Building and Environment 267 (2025) 112268

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Indoor comfort domains and well-being of older adults in residential settings: A scoping review

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ARTICLE INFO

Keywords:
Indoor comfort
Multi-domain environmental impact
Older adults
Residential settings
Well-being

ABSTRACT

This study provides a comprehensive scoping review of the literature on the well-being of residential environments for older adults, addressing multiple domains of indoor comfort. The aim is to investigate the gap in environmental standards research for older adults, acknowledging the global challenge of an ageing population. As residential settings become the primary living spaces for older adults in later life, the interrelated domains of indoor comfort significantly impact their well-being. The concept of "Aging in Place" underscores the importance of appropriate indoor comfort design to enhance the autonomy of older adults. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), this scoping review establishes a broad scientific foundation for future research by identifying, analysing, and categorising existing studies on indoor comfort domains for older adults. The review investigates, in total, 173 studies in six domains of indoor comfort: thermal, air quality, visual, acoustic, ergonomic, and multiple domains, highlighting existing knowledge gaps and suggesting possible directions for future research. There is a growing trend toward holistic research methods integrating physical, psychological, and social factors in indoor comfort research for older adults. The definition of indoor comfort needs and levels for older adults varies across regions due to cultural, climatic, and residential type differences. Furthermore, design recommendations across multiple domains present contradictions that need careful evaluation and application by designers and engineers. Future research could focus on adaptive long-term health impacts and integrate findings across indoor comfort domains to inform policy and practice in residential settings.

1. Introduction

1.1. The global challenge of population ageing

Population ageing is an essential topic of global significance, driven by increased life expectancy and declining birth rates, resulting in a significant increase in the proportion of the older population [1]. As a remarkable challenge for developed countries, this demographic shift has become a worldwide phenomenon affecting healthcare systems, economies, and social structures [2]. According to the United Nations, the proportion of the population aged 65 and over has increased significantly. It is expected to continue to rise, with profound consequences for health care services, resource allocation and social attitudes towards ageing [3]. Life expectancy is higher in developed countries, birth rates are low, and there are long-term challenges in adapting healthcare systems to meet the specific needs of older adults, such as managing chronic and age-related conditions [4,5]. Meanwhile, developing countries are undergoing rapid demographic transitions due to healthcare and socioeconomic development improvements, necessitating rapid healthcare infrastructure adaptation [6,7]. Overall, the global ageing trend highlights the need for comprehensive strategies and innovative solutions to ensure the well-being and dignity of the ageing population.

1.2. Older adults' well-being and aging in place

The growing interest in Ageing in Place (AIP) reflects a significant shift in how society adapts to an ageing population [8,9]. The concept encourages older adults to remain in their homes and communities as they age, driven by personal preference, cost-effectiveness and potential quality-of-life benefits [10]. Many older adults prefer to live in familiar surroundings to maintain their social connections and sense of

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https://doi.org/10.1016/j.buildenv.2024.112268
Received 12 August 2024; Received in revised form 27 October 2024; Accepted 3 November 2024
Available online 7 November 2024

autonomy, contributing significantly to their overall well-being [9–11]. AIP is often considered a type of in-home care. It is a cost-effective alternative to living in home settings, which can reduce the financial burden on individuals and governments. However, this approach poses challenges, such as ensuring adequate support services and adapting living space to adapt to changing needs [12]. In addition, AIP has evolved to include a broader definition that provides for ageing in the community or a residence of one's choice [13]. Therefore, it provides more flexible options to meet different needs. As policies continue to promote ageing in place, these challenges must be addressed to ensure older adults can live safely, comfortably, and independently in the living environment of their choice.

1.3. Older adults' well-being and indoor comfort domains

In the Oxford English Dictionary, 'well-being' means a person or community, the state of being healthy, happy, or prosperous; physical, psychological, or moral welfare [14]. The well-being of older adults is a multifaceted concept, with both physical and environmental aspects being crucial. Physically, happiness is often associated with good health, energy, and the ability to perform daily activities independently [15]. Environmentally, place attachment plays a crucial role, with emotional ties to familiar places and the instrumental value of place supporting daily life and enhancing a sense of identity and continuity [16–18]. These integrated views highlight the importance of addressing the built environment to promote the well-being of older people in various settings, particularly in high-density urban areas [19,20].

Human comfort includes the physical aspects of a home environment, such as thermal, visual, ergonomics, acoustic and air quality [21]. Comfort is a state of physical ease, relaxation, and freedom from distress. When designing a building, it is crucial to ensure the environment is comfortable for its occupants [22]. For example, a well-maintained and comfortable indoor environment is crucial for older adults, as poor conditions, such as leaks, damps, or musty smells, can lead to increased rates of depression and anxiety [23]. Factors such as humidity, ventilation, lighting, and tidiness also play a crucial role. Keeping older adults' indoor environment dry and tidy is essential for physical and mental health. For instance, proper kitchen ventilation can also significantly impact mental health, as it helps reduce indoor air pollution from cooking, which has been linked to symptoms of depression and anxiety [24]. Older adults' comfortable bedroom environment is associated with lower anxiety symptoms, possibly due to improved sleep quality [20, 25]. Managing indoor temperatures is critical because older adults are more susceptible to the health effects of changing temperatures. For example, poor thermal conditions can lead to cardiovascular and respiratory problems, highlighting the importance of adequate home heating and insulation [23,26]. Noise levels and air quality are essential indoor environmental factors. For instance, excessive noise and poor air quality can exacerbate symptoms of dementia and other cognitive impairments, suggesting that these factors must be carefully managed to improve the quality of life for older adults in residential care settings [23,27]. These indoor comfort domains can significantly enhance older adults' ability to manage daily activities and maintain independence in domestic space. Hence, in scoping progress covering indoor comfort, this study identified several essential indoor comfort domains for older adults, including thermal, visual, air quality, and acoustics.

While outdoor environments are considered equally important to older adults' health and well-being, based on the mobility and activities of older adults' daily routines in their later life, this study sets the scope to indoor space [28–30]. Specifically, this study focuses on adaptations to the domestic environment as home modifications [31]. Factors related to human comfort, including thermal comfort, lighting, acoustics, ventilation, and air quality, are closely related to the well-being of older adults [32].

Therefore, the well-being of older adults in indoor comfort must be understood through the lens of their daily activities. This perspective can connect gerontological insights with building environmental research to better address the comfort needs of older individuals. This study outlines a broad framework and reviews relevant literature on physical indoor comfort for scholars. It also suggests future research directions to improve older adults' well-being in residential environments using a two-step scoping review approach.

(1) As a first step, research on the physical indoor environment and its impact on older adults' well-being was reviewed and categorised. This helps assess whether current conclusions and recommendations are adequate for defining and regulating spatial quality in the context of ageing.
(2) The second part focuses on analysing specific domains of indoor comfort for older adults, including thermal, visual, air quality, acoustics, and ergonomics.

2. Method

2.1. Study setting

This study employed a scoping review methodology, a crucial tool for examining the breadth and depth of existing literature on a topic [33]. This approach identified existing knowledge gaps and provided a comprehensive summary of research findings, enhancing our understanding of the scope and detailed characteristics of the research area [34–36]. This paper focused on age-friendly, health, and well-being considerations in physical indoor comfort domains in residential settings. The research steps of this article included: 1. Identifying the research questions; 2. Identifying relevant studies; 3. Study selection; 4. Charting the data; 5. Collecting, summarising and reporting the results.

2.2. Identifying the research question

The following Research Question guided the scoping review:

How do multiple environmental factors related to indoor comfort domains, including thermal, air quality, visual, acoustics and ergonomic, impact the well-being of older adults living in residential settings?

This research question is mainly related to the well-being of older adults and indoor comfort in residential settings. The following sections, from 2.3 to 2.6, outline the screening procedures, inclusion and exclusion criteria, categorisation methods, and analysis techniques used in the study. Literature searches were conducted over a substantial period, from 15 Nov 2021 to 20 May 2024, ensuring a comprehensive review of the available literature.

2.3. Identifying relevant studies

To address the identified Research Question, the authors conducted searches on the Web of Science [37], Scopus [38] and PubMed [39] databases as detailed in Table 1. It presented the search query utilising Boolean "AND" and "OR" operators between keywords designed for the Research Question, targeting all studies concerning indoor comfort and well-being of older adults. This query incorporated common keywords, including terms of older adults, residential settings and indoor comfort domains, resulting in Table 1.

Some grey literature, such as design guidelines, was added through targeted searches [40]. Following the recommendations [41], the grey literature searching involved examining the bibliographies of papers found in the databases and conducting web searches on the topic, including those from professional association websites.

2.4. Study selection

The selection of literature from the primary search on the Web of Science database, Scopus and PubMed was guided by the following

Table 1
Keywords for research question: older adults' well-being and indoor comfort domains.

Older adults and residential settings				Well-being and indoor comfort domains				
Term 1 (OR)	AND	Term 2 (OR)	AND	Term 3 Multiple (OR)	AND	Term 4 Domains (OR)	OR	Term 5 Domains (OR)
Older adults; Elderly; Aging; Aged; Senior Citizen;		Living space; Home; Residential setting; Domestic;		Indoor comfort		Thermal comfort		Temperature; Thermal; Thermal environment; Humidity; Thermo-hygrometric; Hygrometric; Thermo-reception; Thermoreception; Thermo reception
						Visual		Light; Daylight; Visual environment; Light environment; Lighting; Daylighting; Natural view; Sight; Color; Colour; Sense of sight
						Air quality		Olfactory; Odor; Odour; Sense of smell; Smell olfaction; Particulate Matter; Volatile Organic Compounds; Ventilation
						Acoustic		Acoustic; Noise; Sound; Sense of hearing; Acoustical; Hearing
						Ergonomics		Spatial Ergonomics; Accessibility; Anthropometrics; Adjustability; Postural Support

procedure:

- The full texts of the articles that passed the initial screening were accessed and read through open-access resources or the authors' institutional library subscriptions.
- In Internet browsers, automated Plug-ins, such as Easy-scholar [40], exclude articles and journals with lower research quality based on partitions and irrelevant literature types. The authors reviewed them to avoid potential discrimination in unconscious research areas.
- All literature was imported into Zotero [42] for duplication detection to prevent duplication of titles and abstracts. Duplicate articles identified in the primary search will be excluded from the count.
- Streamline the screening process by sorting results by relevance and date, ceasing the review of articles once no additional relevant studies are found.
- Studies were determined whether they addressed the Research Question. As shown in Table 3, the indoor comfort domains, the age group of older adults, the research method, the gender findings, and the living arrangements were considered.

Articles identified through targeted searches were either included or excluded following a comprehensive reading and review of each paper. During the screening process, at least two people in the team (including the authors and the research assistants) read the article and made a comprehensive judgment on whether to include or exclude it based on the criteria in Table 2. If there is any controversy, a third person needs to intervene. Details concerning each phase of the process and the number of articles included and excluded at each stage are presented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart [43] in Fig. 1.

2.5. Charting the data

The data charting process was systematically undertaken by outlining key findings from the primary papers that addressed the research question. Initially, the lead author compiled the data into a structured spreadsheet, which included detailed information extracted from each paper [44]. This information comprised the following variables: author (s), year of publication, research techniques employed, type of publication, and the study's subject field relevant to indoor comfort concerning older adults' well-being within residential settings. Bar graphs and tables were utilised to report findings across comfort domains effectively. Additional variables in the spreadsheet included gender and age, research methodologies, the number of studies reviewed, and specific residential contexts.

2.6. Collecting, analysing, summarising and reporting the results

Table 3 provides a detailed explanation of the considerations outlined in Section 2.5 for collecting and synthesising literature in this study. The scoping review focused on the intersection of older adults' well-being and the indoor environment, mainly targeting the research question on indoor comfort and categorising the findings into indoor building environment domains, as listed in Table 3. The identified domains relating to older adults' well-being included (a) thermal, (b) visual, (c) air quality, (d) acoustics, (e) ergonomics, and (f) multi-domain studies.

After thoroughly reviewing each article's full text, the literature was assigned to the corresponding domain(s). Notably, some studies spanned multiple domains, indicating overlapping findings; these were classified as 'multi-domain'. Additionally, further categories were identified to enhance the characterisation of research on indoor comfort and older adults' well-being within the scoping review. These included age [45], residential setting [46], gender [46], research method, and literature type, with details provided in Table 3.

3. Result

The study included 173 publications addressing the Research Question, as detailed in the PRISMA flow diagram (Fig. 1). As Fig. 4-C illustrates, the majority of these publications were ordinary journal research articles ($n = 147$), supplemented by journal review papers ($n = 12$), conference papers ($n = 5$), and one book or book chapter ($n = 1$). The small number of books or book chapters is because the search tools used in this study (Web of Science, Scopus, PubMed) are mainly collections of academic journals and conference papers. Additionally, reports ($n = 6$) from professional organisations, categorised as grey literature, were included.

The scoping review spans two decades of research from 2004 to 2024, with a significant increase in publications in recent years. Geographically, the research distribution (see Fig. 4-A) is as follows: Asia ($n = 68$), Europe ($n = 73$), North America ($n = 23$), Oceania ($n = 11$), and South America ($n = 4$). Global research on indoor comfort and well-being for older adults has significantly increased, especially since 2015, with Asia and Europe at the forefront and North America showing consistent growth (see Fig. 2). In contrast, Oceania, South America, and Africa have contributed less, suggesting gaps in research focus. The number of studies peaked in 2022 with around 25 publications globally but saw a slight decline in 2023, likely due to the impact of the Covid-19 pandemic.

As Fig. 4-D demonstrates, a significant number of studies are categorised under environmental science ($n = 65$), public health related to the indoor environment ($n = 49$), building physics ($n = 32$), engineering

Table 2
Criteria of inclusion and exclusion.

Criteria	Inclusion	Exclusion
Age Group	Studies primarily focused on older adults or individuals of retirement age and above, as defined by the study region. Review paper on all-age indoor comfort with key messages relevant to older people	Studies that are not exclusively cantered on older adults of retirement age or above.
Type of Space	Indoor environments.	Semi-public or outdoor spaces, including semi-outdoor areas such as stairways, awnings, and outdoor corridors.
Residential Space	General residences, care homes, or institutions specifically serving older populations.	Studies not exclusively focused on residential settings for older adults.
Subject Focus	Research pertaining to environmental science, public health in relation to indoor environments, architectural design, the built environment, or social sciences.	Studies cantered on clinical medicine, toxicology, biology, computer science, or artificial intelligence, related to physical ageing but not indoor comfort.
Research Intervention	Investigations that address at least one domain of indoor comfort (thermal, air quality, visual, acoustics and ergonomics), with relevant monitoring, evaluation, survey or assessment.	Studies examining well-being in non-indoor comfort domain.
Research Outcome	Research providing analysis and conclusions on at least one aspect of indoor comfort: thermal comfort, lighting, acoustics, ventilation, or air quality.	Studies reporting only on non-indoor comfort outcomes, such as frameworks for improving older adults' general well-being, or psychological and sociological research on quality of life improvements. Only interpretation of policy documents.
Study Design	Quantitative, qualitative, mixed methods research, environmental monitoring, computer simulation, case analysis, or literature review.	Study protocols; not an empirical study; a brief description of existing research
Language	English.	Not English.
Type of Publication	Peer-reviewed journal articles, book chapters, or conference proceedings indexed by Web of Science, Scopus, or PubMed.	Non-peer-reviewed publications, proceedings, presentations, theses, essays, dissertations, commentaries, working papers and editorials.

For the inclusion of grey literature in the scoping review, the criteria are as follows:
1. The source must originate from a professional organization or public service department, ensuring credibility and authority.
2. The content should reference the opinions and experiences of recognized experts in the field, contributing valuable insights and practical perspectives.
3. The material must draw upon or cite conclusions from scientific research, demonstrating a connection to established evidence or scholarly work.
4. Grey literature can be reports or public documents.
Sources that do not meet these criteria, such as those lacking professional or authoritative backing, expert insight, or reference to scientific evidence, are excluded from the review.

($n = 14$) and social sciences ($n = 7$). Additional statistical details can be found in the Supplementary Materials (Table A).

As depicted in Fig. 5-D, the majority of the papers examining the indoor comfort domains for older adults focus on thermal ($n = 53$). This is followed by studies on air quality ($n = 49$), multi-domains ($n = 31$), visual ($n = 16$), ergonomics ($n = 12$), and acoustics ($n = 6$). Fig. 3 highlights the research trend from 2003 to 2023, and thermal comfort emerged as the most extensively explored domain. In contrast, acoustic receives considerably less attention and is often integrated into studies addressing multiple domains. The number of studies across all domains has increased noticeably after 2015, with significant growth in multi-domain, thermal, and air quality research. Thermal and air quality are the most extensively studied, likely due to their direct impact on older adults' comfort and health. Publications in these areas have risen sharply since 2015. The growing trend in multi-domain studies reflects a shift toward understanding indoor comfort holistically by considering the interaction of various environmental factors.

Regarding research methods (see Fig. 4-B), the most prevalent approach (64 studies, F4) involved physical monitoring of environmental changes. This was followed by research focusing on older adults and stakeholders' needs and preferences, conducted through questionnaires and interviews (36 studies, F3). Other methods included architectural case analysis (3 studies, F2), guidance on home building space design (5 studies, F5), and literature reviews (9 studies, F1). Additionally, 55 studies employed a combination of multiple research methods.

Regarding the age groups of subjects studied, as depicted in Fig. 5-A, some studies ($n = 95$) highlighted findings of the third age, while others ($n = 78$) addressed the fourth age. Some studies ($n = 54$) did not specify particular age groups within the older adult population. In terms of housing type, studies highlighted the living arrangements of older adults as assisted living ($n = 85$) and independent living ($n = 75$), with a few ($n = 14$) not specifying the housing type. In terms of findings in gender, the majority of studies ($n = 100$) provided general gender findings, followed by findings specifically for female older adults ($n = 12$) and male older adults ($n = 1$). In addition, many studies sampled significantly more female participants than male participants.

Table 4 summarises older adults' indoor comfort across multiple domains, categorised by subject and corresponding interventions, with references supporting these findings. Similarly, Tables 5 through 9 cover different domains of indoor comfort: Thermal (Table 5), Air Quality (Table 6), Visual (Table 7), Acoustic (Table 8), and Ergonomic (Table 9), each providing key subjects and interventions for their respective areas. Fig. 6 shows the overall relationship between the domains and subjects included in the study. Table A (Appendix, Supplementary Material) reports all the details from studies potentially related to indoor comfort domains for older adults, including all the parameters above.

4. Discussion

4.1. Current research focus areas

Over the past five years, research on indoor comfort for older adults has notably increased, particularly in Asia, with a significant focus on China due to its rapidly ageing population. However, there remains a lack of studies from Southeast Asia, Central Asia, the Middle East, and Africa, likely due to younger populations and language barriers in English-language research (see Figs. 2 and 4). As these regions experience demographic shifts, an increase in related studies is anticipated in the coming decades. Section 4.1 summarises indoor comfort focus for older individuals below by different domains. In Section 4.2, the author discussed the weaknesses and considerations of the included studies:

4.1.1. Thermal

Current research on indoor thermal comfort incorporates a variety of methodological approaches to capture and analyse environmental and perceptual data. Field measurements play a pivotal role, with numerous studies utilising instruments such as HOBO data loggers, Delta Ohm devices, and iButtons to monitor key environmental parameters like air temperature, humidity, and air velocity [107,109,122]. Subjective assessments often complement these objective data through standardised surveys, most commonly employing the 7-point ASHRAE Thermal Sensation Vote (TSV) or thermal preference scales. Frequently, such surveys are integrated with field measurements and analysed using Griffiths' equation, accounting for variables like clothing insulation and metabolic rate to refine the understanding of occupant comfort levels

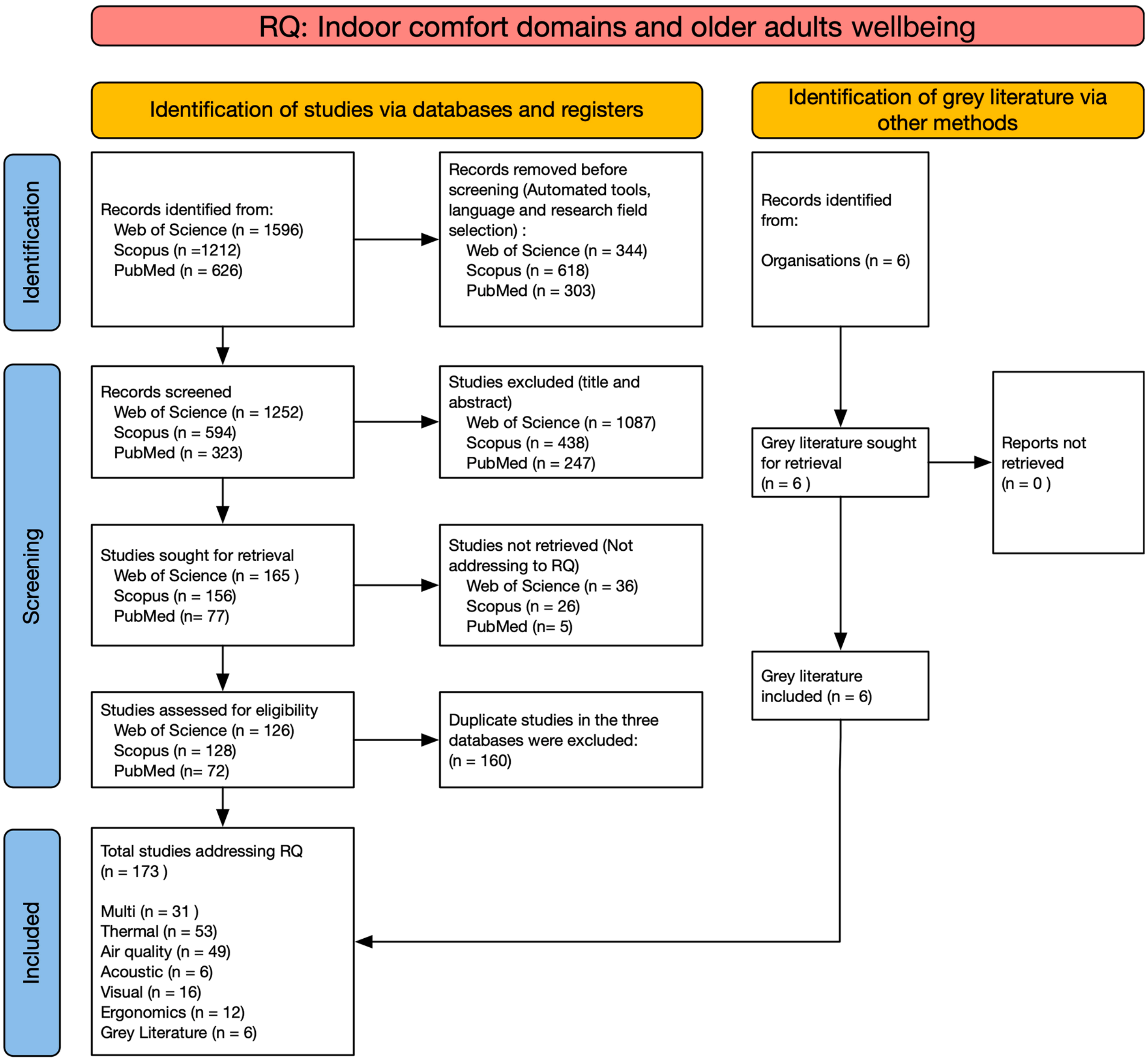

Fig. 1. PRISMA flowchart.

[111,116,122]. Additionally, mixed-method approaches have gained prominence, combining qualitative techniques such as interviews and focus groups with quantitative measurements. This combination provides a richer perspective, particularly valuable for studying thermal comfort perceptions among older adults [114,121]. Simulation and statistical analysis further extend these studies, with tools like ENVI-met, Fluent Airpak, and EnergyPlus used to model thermal environments and evaluate design impacts, particularly in scenarios involving outdoor comfort and climate adaptation [128,217].

4.1.2. Air quality

Indoor air quality research frequently employs cross-sectional and longitudinal designs to investigate the health impacts of air pollutants on vulnerable populations, particularly older adults, by capturing environmental conditions and associated health outcomes over extended periods [24]. Interdisciplinary approaches are evident as studies integrate clinical assessments, such as spirometry, with epidemiological data, encompassing surveys and environmental assessments to reinforce collaboration between medical and environmental researchers [135]. The complexity of indoor air quality dynamics is further addressed through multisite sampling, which spans various geographic locations or seasonal intervals, thus capturing variability in pollutant levels across different spatial and temporal scales [136]. Sensor-based real-time monitoring technologies, including Long Range Wide Area Network (LoRaWAN) and PM2.5 monitors, enable continuous tracking of indoor pollutants like CO_2 and VOCs, providing precise environmental data for immediate analysis [181]. Health risk modelling and simulation tools are extensively utilised to predict health outcomes and support policy-making. Models such as Wells-Riley assess infection transmission risks, while other epidemiological models forecast cognitive decline due to particulate exposure; in parallel, simulation tools like CONTAM are employed to inform policy through predictive modelling of health impacts [218].

4.1.3. Visual

Research on indoor visual environments integrates a multidisciplinary approach, blending environmental psychology, architecture, and interior design within virtual and simulated settings. These studies utilise tools such as Rhinoceros and Grasshopper to model real-world conditions, allowing for precise control over variables like lighting, wall coverage, and layout, thereby supporting experimental rigour in environmental assessments [186]. Advances in human-centred technological approaches demonstrate the application of artificial neural networks (ANN) for optimising lighting conditions in elderly care facilities,

Table 3
Categories of collecting, summarising and reporting the results.

Category		Subcategory	Subcategory ID
Main Categorisations	(a) Indoor comfort older adults' well-being	Related to the thermal	a1
		Related to the visual	a2
		Related to air quality	a3
		Related to the acoustic	a4
		Related to the Ergonomics	a5
		Related to multi-domain aspects	a6
Additional Categorizations	(b) Age of subjects	Third age	b1
		Fourth age	b2
	(c) Gender of subjects	Male	c1
		Female	c2
		General	c3
	(d) Type of residential setting	Assisted Living.	d1
		Independent Living	d2
	(e) Type of studies	Journal Article (ordinary research)	e1
		Journal Article (review paper)	e2
		Conference Proceedings (ordinary research)	e3
		Conference Proceedings (review paper)	e4
		Report	e5
		Book/Book Chapter	e6
	(f) Type of methods	Recommendation based on previous literature	f1
		Paper presenting case studies where principles of indoor design for older adults were applied	f2
		Study using questionnaires or interviews with older adults, stakeholders and/or experts to highlight aspects in indoor design for older adults	f3
		Study on the effects on older of change of the environment (Environmental monitoring)	f4
		Study defining a threshold for indoor environmental design (Design recommendation)	f5

Age group: not all definitions of third-age and fourth age prescribe age range. This study adopted the following explanation for better classification of data statistics [47,48].
1. Third age: Individuals aged 60–79 years, typically experiencing active retirement and relatively good health [45].
2. Fourth age: Individuals aged 80 years and over, often facing increased stigma, societal stereotypes, and more significant health challenges [45].
3. Gender of subject: the conclusion of the study clearly states the findings about females and males. If not, count as general [46].
4. Assisted Living: residential programs providing personal care and assistance with daily activities, and responding to unscheduled needs [49].
5. Independent Living: A range of skills including managing the home, money, meals, hygiene, and emergencies [50].

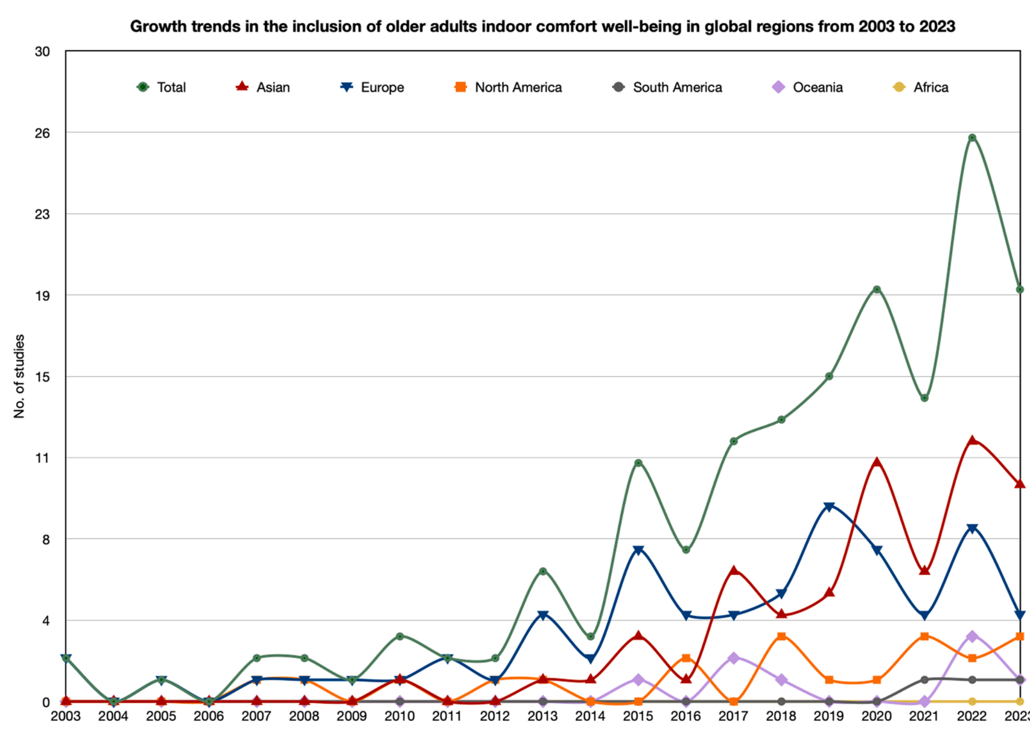

Fig. 2. Growth trends in the inclusion of older adults' indoor comfort domains in major global regions from 2003 to 2023 (The data for 2024 is still ongoing and is not presented in this trend chart).

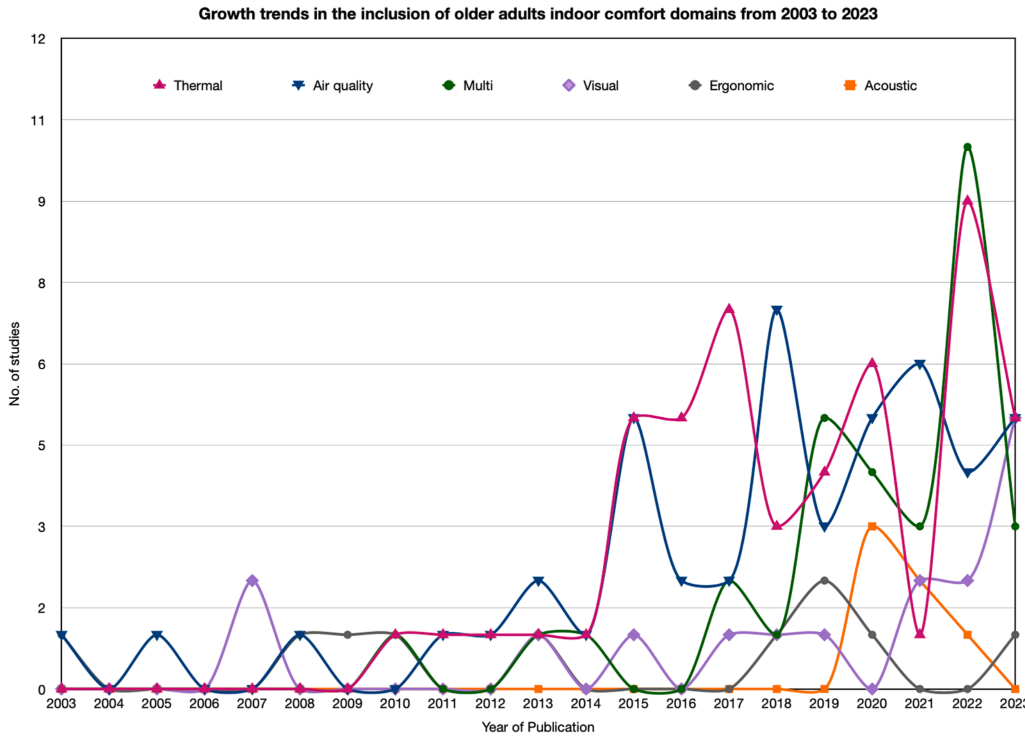

Fig. 3. Growth trends in the inclusion of older adults' indoor comfort well-being in global regions from 2003 to 2023 (The data for 2024 is still ongoing and is not presented in this trend chart).

often combining data science methodologies with engineering tools like MATLAB to enhance energy efficiency and occupant comfort [219]. A significant aspect of these studies is integrating physiological and psychological data. Semantic Differential methods and metrics such as heart rate and blood pressure are employed to gauge environmental impacts on health and well-being [195]. Lighting design research, particularly concerning chronobiology, has shown that specific lighting types, such as blue-enriched or daylight-mimicking LEDs, can benefit older populations by improving sleep quality, mood, and overall health outcomes [183,192]. Finally, elderly-centric design studies focus on enhancing the navigability of spaces and the visual comfort of environments for dementia patients, with structural equation modelling (SEM) applied to elucidate the relationships between environmental factors and health outcomes [184,196].

4.1.4. Acoustic

Research on indoor acoustic environments employs objective and subjective methodologies to assess sound quality and its impact on occupants, particularly older adults. Objective measurements in numerous studies utilise acoustic instruments, including sound level meters and omnidirectional sources, adhering to ISO standards for Reverberation Time (RT) and Sound Pressure Level (SPL) analysis. These standardised approaches provide quantifiable data on noise levels and sound quality across varied settings, contributing to a more precise understanding of acoustic environments [200,202]. Complementing these objective measures, subjective data collection through field surveys, interviews, and questionnaires captures qualitative insights into older individuals' sound perceptions and preferences, enriching the understanding of acoustic comfort from a user-centred perspective [203,204].

4.1.5. Ergonomic

Current ergonomic research integrates mixed-method approaches, blending qualitative and quantitative techniques such as fieldwork, surveys, and interviews to understand ergon [205]. Additionally, studies employ cross-sectional and longitudinal designs, where longitudinal data assess long-term ergonomic effects, and cross-sectional methods evaluate immediate accessibility and usability concerns [205]. This combination of methods provides a multidimensional view, capturing both the immediate and extended impacts of ergonomic interventions on usability and user comfort [206,208,213].

4.2. Weakness and potential suggestion

Based on the research trend of Section 4.1, in the field of indoor comfort research for older adults, the main weaknesses and potentials suggested by the nature of the included studies are:

- Many studies depend on subjective self-reported thermal sensory data, which may be unreliable, particularly for older adults with cognitive or communication difficulties. To enhance accuracy, objective measures like skin temperature and infrared thermography should supplement subjective data [103,113]. Additionally, self-reported data on falls, daily activities, or housing conditions may introduce recall bias, particularly needing a validation method [206,207]. Some studies underreport behavioural factors, such as window-opening behaviours, while research did not fully consider shifts in building occupancy patterns, which significantly impact indoor air quality [178]. In contrast, many studies prioritise the overemphasis of objective environmental data; qualitative insights regarding personal experiences are often insufficiently integrated. This imbalance limits understanding of how subjective well-being interacts with ecological conditions, hindering a holistic approach.
- Many studies have limited generalisability constrained by narrow population samples or specific geographical contexts, limiting the applicability of findings to broader populations. The lack of diversity in socio-economic and cultural backgrounds further restricts the generalisation of thermal comfort preferences. Research often focuses on specific environments, such as individual nursing homes or urban settings, with small sample sizes, reducing the broader relevance of the findings [156]. More studies involving diverse

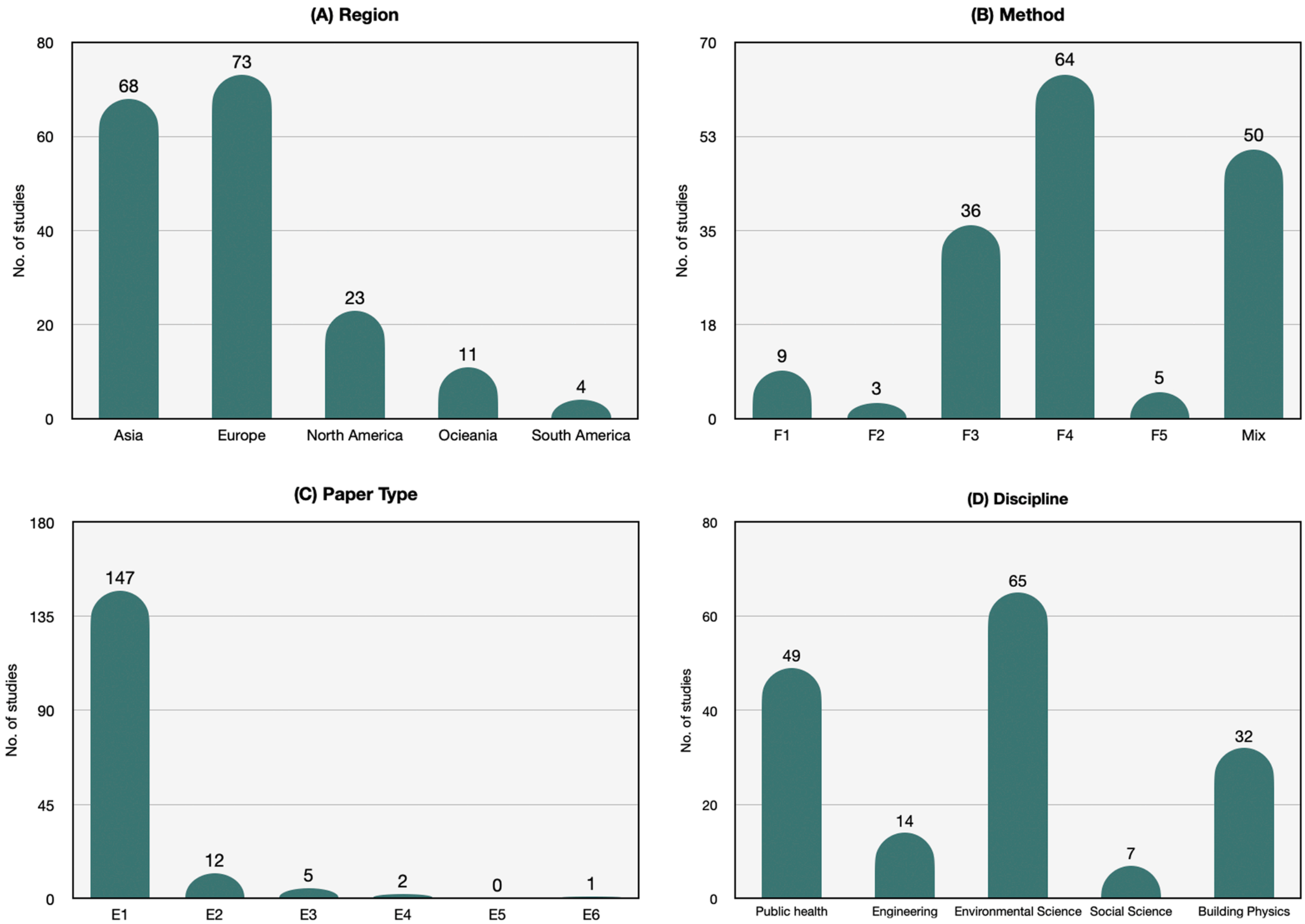

Fig. 4. Statistics about included studies, answering research question (A) Region (B) Methods (C) Paper Type (D) Domains. (Definition of method and paper type refer to Table 3).

populations and geographic regions are needed for comprehensive conclusions.

- Research on older adults with under-representation cognitive impairments, such as dementia, concerning thermal comfort is limited. While some studies address dementia-related populations, there is a gap in understanding how various physical and cognitive impairments affect thermal comfort needs [113]. This under-representation restricts insights into tailored interventions for vulnerable groups. Due to the complexity of this research topic, including interdisciplinary collaboration and ethics of dementia research, this may be a subject that the academic community needs to invest a lot of time in.
- Some studies use simulation models or a single healthy participant to generalise results [65]. This approach reduces ecological validity, as real-world factors like noise, social interactions, and distractions are not accounted for, which may affect actual user experiences. While simulations offer controlled conditions, they fail to capture the complexity of real-life environments [186].
- Many studies involve short-term monitoring or interventions over just a few days or weeks [183,197]. These limited time frames fail to capture long-term variations in environmental quality and health outcomes. The long-term effects and sustainability of interventions, such as light therapy, remain insufficiently explored, raising questions about the durability of their benefits.
- Academic researchers can enhance collaboration with professional bodies and practice groups. Interdisciplinary knowledge and cross-validation of inconsistencies and lessons learned are crucial for building environment design. Grey literature from various studies, such as design principles for extra care housing, interior considerations impact quality of life, accommodation with a support design guide, and design guide for independent living, provides architects and environmental science engineers with theoretical guidance for practical projects [220–225].

4.3. *Indoor comfort domains affecting older women*

Ten European, one Asian and one North American papers focus on older women's interior comfort. Older women in the community had a higher risk of indoor fall accidents due to visual comfort. Women with moderate or severe visual impairment showed an increased fall risk than those with adequate eyesight [185]. Jacobs et al. [163] discovered that particle air pollution raises pulse pressure in older women, especially those on antihypertensive medication, indicating cardiovascular risk. Almeida-Silva et al. [153] stressed the need for air quality monitoring because older women in care centres are exposed to air pollution. Bamzar [205] noted that senior housing with good indoor surroundings promotes mobility and well-being. et al. [154] and Bentayeb et al. [135] found that low indoor air quality harms respiratory health in older women in nursing homes, underlining the need for ventilation. Coelho et al. [177] connected indoor air pollution to home health issues. Fänge and Iwarsson (2003) [208] discovered that subjective usability ratings are essential for practical housing adjustments, emphasising the necessity of accessible and usable living situations for older women. Jin et al. [103] found that indoor thermal and humidity factors significantly affect older adults' comfort and skin condition, highlighting the necessity for ideal indoor climates. Finally, Lindemann et al. [82] found that older women's physical performance diminishes in cold interior

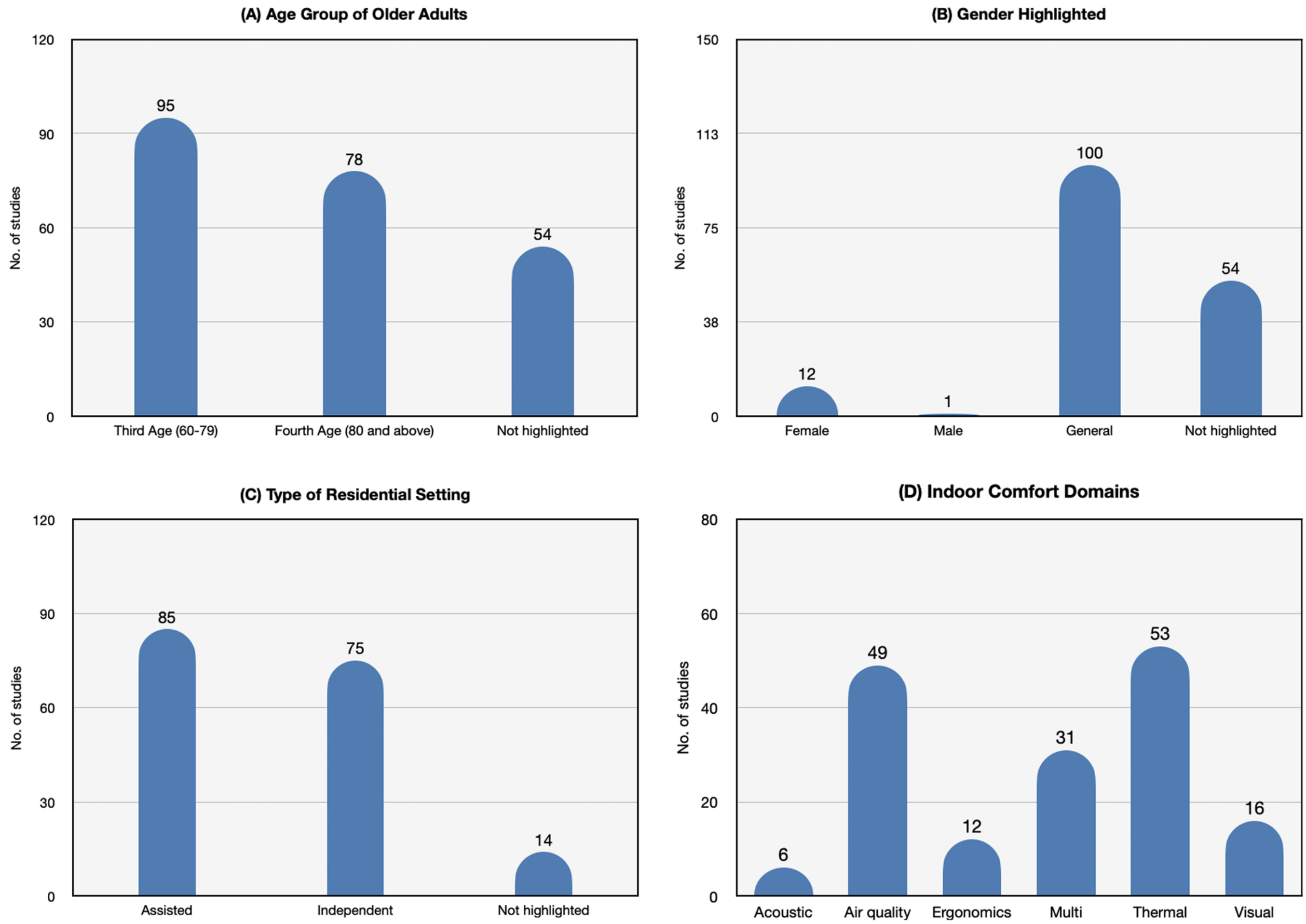

Fig. 5. Statistics about included studies, answering to research question (A) Age group (B) Gender highlight (C) Type of residential setting (D) Indoor comfort domains.

environments, raising fall risks and emphasising the need for proper heating. These studies emphasise the relevance of a healthy interior environment for older women's health and independence. A promising research direction could involve examining how gender-based physical differences in the elderly impact indoor comfort. This includes exploring gender-related variations in family interactions and user behaviours influenced by social divisions of labour better to understand the link between behaviour and indoor comfort.

4.4. Indoor comfort domains on third and fourth age older adults

Older adults in their third and fourth years have health issues influenced by their living conditions. Table 3 explains the definitions of older adults' third and fourth ages. Fourth-age older adults, who are older and frailer, are more sensitive to these issues. Third-age older adults benefit from improved air quality and temperature management, while fourth-age adults require more tailored climate control, illumination, and environmental fit to be healthy. Due to their susceptibility, the fourth-age group needs more targeted and tailored interventions.

Cold indoor conditions are associated with poorer biomarkers in blood and fewer blood pressure checks in third-age adults [85]. Fourth-age thermal sensations vary, especially amongst those with and without dementia, requiring personalised climate control in residential care [113]. Thermoregulation is crucial for this group because high indoor temperatures impair physical function [83]. Poor heating in winter can cause serious health problems, such as respiratory conditions, worsening of chronic obstructive pulmonary disease and infection [108].

Particulate air pollution significantly raises cardiovascular disease risk [163]. High nanoparticle concentrations in third-age nursing homes harm respiratory health, requiring better air quality control [135]. Poor indoor air quality affects fourth-age older persons' respiratory health even more, stressing the necessity for regular monitoring and improvement [154]. Person-environment fit predicts falls more than environmental dangers in the fourth age group, highlighting the necessity for tailored home adjustments [206]. Fourth-age older persons need specialised health management measures due to seasonal blood pressure fluctuations caused by temperature and lighting [95]. Research focused on age groups offers multiple benefits. It not only supports the well-being of older adults but also aids family members and caregivers in delivering improved services and reducing their responsibilities. Findings on age and indoor comfort can guide caregivers in optimising strategies to manage indoor environments more effectively.

4.5. Indoor thermal comfort and older adults' well-being

The studies on thermal comfort and health impacts in older adults highlight a critical trend towards understanding this demographic group's specific thermal comfort needs and vulnerabilities. Van Loenhout et al. [89] and White-Newsome et al. [98] highlight the health risks of high indoor temperatures, including sleep disruptions and dehydration. Additionally, rural home thermal performance is inadequate in China's severe cold regions, causing older adults to suffer due to insufficient insulation and heating [56,126]. Research consistently shows that older adults are more sensitive to temperature extremes, both cold and hot, due to physiological changes associated with ageing and often

Table 4
Key finding of multi-domain of older adults' indoor comfort categorised by subject.

	Subject of Multi-Domains	Correlation Intervention	Citation
1	**Physical health impact**	**Low temperatures** - harm older vulnerable groups **Insulation** - improves health, energy efficiency (1.8:1) **Mortality risk** - reduced in older adults with circulatory issues by insulation **Indoor environment sensitivity** - affects older adults, especially with limited mobility **Poor thermal environment** - increases risks (heat stroke, dehydration, hypothermia, death) **Poor Indoor air quality** - worsens respiratory health **Blood pressure** - increases at temperatures below 15 °C **VOC exposure** - raises risk of pulmonary decline **Age over 85** - less sensitive to humidity, odours	[51–56]
2	**Mental health impact**	**Bright rooms** - enhance physical, mental well-being **CO2 levels** - harmful to older adults, affect mental health **Bright lighting** - improves circadian rhythms, sleep, mental health in older adults **Lighting and colour** - improve social interactions, boost mental well-being in older adults	[54, 57–61]
3	**Indoor comfort preference**	**Low saturation, warm hues** - preferred by older adults for comfort **Warm white light** - moderate colour temperature favoured **Narrow thermal preferences** - age-related physical changes in older adults **Stronger lighting** - preferred, but lighting type has minimal effect **Thermal conditions** - most impactful on indoor comfort **Sound pressure levels** (55–65 dB) - ideal for older adults' comfort **Acoustic environment** - more critical for those with hearing impairments **Warmer indoor temperatures** - needed for comfort (above 25 °C), especially during inactivity **Functionality** - heating, thermal comfort prioritized over home size **Resident behaviour** - impacts indoor environmental quality (IEQ) **Older Women** - prioritize daylight, noise control, fresh air	[60–66]
4	**Indoor Environment Quality (IEQ) and design recommendation**	**Double-glazed windows** - raise CO2 without ventilation **Ventilated doors** - maintain CO2 balance **Avoid High humidity** - reduces thermal comfort in summer **Ventilation, system updates** - essential for comfort and pollutant control **Bed lighting** - enhances security, visibility, mood **High-rise apartments** - need bright, non-glare lighting **Enlarged windows, reflective materials** - improve lighting, reduce energy use **Fireplaces** - affect air quality, ventilation needed **Natural colours, soft materials** - preferred by older adults **IEQ optimization** - balances light, temperature, air quality for comfort **Handrail design** - impacts quality of life, needs improvement to prevent injure **Lack of insulation** - raises temperatures, pollutant levels, impacts thermal comfort	[52–54, 61,63, 67–73]
5	**Indoor facility management and user behaviour**	**Winter indoor temperatures** - drop to 15 °C, discomfort, reduced ventilation **CO2 levels** - decrease with bedroom doors half-open, rise with closed doors **Natural ventilation, behaviour** - strongly affect CO2 levels **Older occupants habit**- infrequent ventilation raises CO2 **Thermal control** - improves older adults' health and comfort, limited in care facilities **Pollutant monitoring** – contribute to air quality tracking **Noise** - minimal impact on acoustic comfort among indoor comfort domains **Daylight preference** - but curtains often kept closed due to glare or vision issues **Vision impairments** - influence light and glare management **Temperature adaptation** - with air conditioning, breathable clothing **Space management** - higher CO2 due to size, extended occupancy **Weakened immunity, respiratory issues** - make IAQ monitoring critical	[53,54,56, 61,74–77]
6	**Accident prevention strategies**	**Home retrofits** - prevent injuries, cost-effective for older adults **Fall risk predictors** - psychotropic medication, vision impairment, vertigo **Falls location**- in staircases, kitchens, bathrooms lead to longest hospitalizations **Bathroom falls** - occur during shower entry/exit, due to lack of safety measures **Night-time falls** - caused by bedcovers, cables, slippery floors **Fear of falling** - and reduced balance confidence increase risk	[51,78]
7	**IEQ in older adults with dementia**	**Warm temperatures** - aid self-care in care homes **Temperature control** - essential for older adults with low activity, impaired thermoregulation	[58,59,79, 80,244]

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Table 4 (*continued*)

Subject of Multi-Domains	Correlation Intervention	Citation
	Automatic air-conditioning - recommended in summer to support caregiver **Window management** - caregivers ensure comfort while ventilating **High colour contrast** - aids dementia patients, homelike decor promotes calm **Colour coding** - helps cognitive decline patients distinguish areas **Good lighting** - improves mood, sleep, reduces depression **Anti-scald devices** - recommended for dementia patients **Social interaction** - encouraged by furniture arrangement **Thermal comfort** - variable for dementia patients, more research needed **Passive temperature control** - better for dementia patients **Active, passive facades** - regulate indoor climate, secure manual windows **Proper ventilation** - essential, avoid noisy fans or drafts **Dry environments** - with antimicrobial coatings, non-slip floors, VOC-free materials **Minimize environmental changes** - use photos, signs, color-coded beds **Steady temperatures** - monitored, with heat-reflective curtains **Noise reduction** - sound-absorbing materials, personalized sound options.	

reduced mobility, which limits their ability to adapt to environmental conditions. Due to the climate crisis, these extremes are becoming more frequent and older adults experience little time to adjust/climatise [226].

A notable research trend is the focus on adaptive strategies and interventions to mitigate thermal discomfort among older adults. These include improving building insulation, adjusting heating and cooling systems, and encouraging behavioural changes like changing clothing or activity levels. According to Zheng et al. [123] and Zong et al. [107], adaptive thermal comfort models must account for seasonal fluctuations and ambient circumstances. Given climate change and the rising frequency of extreme weather events, focused public health measures and policy interventions must address older individuals' thermal comfort needs [226].

Overall, older adults need better-designed dwellings for thermal comfort. This includes upgrading home infrastructure and promoting community awareness and tools for managing heat and cold. Future research could enhance adaptive comfort models to improve thermal conditions in geriatric environments by exploring several key areas. Firstly, while existing studies largely focus on thermal comfort in nursing homes and exclusively older populations, limited attention has been directed towards mixed-age neighbourhoods, where thermal preferences may differ between individuals aged 60–75 and those over 75 [87]. As ageing demographics continue to grow, understanding thermal comfort in these diverse communities is increasingly relevant. Secondly, the potential of advanced technologies, including wearable devices and AI-driven HVAC systems, to provide personalised thermal comfort for older adults remains underexplored [227]. These

Table 5
Key finding of indoor thermal comfort domain of older adults categorised by subject.

Subject of Thermal Comfort Domain			Correlation Intervention	Citation
1	**Physical health impact**	**Decreased physical function**	**Cold homes** - reduce physical performance, grip strength in older adults **Cold temperatures** - impair muscle power, gait speed, functional capacity in older women **Perceived cold homes** - increase frailty risk in older adults **Temperature distribution** - impacts health outcomes in cold climates **Poor indoor thermal environments** - linked to negative health outcomes during heating seasons **Extreme temperatures** - elevate mortality and morbidity risks due to impaired thermoregulation	[81–87]
		Physical discomfort	**High indoor temperatures** - worsen mood, cause physical discomfort **Elevated temperatures** - lead to negative health perceptions, sleep issues, sweating **Cooling devices** - impact thermal comfort, skin temperature, efficiency **Age-related changes** - reduce thermal comfort (metabolic, vascular) **Extreme temperatures** - increase risk of hypothermia, heat stroke, pneumonia	[87–89]
		Effects of biomarkers blood pressure, and disease prevention	**Temperature fluctuations** - affect blood pressure, cardiovascular health **Cold homes** - linked to higher blood pressure, cerebrovascular disease, ECG abnormalities **High temperatures** -	[90–107]

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Table 5 (*continued*)

	Subject of Thermal Comfort Domain		Correlation Intervention	Citation
			increase cardiovascular strain **Blood pressure variations** - correlate with seasonal temperature and daylight changes **Poor insulation** - worsens biomarkers, reduces blood pressure monitoring **Minimum indoor temperature** - 18 °C recommended for cardiovascular, respiratory health **High humidity** - (RH > 60 %) raises health risks in summer **Energy retrofits** - improve temperature stability, no change in perceived comfort **Cold exposure** - linked to nocturia, suggests thermal modifications **Humidity and skin condition** - worsened in older adults, optimal temperature 24–26 °C **Home heating** - lowers blood pressure, improves cardiovascular health **Cold indoor temperatures** - increase fall risk **Warmer evening temperatures** - reduce sleep onset latency, improve sleep quality	
2	**Temperature preferences and adaptations**	**Neutral temperature**	**WHO recommended winter temperatures** - housing design should meet standards **Neutral temperature** - 25.6 °C for older adults, broader comfort range than younger adults **Thermal neutral temperatures** - 25.2 °C in summer, 23.2 °C in winter for older adults **Temperature regulation** - using windows, clothing, and fans, with seasonal comfort ranges **Rural vs urban** - higher thermal neutral temperatures in rural areas compared to urban with central heating	[108–111]
		Temperature perceptions	**Reduced thermal sensation** - in older adults with dementia, comfortable at lower skin temperatures **Temperature extremes** - above 28 °C, below 15 °C harm health, trigger adaptive behaviours **Temperature preferences** - 10–20 °C with thicker clothing, 22–26 °C in urban areas **Nursing home residents** - prefer higher temperatures, tolerate changes better than younger caregivers **Urban vs rural preferences** - urban 22–26 °C in winter, rural 10–20 °C with thicker clothing **Wider comfort range** - 20–28 °C due to adaptive behaviours **Thermal sensation** - dynamic, influenced by individual and environmental factors **Poor thermal comfort** - correlates with poor health and psychological well-being	[100, 112–119]
		Temperature preferences	**Warmer indoor temperatures** - preferred by older adults, less sensitive to changes **Comfortable temperature** - around 26.6 °C for most older adults **Optimal temperature** - approximately 25.3 °C **Higher clothing insulation** - and lower metabolic rates in older adults compared to caregivers	[100, 120–123]

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Table 5 (*continued*)

Subject of Thermal Comfort Domain			Correlation Intervention	Citation
3	**Building and design recommendations**	**Thermal adaptations**	**Homes below 18 °C standard** - common in winter, older adults and disabled maintain warmer homes **Insulation and heating** - improve thermal comfort and health in rural cold regions **Cognitive impairments** - affect housing design, risk of overheating with high insulation **Reduced mobility** - limits adaptation to cold, more HVAC control needed **Clothing adjustment** - older adults adapt but struggle with air conditioning control	[87, 122–126]
		Energy-efficient designs	**Adaptive measures** - needed to protect vulnerable populations from heat stress **Heat-related mortality** - influenced by individual and neighbourhood factors, needs targeted interventions **Higher temperatures** - reduce agitation in dementia patients, improve behaviour **Tailored thermal management** - required due to varying comfort levels in nursing homes **Building design** - impacts indoor temperatures, reliance on AC increases energy costs	[127–132]
		Management and user behaviour intervention	**Centralized thermostats** - prevent residents from turning off heating for safety **Seasonal temperature variation** - morning temperatures lower than evening, especially in living rooms **Passive AC use** - due to costs and discomfort, driven by outdoor temperature	[106,121, 125,133, 134]

Table 6
Key finding of indoor air quality domain of older adults categorised by subject.

Subject of Air Quality Domain			Correlation Intervention	Citation
1	**Exposure assessment**	**Ventilation assessment**	**Inadequate ventilation** - linked to respiratory issues in nursing homes **Air pollutant monitoring** - highlights the need for proper ventilation in healthcare facilities **High CO2 levels** - in winter, exceeding limits in living and dining rooms **Seasonal CO2 variation** - higher in winter due to low ventilation **Poor ventilation** - increases CO2, Total Volatile Organic Compounds levels (TVOC) **Formaldehyde levels** - influenced by winter temperatures and summer humidity	[135–138]
		Sources of pollutants	**Poor Heating, ventilation, and air conditioning (HAVC) management** - health risks, reduces air quality **High Volatile Organic Compounds (VOC) and formaldehyde levels** - linked to negative health effects **Indoor VOCs** - 10 times higher than outdoors due to furniture, cleaning products **Ozone-VOC reactions** - produce harmful compounds like formaldehyde, ultrafine particles **Formaldehyde monitoring -** essential due to volatility and health risks **Emerging pollutants** - PAHs and phthalates largely unregulated, except PAHs by WHO **Indoor air pollution** - worsens respiratory health, including tobacco smoke and particles **VOC risks from cleaning products** - highlight need for safer alternatives **Indoor CO2, NO2, O3 levels** - indicators of poor air quality **Particulate Matter (PM) 10 sources** - contribute to particulate matter in care centres	[137, 139–149]

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Table 6 (*continued*)

Subject of Air Quality Domain			Correlation Intervention	Citation
			Wood stoves - increase exposure to particulate air pollution **Odour management, HVAC inefficiencies** - impact air quality and comfort **Bacteria and fungi** - rise in winter due to low ventilation, high occupancy	
		Health effects	**Particulate matter exposure** - linked to olfactory dysfunction and health risks in older adults **Indoor mould odour** - increases asthma risk in older adults in social housing **Poor indoor air quality** - correlates with respiratory issues and vascular impairment **Air filtration** - improves vascular health and reduces tuberculosis infection **Chronic chemical inhalation** - poses health risks in healthcare settings **Ultrafine particles** - linked to cardiovascular, respiratory issues **Poor Nursing home air quality** - contributes to lung health decline **Aerosol inhalation** - impacts health, requires monitoring **Household fuel combustion** - linked to diabetes risk **Open fires, incense burning** - worsen cognitive function and brain connectivity **Particulate pollution** - linked to pulse pressure changes, cognitive decline, and inflammation **PM10, NO2, VOCs** - reduce lung function in nursing homes	[150–167]
2	**Mitigation strategies**	**Air filtration**	**Portable air filtration** - reduces particulate exposure, improves blood pressure **Air filtration** - decreases cardiovascular and respiratory effects of pollution **PM2.5 reduction** - enhances air quality in care settings	[161, 168–171]
		Ventilation promoting	**Mechanical ventilation** - improves air quality, balances energy in care homes **Supplementary ventilation** - leads to positive health outcomes in aged care **Frequent ventilation** - reduces depression and anxiety in older adults **Air handling units** - with heat recovery maintain indoor air quality **Ventilation and pollutant control** - highlighted by air particulate prediction models **Remedial actions** - include source control, ventilation improvement, and air cleaners **Air conditioner use** - lowers indoor PM2.5 levels	[24,160, 172–176]
3	**Management and user behaviour**	**Life style and pollution source treatment**	**Indoor air pollution** - linked to respiratory issues from poor ventilation, lifestyle **Higher particle exposure** - due to extended indoor time in older adults **Poor ventilation** - contributed to COVID-19 infections in nursing homes **Daily activities** - impacts indoor air quality, affecting CO2 and odour levels **Odour fluctuations** - reflect room activities or events	[145, 177–179]
		Living space management	**Airborne nanoparticles** - higher in living rooms, requiring better air quality management **Asthma in older adults** - higher allergen exposure, highlighting air quality control **Low outdoor air quality** - opening windows doesn't significantly reduce indoor PM2.5 **COVID-19 monitoring** - emphasizes infection risks and ventilation needs **Non-combustion heating systems** - and proper ventilation reduce CO2 levels in nursing homes	[140,160, 169,178, 180–182]

Table 7
Key finding of indoor visual comfort domain of older adults categorised by subject.

Subject of Visual Domain			Correlation Intervention	Citation
1	**Health Impact**	**Neuropsychiatric behaviour**	**Circadian-supportive lighting** - enhances environments for aging and Alzheimer's patients **Light therapy** - mixed effects on sleep and behaviour **Improved lighting contrast** - enhances visual performance	[183,184]
		Circadian rhythm	**Blue-enriched lighting** - improves activity levels and sleep patterns **Circadian-emotion brain connection** - interconnected processing circuits **Smart lighting** - adjustable brightness and colour temperature enhances sleep and functioning **Natural daylight** - supports circadian rhythms, night lighting disrupts them in aging	[183, 185–187]
		Mental well-being	**Subjective lighting perceptions** - impact visual health in older residents **Window size and placement** - enhance daylighting and well-being **Light therapy** - alleviates physical and psychological conditions (depression, circadian disorders)	[186,188]
2	**Safety enhancement**	**Visual comfort**	**Night-time lighting** - impacts safety and comfort in older adults **Therapeutic artificial lighting** - enhances visual comfort and well-being **Lighting for safety** - older adults use indoor lighting to improve comfort and safety **Insufficient lighting** - in key areas like corridors, stairs, and bathrooms **Daylight support** - health benefits, but glare leads to blocking natural light **Adequate lighting and contrast** - improve visual performance, minimize shadows/ glare	[186,189, 190]
		Fall risk reduction	**Insufficient lighting** - increases fall risk and affects visual needs **Improved lighting** - reduces fall risk and enhances health in older adults **Poor lighting** - significant fall risk, especially in older women **Fall risk** - rises during light transitions, particularly around evening sun set **Adequate lighting** - promotes social interaction, independence, reduces falls **Visual impairment** - increases fall risk, vision aids help in prevention **Fall risk factors** - fear of falling, age, gender, balance, dementia, vision issues **Dark corridors** - raise fall risks, night lights and motion sensors assist **Impaired depth perception** - raises fall risk	[185, 191–193]
3	**Environmental Intervention**	**Interior design recommendation**	**Artificial neural networks** - optimize lighting for visual comfort and safety **Proper lighting** - requires brightness, contrast, and reflection for perception **Indoor wood coverage** - impacts comfort and visual experience **Lighting design** - influences navigability and overall well-being **Blue-enriched lighting** - boosts daytime and night-time activity **High-contrast handrails** - improve visibility and safety **Layout and signage** - assist	[183, 187–189, 191,192, 194–196]

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Table 7 (*continued*)

Subject of Visual Domain			Correlation Intervention	Citation
			older adults with orientation **LED lighting** - improves stability, reduces walking time **Lighting arrangement** - affects illumination uniformity and natural light distribution **Dim lighting** - should be avoided; dimmers and sensor-based lights improve control **Wood coverage** - influences ambiance, calmness, and brightness perception **High colour temperature lighting** (17000 K) - affects sleep and agitation **Enhanced lighting** - benefits visually demanding tasks **Higher illuminance** - required in key areas for older adults **Auto-tuning lights** - sync with circadian rhythms, adjust colour and intensity **LED dynamic colour control** - matches daylight to support circadian alignment	
		Dementia support	**Light treatment** - reduces neuropsychiatric behaviours in Alzheimer's patients **Increased daylight** - alleviates depression and symptoms in dementia patients **Visual environment design** - mitigates cognitive and visual impairments, enhances quality of life **Morning daylight exposure** - reduces depression, offers non-pharmacological treatment **Specialized luminaires** - improve dementia symptoms and sleep	[183,184,196–198]

Table 8
Key finding of indoor acoustic domain of older adults categorised by subject.

Subject of Acoustic Domain			Correlation Intervention	Citation
1	**Reduce communication barriers**	**Reverberation time and sound absorption**	**Reverberation time** - affects noise levels and communication (0.6–0.8 s recommended) **Sound-absorbing materials** - minimize sound reflections and dissipate noise energy **High-frequency noise control** - and natural music enhance comfort **Humidifiers** - improve sound quality in nursing homes **Group size** - influences noise levels in nursing homes	[199–201]
		Spatial layout	**Quiet zones and sound-absorbing materials** - needed for hearing-impaired older adults **Excessive noise** - in multi-functional areas and corridors affects well-being **Acoustic design** - should reduce background noise, improve speech intelligibility **Sound perception** - varies by building layout and management style **Noise influenced by activities and layout** – sounds beyond conversations **Large spaces** - cause sound interference, smaller areas recommended **Room layout and sound insulation** - essential for visually impaired older adults	[199,200,202,203]
2	**Mental well-being**	**Sound preference**	**Natural sounds preference** - like water and birdsong; mechanical sounds disliked **Sound for orientation** - relied on by blind older adults, shaped by personal history **Acoustic comfort** - influenced by marital status, income, age, hearing, and sleep conditions	[200,202–204]

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Table 8 (*continued*)

Subject of Acoustic Domain		Correlation Intervention	Citation
		Acoustic tolerance - better in older adults compared to younger individuals **Poor acoustic environment rating** - in common rooms during peak noise levels **Music preferences** - background/foreground music improves comfort **Sound preferences** - favour reducing talking sounds, suggesting noise reduction **Gender and age** - influence sound preferences, with older women favouring natural sounds **Common noise sources** - human, equipment, environmental noise impacting health	
	Social interaction and sleep quality	**Acoustic environments** - impact verbal communication, social interaction, and mental health **Retrofits** - improve acoustic comfort **Poor acoustic environments** - harm sleep and mental health **High SPL and RT** - cause discomfort	[199,200]

technologies could dynamically adapt to individual needs by integrating health data, environmental parameters, and daily routines. Finally, there is a notable gap in cross-cultural research on thermal comfort for older adults, as most studies are centred on regions like Europe, North America, Australia, and China. Expanding research to include low- and middle-income countries, where infrastructure and care practices vary widely, would offer valuable insights into thermal comfort across diverse cultural contexts [228].

4.6. *Indoor air quality and older adults' well-being*

The research on indoor air quality in residential settings highlights a trend in health impact studies. These investigations cover particulate matter, volatile organic compounds, carbon dioxide, nitrogen dioxide and environmental tobacco smoke. Exposure to these contaminants is strongly linked to respiratory difficulties, cardiovascular dysfunction, cognitive decline, and infection risk. Ajmani et al. [150] and Huang et al. [151] relate fine particulate matter exposure to olfactory impairment and systemic inflammation in older individuals. Ventilation and air filtration equipment are essential to reducing health hazards in older care homes.

These studies collectively reveal a significant gap in managing and maintaining Indoor Air Quality (IAQ) in care settings. Despite older adult's vulnerability to air quality-related health concerns, the data show that IAQ is typically neglected or improperly handled in these

Table 9
Key finding of indoor ergonomic domain of older adults categorised by subject.

Subject of Ergonomic Domain			Correlation Intervention	Citation
1	**Safety Enhancement**	**Fall prevention**	**Environmental hazards** - clutter increases fall risk, handrails and lighting enhance safety **Poor physical adaptation** - in kitchens raises fall risk **Bathroom safety** - adaptations improve safety and mobility **Person-environment fit** - predicts falls better than hazards alone **Indoor vs outdoor falls** - indoor more common among frail, outdoor for active older adults **Safety features** - motion-activated lights, automated stove shutoff improve home safety **Cane/crutch use** - and low home usability linked to indoor falls **Indoor falls** - associated with disability, poor health, inactive lifestyles **Falls and health** - can affect even healthier individuals **Poor housing conditions** - increase frailty risk, but not lower extremity performance	[205–210]
		Physical and cognitive ageing	**Physical and cognitive aging** - addressed by innovative but costly technologies **Person-environment fit** - reduces mortality risk, improves well-being **Accessibility features** - prevent relocation, enhance quality of life **Poor housing conditions** - increase physical limitations and frailty risk **Bathroom safety** - linked to residential care moves, ADL difficulties, cognitive limitations **Aging considerations** - focus on accessible spaces over advanced building systems **Poor housing** - associated with sedentariness, nutritional deficiencies, depression **Lack of handrails** - at entrances linked to higher mortality risk	[209, 211–213]
2	**Home modifications**	**Universal Design**	**Power wheelchair use** - indoor mobility is shorter and slower than outdoor **Ergonomic design tools** - simulate postures to improve safety and comfort **Design modifications** - grab bars, lighting reduce fall risks, support independence **Activity and**	[210, 213–216]

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Table 9 (*continued*)

Subject of Ergonomic Domain	Correlation Intervention	Citation
	accessibility - personalized interventions needed for different groups **Functional capacity vs environment** - poor fit leads to Activities of Daily Living ADL dependence **ADL decline** - mixed results on home modification impact **Indoor barriers** - slightly reduce mortality risk with functional limitations **Indoor mobility transitions** - more frequent and shorter than outdoor **Wheelchair mobility** - varies by environment, slower and shorter indoors **Gender and height** - impact elderly comfort and accessibility **Facility optimization** - assessing individual needs reduces musculoskeletal risks	

situations. This disregard is concerning since indoor contaminants might worsen health issues due to their cumulative and synergistic impacts. Poor ventilation and cleaning products with volatile organic compounds can affect respiratory health and raise chronic disease risk [135,146]. The research also highlights geographical and seasonal changes in IAQ, emphasising that local climate and environmental factors require specific IAQ management strategies.

Some articles highlight the need for policy interventions and practical measures to improve IAQ in care facilities. Maher et al. [165] and Du et al. [24] show that improving air quality improves cognitive performance and mental well-being in older persons. This includes high-tech air filtration, strict IAQ regulations, and HVAC system monitoring and maintenance. The findings suggest that society must ensure that older people live healthy lives. Improving IAQ in these facilities is a moral imperative to defend the health and dignity of society's most vulnerable. Further research is essential to enhance the understanding of IAQ dynamics, especially regarding climate change, non-respiratory health impacts, and socioeconomic factors in geriatric settings. Firstly, the interaction between climate change and seasonal variations in IAQ, such as how heat waves or cold spells affect air quality in nursing homes, remains under investigation [229]. Additionally, natural disasters like hurricanes may have significant post-event impacts on IAQ, requiring more study. Secondly, existing research largely focuses on respiratory outcomes, with limited attention to non-respiratory diseases (e.g., cardiovascular disease, diabetes) linked to indoor pollutants. Exploring these connections could provide a broader view of the health risks of poor IAQ [230,231]. Lastly, the relationship between IAQ and socioeconomic factors, especially in low-income senior housing and nursing facilities, is understudied [232]. Understanding how socioeconomic status shapes pollutant exposure could guide interventions to reduce health disparities among older vulnerable groups.

4.7. Indoor visual comfort and older adults' well-being

The literature highlights that visual comfort and strategic lighting design significantly enhance the well-being and safety of older adults, particularly those in care environments or with cognitive conditions like dementia. Increasing attention is given to how well-designed lighting supports 1) psychological and therapeutic benefits, 2) environmental design and navigation, and 3) safety through improved visual comfort.

Both natural and artificial lighting are beneficial for preventing falls and supporting everyday activities [185,191,192]. Proper illumination improves physical safety and reduces sadness and neuropsychiatric issues in dementia patients [197,198]. Artificial intelligence optimises lighting to produce comfortable and energy-efficient spaces [194]. Illumination encouraging daytime alertness and peaceful sleep at night, especially with blue-enriched illumination, can affect sleep patterns differently [187]. Care facilities need intelligent environmental design, including visual signals and user-friendly lighting, to improve orientation and navigation [190,196]. Evidence-based lighting and design in residential and care settings may improve older individuals' well-being and quality of life [184]. Future research into indoor visual environments for older adults should address several underexplored areas that could significantly enhance quality of life and safety. Firstly, the impact of lighting and visual stimuli on cognitive load and visual fatigue in ageing populations requires further examination, especially regarding evolving lighting needs across different stages of ageing [233]. Secondly, AI-driven adaptive systems present another promising area, with the potential to optimise indoor environments in real-time based on health data, yet research in this domain remains limited [227]. Thirdly, the role of navigational aids such as wearable devices, augmented reality, and voice-assistant technologies in facilitating safe and accessible navigation within nursing homes, particularly for individuals with disabilities like partial blindness or reduced mobility, warrants further investigation. Finally, while physical environmental modifications (e.g., improved lighting and flooring) to prevent falls are well-documented, integrating these with behavioural training interventions has been relatively overlooked and deserves a more comprehensive study [234,235].

4.8. Indoor acoustic and older adults' well-being

According to Devos et al. [199] and Mu et al. [202], standard acoustic measures typically fail to meet the demands of nursing home residents, especially those with cognitive impairments like dementia. These studies' models for ambient noise levels and acoustic capacity highlighted the difficulties of balancing verbal communication needs with noise control in these environments. To an extent, Mu et al. [202] examined how acoustic conditions affect residents' comfort in activity spaces and concluded that good acoustics can improve living conditions in such facilities.

The research also points to a gap in existing guidelines for acoustic design in care facilities. Oh and Ryu [201] and Wang and Kang [203] both propose specific acoustic guidelines, particularly for residents with hearing impairments, stressing that noise control is crucial not just for comfort but also for effective communication and safety. Wu et al. [204] extend this discourse by considering the sound perception of blind older adults, advocating for inclusive design practices that consider the diverse sensory needs of all residents. These studies underscore the need to reconsider nursing home acoustic design. While traditional methods prioritise noise reduction, a more comprehensive approach is recommended, one that addresses verbal communication quality and residents' sensory needs. Effective acoustic design reduces stress, enhances social interaction, and improves overall quality of life. However, further research is required to adapt these principles across diverse residential settings and ensure that acoustic improvements are accessible and sustainable. The challenge and opportunity lie in translating these insights into sector-wide standards. An underexplored area is the role of acoustic environments in health, particularly concerning neurodegenerative diseases like Parkinson's [236]. Future research could investigate acoustic adaptations tailored for these populations. Firstly, understanding the impact of acoustic conditions on nursing home staff performance and stress is critical, with a focus on designs that support staff well-being and reduce burnout [237]. Secondly, research should address

Fig. 6. The reviewed literature spans multiple domains (inside the circle), each contributing distinct subject insights. Each domain (blue circle) defines its respective subject (in red and grey).

intergenerational acoustic needs in shared spaces to accommodate diverse age groups [238]. Another understudied area is the long-term health effects of continuous exposure to adverse acoustic conditions, with implications for improving design standards in nursing homes. Finally, studies on advanced acoustic control technologies, including noise mitigation and digital devices, are needed to enhance nursing home environments without disrupting daily routines [239].

4.9. Indoor ergonomic and older adults' well-being

The research trends in housing ergonomics for older adults highlight a growing emphasis on personalised design solutions and integrating advanced technologies. Personalised design and modern technology are becoming more critical in older adult housing and mobility ergonomics research. Studies like Iwarsson et al. [206] and Granbom et al. [211] emphasise person-environment fit over general environmental changes. From this concept, environmental dangers are addressed while customising interventions to people's functional skills and requirements. Yuan [216] shows that digital human modelling allows designers to recreate real-life settings and assess ergonomics during design. Environments that encourage older adults and safety require this strategy.

A critical investigation into these studies shows a continuous problem in applying research findings. Ismail et al. [209] emphasise that accessibility measures are underutilised in home building despite their well-documented benefits. Heller et al. [215] noted that research methods and results vary, making standardisation difficult. Technology like digital human modelling emphasises the need for integrative approaches that integrate ergonomics, architecture, and gerontology. However, making design decision tools accessible and usable for broader architectural practices in an age-friendly indoor environment, especially for non-ergonomics or human factors practitioners, remains an issue. Transitioning is from a one-size-fits-all approach to a more nuanced understanding of older adults' requirements. Ergonomic design advances must be theoretically sound, practicable, and accessible through greater collaboration between researchers, practitioners, and policymakers [212]. Advanced modelling tools and personalised interventions significantly advance ergonomic indoor design for older adults. Still, their widespread adoption will depend on overcoming education, training, and industry standards [210,214].

Research in ergonomics and housing accessibility for older adults identifies several important areas. Firstly, intergenerational housing, though underexplored, offers potential benefits in reducing social isolation through cohabitation models that promote interaction across age groups [240,241]. Secondly, while physical accessibility in nursing homes has been widely studied, integrating advanced technologies in mobility, healthcare, and daily tasks remains limited. Assistive technologies, such as sensor-based health monitoring, hold promise but require further research [242]. Finally, the concept of person-environment fit, particularly its relationship with mortality, demands deeper investigation. Evidence suggests environmental barriers may increase mortality risk in older adults, highlighting the need for studies on the impact of such barriers on longevity and how interventions like home modifications could support life extension [243].

4.10. Multiple indoor comfort domains with older adults' well-being

The research trend across the 31 reviewed studies underscores a comprehensive, multi-dimensional approach to improving the quality of life for older adults. These studies emphasise the importance of considering thermal comfort, air quality, lighting, acoustics, and ergonomics in design and management (see Fig. 6). The literature reflects a growing awareness of older adults' complex needs, advocating for a holistic design approach that integrates multiple indoor comfort domains. This approach addresses physical, psychological, and social factors, as evidenced by two main aspects.

Health Outcomes and Housing Interventions: A growing focus is on the relationship between housing conditions and health outcomes. Interventions such as insulation upgrades, radiator replacements, and air quality improvements are frequently studied for their health impacts. For example, Lv et al. [55]examined the effects of indoor environments on blood pressure, while Zhan et al. [67] explored how environmental factors influence satisfaction and cognitive function in older adults. Most studies integrate fields like environmental science, healthcare, and psychology, often using structural equation modelling (SEM), regression analysis, and software tools like SPSS and AMOS to analyse cross-domain data. Many studies in multi-domains are cross-sectional, capturing a snapshot of environmental quality or population satisfaction at a single point in time. However, the impact of seasonal variations and long-term exposure to suboptimal environments remains underexplored, potentially biasing results, particularly for studies on chronic health outcomes. Similar to many studies on a single domain, many multi-domain studies have small or homogenous samples, often focusing on older adults with stable socio-economic or health conditions. This approach neglects older vulnerable populations, such as those with serious mental illnesses or lower socio-economic status.

Indoor Environmental Quality (IEQ) and Wellbeing: Research on IEQ and well-being highlights the importance of healthy living environments for improving quality of life. Health outcomes commonly addressed include respiratory issues, cognitive function, emotional well-being, and overall quality of life. Variables such as temperature, humidity, carbon dioxide levels, lighting, and acoustics have been shown to affect mental health and comfort in residential settings [53,63,65,68]. Technological advancements in sensor networks have enabled real-time data collection on environmental conditions [58,67]. Some research has also examined adaptation strategies for older adults, such as thermal comfort adaptation and technological solutions for indoor environmental challenges in nursing homes [71,79]. Physical health indicators are well-covered, but psychological factors, e.g., emotional responses to the living environment, are often overlooked. Although behavioural observation techniques link residents' routines to built environment design, there is growing recognition of the importance of psychological comfort, including how factors like window placement, room design, and ventilation influence comfort, social engagement, and mental health.

5. Limitation

This study explores the aspects of older adults' perceptions of indoor comfort. It does not aim to define precise comfort parameters or establish environmental requirements for this demographic, as such determinations require future experimental studies. Instead, the focus is on highlighting the complexity of indoor comfort for older individuals by summarising current research trends and proposing future research directions. Given the enormous volume of relevant studies across diverse fields, rigorous inclusion and exclusion criteria were essential. The final sample was defined by specific requirements, keywords, and databases, typical in a systematic review. Despite efforts to refine the search with precise keywords, potential biases or omissions remain. Studies covering multiple age groups were excluded to streamline the selection process, focusing solely on indoor comfort. Including other perspectives or analysing each comfort domain in isolation could expand the scope, but such considerations fall outside the bounds of this study. A more detailed exploration of each domain would allow for deeper discussion, but that is beyond this study's intent.

6. Conclusion

This scoping review establishes a scientific foundation for studying the comfort and well-being of older adults in residential settings. The growing focus, especially in Asia, underscores the need for interdisciplinary approaches involving environmental science, public health, engineering, and social sciences. The research highlights the necessity of a holistic view of comfort, addressing the interplay of thermal comfort, air quality, visual comfort, acoustics, and ergonomics to enhance well-being.

Thermal comfort remains central, with findings indicating regional variations that call for tailored interventions. Air quality, crucial for health in care facilities, points to improved ventilation. Visual comfort aids fall prevention and supports those with cognitive impairments. While less studied, acoustics impact communication and stress reduction. Ergonomics is vital for fall prevention and accessibility, though challenges remain in standardising ergonomic tools.

Distinct comfort needs among demographic groups, including older women and those in advanced age, demand specific interventions. The trend toward holistic approaches integrating physical, psychological, and social aspects in indoor design is clear. Future research should focus on adaptive thermal models, long-term health outcomes, and cross-domain integration to inform policy and practice in geriatric care. A nuanced understanding of these factors is essential to advance the field and enhance the quality of life for older adults.

CRediT authorship contribution statement

Yijun Chen: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Federico Wulff:** Writing – review & editing, Validation, Supervision, Resources. **Sam Clark:** Writing – review & editing, Validation, Supervision, Resources. **Junjie Huang:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements and funding

We extend our heartfelt gratitude to our dear older lady, Ms Chunmei Lai, for generously sharing her insights into the home spaces of older individuals and for her ongoing encouragement throughout this study. The Paul Hinkin Bursary, Welsh School of Architecture, Cardiff University funded this study. We thank the research assistants, Yuqing Gao and Siyu Li, for their assistance with this scoping review.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.buildenv.2024.112268.

Data availability

Data will be made available on request.

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