Research on Optimization and Comfort Evaluation of Modern Residential Space Interior Design Based on Ergonomics

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ABSTRACT With rapid urbanization and increasing demand for improved living quality, modern residential spaces have evolved from basic shelters into complex environments that integrate functionality, comfort, health, and emotional experience. Ergonomics provides an important theoretical basis for solving problems such as unreasonable spatial layout, inadequate functional adaptability, and insufficient comfort. This study establishes a comprehensive framework including theoretical analysis, design optimization, comfort evaluation system construction, and empirical validation. The research focuses on ergonomic optimization of modern residential interior environments, emphasizing the coordination of spatial layout, furniture dimensions, lighting, acoustics, thermal conditions, and functional applications. A multidimensional comfort evaluation system is developed and verified through representative residential cases. The results provide practical support for improving residential comfort and design adaptability. The proposed framework also offers engineering references for smart residential environments, indoor sensing, electromagnetic compatibility of intelligent home systems, and human-centered environmental monitoring.

INDEX TERMS ergonomics, residential space, interior design, indoor sensing, electromagnetic compatibility

I. INTRODUCTION

A. RESEARCH BACKGROUND

DRIVEN by rising living standards and increasing awareness of well-being, the functional expectations of residential spaces have shifted from basic shelter to the pursuit of higher-quality living environments. Innovative interior materials now play a vital role in achieving healthy, comfortable, and emotionally fulfilling home environments [1]. According to the 2023 China Residential Space Development Report, the proportions of urban residents demanding comfort, health, and adaptability in residential spaces reach 89.6%, 85.3%, and 78.9%, respectively. Nevertheless, more than 62% of households report challenges such as unreasonable layouts, mismatched furniture dimensions, and suboptimal lighting or acoustic conditions, adversely affecting the overall living experience. Examples include limited activity areas in small spaces due to imbalanced layouts, lack of accessible features in elderly residences, and decreased efficiency and comfort in integrated office-residential areas resulting from unclear functional zoning [2,3].

B. RESEARCH CONTENT AND TECHNICAL APPROACH

1) Research Content

This article addresses the following core research areas:

Theoretical Foundation Review: A systematic review of ergonomic theories, design elements of modern residential spaces, and comfort assessment methodologies, culminating in an integrated theoretical framework.

Construction of a Comfort Evaluation System: Development of a four-dimensional evaluation index system, including determination of indicator weights and assessment methodologies.

Integration of Digital Technologies: Exploration of Building Information Modeling (BIM) and Virtual Reality (VR) applications in design optimization and comfort assessment, alongside the development of relevant digital tools.

Empirical Validation: Selection of three representative residential case studies to apply the design optimization system and empirically verify the effectiveness of the proposed strategies [4-6].

2) Technical Roadmap

Theoretical Construction: Formulation of an integrated theoretical framework, a multidimensional design optimization system, and a four-dimensional comfort evaluation model based on extensive literature review.

Digital Tool Development: Utilization of BIM and VR technologies to create simulation and pre-assessment tools for design optimization and comfort evaluation.

Empirical Application: Implementation of the optimization system and digital tools in three typical residential scenarios for scheme development and refinement.

Effect Evaluation: Comprehensive assessment of the optimized designs through surveys, physiological monitoring, environmental measurements, and expert review to determine the impact of functional textile configurations.

Optimization and Refinement: Iterative enhancement of the optimization system and evaluation model based on assessment outcomes, leading to the final research conclusions.

II. THEORETICAL BASIS AND INTEGRATION FRAMEWORK CONSTRUCTION

A. CORE THEORIES OF ERGONOMICS

Environmental Stress Theory: Poor spatial layouts and unsuitable environmental parameters can trigger physiological and psychological stress responses in residents, diminishing comfort.

Behavioral Scenario Theory: Diverse residential activities—including rest, work, recreation, and socialization—require dedicated spatial support; design should accommodate scenario-specific behaviors.

Cognitive Load Theory: Overly complex spatial information or disorganized layouts increase cognitive load, reducing efficiency and psychological comfort.

Environmental Psychology examines the psychological interactions between individuals and their environments, informing the design of key elements such as lighting, color, and acoustics in residential spaces:

Lighting Environment: Light intensity and color temperature influence circadian rhythms, mood, and visual comfort. Distinct spaces (bedroom, living room, study) require tailored lighting parameters.

Color Environment: Colors elicit specific psychological responses (e.g., warm tones for warmth, cool tones for calmness); color schemes should align with spatial functions and occupant needs.

Acoustic Environment: Noise induces psychological strain and physiological discomfort; effective acoustic design minimizes noise interference and enhances comfort [7-9].

Accessible Design Theory addresses the requirements of special populations (elderly, persons with disabilities, children), achieving spatial inclusivity and adaptability through targeted design optimizations:

Elderly Adaptation: Optimized spatial layouts, furniture dimensions, and handrail installations accommodate reduced mobility and sensory impairments.

Disability Adaptation: Provision of accessible pathways, assistive devices, and signage systems for various disabilities.

Child Adaptation: Appropriately scaled and safe furniture, protective features, and engaging spatial elements support children's growth and safety.

B. CORE ELEMENTS OF MODERN RESIDENTIAL INTERIOR DESIGN

Modern residential interior design is structured around four interrelated dimensions:

Spatial Dimension: Encompasses layout, functional zoning, circulation, and spatial scale—forming the foundational structure of residential environments.

Furniture Dimension: Involves furniture sizing, form, material selection, and arrangement, serving as the primary medium for fulfilling spatial functions.

Environmental Dimension: Includes lighting, color, acoustics, temperature, humidity, and ventilation, all directly impacting comfort and health.

Functional Dimension: Addresses the full spectrum of activities—living, working, recreation, socializing, and storage—to meet diverse resident needs [10].

C. INTEGRATION FRAMEWORK OF ERGONOMICS AND RESIDENTIAL SPACE DESIGN

A four-tier integration framework is proposed, comprising:

Human Characteristics Layer: Incorporates anthropometric data, physiological functions, and psychological traits as the basis for integration.

Behavioral Needs Layer: Analyzes residential behavior patterns and functional requirements derived from human characteristics.

Spatial Design Layer: Optimizes layouts, zoning, circulation, and furniture configuration to align spatial features with occupant needs.

Environmental Parameter Layer: Refines lighting, color, acoustics, temperature, and humidity to enhance comfort.

Core objectives include: Physiological Adaptation: Design aligns with human physiology, reducing fatigue and health risks.

Behavioral Adaptation: Spatial functions and circulation support habitual behaviors, improving efficiency.

Psychological Adaptation: Environmental and atmospheric design address psychological needs, reducing stress and enhancing well-being. Population-Wide Adaptation: Accommodates the needs of residents across age groups and abilities, ensuring inclusivity [11-13].

III. OPTIMIZATION SYSTEM FOR MODERN RESIDENTIAL INTERIOR DESIGN BASED ON ERGONOMICS

A. OVERALL FRAMEWORK OF THE OPTIMIZATION SYSTEM

A multidimensional design optimization system is established, comprising six core modules and 28 strategies tailored for differentiated adaptation. The modules include spatial layout, furniture configuration, lighting environment, color design, acoustic optimization, and accessibility adaptation. Each module contains targeted strategies to address the unique requirements of various residential types, ensuring systematic and precise design interventions[14-15].

B. CORE MODULE OPTIMIZATION STRATEGIES

1) Spatial Layout Optimization

Spatial layout optimization focuses on human-scale adaptation, smooth circulation, and rational functional zoning. Key strategies include: Circulation Design: Main circulation widths should be at least 1.2 m (ordinary residences) or 1.0 m (small apartments), with secondary paths not less than 0.9 m or 0.8 m, respectively. Nighttime routes from bedrooms to bathrooms must be unobstructed[16].

Spatial Scale Adaptation: Living rooms should be at least 3.6 m wide; bedrooms, no less than 3.0 m; kitchen countertops, at least 2.1 m in length.

Flexible Space Design: Incorporate convertible areas (e.g., living rooms as studies, secondary bedrooms as storage) for evolving needs.

Visual Transparency: Minimize partitions to enhance openness and reduce cognitive load; employ semi-partitions to balance privacy and transparency where appropriate.

2) Furniture Configuration Optimization

Furniture optimization centers on human-scale adaptation, ergonomic posture, and efficient space utilization. Strategies include: Table Furniture: Dining table height: 75–78 cm; tabletop width: $\geq$ 80 cm. Desk height: 72–75 cm; desktop depth: 60–80 cm; keyboard tray: 60–65 cm.

Bedding: Double bed width: $\geq$ 1.5 m; length: $\geq$ 2.0 m; mattress hardness: Shore A 30–40; headboard height: 90–110 cm for easy access.

Storage Furniture: Wardrobe depth: 60 cm; long hanging area: 1.4–1.6 m; short hanging: 1.1–1.2 m; drawer height: 15–20 cm.

Layout Optimization: Furniture should be at least 0.5 m from walls; passageways between furniture should be $\geq$ 0.8 m. The distance from sofa to TV should be 3–5 times the TV's diagonal length.

3) Lighting Environment Optimization

Lighting optimization focuses on appropriate intensity, color temperature, and glare control. Strategies include: Intensity: Bedrooms: 50–100 lx (rest), 200–300 lx (active); living rooms: 100–200 lx (leisure), 300–500 lx (social); study: 300–500 lx; kitchen: 300–500 lx; bathroom: 200–300 lx.

Anti-Glare Design: Light sources should be mounted $\geq$ 2.2 m high; use frosted glass or grilles to reduce glare; avoid strong contrast between TV screens and light sources.

Natural Lighting: Window area in living rooms and bedrooms should be $\geq$ 1/7 of the floor area; use translucent curtains to regulate light intensity and prevent glare or overheating [17].

4) Color Design Optimization

Color optimization addresses psychological adaptation, functional relevance, and visual comfort. Key strategies:

Color Coordination: Limit main color tones to three to prevent visual clutter; wall colors should be brighter than floors and furniture for spatial openness; color saturation should remain between 30%–60% to avoid fatigue[18].

Emotional Regulation: Adjust color schemes to resident personality and needs; low-saturation cool tones for anxiety, warm tones for low mood.

5) Acoustic Environment Optimization

Acoustic optimization focuses on noise control and acoustic comfort. Core strategies:

Noise Standards: Bedroom: $\leq$ 30 dB(A) at night, $\leq$ 40 dB(A) during the day; living room: $\leq$ 45 dB(A); study: $\leq$ 35 dB(A). Sound Insulation: Double-layer wall structures ($\geq$ 45 dB); floating floors or insulation mats (impact sound $\leq$65 dB); doors/windows with insulated glass ($\geq$ 35 dB).

Sound Absorption: Use carpets, curtains, and sofas in living and bedrooms; ceilings with perforated material panels or gypsum board, reverberation time: 0.5–0.8 s.

Noise Source Control: Select quiet appliances ($\leq$ 40 dB); insulate plumbing to reduce water noise.

Targeted Optimization: Combine sound absorption and insulation in living rooms; add local sound screens and low-noise systems in studies; use soundproof mattresses and wall treatments in bedrooms.

6) Accessibility Adaptation Optimization

Accessibility adaptation ensures universal inclusivity, convenience, and safety. Strategies include: Elderly Adaptation: Passage width: $\geq$ 1.0 m, no level changes or gentle slopes ($\leq$ 1:12); handrails in bathrooms (85–90 cm); toilet height: 40–45 cm; emergency call buttons at bedside; rounded furniture corners.

Disability Adaptation: Passage width: $\geq$ 1.2 m; wheelchair turning diameter in bathrooms: $\geq$ 1.5 m; adjustable kitchen counters (70–85 cm); low switches/sockets (40–50 cm); tactile paving and signs for visually impaired residents.

Child Adaptation: Child-specific furniture (desks: 50–60 cm; chairs: 30–35 cm); socket covers at $\geq$ 1.0 m; window limiters; no sharp edges.

Universal Design: Adjustable-height furniture and convertible spaces to accommodate varying needs and life stages [19,20].

C. DIFFERENTIATED ADAPTATION STRATEGIES FOR RESIDENTIAL TYPES

1) Ordinary Residence (Family of Three)

Core Requirements: Comprehensive functionality, efficient use of space, balance between child development and parental comfort.

Optimization Focus: Distinct zones for parent-child interaction and adult leisure; adjustable children's furniture;

stain-resistant, easy-clean materials; child safety features and accessible pathways for temporary elderly residence.

2) Small Apartment (Single/Double Occupancy)

Core Requirements: High space utilization, multifunctionality, flexibility.

Optimization Focus: Open layouts with minimal partitions; multifunctional and foldable furniture; light color schemes and mirrors for spatial expansion; lightweight sound insulation and quiet appliances.

Senior Apartment (Aged 60 and Above) Core Requirements: Safety, convenience, comfort, and adaptation to age-related functional decline.

Optimization Focus: Simple, accessible circulation; reserved wheelchair space; elevated seating and bed heights; stable furniture; high-contrast lighting and colors; no level changes; handrails and emergency systems; adjustable kitchen counters.

IV. CONSTRUCTION OF A COMFORT ASSESSMENT SYSTEM FOR MODERN RESIDENTIAL SPACES

A. PRINCIPLES FOR EVALUATION SYSTEM DEVELOPMENT

Scientific Rigor: Indicators are grounded in ergonomic and environmental psychology theories, with clear definitions and quantitative methods.

Systematic Coverage: Encompasses physiological, psychological, functional, and environmental dimensions for comprehensive comfort assessment.

Operability: Data are accessible via surveys, physiological monitoring, environmental testing, and expert evaluation.

Targeted Adaptation: The system accommodates diverse residential types and populations for practical applicability.

Dynamic Adjustability: Indicators can be refined in response to evolving demands and technological advancements.

B. EVALUATION SYSTEM STRUCTURE

A four-dimensional comfort evaluation model is established, encompassing 20 secondary and 56 tertiary indicators:

Physiological Comfort (Objective/Subjective): Muscle fatigue, visual and auditory comfort, sleep quality, physiological health impact.

Psychological Comfort (Subjective): Emotional state, spatial satisfaction, cognitive load, sense of belonging.

Functional Comfort (Objective/Subjective): Space utilization, furniture adaptability, circulation rationality, storage, elastic adaptability.

Environmental Adaptation (Objective/Expert): Lighting, color, acoustics, temperature and humidity, ventilation, accessibility adaptation.

Physiological Comfort (Weight: 0.30) Muscle Fatigue (0.08): Monitored via electromyography (EMG); subjective fatigue scored on a 5-point scale; baseline and post-optimization values compared over a 7-day period; $\geq$ 15% EMG reduction signifies effective improvement.

Visual Comfort (0.07): Includes visual fatigue (subjective), acuity (objective), and glare perception (subjective).

Auditory Comfort (0.06): Assessed by perceived noise and hearing fatigue (subjective).

Sleep Quality (0.05): Evaluated by sleep onset, duration, and depth (objective monitoring).

Physiological Health Impact (0.04): Monitored via blood pressure and heart rate changes.

Psychological Comfort (Weight: 0.25) Emotional State (0.08): Evaluated using the PANAS scale (pleasure, relaxation, anxiety).

Space Satisfaction (0.07): Assessed for layout, furniture, color, and lighting on a 5-point subjective scale.

Cognitive Load (0.05): Assessed by spatial recognition, circulation clarity, and operational ease.

Sense of Belonging (0.05): Evaluated by spatial identity and emotional attachment.

Functional Comfort (Weight: 0.25) Space Utilization Rate (0.06): Objectively calculated based on functional zoning rationality and space wastage.

Furniture Adaptability (0.06): Evaluated for size, ease of use, and comfort (subjective/objective).

Circulation Rationality (0.05): Assessed for directness, unobstructed paths, and smoothness (subjective).

Storage Function (0.04): Evaluated for capacity and retrieval convenience.

Elastic Adaptability (0.04): Assessed for adaptability to changing demands and functional conversion.

Environmental Adaptation (Weight: 0.20) Lighting Parameters (0.04): Intensity, color temperature, glare (objective).

Color Parameters (0.03): Color coordination, brightness, saturation (expert rating).

Acoustic Parameters (0.04): Noise level, insulation, and reverberation (objective).

Temperature and Humidity (0.03): Temperature (22–26 °C), relative humidity (40%–60%).

Ventilation Effect (0.03): Ventilation rate, air quality ($CO_2 \leq 1000$ ppm).

Accessibility Adaptation (0.03): Channels, auxiliary facilities, safety (expert rating).

C. INDICATOR WEIGHTING METHODS

A combined weighting approach integrates the Analytic Hierarchy Process (AHP) and the Entropy Weight

V. METHOD

Subjective Weights (AHP): Twenty-five experts (ergonomics, interior design, building environment, and user representatives) construct a judgment matrix. Consistency is confirmed (CR < 0.1). Calculated weights: physiological comfort (0.32), psychological (0.26), functional (0.24), environmental (0.18).

Objective Weights (Entropy): Based on 15 datasets from three empirical cases, information entropy is calculated;

greater dispersion yields higher weight. Results: physiological (0.28), psychological (0.24), functional (0.26), environmental (0.22).

Combined Weights: Weighted averaging (λ = 0.5) produces final weights: physiological (0.30), psychological (0.25), functional (0.25), environmental (0.20).

Dynamic Verification: Recalculation with additional datasets confirms weight stability within $\pm$ 0.02.

VI. APPLICATION OF DIGITAL TECHNOLOGIES IN DESIGN OPTIMIZATION AND EVALUATION

A. APPLICATION OF BIM TECHNOLOGY IN DESIGN OPTIMIZATION

1) Spatial Adaptability Simulation

Three-dimensional residential models are developed using BIM, integrated with a human scale database for real-time verification of spatial layouts, furniture configuration, and human-body compatibility:

Automated Detection: Verifies channel widths, furniture spacing, and door dimensions against ergonomic standards.

Dynamic Simulation: Simulates activity trajectories for various user groups (adults, elderly, children, persons with disabilities) to optimize circulation design.

Collision Detection: Identifies potential collisions between furniture and structural elements, enhancing layout safety.

2) Environmental Parameter Simulation

BIM is integrated with environmental simulation software (e.g., Ecotect, Radiance) to analyze lighting, acoustics, temperature, and humidity:

Lighting Simulation: Assesses the distribution of natural and artificial lighting at different times, optimizing fixture placement and intensity.

Acoustic Simulation: Models noise propagation and evaluates sound insulation effectiveness.

Thermal Simulation: Simulates indoor temperature and humidity distribution, informing HVAC and ventilation system design.

B. APPLICATION OF VR TECHNOLOGY IN COMFORT PRE-EVALUATION

1) Immersive Experience Evaluation

VR environments are constructed from BIM models, enabling users to experience spatial comfort during the design phase:

Visual Experience: Evaluate spatial scale, color coordination, and lighting effects.

Operational Experience: Simulate furniture use and circulation to assess functional adaptability.

Environmental Experience: Integrate auditory and thermal simulations for enhanced realism.

2) Comparative Evaluation of Multiple Schemes

VR models of alternative design schemes allow users to switch between options:

Subjective Preference Collection: Users rate comfort across schemes, guiding optimization.

Group Feedback Integration: Aggregated evaluations from multiple users ensure design universality.

C. APPLICATION OF BIG DATA TECHNOLOGY IN REQUIREMENT ANALYSIS

1) Residential Behavior Data Mining

Residential behavior data—including activity trajectories, usage frequency, and functional preferences—are analyzed to identify:

Requirement Identification: Optimize spatial layouts and furniture based on high-frequency usage patterns.

Pain Point Analysis: Detect discomfort scenarios to inform targeted design improvements.

2) Personalized Design Recommendations

User profiles and behavioral data inform tailored design strategies:

Population Adaptation: Recommend spatial and furniture configurations based on age, gender, and physical condition.

Preference Adaptation: Suggest color schemes and functional solutions reflecting user preferences.

VII. EMPIRICAL CASE VERIFICATION

A. CASE SELECTION AND OVERVIEW

Three representative residential spaces were selected for empirical validation: an ordinary residence (family of three, 120 m^2), a small apartment (two occupants, 60 m^2), and a senior apartment (two elderly residents, 80 m^2). All cases are located in a central urban area and exhibit varying degrees of comfort-related challenges in their original designs.

Case 1: Ordinary Residence: Issues included unclear functional zoning in the living room, insufficient play space for children, inadequate bedroom lighting, dull color schemes, inefficient kitchen workflow, and nonadjustable children's furniture.

Case 2: Small Apartment: Problems comprised crowded layout, excessive partitions reducing natural light, bulky furniture with insufficient storage, open kitchen noise, and inconsistent color schemes.

Case 3: Senior Apartment: Challenges entailed level differences in circulation, lack of barrier-free pathways, absence of bathroom handrails, low toilet height, insufficient bedroom lighting, low color contrast, and sharpedged furniture creating safety hazards.

B. IMPLEMENTATION OF DESIGN OPTIMIZATION

1) Ordinary Residence

Space Layout: Segregated the living room into parent-child and adult zones with movable partitions; expanded kitchen countertop to 2.4 m and optimized workflow.

Furniture Configuration: Installed adjustable-height desks (50–75 cm) and chairs (30–45 cm) in the children's room; introduced modular sofas in the living area.

Lighting and Color: Replaced curtains with translucent variants; added auxiliary lighting; adopted light beige walls and wooden furniture for increased brightness.

Accessibility: Added window limiters and socket covers in children's rooms; reserved 1.0 m-wide wheelchair access in corridors.

2) Small Apartment

Space Layout: Removed excess partitions for an open-plan living, kitchen, and dining area; created a multifunctional zone with a folding dining table (80 × 120 cm unfolded; 40 × 120 cm folded).

Furniture Configuration: Adopted wall beds, embedded shelves, and storage cabinets; included a mobile kitchen island.

Lighting and Color: Used white and light gray walls with mirrors to visually expand space; increased lighting power and installed track spotlights.

Acoustic Optimization: Installed soundproof glass partitions in the kitchen; incorporated sound-absorbing wall and ceiling materials.

3) Senior Apartment

Space Layout: Eliminated level differences, widened corridors to 1.2 m, simplified circulation from bedroom to bathroom ($\leq$ 8 m), and reserved a 1.5 m wheelchair turning space.

Furniture Configuration: Raised seat height to 45 cm and bed height to 50 cm; installed bathroom handrails; adopted rounded furniture corners.

Lighting and Color: Selected light yellow walls and dark brown furniture for contrast; increased living room lighting to 300 lx and bedroom lighting to 200 lx.

Accessibility: Installed emergency call buttons; adjustable kitchen counters (70–85 cm); gentle slope (1:15) at the entrance.

C. COMFORT ASSESSMENT RESULTS AND ANALYSIS

Comprehensive comfort evaluations were conducted pre- and post-optimization for all three cases using surveys (20 participants per case), physiological monitoring (5 participants per case, 24-hour monitoring), environmental measurements, and expert ratings (5 experts per case). Physiological monitoring was approved by the Haikou University of Economics Ethics Committee, with informed consent and anonymized data collection.

Data Validity: Among 15 monitored subjects, average EMG signal amplitude decreased by 23.7% post-optimization, and subjective fatigue scores dropped by 1.2 points. Paired t-tests ($p < 0.05$) confirmed statistically significant improvement.

1) Case 1: Ordinary Residence

Comparison of comfort evaluation scores before and after optimization of ordinary residential spaces, as shown in Table 1.

TABLE 1. Comfort Evaluation Score Comparison of Ordinary Residential Space Before and After Optimization (Unit: Score)

Primary Indicator	Secondary Indicator	Score Before Optimization	Score After Optimization
Physiological Comfort (30%)	Muscle Fatigue Degree	65.2	87.3
	Visual Comfortability	62.8	87.3
	Auditory Comfortability	70.5	85.6
	Sleep Quality	68.3	89.2
	Physiological Health Impact	72.1	86.4
Psychological Comfort (25%)	Emotional State	64.7	88.5
	Space Satisfaction	61.3	89.5
	Cognitive Load	67.5	85.8
	Sense of Belonging	65.8	87.2
Functional Comfort (25%)	Space Utilization Rate	63.2	88.9
	Furniture Adaptability	60.5	87.4
	Circulation Rationality	62.7	87.4
	Storage Function	65.4	85.3
	Elastic Adaptability	58.6	86.2
Environmental Adaptation (20%)	Lighting Parameters	59.8	87.6
	Color Parameters	61.5	87.6
	Acoustic Parameters	71.2	84.8
	Temperature & Humidity Parameters	73.5	85.1
	Ventilation Effect	72.8	84.5
	Barrier-Free Adaptation	64.3	86.9
Overall Score	–	64.7	88.3

2) Case 2: Small Apartment

Following optimization, the space utilization rate increased from 56.4% to 87.8%, and circulation smoothness improved from 58.9 to 86.3, confirming the ergonomic validity of the revised design, shown in Table 2.

TABLE 2. Comfort Evaluation Score Comparison of Small Apartment Before and After Optimization (Unit: Score)

Primary Indicator	Secondary Indicator	Score Before Optimization	Score After Optimization
Physiological Comfort (30%)	Muscle Fatigue Degree	62.3	86.5
	Visual Comfortability	58.7	86.9
	Auditory Comfortability	55.2	84.3
	Sleep Quality	66.5	88.4
	Physiological Health Impact	70.1	85.7
Psychological Comfort (25%)	Emotional State	60.2	86.8
	Space Satisfaction	57.8	86.5
	Cognitive Load	59.3	84.6
	Sense of Belonging	61.5	85.9
Functional Comfort (25%)	Space Utilization Rate	56.4	87.8
	Furniture Adaptability	54.7	87.8
	Circulation Rationality	58.9	86.3
	Storage Function	53.2	85.6
	Elastic Adaptability	55.8	84.7
Environmental Adaptation (20%)	Lighting Parameters	54.3	85.8
	Color Parameters	52.6	85.8
	Acoustic Parameters	50.4	83.9
	Temperature & Humidity Parameters	71.3	84.2
	Ventilation Effect	68.5	83.7
	Barrier-Free Adaptation	62.7	84.1
Overall Score	–	58.6	87.2

3) Case 3: Senior Apartment

Optimization increased circulation rationality from 55.8 to 89.2, and the perceived passage convenience for elderly participants improved from 5.2 to 8.7 (on a 10-point scale), demonstrating enhanced alignment with the physiological needs of older adults, shown in Table 3.

TABLE 3. Comfort Evaluation Score Comparison of Senior Apartment Before and After Optimization (Unit: Score)

Secondary Indicator	Score Before Optimization	Score After Optimization	Improvement Rate
Muscle Fatigue Degree	59.6	88.3	48.2%
Visual Comfortability	56.4	87.5	55.1%
Auditory Comfortability	63.2	85.8	35.8%
Sleep Quality	64.7	89.1	37.7%
Physiological Health Impact	68.3	86.9	27.2%
Emotional State	61.8	88.2	42.7%
Space Satisfaction	59.3	89.4	50.8%
Cognitive Load	62.5	86.7	38.7%
Sense of Belonging	63.7	87.6	37.5%
Space Utilization Rate	64.2	85.3	32.9%
Furniture Adaptability	57.5	88.6	54.1%
Circulation Rationality	55.8	89.2	60.0%
Storage Function	62.4	84.5	35.4%
Elastic Adaptability	60.7	83.8	38.1%
Lighting Parameters	53.8	88.9	65.2%
Color Parameters	54.2	87.3	61.1%
Acoustic Parameters	65.7	84.6	28.8%
Temperature & Humidity Parameters	72.4	85.3	17.8%
Ventilation Effect	70.6	84.9	20.3%
Barrier-Free Adaptation	48.6	89.7	84.6%
–	60.5	88.3	46.0%

D. ANALYSIS OF EVALUATION RESULTS

1) Comprehensive Effect Analysis

The average comfort score improvement across all cases was 37.2%. Small apartments exhibited the greatest improvement (47.9%), followed by senior apartments (46.0%) and ordinary residences (36.0%), validating the effectiveness of the proposed optimization system. Key findings include: Functional Comfort: Average improvement of 39.5%, notably in space utilization, furniture adaptability, and circulation rationality.

Environmental Adaptation: Average improvement of 42.6%, particularly in lighting, color, and acoustic parameters, aligning with ergonomic standards.

2) Case-Specific Optimization Analysis

Ordinary Residence: Greatest improvements were observed in elasticity and furniture adaptation (47.1% and 46.9%), meeting the diverse needs of families with children.

Small Apartment: Significant gains in space utilization, storage, and acoustic performance (over 50% improvement), addressing the challenges of limited space.

Senior Apartment: Marked improvements in accessibility, lighting, and circulation (over 60%), tailored to the physiological and safety requirements of elderly residents.

VIII. CONCLUSION

This study systematically investigates the application and optimization of ergonomic principles in modern residential interior design, emphasizing the integration of functional materials to enhance the synergy between human physiological needs and the built environment. The findings demonstrate that designs informed by anthropometric and biomechanical data significantly improve spatial comfort and usability—through the rational planning of storage, optimization of furniture dimensions, and circulation layouts, physical strain is reduced and efficiency is enhanced. Comfort assessments confirm that schemes integrating both static and dynamic user needs yield superior physiological adaptability and psychological satisfaction. Future advancements will further integrate intelligent technologies and smart systems, paving the way for personalized, adaptive living environments and providing a robust scientific foundation for the development of healthy residential spaces.

AUTHOR CONTRIBUTIONS

Shengze Wu designed, collected and analyzed the data, and drafted the manuscript. Shengze Wu conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Shengze Wu participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This studywas approved by the Ethics Committee of Haikou Univer-sity of Economics and was performed in accordance with the principles of the Declaration of Helsinki.
All eligible participants signed an informed consent form.

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