluators, and conducting evaluations using different methods may yield inconsistent results, making it difficult to determine the superiority or inferiority of the materials; (3) Using only one method for evaluation has its limitations.

7.4.1 Comparative Analysis of Subjective and Objective Evaluation Results for Ground Materials

7.4.1.1 Comparative Analysis of Subjective and Objective Evaluation Results for Ground Materials

To facilitate the analysis of evaluation results for tactile comfort indicators of various sample materials, the sample materials were divided into three groups based on material categories. A comparative analysis was then conducted on the subjective and objective evaluation results for each group. The specific grouping is shown in Table 7-48.

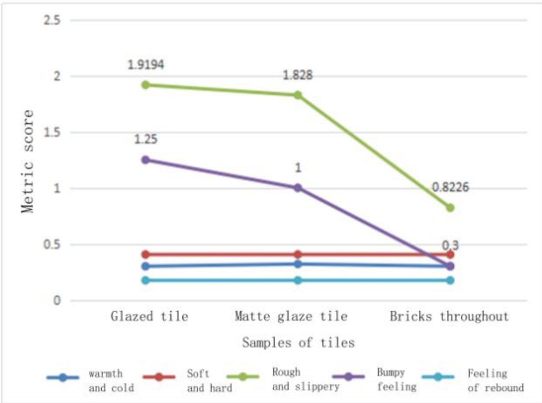
Table 7- 48 Surface material sample grouping

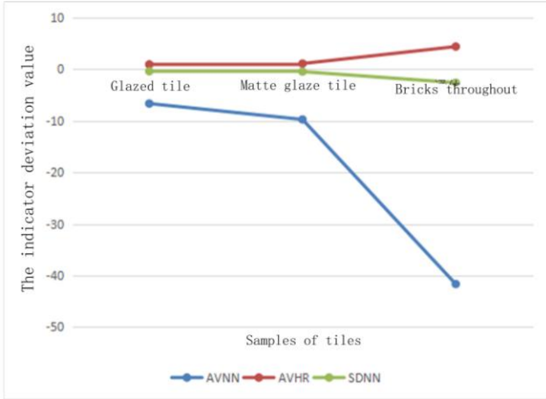
group number	Material category	Material composition
1	ceramic tile	Glazed tiles, matte glazed tiles, whole body tiles
2	carpet	Long-pile carpet, short-pile carpet
3	floor	Solid wood flooring, parquet flooring, laminate flooring, cork flooring bamboo flooring, floor leather, plain vinyl flooring, striped vinyl flooring

(1) Comparative Evaluation Results for Tiles

Table 7- 49 Comparison of the evaluation results and outlook of ground materials

Subjective scoring results	Evaluation results of physiological feedback experiment





Based on the comparative analysis of subjective and objective evaluation results in Table 7-49, the following patterns can be observed:

①When evaluating the tactile comfort of the sample tiles using subjective ratings, the differences in comfort scores are mainly attributed to the surface smoothness and roughness. The comfort ranking is as follows: glazed tiles > matte glazed tiles > full-body tiles. Specifically, for the roughness sensation score: glazed tiles scored 1.92, matte glazed tiles scored 1.83, and full-body tiles scored 0.82; for the roughness sensation score: glazed tiles scored 1.25, matte glazed tiles scored 1, and full-body tiles scored 0.3.

②In the physiological feedback evaluation results, the deviation values are as follows: glazed tiles - 2.65, matte glazed tiles - 3.76, full-body tiles - 16.23. The parameters AVHR increase, while AVNN and SDNN decrease, indicating an increasing deviation from the baseline values. This suggests a greater impact on the physiological state of the elderly, leading to increased heart rate, increased myocardial blood supply demand, and increased cardiac workload.

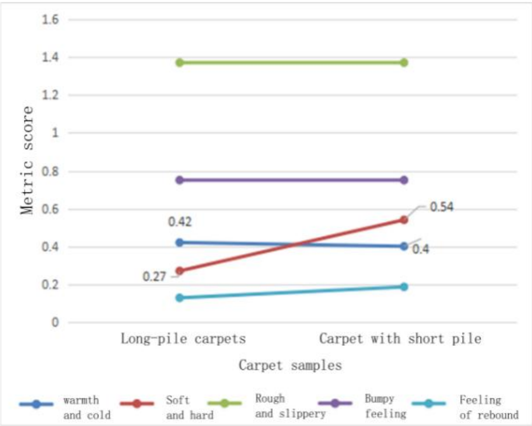
③In terms of the subjective and objective evaluation results, there is relatively little difference between glazed tiles and matte glazed tiles, indicating a good level of comfort. Full-body tiles, on the other hand, have lower tactile comfort. The subjective and objective evaluation results tend to be consistent.

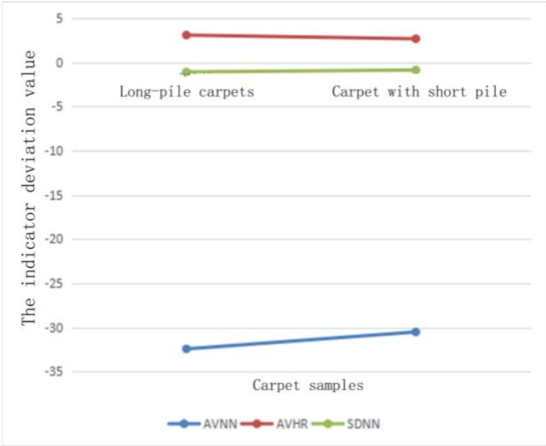
④The roughness of the tile surfaces follows the order: glazed tiles < matte glazed tiles < full-body tiles. Additionally, in the evaluation of roughness sensation using the SD method, glazed tiles scored 1.8, indicating a smoother surface, matte glazed tiles scored -1, indicating a relatively rough surface, and full-body tiles scored -1.9, indicating a coarser surface. As the roughness of the tile surface increases, the tactile comfort for the elderly decreases.

(2) Comparative Evaluation Results for Carpets

Table 7- 50 Comparison of the evaluation results of subjective and objective view of the carpet

Subjective scoring results	Evaluation results of physiological feedback experiment





From the comparative analysis of the subjective and objective evaluation results in Table 7-50, we can know the following rules:

①Soft comfort and rebound comfort were the main manifestations of the difference in tactile comfort between long-pile and short-pile carpets in the subjective evaluations, and thus the results of the comparative subjective evaluations indicated that the comfort scores showed a gradual tendency to improve. The scores for softness comfort are 0.27 for long pile carpet and 0.54 for short pile carpet, while the scores for resilience comfort are 0.42 for long pile carpet and 0.4 for short pile carpet.

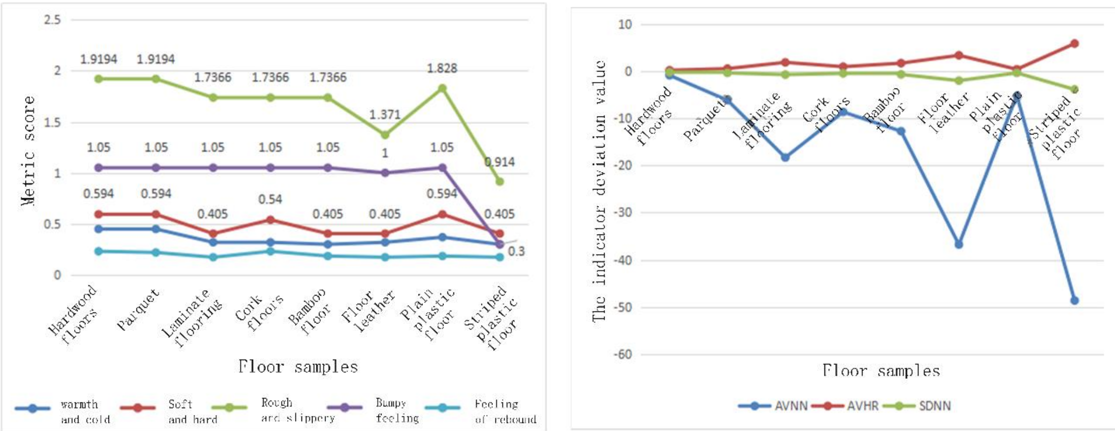
②In the physiological feedback evaluation results, there is a decrease in AVHR (average heart rate), an increase in AVNN (average NN interval), and an increase in SDNN (standard deviation of NN intervals). This indicates a smaller deviation from the baseline values, suggesting minimal impact on the health of elderly individuals. The touch process is accompanied by a decrease in heart rate, reduced cardiac blood flow, and decreased cardiac load, among other physiological responses. The physiological feedback deviation values for long pile carpet and short pile carpet are 12.2 and 11.34, respectively.

③The two evaluation results are consistent, indicating that short pile carpet with a certain level of hardness and resilience provides better tactile comfort.

(3) Comparison of floor evaluation results

Table 7- 51 Comparison of the evaluation results of subjective and objective view of the floor

Subjective scoring results	Evaluation results of physiological feedback experiment



From the comparative analysis of the subjective and objective evaluation results in Table 7-51, the following rules can be known:

①In terms of subjective evaluation scores, solid wood flooring, engineered wood flooring, and flat-patterned PVC flooring received higher scores. The scores are as follows: solid wood flooring - 4.254, engineered wood flooring - 4.234, flat-patterned PVC flooring - 4.027. Correspondingly, the deviation values of the physiological indicators are relatively small: solid wood flooring - 0.42, engineered wood flooring - 2.34, flat-patterned PVC flooring - 1.95. The subjective and objective evaluation results tend to be consistent.

②Carpet with a rough or slippery feeling received lower subjective comfort scores. According to feedback from the elderly participants, the low scores were due to the carpet being too slippery. Comparing the physiological indicators, it is evident that the deviation values are larger, indicating a greater physiological impact on the elderly. Therefore, materials with a moderate level of roughness and slipperiness offer better comfort.

③Striped PVC flooring received lower subjective ratings for roughness and unevenness sensations. Elderly people are susceptible to flooring with a pronounced striped texture and accordingly older people show the highest deviations in physiological indicators.

7.4.1.2 Preferred Ground Materials

During the material selection process, it is important to consider both the subjective experience of the elderly and their physiological responses to different materials. Therefore, a combined evaluation space was constructed by combining the subjective evaluation results with the physiological feedback experimental results. This allowed for the analysis of score distribution and material categorization, as shown in Fig. 7-32.

From Fig. 7-32, it can be observed that different ground material samples exhibit correlation in their scores within the two-dimensional combined evaluation space. Based on the differences in comprehensive scores, this study compared and selected different categories of ground materials. The tactile comfort of the ground materials was classified into four levels, denoted as I, II, III, and IV, according to the reference of subjective ratings and physiological feedback results. The levels range from I (highest comfort) to IV (lowest comfort), as shown in Table 7-52.

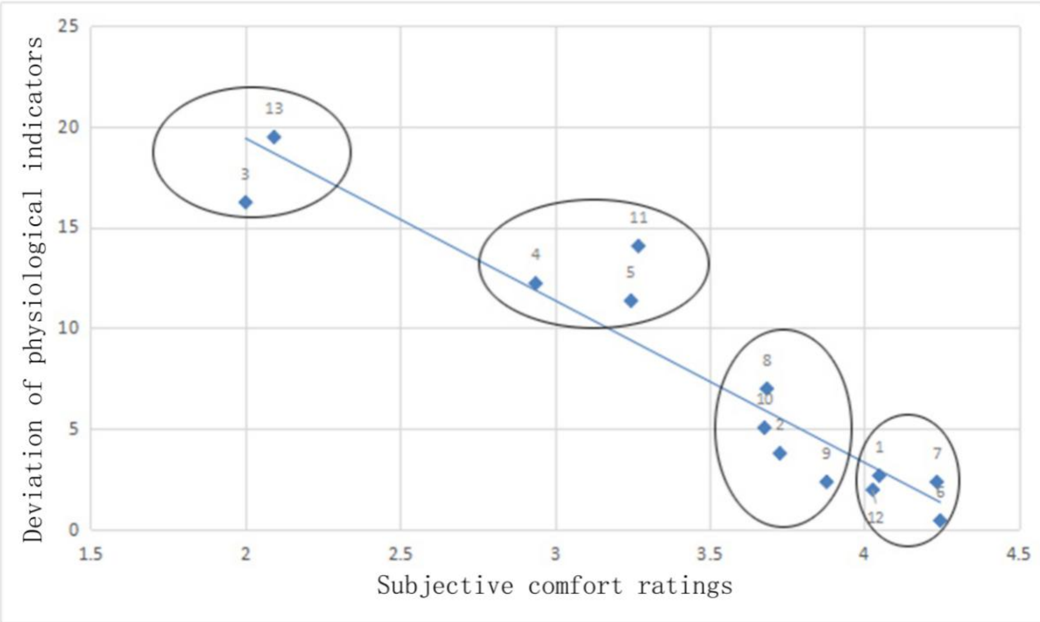


Fig. 7-32 Subjective and objective evaluation score space

Table 7- 52 The ground material is preferably a map

Tactile comfort level	I	II	III	IV
ground material	glazed tile wooden floor Parquet Plain vinyl flooring	Matt glazed tile cork floor bamboo floor Laminate flooring	plush carpet low pile carpet floor leather	Whole body brick Striped vinyl flooring

7.4.2 Comparative Analysis of Subjective and Objective Evaluation Results for Wall Materials

7.4.2.1 Comparative Analysis of Subjective and Objective Evaluation Results for Wall Materials

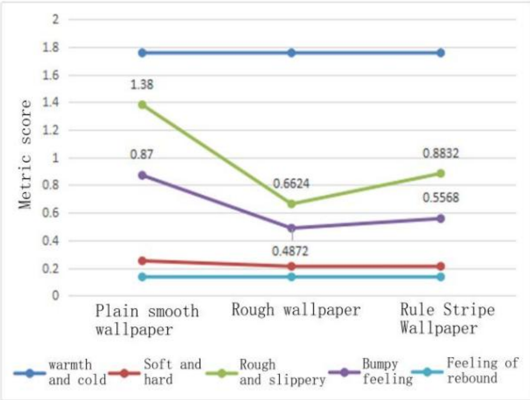
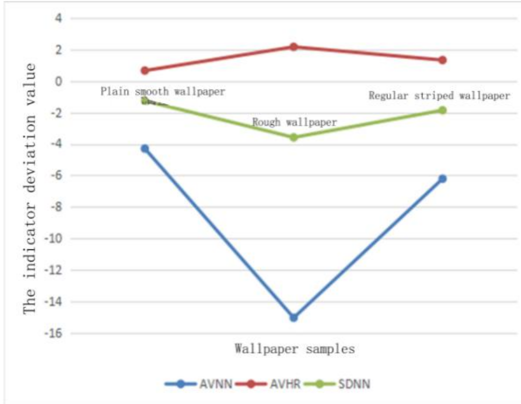
To facilitate the analysis of tactile comfort indicator evaluation results for various sample materials, the sample materials were divided into three groups based on material categories. A comparative analysis was then conducted on the subjective and objective evaluation results for each group. The specific grouping is shown in Table 7-53.

Table 7- 53 The wall material sample grouping

group number	Material category	Material composition
1	wallpaper	Plain smooth wallpaper, rough wallpaper, regular striped wallpaper
2	ceramic tile	Glazed tiles, matte glazed tiles, mosaics
3	coating	latex paint, diatom mud

(1) Comparative Evaluation Results for Wallpaper

Table 7- 54 Comparison of the evaluation results and outlook wallpaper

Subjective scoring results	Evaluation results of physiological feedback experiment
	

Based on the comparative analysis of subjective and objective evaluation results in Table 7-54, the following patterns can be observed:

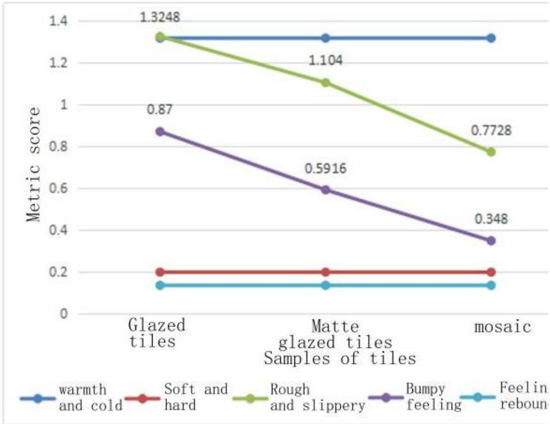
①In terms of subjective ratings, there are differences in tactile comfort scores for wallpaper materials, primarily related to the sensations of roughness and smoothness. Specifically, plain smooth wallpaper scored 4.392, rough wallpaper scored 3.252, and regular striped wallpaper scored 3.542. Comparing these subjective ratings with the deviations of physiological indicators, plain smooth wallpaper had a deviation value of 2.07, rough wallpaper had 6.94, and regular striped wallpaper had 3.13.

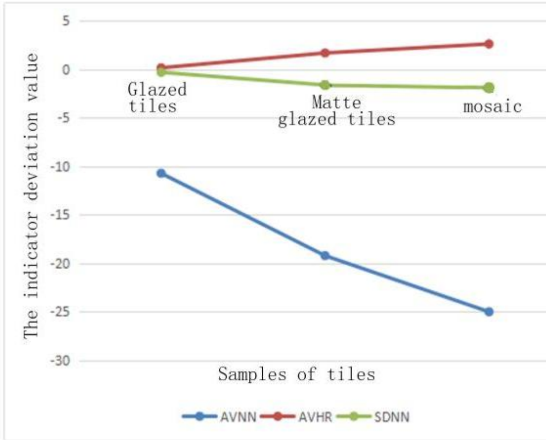
②Comparing the subjective and objective evaluation results for the three types of wallpaper, considering the combined assessment of roughness and smoothness sensations, as well as deviations and SD-based tactile characteristic evaluations, it can be concluded that for elderly individuals, wallpapers that are smooth without prominent irregularities offer higher tactile comfort.

(2) Comparative Evaluation Results for Tiles

Table 7- 55 Comparison of the evaluation results of subjective and objective view of ceramic tile

Subjective scoring results	Evaluation results of physiological feedback experiment





Based on the comparative analysis of subjective and objective evaluation results in Table 7-55, the following patterns can be observed:

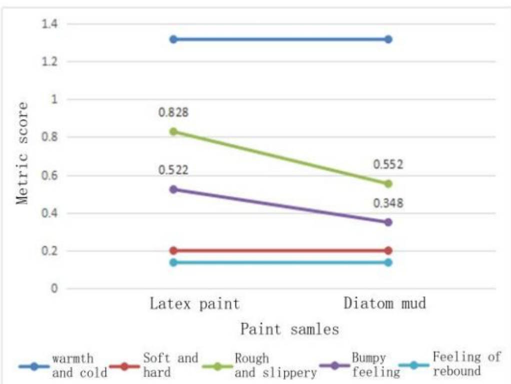
①In terms of subjective ratings, there are differences in tactile comfort scores for glazed tiles, matte glazed tiles, and mosaic tiles, mainly related to the sensations of roughness and smoothness. Tactile comfort shows a decreasing trend. Specifically, for the roughness sensation, glazed tiles scored 1.32, matte glazed tiles scored 1.10, and mosaic tiles scored 0.77. For the unevenness sensation, glazed tiles scored 0.87, matte glazed tiles scored 0.59, and mosaic tiles scored 0.35. Comparing these subjective ratings with the deviations of physiological indicators, the subjective and objective evaluation results tend to be consistent.

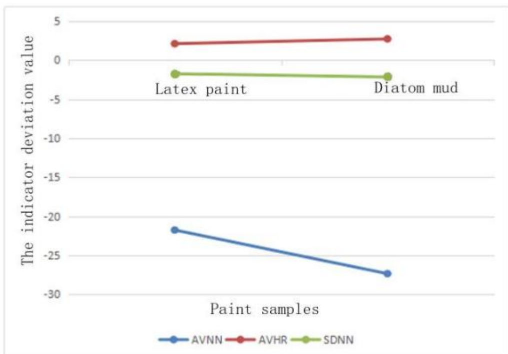
②Comparing the subjective and objective evaluation results for the three types of tiles, considering the combined assessment of roughness and smoothness sensations, as well as deviations and SD-based tactile characteristic evaluations, it can be concluded that for elderly individuals, wall tiles with a smooth surface and no prominent irregularities offer higher tactile comfort.

(3) Comparative Evaluation Results for Paints

Table 7- 56 Comparison of the evaluation results of subjective and objective view of paint

Subjective scoring results	Evaluation results of physiological feedback experiment





Based on the comparative analysis of subjective and objective evaluation results in Table 7-56, the following patterns can be observed:

①In terms of subjective ratings, there are differences in tactile comfort scores for latex paint and diatomaceous earth-based paint, primarily related to the sensations of roughness and smoothness. The comfort scores show a decreasing trend. Specifically, for the roughness sensation, latex paint scored 0.83, and diatomaceous earth-based paint scored 0.55. For the unevenness sensation, latex paint scored 0.52, and diatomaceous earth-based paint scored 0.35. Comparing these subjective ratings with the deviations of physiological indicators, the subjective and objective evaluation results tend to be consistent.

②Latex paint has a smoother surface compared to diatomaceous earth-based paint. In the SD-based tactile characteristic evaluation, latex paint scored -0.6 for roughness, indicating a moderate level of roughness, while diatomaceous earth-based paint scored -1.8, indicating a higher level of roughness. Correspondingly, the tactile comfort decreases as the surface roughness of the paint increases. This suggests that increased surface roughness of the paint leads to decreased tactile comfort for the elderly.

7.4.2.2 Preferred Wall Materials

A combined evaluation space was constructed as shown in Fig. 7-33, where I represents plain smooth wallpaper, II represents rough wallpaper, III represents regular striped wallpaper, IV represents glazed tiles, V represents matte glazed tiles, VI represents mosaic tiles, VII represents latex paint, and VIII represents diatomaceous earth-based paint.

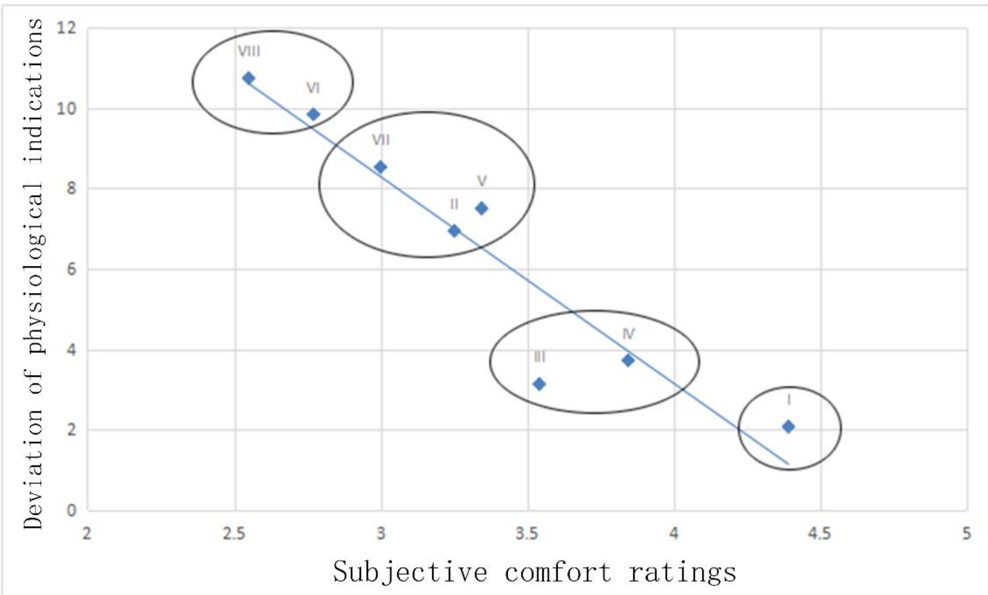


Fig. 7-33 Subjective and objective evaluation score space

From Fig. 7-33, it can be observed that different wall materials exhibit correlation in their scores within the two-dimensional evaluation space. Taking into consideration the subjective and objective experimental results, a comparison of tactile comfort and material selection for the chosen wall samples was conducted. Based on the combined evaluation scores, the wall materials were categorized into four levels of tactile comfort, denoted as I, II, III, and IV. The tactile comfort gradually decreases from level I to level IV. Please refer to Table 7-57 for the detailed classification.

Table 7- 57 The wall material optimization map

Tactile comfort level	I	II	III	IV
wall material	Tabby Smooth Wallpaper	Regular stripes wallpaper glazed tile	rough wallpaper Matt glazed tile latex paint	mosaic Diatom mud

7.4.3 Comparative Analysis of Subjective Evaluation Results for Furniture and Decorative Materials

To facilitate the analysis of tactile comfort indicator evaluation results for various sample materials, the sample materials were divided into two groups based on their functional use. A comparative analysis was then conducted on the subjective evaluation results for each group. The specific grouping is shown in Table 7-58.

Table 7- 58 Furniture and decoration materials sample grouping

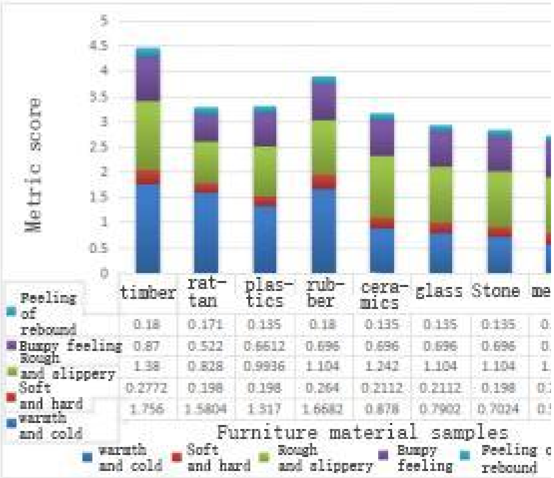
group number	Material category	Material composition
1	furniture material	Wood, Rattan, Plastic, Rubber, Ceramic, Glass, Stone, Metal
2	soft furnishing material	Cotton, Linen, Leather, Silk, Yarn

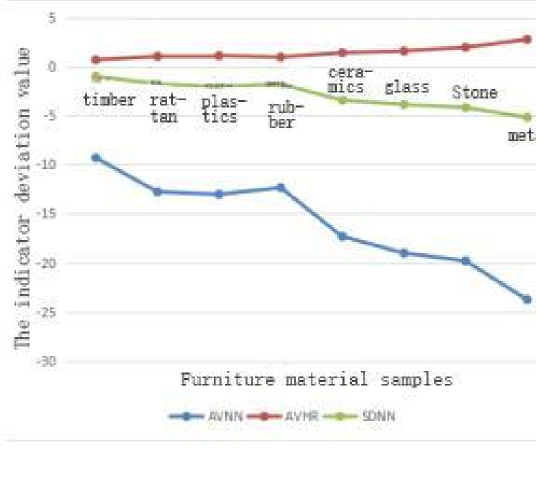
7.4.3.1 Comparative Analysis of Subjective and Objective Evaluation Results for Furniture and Decorative Materials

(1) Comparative Evaluation Results for Furniture Materials

Table 7- 59 Comparison of the evaluation results and outlook of furniture materials

Subjective scoring results	Evaluation results of physiological feedback experiment





Based on the comparative analysis of subjective and objective evaluation results in Table 7-59, the following patterns can be observed:

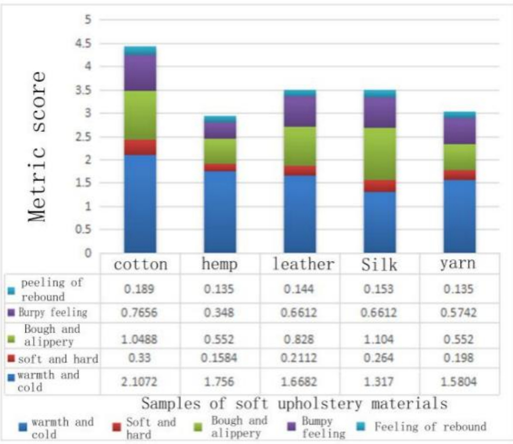
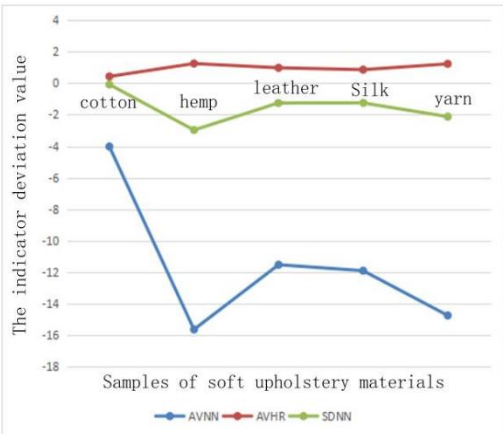
①In terms of subjective ratings, wood and rubber materials received higher scores in tactile comfort. Rattan and plastic materials followed next. Ceramic, glass, stone, and metal materials received relatively lower scores in comfort, mainly due to lower scores in the warmth sensation indicator, with comfort scores below 1.

②In terms of physiological feedback experiment evaluation results, wood materials showed smaller deviations in physiological indicators, indicating a lesser impact on the elderly. Rattan, plastic, and rubber materials had comparable deviations in physiological indicators, suggesting similar impacts on the elderly. Ceramic, glass, stone, and metal materials exhibited larger deviations in physiological indicators due to their lower surface temperatures, resulting in greater impact on the elderly[16].

③Overall, the subjective and objective evaluation results tended to be consistent.

(2) Comparative Evaluation Results for Soft Decorative Materials

Table 7- 60 A comparative evaluation of the results in view of soft decoration materials and

Subjective scoring results	Evaluation results of physiological feedback experiment
	

Based on the comparative analysis of subjective and objective evaluation results in Table 7-60, the following patterns can be observed:

①In terms of subjective ratings, cotton materials received higher scores in tactile comfort. Among them, cotton received higher scores in the warmth sensation and softness sensation compared to other materials, with scores of 2.10 and 0.33, respectively. Leather and silk followed next in terms of tactile comfort. Linen and yarn materials received lower scores, particularly in the roughness sensation, with linen scoring -0.552 and yarn scoring -0.552 in roughness sensation.

②In terms of physiological feedback experiment evaluation results, cotton materials exhibited smaller deviations in physiological indicators, indicating a lesser impact on the elderly. Leather and silk materials had comparable deviations in physiological indicators, suggesting similar impacts on the elderly. Yarn and linen materials showed larger deviations in physiological indicators, indicating a greater impact on the elderly.

③Overall, the subjective and objective evaluation results tended to be consistent. In the SD-based evaluation of roughness sensation, yarn scored -0.8, indicating a rough texture, while linen scored -1.7, indicating a rough texture as well. This indicates a decrease in tactile comfort as the surface roughness of the fabric increases, affecting the tactile comfort of the elderly.

7.4.3.2 Preferred Furniture and Decorative Materials

A combined evaluation space was constructed as shown in Fig. 7-34, where the materials are represented as follows: A – Wood, B – Rattan, C – Plastic, D – Rubber, E – Ceramic, F – Glass, G – Stone, H – Metal, I – Cotton, J – Linen, K – Leather, L – Silk, M – Yarn.

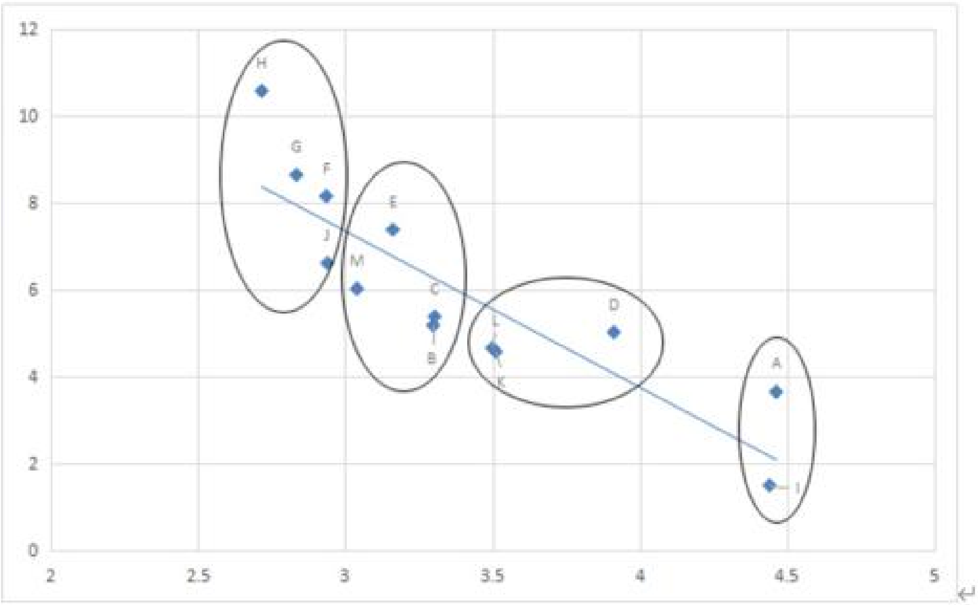


Fig. 7-34 Subjective and objective evaluation score space

Based on Fig. 7-34, it can be observed that the different types of furniture and decorative materials exhibit correlation in their scores within the two-dimensional evaluation space. Using the subjective and objective evaluation results, a comparison of tactile comfort and material selection for furniture and decorative materials was conducted. Based on the combined evaluation scores, the tactile comfort of furniture and decorative materials was classified into four levels, denoted as I, II, III, and IV, with the tactile comfort gradually decreasing from level I to level IV. Please refer to Table 7-61 for the detailed classification.

Table 7- 61 Material selection of furniture and accessories

Tactile comfort level	Ⅰ	Ⅱ	Ⅲ	Ⅳ
wall material	wood cotton	silk leather rubber	rattan plastic ceramics yarn	numb Glass stone Metal

7.4.4 Summary

In this chapter, we compared the subjective evaluation results of tactile comfort with the physiological feedback experiment results and analyzed the relationship between subjective and objective evaluation results. This analysis further expands upon the evaluation results presented in Chapters 3 and 4. To facilitate the comparison of evaluation results, we grouped the materials by category and conducted a cross-comparison of subjective evaluation scores and physiological feedback results within each group. This allowed us to determine the relative tactile comfort of different material samples for the elderly. Lastly, by constructing a combined evaluation space, we categorized the distribution of materials based on the evaluation scores, resulting in four levels of tactile comfort. We proposed a material selection chart based on tactile comfort for the elderly.

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Chapter 8

8. CONCLUSION AND PROSPECT

CHAPTER EIGHT：CONCLUSION AND PROSPECT

8.1 Conclusion

8.1.1 Research conclusion of visual comfort of elderly care space

Based on the previous literature review, this paper summarizes the visual features of the elderly. Then, aiming at the existing practical problems, we conducted a questionnaire survey on the satisfaction of the current living space environment and the factors affecting visual comfort. Finally, based on the factors affecting visual comfort as a starting point, the necessary spatial behaviors related to the visual comfort of the elderly are investigated, and the visual comfort of the elderly is studied, using behavior as a way of description.

Then, according to the above spatial behaviors, human factor experiment was conducted respectively. Starting from human visual perception comfort, physiological indicators of the elderly were obtained through human factor experiment, and corresponding spatial characteristics were obtained. Through spatial characteristics, the corresponding spatial indicators are further studied. The research conclusions of the main chapters of this article are as follows:

1) In the experimental study of spatial brightness perception comfort, for the behavior of the elderly reading newspapers in the living space, we conducted the data query, designed the experiment, collected the EDA index, analyzed the index data and completed subjective questionnaire, finally came to the conclusion that the most comfortable visual illumination value of the elderly is in between 600 and 900lux. Finally, based on the comfortable illumination value, the software simulation of natural illumination is carried out to obtain the best visual comfort window size and guide the architectural design.

2) In the experimental study of distance perception comfort, for the behavior of the elderly watching TV in the living space, we conducted the data query, designed the human factor experiment, collected the EDA index, analyzed the index data and completed subjective questionnaire, finally came to the conclusion that the most comfortable distance for the elderly to watch TV is between 1600 and 1900mm. According to this result, reflecting back to the real life, it is found that when the elderly watching TV sitting in the bed they feel uncomfortable because of the lack of back support. The elderly need to sit in a place with a backrest like a sofa. The method of enlarging the width of the living space, extending the depth of the living space or setting up suites can be adopted to set up satisfy the behavior of watching TV separately, and set up sofa seats for the elderly to watch TV in the comfortable distance.

3) In the spatial transition experimental study, for the weakened spatial perception of the elderly and their tendency to fall or bump when they enter and exit the bathroom in the living space, we conducted the research on the ground height difference of the toilet and the data query based on spatial perception behavior, designed the experiment, collected the eye movement indicators of the elderly: total fixation duration and time of first entry, analyzed and summarized to get the height difference of the toilet floor most easily seen by the elderly. The final result is that when the height difference is 150mm. The first entry time of the elderly is 0.94s, which is the height difference data with the shortest time, while the total fixation duration is 0.82s, which is the height difference data with the longest time. Therefore, 150mm is the most easily recognized bathroom floor height difference for the elderly, but 15 out of 30 elderly people did not notice the height difference. According to the questionnaire survey, the elderly are generally not satisfied with the setting of

height difference, although elderly people can intuitively observe the height difference of 150mm. Based on the physical difficulty of the elderly, the suggestion given in this paper is to cancel the setting of height difference, and gives the specific measures to eliminate the height difference.

4) In the experimental study of comfort color identification, for the color preferred by the elderly in the living space, we referred to the literature to develop the experiment, collected the total fixation duration and pupil diameter indicators of the elderly, analyzed the visual perception state of the elderly for color, completed the subjective questionnaire and finally came to the conclusion that the elderly think that the colors of visual comfort are orange and green, and the most eye-catching color is red, so the design points suggested that the elderly room wall should be painted in orange or green. Green potted plants should be used to beautify the environment and to purify the air. Identification objects in the living space, such as alarm call button, door knob, lamp switch should be red to stimulate eye-catching effect and to increase security in the daily lives of the elderly.

8.1.2 Auditory comfort and elderly care space

In this paper, the living space and dining space of nursing homes are taken as the space objects of the research, the elderly in nursing homes are taken as the human body objects of the research, and the ultimate research goal is to explore the correlation between the space of nursing homes and the auditory comfort of the elderly. Based on the field research of nursing homes and the theoretical knowledge of auditory comfort, the paper proposes the relationship between the space of nursing homes and auditory comfort, respectively: there is a correlation between “hearing distance” and auditory comfort in the living space of nursing homes, and there is a correlation between population density and auditory comfort in the dining space of nursing homes. On the basis of the theory and correlation verification, the further experimental design analysis is carried out. In the experiment on the correlation between “hearing distance” and auditory comfort in living space, the research method of human physiological perception technology was used. In the experiment on the correlation between population density and auditory comfort in dining space, acoustic measurement, subjective questionnaire and statistical software were used, and the following conclusions were finally obtained:

As for the correlation experiment between “hearing distance” and auditory comfort in the living space of elderly care institutions, human factor technology was used to conduct experimental simulation, and the results were analyzed by combining subjective questionnaire. The conclusions are as follows:

1) For the elderly with good hearing, the auditory comfort distance was 2.8m in watching TV and 1.6m in talking.

2) For the hearing impaired elderly, the auditory comfort distance was 1.6m in watching TV and 0.9m in talking.

In-depth subjective evaluation survey, population density observation and objective sound pressure level measurement were conducted on dining space of nursing homes, and the following conclusions were obtained:

1) The evaluation of the subjective comfort level of the elderly with good hearing on the

background noise sound pressure level of the dining space and the measured sound pressure level were analyzed by SPSS statistical software. It was concluded that when the subjective hearing of the elderly was comfortable, the background noise sound pressure level of the dining space was within the range of 58dB.

2) The population density and background noise pressure level of the two groups of elderly people with good hearing and hearing impairment in the dining space of nursing homes were analyzed by statistical software SPSS. It was concluded that the population density of the elderly with good hearing level was ≤0.291 people/m2, and the population density of the elderly with hearing impairment was ≤0.238 people /m2.

3) In reality, the listening levels of the diners in the dining space of nursing homes are different and the quantity ratio between different listening levels is difficult to be fixed, so the population density of dining space of nursing homes under the actual situation is summed up as ≤0.291 people/㎡. According to the relationship between population density and per capita use area, based on the auditory comfort of the elderly, the per capita use area of dining space in nursing homes is more than 3.4 m2.

8.1.3 Thermal comfort and elderly care space

The conclusions of this paper are mainly divided into three aspects:

1) Through the research of references and the collection of network data, and with thermal comfort and human factor technology as the support point, the psychological and physiological differences of elderly people in nursing homes are discussed, and the real needs of elderly people in nursing homes for living space comfort are analyzed.

2) Based on the physiological characteristics of the elderly in Shenyang, field survey was conducted in the nursing homes in Shenyang. Human factor technology was used to measure the elderly physiological indicators. It is concluded that the comfortable temperature of the elderly in Shenyang in winter is 22℃-27℃, and the comfortable temperature in summer is 24℃-28℃. The comfortable humidity is 25%-50% in winter and 50%-59% in summer. The comfortable wind speed in summer is 0m/s-0.4m/s.

3) Aiming at the thermal comfort of the elderly in nursing homes, the design is optimized from the three aspects of temperature, humidity and wind speed. The temperature comfort and wind speed comfort are optimized for the renovation of Tianzhu Mountain Nursing Home, and the humidity comfort is optimized for the renovation of Qinchunyuan Nursing Home. Based on the experience of transformation and optimization, this paper puts forward strategic suggestions on the design of nursing institutions in Shenyang area, mainly from the reasonable site design, the functional area design, the selection of the envelope structure, the choice of shading mode, the details of the design of doors and windows.

8.1.4 Tactile comfort and elderly care space

This article investigates the tactile comfort of decorative materials and furniture accessories in living spaces for the elderly. Two evaluation methods, subjective evaluation and physiological feedback experimental method (objective evaluation), were adopted. A total of 80 physically healthy and self-care elderly individuals were selected to participate in the evaluation experiment for material tactile comfort. Based on the comprehensive evaluation results from both subjective and objective measures, material selection recommendations were proposed. The main conclusions are as follows:

(1) Optimal Chart for Tactile Comfort of Materials in Elderly Living Spaces

Based on the distribution relationship of the evaluation results from subjective and objective measures, an optimal chart for the selection of decorative materials and furniture accessories in elderly living spaces, considering tactile comfort, is presented. Please refer to Table 9-1-Table 9-3.

Table 8- 1 Under the tactile comfort of the elderly living space ground material selection based on map

Tactile comfort level	I	II	III	IV
Flooring	Glazed tile solid wood floor Engineered wood flooring Plain plastic flooring	Matte glazed tiles Cork Flooring Bamboo flooring Laminate flooring	Plush carpet low level loop pile carpet Floor leather	The brick Striped plastic flooring

Table 8- 2 Under the tactile comfort of the elderly living space wall material optimization based on map

Tactile comfort level	I	II	III	IV
Wall covering	Plain smooth wallpaper	Regular striped wallpaper Glazed tile	Rough wallpaper Matte glazed tiles Emulsion	Mosaic Diatom ooze

Table 8- 3 Under the tactile comfort of the elderly living space furniture and decoration materials selection based on map

Tactile comfort level	I	II	III	IV
Furniture and decorative materials	wood Cotton	Silk Leather Rubber	Rattan Plastic Ceramic Yarn	Linen Glass Stone Metal

(2) Weighting values of material tactile comfort indicators under different contact modes

Material tactile comfort is a comprehensive sensation. In the process of constructing a subjective evaluation system, it is necessary to assign weights to each evaluation indicator, that is, determine the proportion of each indicator. The weighting values of the indicators are related to the contact modes. They can be mainly divided into two categories: contact with the hands and contact with the feet (ground). For specific classifications and weighting values of indicators, please refer to Table 8-4-Table 8-5.

Table 8- 4 The surface material tactile comfort evaluation index weight

Comfort index	Cold and warm sensation	Soft and hard feeling	Coarse and smooth feeling	Sense of Concavo-Convex	Rebound sensation
Weight value	0.100	0.135	0.457	0.250	0.058
Sort	4	3	1	2	5

From the weight values of the indicators in Table 6.4, it can be seen that the roughness and unevenness of the material surface have a significant impact on the tactile comfort of the ground material.

Table 8- 5 Hand contact material tactile comfort evaluation index weight

Comfort index	Cold and warm sensation	Soft and hard feeling	Coarse and smooth feeling	Sense of Concavo-Convex	Rebound sensation
Weight value	0.439	0.066	0.276	0.174	0.045
Sort	1	4	2	3	5

From the weight values of the indicators in Table 6.5, it can be seen that the material's warmth and roughness have a significant impact on the tactile comfort of the hand.

(3) Summary of Experimental Points for Subjective and Objective Evaluation of Material Tactile Comfort This article evaluates the tactile comfort of materials through both subjective and objective experiments Minimize the impact of unrelated variables, human errors, and experimental environment on the results as much as possible. The specific experimental points are summarized in the Table 8-6-Table 8-7.

Table 8- 6 Main points of experimental design for subjective evaluation of tactile comfort of materials

Experimentation	Main experimental steps	Key points of the experiment
Prior to the experiment	Sampling	Material samples are mainly screened from two aspects: type and size. The types of materials should be comprehensive and representative. (1) Comprehensiveness: Rich variety of materials, covering commonly used interior decoration And furniture and accessory materials; (2) Representative: Different material samples can pass 5 evaluations Distinguish one or several indicators; The material size should meet the normal behavior of elderly people such as stepping, walking, and touching;

	Determination of experimental personnel	Select self-care elderly people aged 60-74 who are in good physical condition, able to move freely, and have smooth language expression as the research subjects. Before the experiment, explain the detailed process that needs to be carried out to the elderly.
	Selection of evaluation indicators	The evaluation indicators should have the following characteristics: (1) Scientific and systematic: indicators are scientific, reasonable, comprehensive, and objective; (2) Simplicity: The words used to describe indicators are easy to understand; (3) Representative: able to reflect different material characteristics; Independence: there is no duplication of content between indicators;
	Weight analysis of evaluation indicators	According to the different ways and locations of contact between the elderly and materials, the evaluation experiment of material tactile comfort should be divided into two parallel processes: contact with the hands of the elderly and contact with the feet of the elderly;
	Pre-Experiment	Conduct pre experiments in advance, grasp the approximate experimental time and shortcomings in the experiment, improve in a timely manner, and increase the design of experimental details;
Mid experimental period	Evaluation process	(1) Ensure the quiet and comfortable evaluation environment, and ensure the stable and safe placement of samples; (2) Reasonably grasp the duration of tactile experience of material samples based on the pre experiment, ensuring that there is no mutual influence between the front and rear samples during the experience process; (3) In the experiment, several pairs of rubber soled slippers of different sizes were prepared based on the research results of elderly people wearing in the living space in the early stage; (4) When experiencing the sample, the experimenter needs to visually inspect the front and conduct a touch experience to avoid the impact of different material colors on the results; (5) The order of experience for the elderly material samples in the experiment is not entirely the same, that is, some elderly people start experiencing from the ground material samples, some elderly people start experiencing from the wall material samples, and so on, in order to

		exclude the impact of fatigue on the results; According to the difficulty level of comfort evaluation for elderly people in the pre experiment, a 5-level scoring method is used;
Later stage of the experiment	Analysis of evaluation results	Summarize and screen the tactile comfort rating results of different material samples, and finally conduct validity analysis on feasible sample data

Table 8- 7 Material tactile comfort physiological feedback experiment design

Experimentation	Main experimental steps	Key points of the experiment
Prior to the experiment	Sampling	Key points for sample selection can be found in section Table 9-6
	Determination of experimental personnel	(1) Select self-care elderly people aged 60 to 74 who are in good physical condition, able to move freely, and have smooth language expression as the research subjects. Before the experiment, explain the detailed process that needs to be carried out to the elderly; (2) Ensure good sleep quality the previous day, eat before the experiment, do not engage in intense exercise, and maintain emotional stability;
	Debugging of instruments and spare parts	Instruments and spare parts mainly include two parts: detection and analysis processing (1) Debug the position of the photocapacitance pulse generator (PPG), signal receiver, and camera to ensure normal collection of physiological indicators and recording of the process; (2) Install Ergo lab analysis software and perform pre operation of relevant modules before the experiment; Ensure that the instrument has sufficient power and avoid replacing the instrument midway;
	Determination of experimental methods and physiological indicators	According to the characteristics of Heart rate variability method, time-domain analysis method is selected; The specific analysis indicators are as follows: AVNN, AVHR, SDNN, RMSSD, PNN50%;
	Determination of experimental time	Based on the experimental process and the characteristics of HRV time-domain analysis, select a short-range HRV time-domain analysis method with excellent stability, good repeatability, and easy control of influencing factors; Based on relevant research on heart rate variability, the final determination of the material sample experience time is 2 minutes;
	Pre-Experiment	Conduct pre experiments in advance, grasp the approximate

		experimental time and shortcomings in the experiment, improve in a timely manner, and increase the design of experimental details;
Mid experimental period	Evaluation process	(1) Before the formal start of the experiment, gently rub the earlobes of the elderly with your fingertips to prevent the low temperature from affecting the experimental results; (2) During the experiment, it is prohibited for the elderly to eat any food or drink beverages containing alcohol, caffeine, etc; (3) Before collecting samples of elderly people who have not come into contact with any materials, physiological indicators in a quiet state are used as comparative data, and the collection time is more than 5 minutes; During the experiment, corresponding video cutoff points were set when experiencing different materials to facilitate the capture of physiological indicator information segments in the later stage;
Later stage of the experiment	Analysis of evaluation results	(1) Organize and analyze the collected physiological indicator data for validity, and determine the final evaluation indicators; (2) Analyze the effectiveness of evaluation results;

8.2 Prospect and deficiency

8.2.1 Prospect and deficiency of visual comfort of elderly care space

1) In the experimental study of spatial brightness perception and comfort, it is concluded that the elderly have a specific visually related behavior in living space -- reading newspaper. Specific experiments are designed for this behavior. The elderly participants in the experiment will have different cognition of the experiment due to their age, educational background, habits and preferences, which may have a certain impact on the experimental results.

2) In the future, the size of the window was studied according to the illumination value. Indoor lighting was simulated, and the size of the comfortable window was obtained. However, the size of the window was obtained without in-depth study on the size of the living space. It is hoped that the size of the living space could be further studied according to the illumination and comfortable window size.

3) In the experimental study of comfortable color identification, we wanted to find out the old people's favorite color. We tried to enrich the monotonous bedroom space, consulted the data and research to get the common bedroom color, used the computer to present the color, used the eye tracker to record the indicators of the subjects, analyzed the indicators and finally got the favorite color ranking. Because the experimental instrument can only produce an effective response to distinguish obvious colors, that is, only for different colors, but not for a specific color with different brightness and saturation. According to experimental research, it is concluded that the elderly like the color of orange, but we can not get how the elderly like the orange of different

brightness and saturation through the experiment. It is hoped that with the progress of science and technology, as well as the development of experimental equipment, we can divide the brightness and saturation of different colors carefully to obtain scientific data and optimize the architectural design.

8.2.2 Prospect and deficiency of auditory comfort of elderly care space

Sound perception is an important means for people to understand the external world, and language communication is a necessary way for people to communicate. Hellen Kate once said, "The loss of sight is the loss of the connection between people and things, but the loss of hearing is the loss of the connection between people." Old age is an important stage in life. The elderly are in contact with sound all the time in their daily life. Comfortable hearing environment can not only improve the quality of life of the elderly, but also greatly benefit their mental and physical health. Therefore, no matter in the field of architecture or acoustics, it is necessary to have a comprehensive understanding of the psychological, physiological and behavioral characteristics of the elderly. From the beginning, a people-oriented comfortable and warm environment for the elderly should be designed .

The living space studied in this paper is only the twin room type chosen by most users of nursing homes in Shenyang. As for other regions, due to regional differences and other factors, the research conclusions are only for reference in other regions. The research method used for dining space is a combination of traditional subjective questionnaire and acoustic measurement. Whether the results given by the elderly are affected by other subjective factors, such as whether other environment of the nursing home interferes with them, needs to be further improved. However, from a new perspective, we obtained the comfortable distance of the elderly when talking and watching TV and the per capita use area of the dining space suitable for auditory comfort, which provides some reference ideas for the design of the elderly building in the future. In addition, by continuing this route, we can also explore other aspects of the elderly's vision, touch and so on in the future. Meanwhile, we also hope to provide inspiration for other studies on the elderly's architecture in the future.

8.2.3 Prospect and deficiency of thermal comfort of elderly care space

The aging development in Shenyang is very rapid, and the development levels of nursing homes are not balanced. Some nursing homes do not carry out architectural design from the perspective of users. The design of nursing homes should be carried out from a more long-term perspective, and pay attention to the interdisciplinary design of medicine, psychology, sociology and other perspectives, and in a more systematic and comprehensive way.

In addition, due to the limitations of the author's research level and energy, this paper still has the following deficiencies:

1) The temperature, humidity and wind speed of the living space were only studied from the comfort of the elderly, but the light environment, sound environment, smell environment and other aspects are not involved.

2) For optimized design, only two representative nursing homes were selected. However, there are other problems of other nursing homes in Shenyang area, and the thermal comfort factors are

numerous and complex.

3) The simulation of optimized design was carried out by building simulation software under idealized environment and materials. However, there may be certain differences in actual real life. Therefore, practical optimized design experience is needed.

8.2.4 Prospect and deficiency of tactile comfort of elderly care space

The elderly are an important stage in life, and a safe and comfortable living space is their basic needs. Elderly people spend most of their time indoors, constantly in contact with materials. A comfortable tactile environment is of great help in improving their quality of life and maintaining their physical and mental state. Therefore, whether in the field of architecture or product design, it is necessary to have a comprehensive understanding of the physiological, psychological, and behavioral characteristics of the elderly, starting from details and putting people first, to create a comfortable and warm living environment for the elderly.

Due to limitations in the author's reading volume, research level, and experimental conditions, there are several issues with this article:

(1) During the experimental process, due to practical operational difficulties and the size of the experimental site, the selection area of ground material samples is relatively small, which cannot meet the requirements of simulating the real free walking state of the elderly. The limited area has a certain impact on the evaluation of the results;

(2) There are various types of materials in residential spaces, and the 34 selected samples only represent a portion of common materials. The impact of different material surface characteristics on the tactile comfort of the elderly still needs to be further explored;

(3) Due to limitations in the selection of experimental subjects and experimental time, a total of 80 elderly people were selected for subjective and objective evaluation of material tactile comfort in this study. The available experimental sample data is relatively limited, and it is hoped that these shortcomings will be addressed in future research.