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A Review on the Methods Used in the Study of Thermal Comfort for the Elderly

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ABSTRACT

Thermal comfort for the elderly is severely challenged by factors such as reduced self-regulation and poor health. However, there are few summaries on thermal comfort in the elderly, which hinder our understanding of their thermal comfort needs. This study employs a systematic literature review methodology, in which articles on specific topics were identified through keyword searches, yielding 73 publications. A cross-thematic analysis was conducted to summarize the factors influencing thermal comfort among the elderly, along with the corresponding data collection techniques and evaluation approaches. This study selects articles on specific topics using keywords, conducts cross-analysis, and summarizes the influencing factors, data collection methods, and evaluation methods related to thermal comfort for the elderly. The review identifies that the primary influences on thermal comfort in the elderly encompass physical, physiological, psychological, and socio-cultural factors. Physical and physiological factors are measured through direct assessment or simulation, whereas psychological and socio-cultural factors are derived from subjective surveys. Currently, simulation, measurement, and subjective surveys represent the predominant data collection methods for assessing thermal comfort. This review provides a comprehensive understanding of the key elements of thermal comfort for older adults and can create a better outdoor environment for them.

Keywords: Data method, Elder-friendly outdoor spaces, Influence factors, Outdoor thermal comfort, The elderly.

INTRODUCTION

Outdoor thermal comfort (OTC), the state of psychological satisfaction for an individual in relation to their surrounding thermal environment, has been defined by ASHRAE (Hami et al., 2019). Global climate change combined with the UHI effect leads to a higher frequency of extreme weather conditions within urban areas, posing major problems to the local community. Air temperature has been shown in several studies to be associated with a wide range of health problems, including cardiovascular

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and respiratory diseases, and is therefore an important risk factor (Moghadamnia et al., 2017). Furthermore, older adults exhibit significant physiological differences relative to young adults due to aging (Browning et al., 2019). The metabolism of the human body is decreasing with increasing age, and therefore also the production of inner heat (Aghamolaei & Lak, 2023). The elderly exhibit a different thermal response than the younger population and require warmer ambient conditions or additional insulation to achieve thermal balance (Larriva et al., 2023). The aging process also results in a decline in cutaneous thermoreceptor concentration, leading to reduced perception of environmental temperature changes (Giamalaki & Kolokotsa, 2019). Hence, older adults typically require greater temperature differences to perceive thermal discomfort (Aghamolaei & Lak, 2023). In addition, reduced physiological function reduces their ability or willingness to take immediate behavioural action to thermoregulate, leading to notable variations in adaptive thermal comfort behaviours across ages (Lai et al., 2020). Furthermore, the density of thermoreceptors in the skin declines with age, reducing sensitivity to temperature fluctuations (Giamalaki & Kolokotsa, 2019). As a result, greater temperature differentials are often required for the elderly to perceive “cold” or “heat” sensations (Aghamolaei & Lak, 2023).

The evaluation of people’s thermal comfort in outdoor spaces results from multiple factors. Factors affecting human OTC include physical, physiological, psychological, and social factors (Lai et al., 2019). Physical and physiological factors are the primary determinants, and their relevant data can often be measured. Psychological and social factors are indirect influences, and the appropriate research is primarily qualitative at present (Lai et al., 2020). There are two approaches to investigating OTC studies. Firstly, objective data for OTC studies were obtained using measurements or simulations, which were then used to evaluate or modify the indicators. Secondly, multiple regression analyses were conducted using subjective and objective data to understand OTC comprehensively (Coccolo et al., 2016). These factors are universal and apply equally to older people, although existing studies are mainly described for all-aged groups.

Vegetation is the “natural” solution for cooling and the most effective outdoor cooling measure (Zou & Zhang, 2021). Trees not only influence the physical factors of the outdoor thermal environment (An et al., 2021), but also improve physiological indicators of the human body, lowering heart rate, blood pressure, and skin temperature (Abdullah et al., 2022), and also enhances one’s psychological state (Cheng et al., 2022), thus affecting thermal comfort. Vegetation can adapt to improve the thermal environment of older adults in two ways: through structure and function (Browning et al., 2019). Leaves can reduce solar radiation through shading, thereby significantly reducing the heat load on their surroundings (Zhao et al., 2023). Studies have shown that green spaces help regulate physiological cardiac responses among older adults, including reduced heart rate and blood pressure, accompanied by improved mood (Yuan et al., 2023). These physical and mental advantages enable older adults to tolerate a broader range of temperatures, compensating for the reduced thermoregulatory efficiency associated with advancing age (Du et al., 2024).

However, the literature on older adults still exhibits several significant gaps, such as limited geographic coverage, few studies on thermal comfort among older adults, and a focus primarily on urban parks, streets, and urban blocks (Ding et al., 2023; Ma et al., 2021). Rural areas, as well as conventional towns, remain less studied. Previous research has shown that older adults living in cities have much greater heat vulnerability than those living outside cities (Li et al., 2023; Wu et al., 2023). Older people living in the countryside are shown to prefer more natural ventilation and wear warmer clothing, and have higher metabolism due to more physical activity (Xiong et al., 2019); Yuan et al. (2023) have pointed out a discrepancy between them, such that findings on older adults living in urban communities cannot be directly transferred to those living in rural regions. Methodologically, current studies primarily rely on physiological parameters to assess thermal comfort among older adults, often overlooking important psychological and sociocultural factors (Hami et al., 2019; Lai et al., 2019). Studies have shown that psychosocial factors play an important role in determining thermal sensation among older adults (Deng et al., 2020; Klemm et al., 2015). Thus, there is an urgent need for more comprehensive investigations of thermal comfort among the elderly population to better understand systematic differences across regions, the built environment, and contributing factors.

METHODOLOGY

Literature Search Strategy

This study was conducted as an extensive, methodical literature search following PRISMA 2020 guidelines (Page et al., 2021) to ensure neutrality, transparency, quality, and reproducibility of articles on thermal comfort in outdoor environments among older adults, using three primary databases: WOS, Scopus, and Google Scholar. We conducted our search over the past decade (2015-2024). Boolean operators were used systematically for combining keywords such as age group (“elderly”, “old age”, “senior citizen”, “elderly people”, “seniors”), main topics of investigation (“outdoor thermal environment”, “thermal environments”, “outdoor climate”, “outdoor thermal conditions”), and important driving factors (“vegetation”, “forest cover”, “green spaces”).

Literature Screening

In order to ensure the quality and relevance of included papers, we followed up with a series of selection steps after our first round of searching for relevant papers. Firstly, removing duplicate articles. We then reviewed the titles and abstracts of all articles for consistency with our inclusion and exclusion criteria: field trials and experiments with well-defined approaches to information collection, component analysis, or comfort models. In the final filter, we excluded studies that examined only indoor temperatures; cross-cohort studies without a dedicated older adults group; and other published or unpublished works. After careful filtering, we identified 73 scientific articles for detailed review. Data were organized by theme to use thematically aligned categories across all microclimate parameter types simultaneously.

This systematic review encompasses three dimensions: climatic variables, physiological responses, and psychological perceptions. It integrates commonly employed methodologies for data collection and analysis, enabling a comprehensive assessment of how various elements of urban green spaces collectively influence thermal perceptions among elderly populations through the dual perspectives of cooling effects and affective impacts.

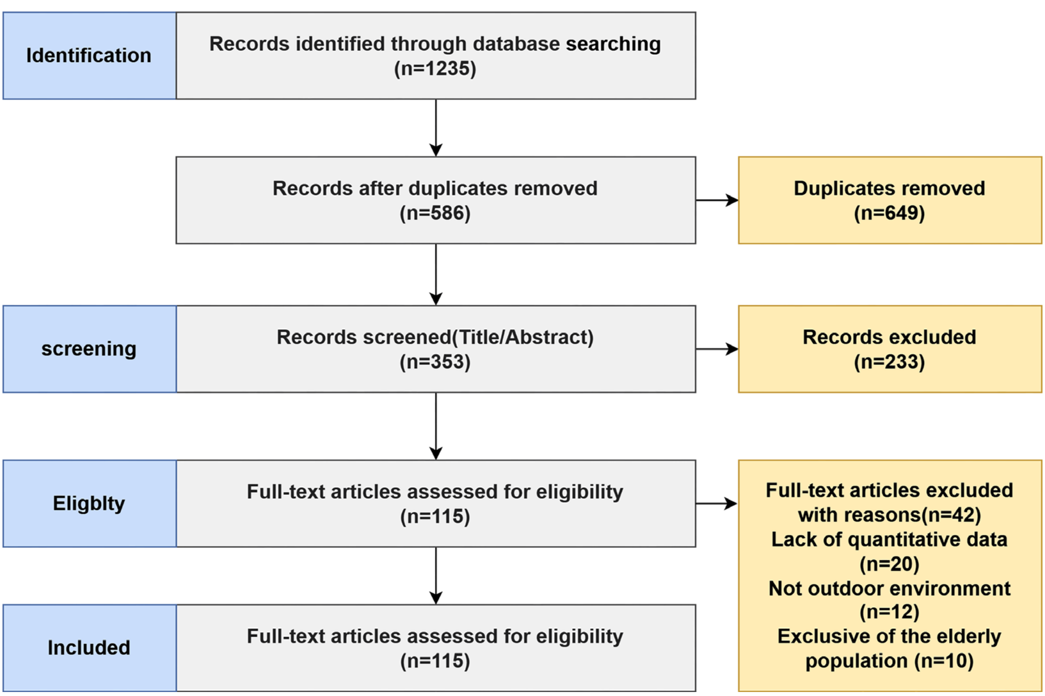

Figure 1. PRISMA 2020 Flow Diagram

RESULTS

Influence factors

Outdoor Thermal Comfort (OTC) is vital to people's health and happy lives (Anders et al., 2023). Exploring the factors influencing OTC is of great significance for improving the understanding of thermal comfort. Studies by Das and Subudhi (2022) and Lai et al. (2019) identified four main categories of factors affecting human OTC: physical, physiological, psychological, and social and cultural factors, as shown in Table 1. Physical and physiological factors are direct influences whose relevant data can often be measured directly. Psychological and social factors are indirect influences, for which research is primarily qualitative at present (Lai et al., 2020).

Table 1
Outdoor Thermal Comfort Influence Factors

	Main Factors	Sub-factors	
Direct Factors	Physical Factors	Air Temperature	Wind
		Thermal Radiation	Relative Humidity
	Physiological Factors	Gender	Metabolic Rate
		Age	Clothing Resistance
		Skin Temperature	Thermal Exposure
		Heart Rate	Blood Pressure
Indirect Factors	Psychological Factors	Thermal Experience	Activity Characteristics
		Thermal Expectations	Satisfaction
		Thermal Perception	
	Social & Cultural Factors	Climate Zone	Economy
		Topography	Social
		Traditions and Customs	

(Source: Das & Subudhi, 2022; Lai et al., 2019)

Physical factors

The main factor affecting individual thermal comfort is the surrounding microclimate environment, also known as a thermal environment. Heat convection, radiation, and evaporation functions between the human body and the surrounding environment depend significantly on the thermal environment (Lindner-Cendrowska & Błażejczyk, 2018). It consists of eight leading indicators: solar radiation, wind, temperature, humidity, barometric pressure, precipitation, radiation balance, and surface parameters (Bartesaghi-Koc et al., 2020). As shown in Figure 2, solar radiation, air temperature (Ta), relative humidity (RH), and wind (Va) have a direct and significant impact on human thermal comfort. The experimental studies by Huang et al. (2023) and Kang et al. (2017) identified these four physical parameters, and the results indicate that these parameters significantly affect the thermal environment, as shown in Table 2.

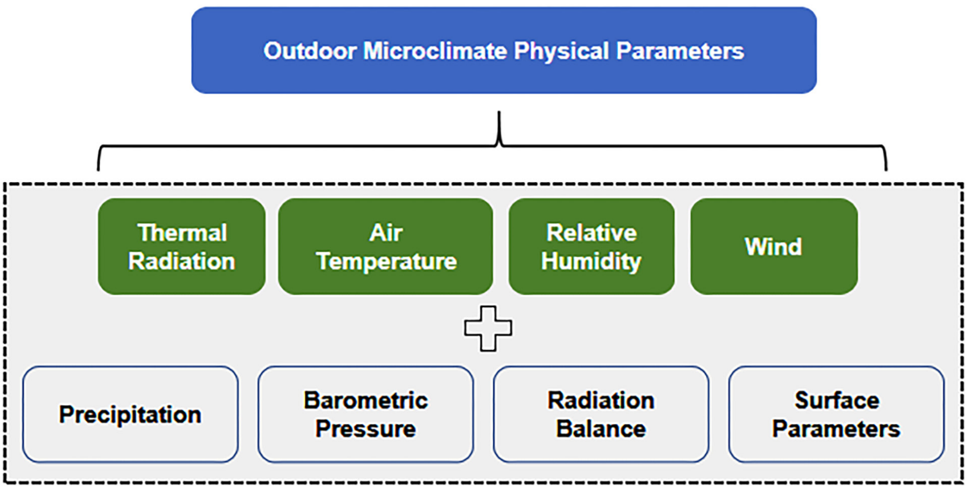

Figure 2. Physical parameters of outdoor microclimate

Table 2
The influence of physical factors on outdoor thermal comfort

Parameters	Summary	Reference
Temperature	Outdoor thermal comfort is most significantly affected by air temperature.	(Chen et al., 2018; Tsitoura et al., 2014)
Thermal Radiation	The most significant factor is radiation.	(Liu et al., 2016; Shih et al., 2017)
Wind	Wind has a greater influence than other factors.	(Krüger & Rossi, 2011; Li et al., 2020; Liu et al., 2022)
	Wind and radiation are equally important to the human body.	(Hong & Lin, 2015; Lau et al., 2019)
Humidity	Most of the time, the effect of humidity is negligible, except in extremely high or low temperatures.	(Chow et al., 2016; Sobolewski et al., 2021)

(Source: Lai et al., 2019)

(1) Thermal radiation: Thermal radiation exerts a profound influence on OTC (Ji et al., 2022). The radiative heat stress experienced by the human body is typically quantified through the Mean Radiant Temperature (Tmrt). In complex outdoor settings, this is characterized by short-wave solar radiation as the primary source, with long-wave radiation emitted by surrounding surfaces and objects (Shih et al., 2017). As illustrated in Figure 2, Tmrt denotes the weighted average of all surface temperatures that contribute to radiative heat exchange with the human body (Guo et al., 2022). Furthermore, solar radiation is the primary determinant of the broader thermal environment. It significantly modulates secondary climatic parameters, including air temperature, humidity, wind patterns, and precipitation (Zou & Zhang, 2021). Meanwhile, radiation patterns become

a decisive factor in urban design, dictating critical parameters such as site selection, building layout, orientation, and building spacing to optimize the microclimate (Bande et al., 2019; Rahman et al., 2020).

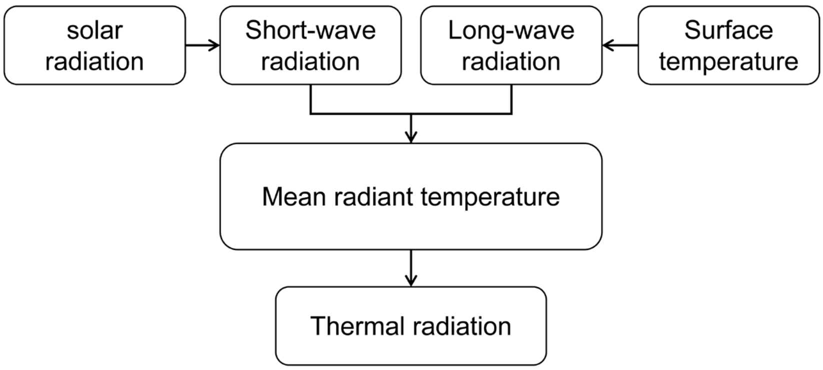

Figure 3. Thermal radiation composition

Figure 3 demonstrates that solar radiation is the main factor determining the thermal environment. It shows that sunlight significantly affects other climatic factors, such as temperature, humidity, wind, and precipitation, and thus plays a critical role in determining the location and layout of urban planning and the orientation and spacing of buildings (Zou & Zhang, 2021).

(2) Air temperature (Ta): Ta has a significant impact on OTC (Chen et al., 2018). The temperature range is between 25-37 °C, people are not sensitive to the temperature, and when it goes beyond this range, the body feels uncomfortable or stuffy (Eggenberger et al., 2021). Climatic regions primarily determine temperatures but are also influenced by four factors: wind, urban geometry, road subsurface, and anthropogenic heat emissions (Norton et al., 2015). Research indicates that the most critical parameter affecting comfort is air temperature, followed by wind speed, solar radiation, and relative humidity (Tsitoura et al., 2014).

(3) Wind (Va): Va also dramatically influences the environment. The heat carried away from the surface of the human body is affected by the wind speed. The wind is characterized by average speed, including but not limited to wind speed, wind direction, and turbulence intensity (Roshan et al., 2020). Different outdoor wind-speed conditions affect different aspects of human thermal comfort. Liu et al. (2022) conducted a longitudinal study of OTC in China. They found that changes in wind speed and solar radiation significantly affected the outdoor thermal perception of the human body. Other scholars, e.g., have also reached similar conclusions,

(4) Relative Humidity (RH): RH affects the human body's heat, water, and salt metabolism. The influence of humidity is not significant when the temperature is moderate (Tung et al., 2014). However, when the temperature is high or low, it is crucial for the human body's thermal balance and sense of warmth. High humidity is the most uncomfortable cause of high-temperature environments (Sobolewski et al., 2021).

Physiological Factors

Physiological factors refer to the responses of the human body to changes in its activities and to dynamic changes in the external environment (Persiani et al., 2021). The influence of outdoor thermal conditions is quantitatively evaluated primarily through physiological parameters, and there is a strong physiological correlation between the two, which provides the physiological basis for the objective evaluation of OTC (Lai et al., 2019). A study by Chow et al. (2016) found a correlation between heart rate variability and environmental comfort, which is the most notable. Meanwhile, a study by Aljawabra and Nikolopoulou (2018) found that when the human body is in a lukewarm state, hand skin temperature fluctuates significantly, indicating that changes in skin temperature are closely related to OTC. The differences in the amount of activity and metabolic rate generated by individual activities at different ages lead to differences in the evaluation results of thermal comfort (Luo et al., 2018).

Psychological Factors

Since thermal comfort is defined as a "mental state", people's subjective mental state will be a fundamental factor influencing thermal comfort. Psychological factors mainly refer to the influence of travel purpose, travel type, thermal adaptation, and other personal psychological effects on people's thermal perception, thermal expectation, and thermal experience (Böcker et al., 2016; Deng et al., 2020). As shown in Table 3, the influence of experience, expectations, and perceptions has been confirmed in research. Psychological factors can explain why similar objective data yield vastly different subjective thermal sensations.

Table 3

Psychological parameters in outdoor thermal comfort

Parameters	Summary	Reference
Experience	Past temperature experience influences the occupant's current neutral temperature.	(Cheung & Jim, 2018; Potchter et al., 2018)
Expectation	Occupants' thermal expectations influence their thermal perceptions.	(Chen et al., 2018; Lam et al., 2018)
Perceived control	The more control people have over the temperature, the wider their thermo-neutral temperature.	(Johansson et al., 2018; Lam et al., 2018)

Psychological factors were first proposed by Nikolopoulou et al. (2001) in a study of urban open space, and the questionnaire and theoretical prediction data differed substantially due to their influence. As a result, psychological factors are beginning to be emphasized for a more complete and accurate understanding of thermal comfort (Ma et al., 2021). The common method is to use surveys, including questionnaires and measurements. Objective environmental data and subjective thermal sensation polling results are modeled in a linear regression model to derive a regional thermal sensation polling model and a range of thermal comfort thresholds. Among these, subjective thermal sensation voting results are primarily used to infer individuals' actual thermal responses via a questionnaire survey (Tang et al., 2022).

Social and Cultural Factors

The social environment is not a direct factor that affects the outdoor thermal environment. However, it impacts people's thermal comfort and is also an essential factor in determining whether some Outdoor Spaces are accepted by the public (Kemperman & Timmermans, 2014). Social and cultural elements mainly include social organization, social customs, economic level, historical traditions, and customs (Jiao et al., 2020). The influence of secondary factors helps explain differences in people's thermal comfort evaluations across regions. For example, regional clothing, cultural concepts, and national character all affect people's perception of heat (Balbis-Morejón et al., 2020), thereby further influencing perceptions of climate factors. In East Asia, whiteness is considered beautiful; people pursue a healthy skin tone in the West (Aljawabra & Nikolopoulou, 2018). This concept will affect differences in clothing and shading behaviour, thereby further influencing perceptions of the sun.

Method used in the OTC

As shown in Figure 3.4, thermal comfort data are classified as objective and subjective. Objective data include physical and physiological indicators, obtained directly via equipment. The collection of objective data mainly includes two methods: measurement and simulation (Das & Subudhi, 2022b; Lai et al., 2019). The measurement primarily includes climate laboratory measurements, field measurements, and remote sensing. Subjective data include psychological, social, and cultural indicators derived from questionnaires, observations, interviews, and literature reviews. Objective data can be used on its own for the correction of indices. It can also be combined with subjective data to perform multiple regression analyses for a comprehensive understanding of OTC (Coccolo et al., 2016).

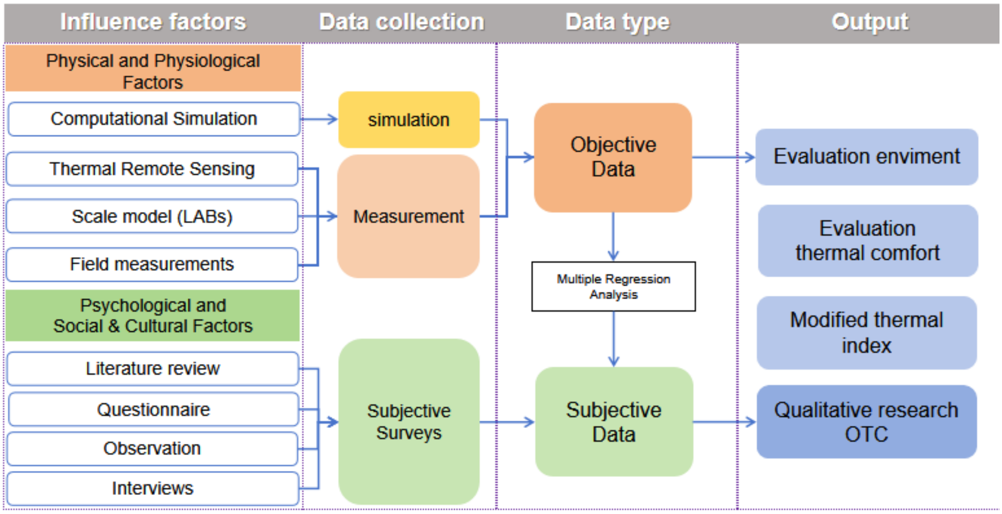

Figure 4. Methodology for outdoor thermal comfort
(Source: Lai et al., 2019)

Computer Simulation

Outdoor environmental factors are highly complex, and field measurements often cannot accurately control a single impact factor to study its influence and mechanism (Toparlar et al., 2017). Computer simulation can effectively control a single variable. Notably, ENVI-met is a CFD-based microclimate simulation software program. Liu et al. (2021) summarised thermal comfort studies conducted using ENVI-met in recent years, reaching a peak of 32 in 2020. Numerous studies have shown that ENVI-met simulations exhibit a high degree of agreement with actual measurements.

Scale Model

The outdoor climate lab comes in the form of equal-scale simulations. These LABS provide scientists with a controlled environment that simulates various climate conditions, enabling relevant research (Pisello et al., 2021). By conducting laboratory experiments, researchers can assess human physiological and psychological responses under varying Ta and RH conditions, including thermoregulatory mechanisms, heart rate changes, skin humidity, and perceived comfort (Shafavi et al., 2020).

Remote Sensing

Remote sensing technology is primarily utilized to acquire large-scale surface temperature characteristics in OTC research, facilitating the evaluation and optimization of urban thermal environments (Liu et al., 2023). However, as OTC is modulated by multiple variables including shading, Va, and RH surface temperatures derived from remote sensing data do not comprehensively represent actual human heat exposure (Coutts et al., 2016).

Field Measurement

Outdoor climate parameters vary significantly from one climatic region to another and from one point in time to another. To study the impact of a specific feature, places with different characteristic indicators are selected, and their thermal environment parameters are monitored. For example, Qaid et al., (2016) memeasuredhe urban thermal environment in Putrajaya, Malaysia, wewasade along a 4-8 km route usalong whichensors mounted on top of the vehicle.

Subjective Surveys

Questionnaires, interviews, and observations are common methods of subjective surveys, with questionnaires being the most representative. Studies using questionnaires currently occupy the majority (Fu et al., 2022). Questionnaires are often conducted for people in an urban thermal environment (Lai et al., 2020). For different research purposes, there are two sampling methods for questionnaire surveys: a horizontal survey and through extensive data collection and statistical analysis, the average thermal perception of people in static climate conditions is estimated (Lai et al., 2020). The other is a longitudinal study that uses a relatively small sample to follow changes in each subject's thermal perception across different climates (Liu et al., 2022). These two survey methods will complement each other in specific studies and obtain a more comprehensive understanding. In questionnaire surveys, personal information (e.g., dress, activity, age, and gender) is typically collected to characterize the interviewees' composition, inform appropriate sampling in the study, and support further classification analysis.

Evaluation Indices

For OTC, the four most commonly used metrics are Predicted Mean Vote (PMV), Standard Effective Temperature (SET), Physiologically Equivalent Temperature (PET), and Universal Thermal Climate Index (UTCI) (Tao et al., 2023).

A typical thermal balance model is the PMV proposed by Fanger in 1973 and the later modified model PMV-PPD (Lai et al., 2019). Afterward, Gagge proposed SET, defined as the condition in which the skin temperature and humidity of a person wearing standard clothing are the same as those in the natural environment at a constant temperature and relative humidity of 50%. However, the index calculation needs accurate human skin temperature and humidity, which is difficult to obtain and inconvenient (Lai et al., 2019). Subsequently, PET was proposed to address the shortcomings of the aforementioned model. This index mainly considers the influence of the surrounding environment, individual factors, and clothing. PET can be used to assess OTC, the air temperature at which human skin and body temperatures reach a thermal state comparable to that of a typical indoor environment when outdoor ambient conditions reach a certain range

(Potchter et al., 2022). In 2009, under the organization of the International Biometrical Society, the UTCI, based on a multi-node model, was established. The results show that UTCI is more accurate and comprehensive than other indicators in evaluating different climatic regions, different weather conditions, and different time points (Blazejczyk et al., 2012).

At present, the PET index is the most widely used index for evaluating outdoor thermal environments. An analysis of 117 studies spanning from 2001 to 2017 summarized the prevalent thermal comfort models utilized. The study revealed that four key models, PET, PMV, UTCI, and SET, collectively comprised 53.3% of the studies' methodologies. Notably, PET emerged as the most frequently applied model, accounting for 30.2% of the total usage, showcasing its prominence in the field. The index facilitates objective evaluation of human thermal comfort in complex environments, yielding more reliable scientific results (Potchter et al., 2022).

However, in light of physiological characteristics such as reduced metabolic rate and diminished sensory perception in older adults, the existing thermal comfort evaluation framework is undergoing pivotal refinements (An et al., 2021). Regarding metric adjustments, the Adapted Universal Thermal Climate Index (UTCI) has significantly lowered the comfort threshold to account for the elderly population's heightened sensitivity to cold and reduced heat tolerance in severely cold regions. From a modeling perspective, researchers recommend adopting narrower comfort bounds to recalibrate conventional adaptive models (Jiao et al., 2020). Most notably, the integration of neurophysiological monitoring represents a breakthrough: electroencephalography (EEG) data have been validated as an objective and real-time measure of thermal comfort and psychological stress in older adults, thereby effectively overcoming the latency inherent in subjective questionnaire-based assessments (Ma et al., 2023).

DISCUSSIONS

Thermal Comfort Characteristics of the Elderly

Research on thermal comfort and adaptation of the elderly began in countries that took the lead in aging, such as the United States, France, and Japan (van Cauwenberg et al., 2018). The research scope primarily encompasses differences in thermal comfort between the elderly and the young, the elderly's sensitivity to temperature and climate change, the applicability of thermal comfort indices to the elderly, and the elderly's thermal adaptation behavior (Jiao & Yu, 2019).

The theoretical origin of the influence of trees on the thermal comfort of the elderly can be traced back to de Dear's thermal adaptability theory in 1998 (de Dear & Brager, 1998). After integrating a large amount of experimental data from ASHERS, he formally proposed the adaptive thermal comfort mechanism. This mechanism holds that people are not passively affected by the environment but actively regulate their own body temperature to achieve thermal comfort. Psychological regulation is a key regulatory mechanism (Nikolopoulou & Steemers, 2003). It mainly consists of factors such as thermal expectation, thermal experience, and thermal satisfaction (Lai et al., 2020).

In early research on human thermal comfort dating back to 1967, it was found that older people have a lower neutral temperature than young adults. According to ASHRAE, older adults prefer higher air temperatures but also have a lower neutral temperature than younger adults (Liu et al., 2018). Similar findings have been reported by Baquero et al. (2023). They found that older adults are less comfortable than younger adults due to limited ability to adapt to environmental changes, as well as altered physiological and psychological characteristics, such as low metabolic rate and poor heat-regulation capacity. Separately from this work, Schellen et al. (2010) explored differences in thermal comfort across age groups in a naturally ventilated environment, suggesting that environmental temperature strongly influences older users' perception of thermal sensation and that skin temperature is an important factor influencing younger users' perception as well. In other research, Daanen and Herweijer (2015), who investigated 16 subjects from both young and old groups, found that the latter had lower sweat rates at elevated ambient temperatures. Yuan et al. (2020) conducted a comparative study of 225 people in Dalian, a cold region of China, and found that older people prefer cold thermal environments.

However, research on thermal comfort among older adults remains relatively limited, and the consistency of results is poor. Their research process is evaluated mainly by physical and physiological factors (Lai et al., 2020). Research on subjective factors has rarely been addressed (Jiao & Yu, 2019). Therefore, further research is needed to incorporate subjective factors to more accurately characterize thermal comfort among older adults.

Vegetation Improves Thermal Comfort for the Elderly

Vegetation has a positive effect on older adults' OTC. Firstly, vegetation is the most effective of the outdoor cooling measures (Zou & Zhang, 2021). Cross-regional studies have consistently demonstrated that trees effectively mitigate ground-level thermal load by intercepting shortwave radiation, minimizing longwave radiative exchange, and enhancing evaporative cooling through reduced water consumption. Sodoudi et al. (2018) concluded that trees with high canopies can increase PET by more than 15 °C, confirming the substantial improvement in thermal comfort provided by trees. Similar effects have been confirmed in Wang et al. (2022), Sun et al. (2017), and Wang and Akbari (2016), whose studies all suggest that tall trees can effectively reduce thermal stress.

Furthermore, vegetation is aesthetically pleasing and psychologically calming for occupants, which, in turn, may positively affect their perceived thermal comfort. The results from Lenzholzer and De Vries's study (2020) were corroborated by Yan et al. (2023)'s finding that pleasant outdoor environments could improve occupants' mood, as mood acts as an intermediary variable between outdoor environment and occupants' thermal perception. consistently matches the findings from other studies. Li et al. (2022) reported similar findings, showing that vegetation can create a mental "coolness" bias in cities for many people. This holds even when the weather is not cool; the aesthetic appeal of trees creates an impression that it is cooler outside and thus encourages people to go out (Qiu et al., 2021). Elderly people prefer water bodies and semi-shaded spaces (Klemm et al., 2015). They also found the highest perceived thermal comfort scores when both trees and garden designs are involved. A more diverse landscape provides greater perceptual experiences, increasing positive feelings, which in turn lead to better thermal evaluations. This is also confirmed by Liu et al. (2021).

However, previous research failed to explore the influence of mental mechanisms caused by plants on thermal comfort in old age, specifically: how tree arrangements – in terms of size and placement in the environment, and specific design features – influence the thermoregulatory responses and comfort of older people.

Implications for Urban Planning and Landscape Design

In the planning of cities or parks for older adults, it is necessary to pay particular attention to the selection of trees and other plants, taking into account the specific conditions required by these users' physical and cognitive abilities. Regarding tree selection, deciduous tree varieties with tall trunks and broad leaves are desirable, as they provide shade during the summer months while allowing solar access in winter for common spaces (Deng et al., 2023). Previous studies have shown that linear tree arrangement is more effective than clustering planting in alleviating thermal discomfort (Zhao et al., 2018). Psychologically, planners must consider the use of bright-colored plants and symbolic meanings in therapeutic landscapes (which could enhance heat resistance and mental well-being via visual stimulus (Lu et al., 2021). Additionally, it is important to recognize that older adults in different climatic regions exhibit distinct thermal responses, necessitating consideration of regional experience and adaptability in plant configuration (Lai et al., 2019).

CONCLUSION

This study reviews factors influencing thermal sensation in older adults in outdoor settings and the methods used in the current literature to assess these factors. Although previous work has identified physiological effects of the three dimensions of thermal comfort, there are significant differences between older and younger generations. Regarding study methodology, the most recent literature focuses on quantifying weather, environmental, and behavioral effects, but not on mental health outcomes or cultural and social factors, which are also poorly understood and warrant greater research attention.

Trees are one of the most important natural elements that regulate ambient temperature. Most prior literature has focused on how trees respond to the abiotic environment; recent studies show that they positively affect psychological well-being in older age and thereby improve thermal comfort. This important but often overlooked topic in thermal comfort research has recently attracted the attention of specific research communities, including healing gardens and phytotherapeutic landscaping.

Future aging planning and design should move beyond conventional physical parameter studies and prioritize integrating precise shading strategies with multisensory landscape interventions to compensate for the diminished thermoregulatory capacity in older adults. Particular emphasis must be placed on environmental equity, with targeted approaches for underserved elderly populations in rural communities and disadvantaged urban districts, as current research inadequately addresses these demographic segments.

Research contributions

GP was responsible for screening and reviewing the articles. GP prepared a draft of the manuscript. AAG was responsible for establishing the concept of the full text, implementing it, and checking the content. LBY and AJG were involved in supervising and proofreading the paper.

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