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Study on thermal comfort of elderly in community parks: An exploration from the perspectives of different activities and ages

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ABSTRACT

Community parks are significant green spaces for outdoor activities among the elderly in urban areas, further serving as crucial environments for their social interaction and mental restoration. This study comprehensively investigated outdoor thermal perception among the elderly in community parks during the winter in Huangshan, utilizing meteorological measurements, questionnaires, interviews and activity observations. It delved into the relationship between the elderly's outdoor thermal perception, age, and activities. Findings are as follows: 1) T_a and T_g were the primary factors influencing thermal perception in the elderly, with RH also being an important factor. Additionally, thermal sensation among individuals aged 80 and above was influenced by wind speed. 2) The NPET was 5.84 °C, with NPETR of 0.22–11.46 °C. The 80% TAR was 3.32–28.91 °C. Outdoor thermal benchmarks varied significantly among elderly individuals in different age groups. 3) The intensity and content of activities significantly influenced the elderly's outdoor thermal perception from physiological and psychological perspectives. Moreover, spatial satisfaction, thermal experience, and thermal adaptation behavior also influence outdoor thermal perception among the elderly. 4) Planning and design strategies for urban public spaces were proposed to enhance elderly residents' outdoor thermal comfort. The findings can guide community park designers in meeting the specific needs of elderly individuals and promoting healthy aging.

1. Introduction

Population aging is one of the foremost trends of the 21st century. It is projected that by the year 2050, the global population aged 60 and above will increase to 20% [1]. Population aging is not a remote apprehension anymore, but a current catastrophe that already poses a threat to both humans and natural habitats worldwide. However, Due to physiological changes, there are significant differences in outdoor thermal perception between elderly individuals and other age groups [2–6]. Additionally, change in the psychological state and decline in cognitive abilities among older adults may hinder their ability to accurately and objectively assess the thermal environment, making it less likely for them to make necessary adaptations to protect their health. Thus, in the context of intensified global climate change, elderly individuals experience higher risks of thermal health issues.

The expanding population of the elderly serves as a crucial user group of urban open spaces [7–9]. And thermal comfort emerges as one of the pivotal determinants determining the quality and frequency of utilization of outdoor public spaces [10–12]. The World Health Organization and the American Association of Retired Persons advocate for particular attention to be given to providing parks and open spaces for elderly individuals, aiming to promote their social interactions and community connections, thereby enhancing their physical and mental well-being and overall happiness.

In China, community parks are significant green spaces within urban environments. They serve as essential venues for outdoor activities among elderly individuals and play a crucial role in fostering social interactions and mental restoration for the elderly population [13–20]. Therefore, creating a favorable thermal environment in community parks is an important issue to promote active and healthy aging among older adults.

Recently, research on the outdoor thermal comfort of the elderly has delved deeper. Many studies have explored the relationship between thermal sensitivity and age in the elderly [21], as well as the meteorological parameters to which the elderly are particularly sensitive [22]. However, the research conducted on this demographic is primarily

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limited to certain climatic regions, and the seasons of study are mainly concentrated in the summer [23]. To date, it remains unclear the outdoor thermal perception of elderly people during wintertime in typical cities in hot summer and cold winter zones of China. Moreover, what is most crucial is that there has been a dearth of research specifically focusing on the special physical and social needs of the elderly population, along with their usage preferences.

On the other hand, a multitude of prior studies have explored the factors that influence thermal comfort and its correlation with outdoor activities [24–26]. The research conducted during the winter in Chongqing suggests that, compared to microclimates, activity exhibited the most significant influence on TSV or TCV of different age groups [27]. Yung found that the selection of open spaces by older adults in winter is primarily influenced by their activity level [28]. The research in Taiwan explored the impact of different activity intensities on park attendance from the perspective of thermal comfort [29].

However, focusing solely on activity intensity is insufficient to comprehend the outdoor thermal comfort of the elderly. Previous studies have shown that differences in thermal adaptation [30–32], psychological factors [33,34], or the pursuit of thermal sensation among individuals engaging in various activity contexts [35] can contribute to variations in outdoor thermal comfort.

For elderly individuals, diverse content of activities exerts varying influences on the physical, cognitive, psychological, and overall well-being, consequently influencing thermal perception. For example, playing card games is an important social activity for elderly individuals in China, providing effective emotional support, which can, in turn, influence their evaluation of thermal comfort through psychological pathways [36]. Additionally, the specific attendance patterns and activity expectations unique to the elderly can also subtly impact thermal perception. However, there is limited research on the impact of different activity content on the social and psychological aspects of outdoor thermal comfort in older adults.

In summary, previous research has substantiated the moderating role of these factors such as age, activity intensity, activity content and the associated social and psychological impacts on thermal perception. However, existing literature has not adequately addressed the interplay between outdoor thermal perception and these factors.

And there is an imbalance in the previous selection of research climate zones and seasons. Moreover, previous studies have overlooked the guiding role of these influencing factors in practical design considerations.

In light of this, this study investigated a community park in a hot summer and cold winter zone as a case study. The specific research objectives were as follows:

1) determine the most significant climatic factors influencing thermal perception in the elderly;
2) establish outdoor thermal benchmarks for elderly individuals in the study area and elucidate the relationship between age, activity and their thermal perception;
3) provide practical strategies for park design to enhance winter thermal comfort for the elderly based on the influence of meteorological, physiological, social and psychological factors on the thermal perception of the elderly.

2. Methods

2.1. Study area

Huangshan (29°43′20.2″N,118°19′52.21″E) is the only city in Anhui Province located in the Qiantang River Basin, situated at the junction of Anhui, Zhejiang, and Jiangxi provinces, as shown in Fig. 1a.The population of Huangshan City has been continuously aging. According to the 2018 report from the Huangshan City Statistical Bureau, the population aged 60 and above in the city has reached 23.16% of the total population

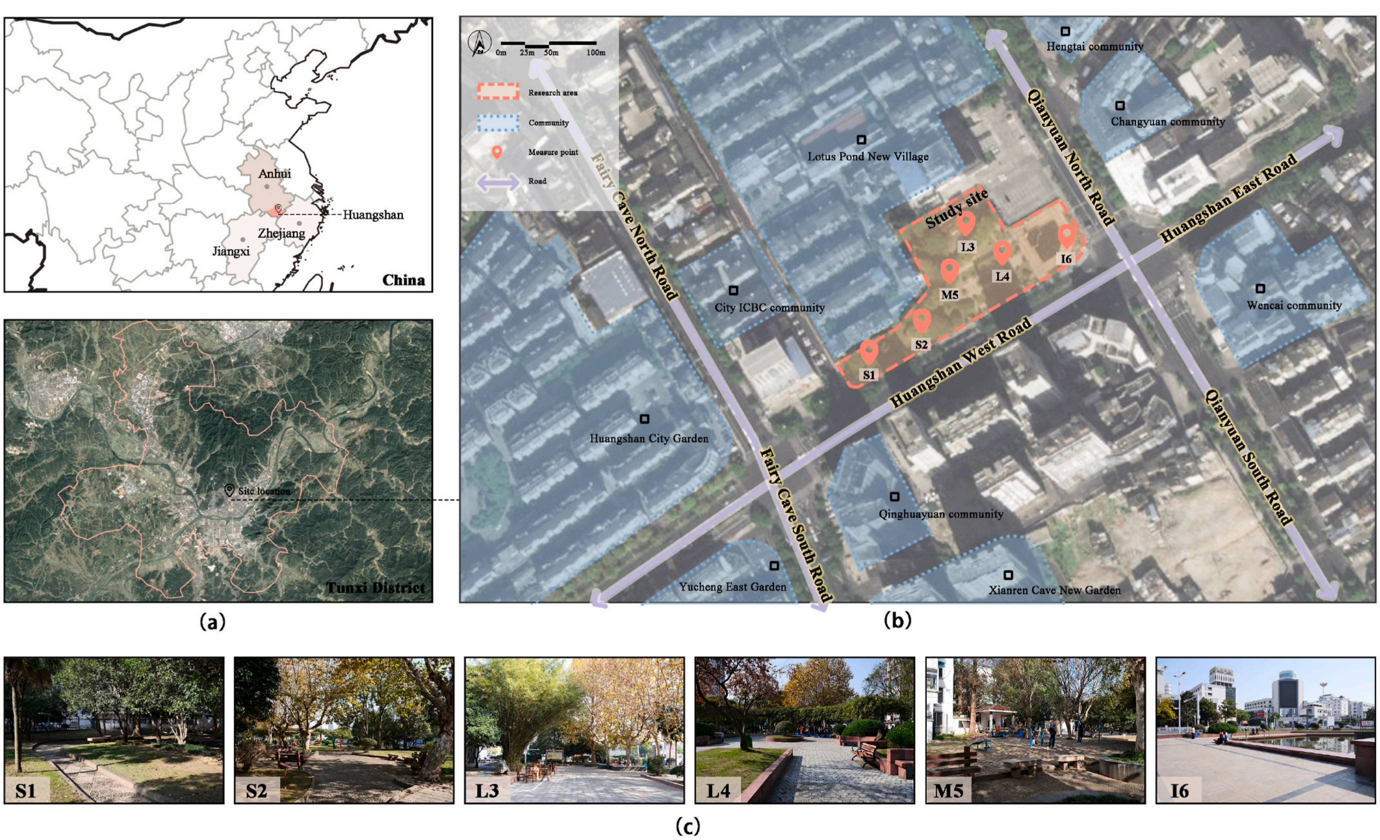

Fig. 1. Geographical location of the study area (a); Distribution of the measurement sites (b); site configuration (c).

[37].

Huangshan exhibits a typical subtropical monsoon humid climate and is a typical hot summer and cold winter area in China. It has cool summers and cold, humid winters, with many clouds, high humidity and precipitation. According to the weather station data in Huangshan spanning from 1981 to 2010, the annual average T_a and RH are approximately 16.7 °C and 79%, respectively. The highest monthly average temperature occurs in July, reaching 33.3 °C, while the lowest monthly average temperature is recorded in January at 1.2 °C. The coldest months are December and January, with monthly average temperatures ranging from 1.2 °C to 1.9 °C and monthly average RH fluctuating between 79% and 80%.

The community park, occupying approximately 0.7 ha, is centrally situated in Huangshan and has been established for a considerable period as a representative community park in the area. It boasts excellent facilities and various spaces, offering a variety of activities to cater to individuals or groups with different activity levels. It is situated near several typical old residential areas, and the entire community is showing typical signs of aging. Through an immersive survey conducted over nearly a month, it was observed that the community park has become a frequented and stable gathering place for the elderly population. The park provides an ideal setting for studying the thermal comfort of elderly individuals within community parks.

Drawing upon previous observations, this study selected six typical spatial categories within the community park, each site configuration is shown in Fig. 1c.

2.2. Meteorological measurement

The meteorological measurements were conducted from January 16, 2023 to J February 2nd, 2023. A total of 6 survey trips were conducted on January 16th (JAN-16), 17th (JAN-17), 18th (JAN-18), 19th (JAN-19), 29th (JAN-29) and February 2nd (FEB-2), which spanned the typical winter humid and cold weather in Huangshan. The field measurements were conducted on both sunny and cloudy days, avoiding rainy, snowy days and holidays. And it was taken from 9:00–12:00 and 13:00–16:00, when the community park is most frequently used.

Meteorological parameters were collected and recorded at 1 min intervals, including air temperature (T_a), relative humidity (RH), wind speed (V_a), and globe temperature (T_g). The measurement range and accuracy of the instruments used are provided in Table 1. The temperature probe of the HOBO weather station is shielded with a radiation shield to prevent radiation effects on the air temperature. The recording interval for all microclimate parameters was set to 1 min. All instruments were installed at a height of 1.5 m above the ground.

The calculation of MRT was conducted following the ISO 7726 standard, and expressed as:

$$MRT = \left[\left(T_g + 273.15\right)^4 + \frac{1.1 \times 10^8 \times v^{0.6}}{\varepsilon \times diam_g} \times \left(T_g - T_a\right) \right]^{0.25} - 273.15$$

where $diam_g$ is globe diameter ($diam_g = 0.05$ m in this study) and ε_g is emissivity ($\varepsilon_g = 0.95$ for a black globe).

2.3. Questionnaire investigation

Given that Chinese law defines individuals aged 60 and above as elderly and previous research has shown that the physical health of elderly people can significantly and complexly affect their thermal response [4,38,39], this study conducted a survey among participants aged 60 and above who were free of chronic diseases and engaged in activities within the measurement space, with simple dialogue interviews during the process.

The questionnaire consisted of three parts: basic information, thermal perception, and site evaluation (Appendix I). Part I of the questionnaire investigated the personal information, dressing level, and activity level of the respondents.

The clothing insulation of the respondents was determined based on the ASHRAE Standard 55–2017. The calculation of activity level employed the adjusted metabolic rate for the elderly, with values of 1 met equivalent to 43.1 W/m^2 for males and 38.6 W/m^2 for females [40].

The second part examined the thermal perceptions of the respondents, encompassing their sensations, preferences, comfort and acceptability [41,42]. The respondents were asked to express their thermal sensations using a 9-point scale. Additionally, thermal acceptability and thermal comfort were recorded using a 4-point scale. The aforementioned scale has been extensively utilized in research on outdoor thermal comfort [43]. Furthermore, existing studies indicate that individuals' outdoor thermal perception is influenced by the purpose and frequency of their outdoor activities [44]. Simultaneously, people's activities in public spaces and their frequency are to some extent associated with the functionality of the space, such as the spatial landscape and available facilities [45–47]. Hence, this study incorporated a third part of the questionnaire to record respondents' satisfaction with the facilities and landscape of the research site. After the instrument stabilized in the measurement area, the researchers distributed the questionnaire.

2.4. Space activity observation

Space activity observation was conducted simultaneously with climate measurement and questionnaire surveys. During the experiment, the investigators positioned themselves in a location that provided a comprehensive view of the entire measurement area and diligently documented the use of various spaces, including the content of activities and the number of people engaged in each activity. We employed a statistical time interval of 30 min and used on-site annotation to directly record behavioral activities in relatively closed or small areas. In areas with high pedestrian traffic, we used cameras to capture user activities every 2 min and transcribed the images and data later. Passersby and those who temporarily stayed in the area were not counted.

2.5. Thermal comfort index

PET is a comprehensive evaluation index of meteorological parameters used in the heat balance model of the human body. Different from indoor thermal comfort indices based on steady-state heat transfer, the thermal comfort index PET is widely used outdoors because it incorporates the human body's thermoregulation mechanism using the MEMI two-node model, as well as the clothing and metabolic models [22,48].

In this study, PET was employed as the thermal index, and its calculation was performed using the RayManPro software.

Table 1
Instruments used for measurement of micro-meteorological variables measurement.

Name	Parameter	Range	Accuracy
HOBO onesie U23-001	Air temperature	−40–70 °C	±0.21 °C
	Relative humidity	0–100 %	±2.5 %
Delta OHM HD32.3 TC	Globe temperature	−30–120 °C	1/3 DIN
	Wind speed	0.05–5 m/s (0–80 °C)	± (0.05 + 0.5 % measure) m/s

Table 2
Values of the measured micrometeorological variables at selected sites.

Point	Air temperature (°C)			Relative humidity (%)			Wind speed (m/s)			Global temperature (°C)		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
S1	11.86	−0.58	5.94	62.71	21.69	47.03	2.29	0.02	0.83	18.1	−0.5	6.95
S2	12.16	−0.33	6.37	66.5	19.59	46.03	4.32	0.00	0.87	16.6	0.7	9.47
L3	12.55	1.05	5.96	76.75	21.32	48.65	3.31	0.04	0.96	20	3.1	9.57
L4	11.6	0.53	6.47	68.03	24.08	46.60	4.09	0.06	0.94	24.8	2.6	11.78
M5	12.67	0.23	5.79	78.56	20.86	49.53	2.71	0.01	0.91	22.7	1.6	8.68
I6	12.85	1.01	6.53	62.91	20.9	45.75	5.38	0.05	1.11	26.2	3.8	12.43

Fig. 2. Activities of four categories of spaces.

3. Results

3.1. Descriptive statistics

3.1.1. Meteorological parameters

The measured meteorological parameters are provided in Table 2. Among the six measuring points, the air temperature exhibited a range of variation from −0.58 to 12.85 °C. The RH displayed a substantial span, ranging from 19.59% to 78.56%. The I6 point exhibited the highest mean V_a, while the S1 point had the lowest mean V_a. The temperature variation range of T_g was significantly larger than that of T_a, ranging from −0.5 °C to 26.2 °C.

The I category exhibited the highest average T_a and average T_g among all categories, while simultaneously recording the lowest average RH. Conversely, the meteorological parameters of the S category displayed an opposite trend compared to the I category, with the T_g being notably distinct between the two categories.

The maximum value of T_g in point S2 was lower than that in point I6 by 9.6 °C, and the minimum value of T_g in point S1 was lower than that in I6 by 4.3 °C. The M category exhibited the highest average RH among all categories, while simultaneously recording the lowest average T_a.

As for the L category, the meteorological parameters of L4 were close to the point I6, with the average T_a, the average V_a, and the average T_g being lower by 0.06 °C, 0.17 m/s, and 0.65 °C, respectively, while the average RH is higher by 0.85%.The outdoor built environment within the community parks exerted a substantial influence on the microclimate of the measurement sites.

3.1.2. Respondents

Considering that the experiment was carried out during the critical period of the COVID-19 pandemic, many elderly people were unwilling to cooperate with the questionnaire survey, and finally 424 questionnaires were collected. The participants were categorized into three age groups: 60–69 years (14.8%), 70–79 years (38.6%), and over 80 years (46.4%). The average height for males was 170 cm, while for females it was 155 cm. The average body weight for males was 62 kg, while for females it was 50 kg. The average thermal resistance of clothing was 1.46clo. It is important to note that all respondents had resided in Huangshan for at least 3 years. Consequently, they are able to accurately and objectively evaluate the outdoor thermal environment.

3.1.3. Defining spaces based on activities

In this study, activity comprised two aspects: activity intensity (static, low-intensity, moderate-intensity, and intense-intensity) and activity content (single-person and multi-person). Based on this, four spatial categories have been defined (Fig. 2.).

The intensity of activities was determined based on the predominant level of engagement in activities by the majority of individuals within a specific space. The activity intensities of the spaces were assessed according to MET values; that is, the static activity space was designated for areas where the MET fell within the range of 1.0–1.5; the light activity space was designated for areas where the MET fell within the range of 1.6–2.9; the moderate activity space was designated for areas where the MET fell within the range of 3.0–6.0. Due to the limited activity intensity of older adults, the high-intensity activity space was defined as areas with a MET value greater than or equal to 6.0 [49,50].

During the spatial usage observe at the M5 site, it was observed that 90% of the population used air walkers as a form of exercise equipment. Therefore, in this study, the activity intensity of the M5 site was defined based on the exercise intensity of air walkers [51].

3.2. Analysis of outdoor thermal comfort investigation

3.2.1. Thermal sensation voting and thermal comfort voting

3.2.1.1. Analysis of thermal sensation voting. Thermal sensation voting is the most intuitive data that expresses the degree of warmth of the human body at that time. The distribution of thermal sensation votes in the community park is shown in Fig. 3.

69.81% of the elderly people’s thermal sensation was slightly warm (26.42%), neutral (22.64%), and warm (20.75%). None of the respondents felt very cold or very hot. The lowest proportions of respondents, 1.18% and 3.07% respectively, felt hot or cold. The proportion of neutral, slightly cool, cool, cold, and very cold thermal sensations increased with age, while the proportion of slightly warm, warm, and hot thermal sensations decreased with age.

The votes indicating a tendency towards feeling hot were predominantly concentrated in the I category space. Furthermore, 88% of the respondents in the I category exhibited a thermal sensation that was at least neutral, making the highest percentage among the four spatial categories. Contrarily, the S category space displayed a contrasting pattern to that of the I category space. Approximately 50% of the votes in the S category indicated a predisposition towards perceiving cold, surpassing the other three categories. The distribution of TSV in both the L category space and the M category space exhibited similarities. However, a notable difference was the presence of a 5.32% ratio of “cold” votes in the L category space.

3.2.1.2. Analysis of thermal comfort voting. Thermal comfort voting is the most intuitive data that express the degree of comfort of the human body at that time. The distribution of thermal comfort votes in the community park is shown in Fig. 4.

68.16% of the respondents felt "comfortable", followed by a smaller proportion who felt “slightly comfortable” at 26.65%. Only a small proportion of the elderly indicated “slightly uncomfortable” at 5.19%, and no one felt “uncomfortable”. Meanwhile, the proportion of “comfortable” votes of all age groups was above 60%, and the proportion of “slightly uncomfortable” votes of all age groups was below 10%. The

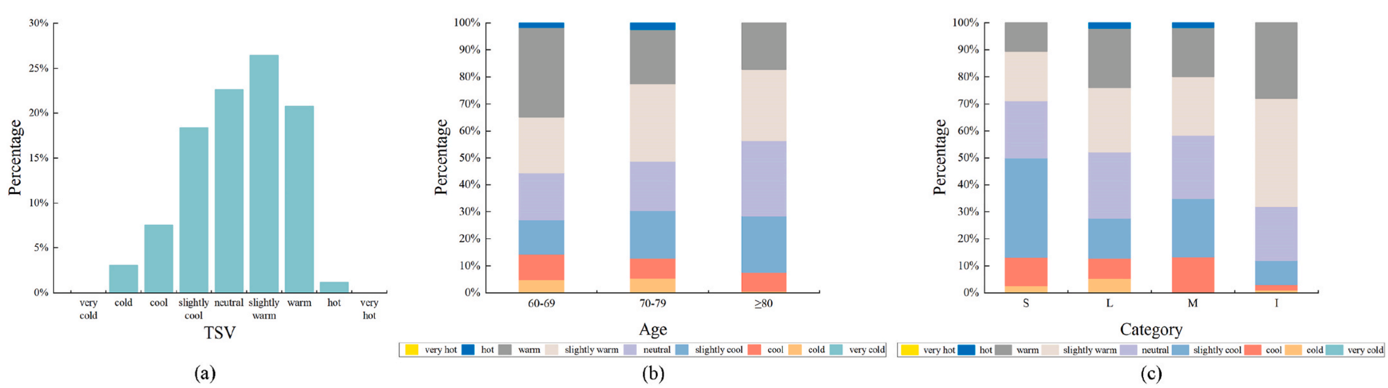

Fig. 3. Distribution of thermal sensation voting of all respondents (a); of all age groups (b); in four space categories (c).

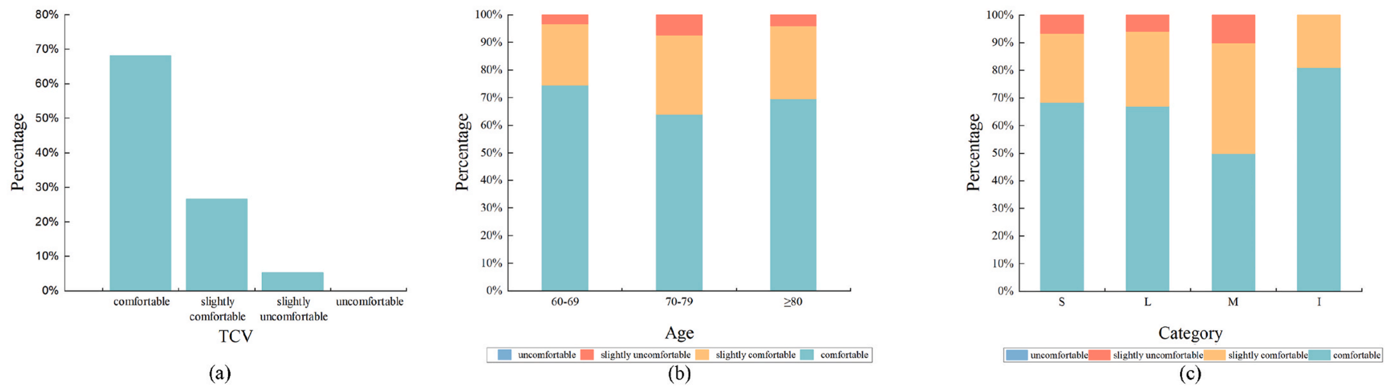

Fig. 4. Distribution of thermal comfort voting of all respondents (a); of all age groups (b); in four space categories (c).

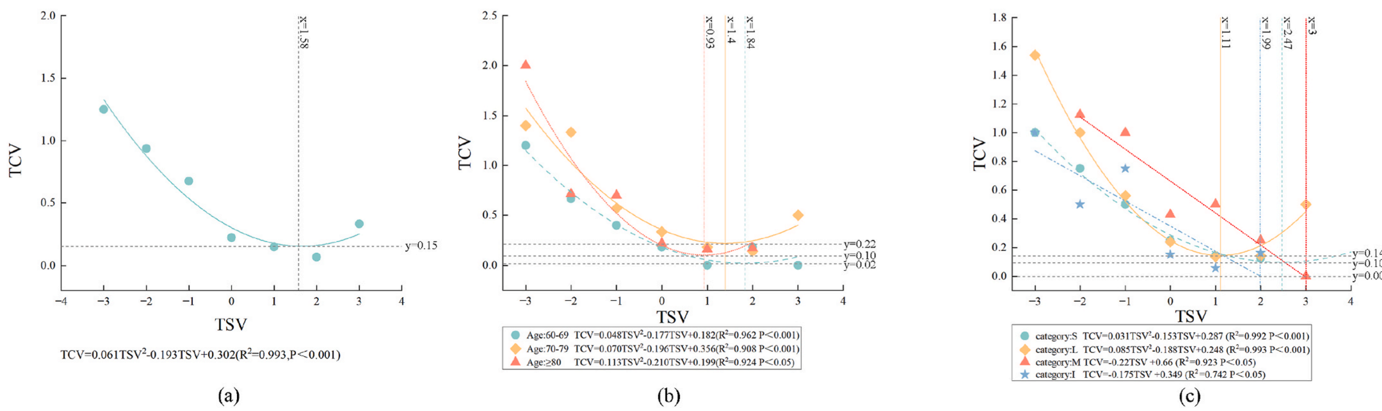

Fig. 5. Correlation between thermal sensation voting and thermal comfort voting of all respondents (a); of all age groups (b); in four space categories (c).

TCV in the four category spaces exhibited significant differences from one another. The proportion of votes for “comfortable” is the highest in the I category space at 81%, followed by the S category space at 68.42%, the L category space at 67.02%, and the M category space at 50%.

3.2.1.3. Functional relationship between thermal sensation voting and thermal comfort voting. In this study, we explored the functional relationship between TSV and TCV within each unit TSV interval. We derived the fitting equations for TSV and TCV for all participants, participants of different age groups, and participants in four space categories, as illustrated in Fig. 5.

When TSV ≥ -2, TCV$\leq$1, suggests that the elderly people can experience a comfortable or slightly comfortable thermal perception in the humid and cold winter of Huangshan. Elderly participants reported the most comfortable when TSV = 1.58, while discomfort increased noticeably when TSV ≤ -1. This indicated that elderly people were more likely to perceive comfort in slightly warm to warm sensations, especially those aged 60–79 and users in L and I category spaces. Older adults aged 80 and above were more likely to perceive comfort in neutral to slightly warm sensations. Elderly individuals in S and M category spaces were more likely to perceive comfort in warm to hot sensations.

Their long-term exposure to this climate has led to adaptation, but they still prefer warmer conditions to enhance comfort. Additionally, excessively cold or hot environments could lead to discomfort.

3.2.2. Thermal acceptable voting

The distribution of thermal acceptability voting for community parks is shown in Fig. 6. 60.61% of the respondents felt “absolutely acceptable”, followed by a smaller proportion who felt “acceptable” at 29.72%. 8.02% of the respondents felt “unacceptable”. Only a small proportion of

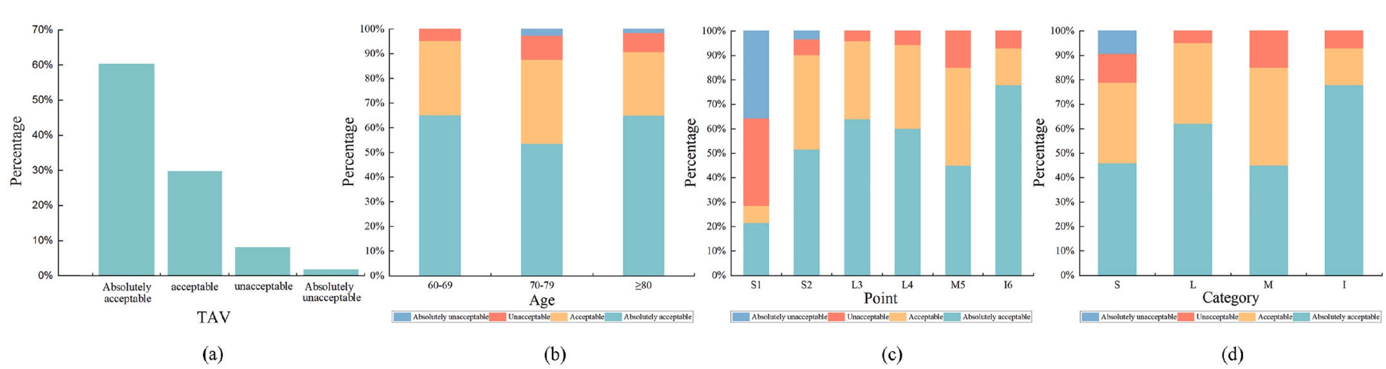

Fig. 6. Distribution of thermal acceptability voting of all respondents (a); of all age groups (b); in six measurement points (c); in four space categories (d).

the elderly indicated “absolutely unacceptable” at 1.65%. The elderly aged 60–69 displayed the highest overall acceptance of outdoor thermal environments. Among the outdoor spaces, the highest level of acceptance is in the L category spaces, reaching 95.21%, followed by the I category space (93%). The level of unacceptability for the M category space reached 15%, but no one selected the option of absolutely unacceptable. The S category spaces had the highest level of unacceptance (21.05%), however, it is worth noting that the S2 site exhibited relatively better acceptance, with only 9.68% of individuals selecting “unacceptable” or “absolutely unacceptable”.

3.2.3. Acceptance and preference of meteorological parameters

3.2.3.1. Acceptance voting of meteorological parameters. The elderly’s acceptance voting of meteorological parameters is depicted in Fig. 7. Elderly individuals generally exhibited a higher acceptance of outdoor thermal environmental parameters. Humidity had the highest level of acceptance at 95.29%, followed by air temperature at 88.68%, wind speed at 86.32%, and solar radiation at the lowest acceptance rate of 80.66%.

3.2.3.2. Preference voting of meteorological parameters. The respondents’ preferences for microclimate parameters (T_a, RH, V_a, T_g) of different age groups, at six measurement points and in four space categories are illustrated in Fig. 8.

Overall, respondents of all age groups indicated a higher desire to enhance air temperature and solar radiation, which was consistent with the conclusion of the outdoor winter thermal comfort study in Chongqing, China. Specifically, the preference for increased solar radiation was positively correlated with age, indicating that older individuals have a greater inclination towards enhancing solar radiation. Moreover, among individuals aged 70 and above, more than 40% expressed a desire for a reduction in wind speed. In contrast, the willingness to improve relative humidity was lower, with at least 85% of respondents of each age group expressing a preference for the current relative humidity to remain unchanged. This indicated that elderly individuals exhibit limited sensitivity to RH during the winter. At the same time, the preference for reduced humidity became more pronounced as they aged.

The respondents’ preferences for microclimate parameters at each measurement point varied. Regarding T_a, more than 54% of the respondents expressed a preference for higher air temperature at each point, with S1 reaching 71.43%. The analysis of respondents’ wind speed preferences revealed a prevailing inclination towards maintaining the existing conditions. However, the preference for “lower” wind speed was highest at the S1 point, reaching 57.14%. In terms of solar radiation, over 38% of the respondents expressed a preference for stronger solar radiation, particularly at the S1 point where sunlight obstruction was more severe, reaching 100%.

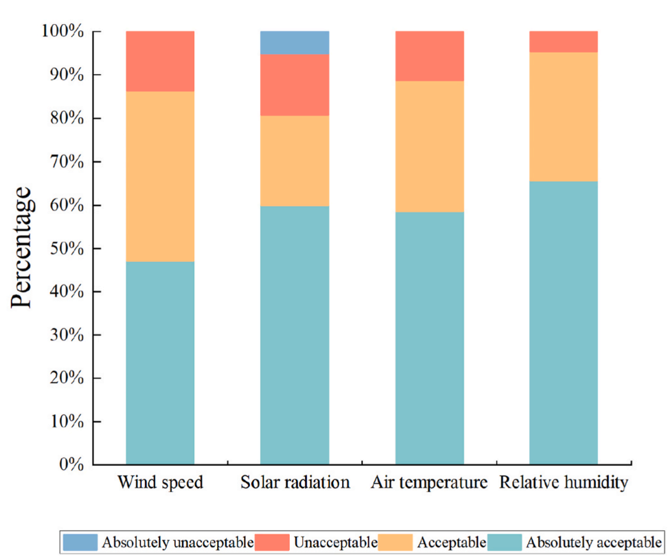

Fig. 7. Acceptability voting for meteorological variables.

3.2.3.3. Impact of meteorological parameters on outdoor thermal sensation. In order to assess the effects of meteorological parameters on TSV, a Spearman correlation analysis was conducted between meteorological parameters and TSV, as shown in Table 3.

TSV showed a significant positive correlation with T_a, T_g, and T_{mrt}, while it exhibited a significant negative correlation with RH. T_g and T_a were identified as the primary meteorological parameters influencing thermal perception in the elderly population.

For individuals aged 80 and above, TSV exhibited a negative correlation with V_a, suggesting that the elderly experienced a heightened sensation of cold as the wind speed increased, indicating a potential relationship with increased V_a.

3.3. Outdoor thermal benchmarks

3.3.1. Neutral temperature and neutral temperature range

NPET is defined as the temperature at which an individual feels neither cold nor hot [52]. The NPETR was identified when TSV values ranged from −0.5 to +0.5, where a TSV value of 0 corresponded to a neutral PET [53].In this study, a linear regression analysis was used to examine the relationship between TSV and PET. The weighted average of the TSV for each 1 °C PET interval was calculated using linear fitting analysis. Regression analysis was then conducted, with PET as the independent variable. To ensure the reliability of the analysis and avoid outliers, each PET interval was required to contain at least two responses.

The fitting equations for TSV and PET for elderly participants during the typical cold and humid winter in Huangshan City, encompassing the overall, distinct age groups, and varied spatial categories, are presented in Fig. 9, Table 4.

Overall, the NPET of the elderly in Huangshan was 5.84 °C, and the NPETR was 0.22–11.46 °C. R^2 was 0.709, suggesting that PET effectively captured the true thermal sensation experienced by individuals.

The changes in PET corresponding to one unit of TSV in Table 4 indicated that as age advanced, the sensitivity of the respondents to the thermal environment gradually diminished. Furthermore, the lower limits of NEPTR for the three age groups decrease with advancing age, suggesting that older individuals are less sensitive to cold conditions, and they also require lower PET values to attain thermal neutrality. This finding aligned with previous research conducted in climate chambers [54]. Moreover, as the activity level increased, the temperature required to achieve a thermal neutral state decreased.

3.3.2. Thermal acceptability range

Thermal acceptability range denotes the temperature range that is deemed acceptable by a minimum of 80% of the respondents under normal conditions, or by at least 90% of the respondents under strict conditions [55]. We calculated the thermal unacceptable rate (URV) of the PET in the 1 °C bin, and fitted it to an exponential function as shown in (Fig. 10; Table 4). According to the equations of URV and PET, the temperature range acceptable to 80% population was 3.32–28.91 °C in Huangshan (Fig. 10).

Respondents of three age groups had varying ranges of acceptability, with 80% acceptability ranging from narrowest to widest as follows: respondents aged 60–69, respondents aged 70–79, and respondents aged 80 and above. Furthermore, the lower limit of the 80% acceptable temperature range decreased with increasing age, indicating that older individuals were more tolerant of lower temperatures in humid and cold winters.

Fig. 8. Preference voting for meteorological variables of all age groups (a-d); in six measurement points (e-h); in four space categories (i-l).

Table 3
Spearman correlation coefficient between subjective feeling and thermal environment parameters.

TSV	Air temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Global temperature (°C)	Mean radiant temperature(°C)
TSV (All)	0.504**	−0.420**	−0.077	0.542**	0.366**
TSV (Age:60–69)	0.738**	−0.640**	−0.107	0.698**	0.295**
TSV (Age:70–79)	0.569**	−0.494**	0.021	0.607**	0.435**
TSV (Age:≥80)	0.344**	−0.228**	−0.165**	0.426**	0.298**
TSV (Category: S)	0.607**	−0.346**	−0.096	0.578**	0.346**
TSV (Category: L)	0.500**	−0.438**	−0.128	0.531**	0.275**
TSV (Category: M)	0.458**	−0.594**	0.060	0.538**	0.413**
TSV (Category: I)	0.415**	−0.264**	−0.069	0.467**	0.243*

* Significance at 0.05 level.
** Significance at 0.01 level.

Additionally, for all age groups, the lower threshold of the 80% acceptable thermal range surpasses the lower limit of the neutral temperature range. This suggests that elderly people in the region may not necessarily find the temperature acceptable even when it falls within the thermally neutral range for them.

Elderly respondents in the four spatial categories exhibited varying ranges of thermal acceptability. Those in the I category space demonstrated the highest level of environmental tolerance. Conversely, respondents in the M category space had the narrowest acceptable temperature range. Respondents in the L category space displayed the lowest tolerance for low temperatures, followed by those in the M and S category spaces. Respondents in the I and L category spaces manifested a strong tolerance for warm conditions, while those in the M category space showed a lower tolerance for warmer conditions.

4. Discussion

4.1. Outdoor thermal benchmarks

4.1.1. Comparison of winter outdoor thermal benchmark studies

A comparison of the winter outdoor thermal benchmarks in other regions is shown in Table 5.

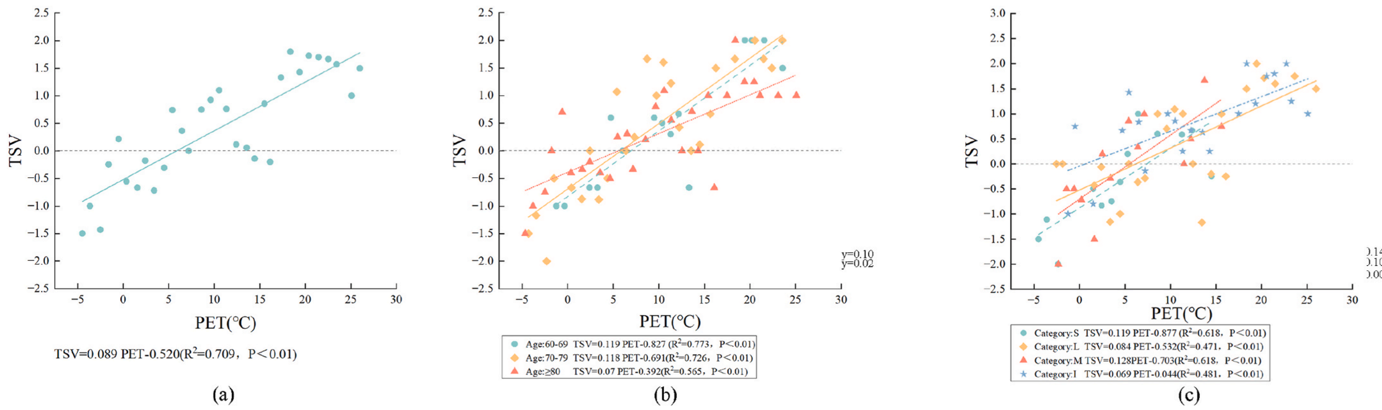

Fig. 9. Correlation between PET and TSV of all respondents (a); of all age groups (b); in four space categories (c).

Table 4
Outdoor thermal benchmarks for respondents

Respondents		NPETR(°C)	NPET(°C)	80% TAR(°C)
All respondents		0.22–11.46 (11.24)	5.84	3.32–28.91 (25.59)
Age groups	Age:60-69	2.75–11.15 (8.4)	6.95	4.10–25.07 (20.97)
	Age:70-79	1.62–10.09 (8.47)	5.86	3.93–26.25 (22.32)
	Age:≥80	−1.54–12.74 (14.28)	5.6	2.80–27.58 (24.78)
Space categories	In S category spaces	3.17–11.57 (8.4)	7.37	2.09–19.01 (16.92)
	In L category spaces	0.38–12.29 (11.91)	6.33	3.20–28.13 (24.93)
	In M category spaces	1.59–9.40 (7.81)	5.49	2.28–15.90 (13.62)
	In I category spaces	−6.61–7.88 (14.49)	0.64	0.49–34.68 (34.19)

Huangshan shares a subtropical monsoon climate with Hangzhou, Chengdu, and Changsha. Despite their similar average annual temperatures, the neutral temperature in these cities is respectively higher than that of Huangshan by 11.16 °C, 6.76 °C, and 9.06 °C. These variations may be attributed to differences in the surveyed population, types of green spaces, and other factors.

The characteristics of community parks may result in variations in experimental outcomes. On the one hand, the presence of residential buildings near the park creates more shaded areas, leading to lower air temperature and solar radiation. On the other hand, there is a strong correlation between the physical activities of elderly individuals in the community and the hours of the day [56]. Elderly individuals have unique needs and usage patterns when it comes to using the park. In this study, the surveyed elderly individuals tend to do more vigorous physical activities (square dancing, calisthenics, etc.) during the morning and evening, while they often choose to rest at home during the warmer noon period, such as taking a nap or caring for children, rather than being active in the park. In contrast, large urban parks have fewer elderly individuals visiting during the winter mornings. Considering these factors, more elderly people attend and tend to have higher-intensity outdoor activities when the temperature and solar radiation are lower in community parks, which may lead to lower neutral temperatures and acceptable temperature thresholds.

Therefore, activity patterns, visitation time patterns, thermal history, and individual adaptation all contribute to people's acceptance and adaptability to heat [30,57]. Elderly individuals who regularly engage in activities in community parks exhibit greater tolerance to cold temperatures in winter. This finding is consistent with the existing research, suggesting that older adults are more willing to accept unfavorable weather when being active [58].

In comparison to other studies on outdoor thermal benchmarks for elderly individuals, this study found that the NPET, NPETR, and 80% TAR for the surveyed elderly participants were relatively lower. Specifically, the lower limits of the NPETR and 80% TAR for the surveyed elderly were similar to those in Xian, while the upper limits were lower by 14.14 °C and 3.29 °C, respectively. Additionally, the NPETR in this study was notably lower compared to that among elderly individuals in Lhasa.

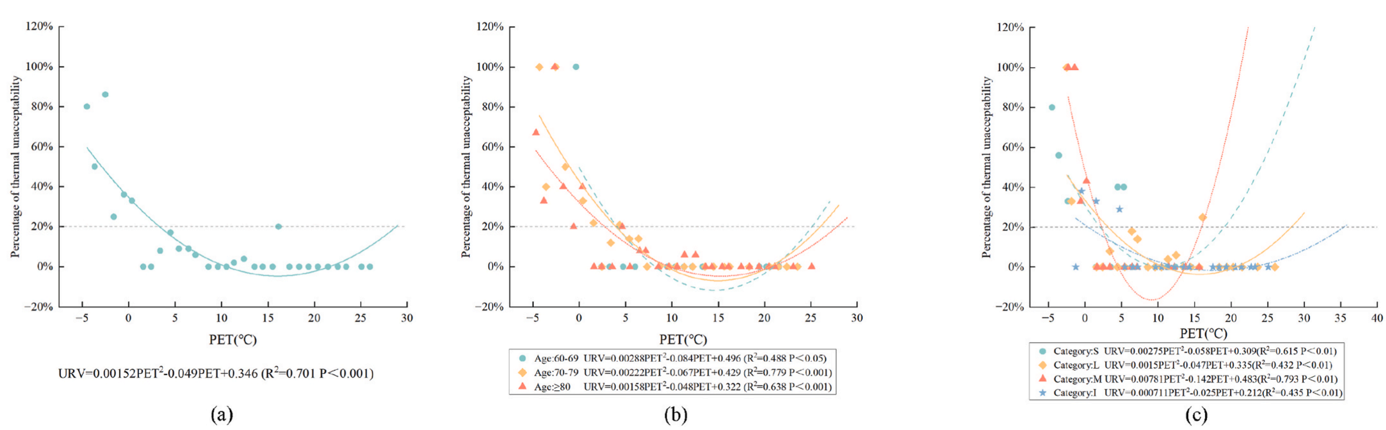

Fig. 10. Relationship between thermal unacceptable rate and PET of all respondents (a); of all age groups (b); in four space categories (c).

Table 5
Comparison of wintertime outdoor thermal benchmarks in different areas.

Region	climate zone	context	Population	NPET(°C)	NPETR (°C)	80% TAR (°C)	TSV when most comfortable
Huangshan	Hscw	Community park	Elderly people	5.84	0.22–11.46	3.32–28.91	1.58
Chengdu [43]	Hscw	Urban park	Mixed ages	12.6	6.7–18.2	–	–
Changsha [65]	Hscw	outdoor public spaces	Young people	14.9	11.8–18.0	–	–
Hangzhou [66]	Hscw	the West Lake scenic area	Young people	17.0	9.7–24.2	–	–
Xi'an [21]	Cold	Urban park	Elderly people	13.2	1.0–25.6	4.6–32.2	−0.23
Lhasa [22]	Severe cold	Typical urban spaces	Elderly people	20.6 (male)	8.4–17.11 (male) 6.0–16.2 (female)	–	−0.45
Changchun [67]	Severe cold	Residential area	Elderly people	−0.5	−2.7–1.6	–	–
Chengdu [68]	Hscw	Urban park	Elderly people	–	–	–	0.71

The main reason for these differences may lie in the varying patterns of outdoor activities among the elderly. Compared to Xi'an and Lhasa, the probability of extreme winter climates in the Huangshan region is relatively low. Consequently, the elderly population in Huangshan exhibits higher attendance rates and greater engagement in outdoor activities [59,60], which aligns with the findings of Jones GR's research [56]. During outdoor exercise, the muscles generate heat, raising the core body temperature of elderly individuals [61]. This enables them to achieve a state of thermal neutrality even at lower temperatures, as well as reducing their tolerance for higher temperatures. Additionally, existing studies have indicated that participants' acceptable temperature ranges can significantly influence overall park attendance during different seasons [29].The elderly in Xi'an generally accept higher temperatures in winter, which may lead to a reduction in the outdoor attendance rate of the elderly in winter, prompting the elderly in this area to have fewer outdoor activities. This, in turn, could explain the potential reasons behind the lower cold tolerance observed among the elderly population in Huangshan compared to the Xi'an region.

In this study, the elderly participants reached a state of thermal comfort in slightly warm to warm sensations. Similarly, in Chengdu, which is also a hot summer and cold winter zone, the elderly individuals achieved thermal comfort in neutral and slightly warm sensations. In contrast, the elderly individuals in the cold zone of Xi'an and the severe cold zone of Lhasa reached thermal comfort in neutral and slightly cool sensations. These differences may be attributed to the participants' activity levels and their previous experiences with heat [62]. By comparing the variations in the lower limit of NPET and the lower limit of TAR between the elderly individuals in Huangshan and Lhasa, it is evident that the elderly population in Huangshan exhibits higher cold tolerance compared to those in Xi'an and Lhasa. This may be attributed to the lesser use of heating devices in hot summer and cold winter zones, leading to lower expectations regarding cold temperatures compared to colder and extremely cold zones [63,64].

Analysis results indicate that the long-term experience of living in cold and humid winters, along with adaptability and higher levels of outdoor activity, enable the surveyed elderly individuals to better cope with the cold and humid winter environment. However, they still long for a warmer and less humid environment to achieve thermal comfort. In addition, older adults in the study area are more susceptible to cold temperatures during the morning and evening hours in community parks.

4.1.2. Comparison of outdoor thermal benchmarks between different ages

Huangshan and Hangzhou are very close approximately 200 km apart. However, the NPET for young individuals in Hangzhou [66] is higher by 11.16 °C compared to the elderly in Huangshan. This indicates that, relative to younger individuals, the elderly demonstrate a higher tolerance towards cold environments, and older individuals have lower sensitivity to cold conditions.

Within the elderly demographic, there are distinctions in outdoor thermal benchmarks across different age groups. In alignment with the research conducted in Xi'an [21], Huangshan also reveals a similar lower threshold of NPETR for elderly individuals across various age groups. This suggests that the elderly perceive minor distinctions in the cold winter. Moreover, both studies demonstrate a consistent downward trend in NPETR lower bounds as age increases, indicating that older individuals require lower temperatures to achieve thermal neutrality.

Furthermore, research on the perception of humidity among the elderly in damp and cold winters indicates that elderly individuals in this study have a higher tolerance for humidity but desire a less humid environment during the winter.

4.1.3. Comparison of outdoor thermal benchmarks between different activities

Existing studies have demonstrated an overall "inverted U-shaped" relationship between temperature and physical activity, where activity levels tend to decrease both in low and high temperatures. However, the thresholds for different seasons and locations may vary [69,70]. It is worth noting that the research conducted in Changchun was carried out within residential areas [67], where elderly participants had easier access to indoor environments compared to urban parks. The surveyed elderly individuals in this context often engaged in activities such as gymnastics, jogging, and brisk walking. This may cause its NPETR being significantly lower than that of Lhasa [22], which is also a severe cold zone, but closer to Huangshan, which is a hot summer and cold winter zone.

Therefore, on the one hand, outdoor microclimates directly influence the thermal comfort of respondents, consequently impacting their level of outdoor activities. On the other hand, the level of outdoor activities can also influence the outdoor thermal comfort experienced.

In addition to activity intensity, different content of activities can also lead to variations in thermal perception. This study has summarized the disparities in outdoor thermal environments within various spatial categories of community parks (Table 4.) and conducted a detailed analysis.

Activities within S category spaces mainly consist of essential tasks such as dog walking and making quiet phone calls. These activities require a secluded environment, limiting people's choices in terms of space. The limitation may increase their attention to the thermal environment and heighten thermal sensitivity. Furthermore, the surveyed participants in S category spaces may have a psychological expectation of a neutral to cool thermal sensation, which results in a lower upper limit for the 80% acceptable temperature range. In cold and humid winters, users in S category and M category spaces are more likely to feel discomfort at the same TSV, while users in L category and I category spaces are more likely to feel comfortable. This could be related to the presence or absence of companions during activities. Existing studies have shown that individuals without companions tend to be more uncomfortable in open outdoor spaces compared to those with companions [71,72]. It is noteworthy that a favorable landscape design may contribute to a more favorable perception of the environment by older adults, as observed in the S2 Site. Previous research has indicated that thermal sensation and thermal comfort of the elderly are susceptible to the influence of acoustic and visual environments [73]. Moreover, perceiving a favorable environmental quality can enhance thermal comfort and tolerance [74].

In L category spaces, elderly individuals exhibit noticeable autonomous behavior. In these spaces, they often bring their own tables and chairs, allowing them the freedom to engage in card activities and have the autonomy to choose their preferred locations. They make choices based on different weather conditions, selecting different positions and orientations for their activities. During lower temperature conditions, elderly individuals proactively move to environments with higher sunlight exposure in winter. These behaviors increase the lower limit of the 80% acceptable temperature range for participants at L category spaces. This phenomenon also demonstrates the significant role of thermal adaptation behavior in outdoor thermal perception and emphasizes the importance of unshaded areas in parks during cold and damp winter weather [75,76].

The M5 site is the only area within the community park that is equipped with fitness equipment. However, due to the immobility of these fitness equipment, there is limited freedom in space selection. When individuals have control over the facilities within a space, their satisfaction with the thermal environment increases, making them more accepting of the outdoor thermal environment [29][77–79]. However, it is possible that even under favorable microclimatic conditions, the thermal comfort and acceptability in this area are still suboptimal, potentially due to lower satisfaction with the M5 site [80]. Research conducted in Hong Kong has demonstrated a positive correlation between the thermal acceptability of elderly individuals and their overall satisfaction with open spaces in both summer and winter seasons. Overall spatial satisfaction is an important factor influencing outdoor thermal acceptability among elderly individuals [28]. Furthermore, previous research has explored the factors influencing the satisfaction of elderly individuals with urban parks, revealing that social connections are the most decisive factor [14]. The lower satisfaction level at the M5 measurement point may be attributed to the relatively limited social interactions among elderly individuals in that space.

It is noteworthy that the upper limit of the acceptable temperature range at the I6 site was relatively high, which could be influenced by the activity expectations of the respondents. Elderly individuals who frequent this space are usually engaged in activities such as dancing, and they tend to seek a warm or slightly warm thermal sensation. Moreover, the elderly in the I6 site confer significant autonomy, leading to a higher tolerance for the environment [81,82]. Consequently, this may result in them possessing a higher tolerance for elevated temperatures while also enduring lower temperatures.

As a result, they may have a higher tolerance for higher temperatures. This finding aligns with previous research conclusions that individuals who visit open spaces during winter due to thermal reasons have higher expectations of the thermal environment [28].

These differences demonstrate that various social and psychological factors, such as companionship, thermal adaptation behaviors, spatial satisfaction, activity expectations, and autonomy, have an impact on the perception of thermal comfort among older individuals during different types of activities. Therefore, it is imperative to take into account the

Fig. 11. Activities at measurement points.

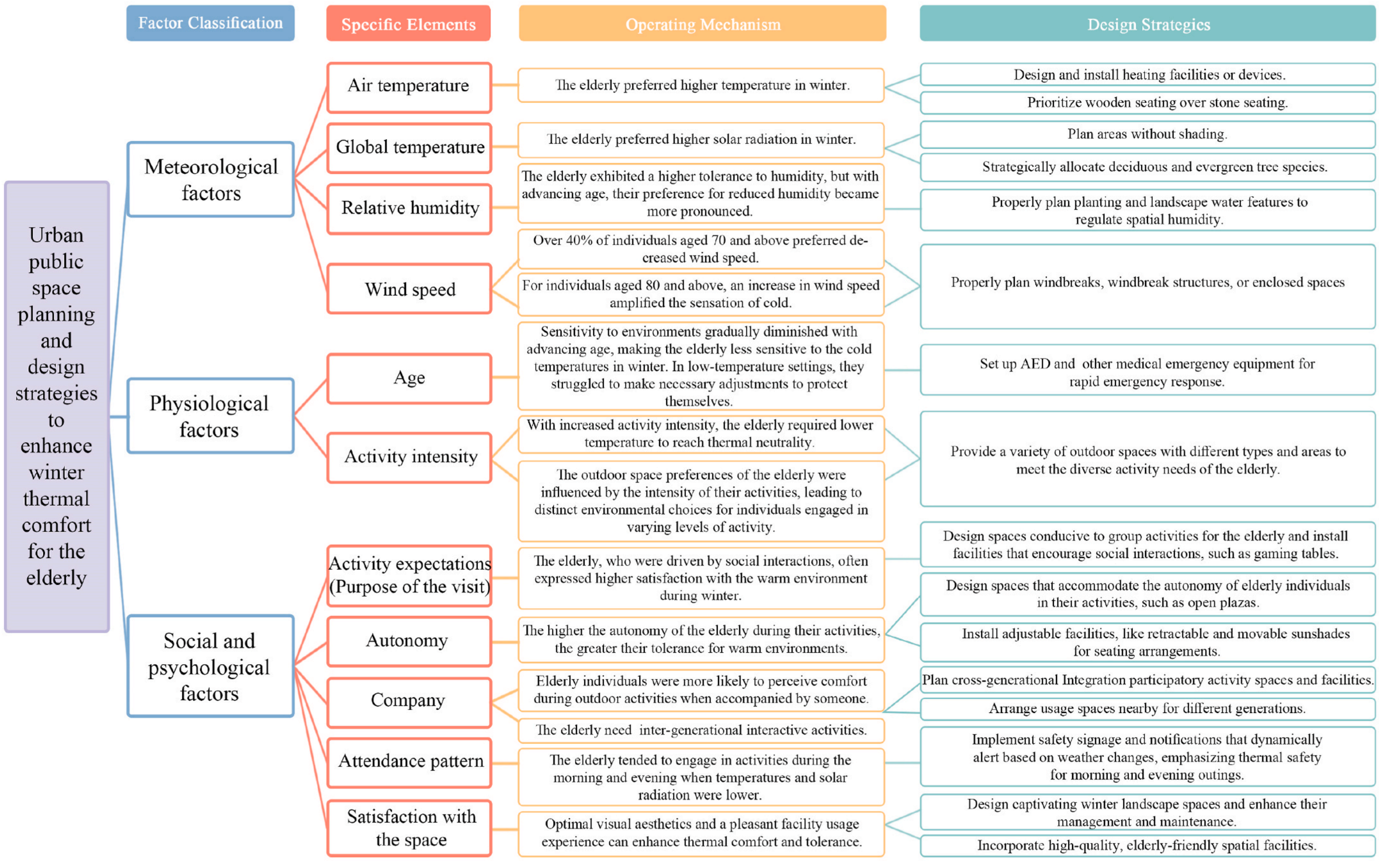

Fig. 12. Urban public space planning and design strategies to enhance winter thermal comfort for the elderly.

socio-psychological factors of the elderly when planning and constructing community parks.

4.2. Design implications

The design of urban open spaces aimed at assessing thermal perception among the elderly should consider the differences in thermal environmental requirements based on different age groups, activity intensities, and social-psychological needs of individuals. Being aware of these issues can enrich the possibilities for architects, planners, and designers in their design endeavors (Fig. 12).

Therefore, to cater to the outdoor usage of the elderly during winter, it is recommended to consider additional facilities (such as heating devices, wooden seats are preferred over stone seats), and setting up rest chairs in unsheltered squares to respond to the ever-changing climate conditions. It can increase the chances of finding environments that are more suitable within their thermal comfort range. Additionally, interactive adaptations in outdoor spaces can also influence thermal perception, gaining appreciation from the users of the space [83]. Existing research has shown that environments with options are more preferred by users [81]. However, it is important to note that thermal perception of the same space may vary or even be reversed in different seasons [60]. Hence, it is recommended to consider the use of different spaces during various seasons while designing community parks.

Moreover, wind sensation and radiant sensation were also significant factors that influence the activities of older individuals. Increased wind speed enhances the body's evaporative rate, leading to the removal of body heat and an increased sensation of cold [84]. Harsh winter winds make it challenging to tolerate the cold climate, causing older adults to shorten their activity duration, resulting in a notable decrease in overall physical activity [85]. Therefore, it is crucial to emphasize the importance of providing areas without shading in winter and incorporating windbreaks and wind-blocking structures. Careful placement of deciduous trees and the consideration of wind-resistant tree species should be taken into account during the design process.

The outdoor space options and thermal perception of older individuals are influenced by their activity levels. Most individuals prefer engaging in low-intensity activities in hot environments, while they tend to shift towards moderate or high-intensity activities in colder environments [60].Therefore, it is recommended to provide diverse categories of spaces that cater to their activity needs in comfortable thermal sensations, which can foster their participation in outdoor activities during the winter season, consequently enhancing the health and overall sense of well-being among the elderly population. For instance, open and spacious plazas can be designed to accommodate residents who enjoy activities such as square dancing, while appropriately sized squares can be designated for residents who prefer activities like playing cards.

Regarding social and psychological factors, the purpose of the visit, spatial satisfaction, and autonomy are significant factors that influence thermal sensation and thermal comfort. Older individuals who visit for social interaction purposes, such as playing cards, participating in square dancing, singing, or duo dancing, tend to rate the thermal environment more favorably in winter. This is due to their high thermal expectations and perception control. Therefore, in the design of community parks, it is essential to consider enriching activities and amenities that foster social engagement. Creating opportunities for social interactions among elderly individuals within the park, such as organizing regular activities catering to their interests, should be prioritized. Additionally, since many seniors prefer intergenerational interactions, it would be beneficial to design facilities and spaces that meet the needs of both the elderly and children. Additionally, older individuals who exhibit higher satisfaction with spatial facilities and landscapes, as well as a greater sense of autonomy, also tend to be more accepting of the environment.

Therefore, it is recommended to provide age-appropriate sports facilities for the elderly and spaces that cater to their social needs within the park. Emphasis should be placed on the quality of the facilities and the aesthetic appeal of the spaces. Additionally, it is important to prioritize spaces that enhance activity autonomy, such as open plazas with resting benches. These benches can be equipped with retractable and movable awnings, allowing users to choose whether to open them or not. A design like this ensures that the park accommodates residents who come for exercise as well as those who come for socializing and conversations.

5. Conclusions

This study investigated the outdoor thermal comfort of elderly individuals in community parks in Huangshan City. Based on the activity intensity of the sites, six sites were categorized into four types. Through field measurements and questionnaire surveys, an outdoor thermal benchmark for the elderly population in the area was established, and the influences of different age groups and space types on outdoor thermal comfort for the elderly were analyzed. The main findings were as follows:

1) Thermal sensation among the elderly was primarily influenced by T_a and T_g, with RH also being an important factor. Additionally, thermal sensation among individuals aged 80 and above was influenced by wind speed.
2) NPET of the elderly in Huangshan was 5.84 °C, with a range of 0.22–11.46 °C. The PET range of thermal acceptability by 80% of respondents was 3.32–28.91 °C. NPET, NPETR, and TAR exhibited significant differences across different climate zones, demographic compositions, and activity types. For the study area, these values are relatively low, indicating that the elderly individuals under investigation displayed a higher tolerance to humid and cold environments.
3) The intensity and content of activities among the elderly in community parks significantly influence their outdoor thermal perception from both physiological and psychological perspectives. The content of activities triggers distinct expectations, attendance patterns, activity autonomy, and engagement perception among the elderly, subtly impacting thermal perception. Moreover, spatial satisfaction, thermal experience, and thermal adaptation behavior also influence outdoor thermal perception among the elderly.
4) Commencing from meteorological, physiological, social and psychological perspectives, this study focus on the specific elements within each perspective and elucidate the mechanistic influences on thermal perception among the elderly. This aims to provide strategies for urban public space planning and design for enhancing thermal comfort for the elderly during the winter.

CRediT authorship contribution statement

Wenqing Wang: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Yanhan Li:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Liang Li:** Writing – review & editing, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Ruosang Wang:** Visualization, Data curation. **Yiqi Wang:** Visualization, Data curation.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2023.111001.

References

[1] ageing-in-the-twentyfirst-century-a-celebration-and-a-challenge, (n.d.). https://doi.org/10.1163/2210-7975_HRD-9997-0045.
[2] K.J. Collins, A.N. Exton-Smith, C. Doré, Urban hypothermia: preferred temperature and thermal perception in old age, Br. Med. J. Clin. Res. Ed. 282 (1981) 175–177.
[3] Y. Zhang, Thermal Comfort Implications of the Aging Effect on Metabolism, Cardiac Output and Body Weight, (n.d.) https://www.academia.edu/225032/Thermal_Comfort_Implications_of_the_Aging_Effect_on_Metabolism_Cardiac_Output_and_Body_Weight (accessed June 24, 2023).
[4] M.T. Baquero Larriva, E. Higueras, Health risk for older adults in Madrid, by outdoor thermal and acoustic comfort, Urban Clim. 34 (2020), 100724, https://doi.org/10.1016/j.uclim.2020.100724.
[5] S. Guergova, A. Dufour, Thermal sensitivity in the elderly: a review, Ageing Res. Rev. 10 (2011) 80–92, https://doi.org/10.1016/j.arr.2010.04.009.
[6] L. Schellen, W.D. Van Marken Lichtenbelt, M.G.L.C. Loomans, J. Toftum, M.H. De Wit, Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady-state condition, Indoor Air 20 (2010) 273–283, https://doi.org/10.1111/j.1600-0668.2010.00657.x.
[7] E. Pleson, L.M. Nieuwendyk, K.K. Lee, A. Chaddah, C.I.J. Nykiforuk, D. Schopflocher, Understanding older adults' usage of community green spaces in taipei, taiwan, Int. J. Environ. Res. Publ. Health 11 (2014) 1444–1464, https://doi.org/10.3390/ijerph110201444.
[8] S. Wang, E.H.K. Yung, Y. Sun, Effects of open space accessibility and quality on older adults' visit: planning towards equal right to the city, Cities 125 (2022), 103611, https://doi.org/10.1016/j.cities.2022.103611.
[9] Y. Liu, Y. Guo, S. Lu, O.F. Chan, C.H.K. Chui, H.C. Ho, Y. Song, W. Cheng, R.L. H. Chiu, C. Webster, T.Y.S. Lum, Understanding the long-term effects of public open space on older adults' functional ability and mental health, Build. Environ. 234 (2023), 110126, https://doi.org/10.1016/j.buildenv.2023.110126.
[10] L. Chen, E. Ng, Outdoor thermal comfort and outdoor activities: a review of research in the past decade, Cities 29 (2012) 118–125, https://doi.org/10.1016/j.cities.2011.08.006.
[11] L. Martinelli, T.-P. Lin, A. Matzarakis, Assessment of the influence of daily shadings pattern on human thermal comfort and attendance in Rome during summer period, Build. Environ. 92 (2015) 30–38, https://doi.org/10.1016/j.buildenv.2015.04.013.
[12] M. Nikolopoulou, S. Lykoudis, Use of outdoor spaces and microclimate in a Mediterranean urban area, Build. Environ. 42 (2007) 3691–3707, https://doi.org/10.1016/j.buildenv.2006.09.008.
[13] S. de Vries, R. Verheij, P. Groenewegen, P. Spreeuwenberg, Natural environments—healthy environments? An exploratory analysis of the relationship between greenspace and health, Environ. Plann. 35 (2003) 1717–1731, https://doi.org/10.1068/a35111.
[14] H.K. Y. Esther, K.O. H. Winky, H.W. C. Edwin, Elderly satisfaction with planning and design of public parks in high density old districts: an ordered logit model, Landsc. Urban Plann. 165 (2017) 39–53, https://doi.org/10.1016/j.landurbplan.2017.05.006.
[15] A. Joseph, C. Zimring, Where active older adults walk: understanding the factors related to path choice for walking among active retirement community residents, Environ. Behav. 39 (2007) 75–105, https://doi.org/10.1177/0013916506295572.
[16] D. Li, Y. Zhai, Y. Xiao, G. Newman, D. Wang, Subtypes of park use and self-reported psychological benefits among older adults: a multilevel latent class analysis approach, Landsc. Urban Plann. 190 (2019), 103605, https://doi.org/10.1016/j.landurbplan.2019.103605.
[17] J. Maas, S.M.E. van Dillen, R.A. Verheij, P.P. Groenewegen, Social contacts as a possible mechanism behind the relation between green space and health, Health Place 15 (2009) 586–595, https://doi.org/10.1016/j.healthplace.2008.09.006.
[18] T. Sugiyama, C.W. Thompson, Environmental support for outdoor activities and older people's quality of life, J. Hous. Elder. 19 (2006) 167–185, https://doi.org/10.1300/J081v19n03_09.

[19] H.E.A. Tinsley, D.J. Tinsley, C.E. Croskeys, Park usage, social milieu, and psychosocial benefits of park use reported by older urban park users from four ethnic groups, leis, Science 24 (2002) 199–218, https://doi.org/10.1080/01490400252900158.
[20] D. Umberson, J.K. Montez, Social relationships and health: a flashpoint for health policy, J. Health Soc. Behav. 51 (2010) S54–S66, https://doi.org/10.1177/0022146510383501.
[21] X. Ma, Y. Tian, M. Du, B. Hong, B. Lin, How to design comfortable open spaces for the elderly? Implications of their thermal perceptions in an urban park, Sci. Total Environ. 768 (2021), 144985, https://doi.org/10.1016/j.scitotenv.2021.144985.
[22] F. Yao, H. Fang, J. Han, Y. Zhang, Study on the outdoor thermal comfort evaluation of the elderly in the Tibetan plateau, Sustain. Cities Soc. 77 (2022), 103582, https://doi.org/10.1016/j.scs.2021.103582.
[23] X. Ma, L. Song, B. Hong, Y. Li, Y. Li, Relationships between EEG and thermal comfort of elderly adults in outdoor open spaces, Build. Environ. 235 (2023), 110212, https://doi.org/10.1016/j.buildenv.2023.110212.
[24] D. Lai, D. Guo, Y. Hou, C. Lin, Q. Chen, Studies of outdoor thermal comfort in northern China, Build, Environ. Times 77 (2014) 110–118, https://doi.org/10.1016/j.buildenv.2014.03.026.
[25] L. He, R. Pan, Y. Huang, Study on the correlation between microclimate in urban parks and activity behavior of the elderly——a case of luolong park in kunming, Urban. Archit. 17 (2020) 121–126.
[26] H. Jin, L. Qiao, P. Cui, Research on winter thermal comfort of campus in severe cold regions based on outdoor activities, Build. Sci. 37 (2021) 87–92+103, https://doi.org/10.13614/j.cnki.11-1962/tu.2021.08.11.
[27] K. Xiong, B.-J. He, Wintertime outdoor thermal sensations and comfort in cold-humid environments of Chongqing China, Sustain. Cities Soc. 87 (2022), 104203, https://doi.org/10.1016/j.scs.2022.104203.
[28] E.H.K. Yung, S. Wang, C. Chau, Thermal perceptions of the elderly, use patterns and satisfaction with open space, Landsc. Urban Plann. 185 (2019) 44–60, https://doi.org/10.1016/j.landurbplan.2019.01.003.
[29] Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types, Build. Environ. 59 (2013) 599–611, https://doi.org/10.1016/j.buildenv.2012.10.005.
[30] M. Nikolopoulou, S. Lykoudis, Thermal comfort in outdoor urban spaces: analysis across different European countries, Build. Environ. 41 (2006) 1455–1470, https://doi.org/10.1016/j.buildenv.2005.05.031.
[31] J. Yin, Y. Zheng, R. Wu, J. Tan, D. Ye, W. Wang, An analysis of influential factors on outdoor thermal comfort in summer, Int. J. Biometeorol. 56 (2012) 941–948, https://doi.org/10.1007/s00484-011-0503-9.
[32] T.-P. Lin, R. de Dear, R.-L. Hwang, Effect of thermal adaptation on seasonal outdoor thermal comfort, Int. J. Climatol. 31 (2011) 302–312, https://doi.org/10.1002/joc.2120.
[33] I. Eliasson, I. Knez, U. Westerberg, S. Thorsson, F. Lindberg, Climate and behaviour in a Nordic city, Landsc. Urban Plann. 82 (2007) 72–84, https://doi.org/10.1016/j.landurbplan.2007.01.020.
[34] I. Knez, S. Thorsson, Influences of culture and environmental attitude on thermal, emotional and perceptual evaluations of a public square, Int. J. Biometeorol. 50 (2006) 258–268, https://doi.org/10.1007/s00484-006-0024-0.
[35] K. Pantavou, G. Theoharatos, M. Santamouris, D. Asimakopoulos, Outdoor thermal sensation of pedestrians in a Mediterranean climate and a comparison with UTCI, Build. Environ. 66 (2013) 82–95, https://doi.org/10.1016/j.buildenv.2013.02.014.
[36] Z. Liu, A. Kemperman, H. Timmermans, Social-ecological correlates of older adults' outdoor activity patterns, J. Transport Health 16 (2020), 100840, https://doi.org/10.1016/j.jth.2020.100840.
[37] Statistics Department of Huangshan, n.d. https://web.archive.org/web/20201009023941. (Accessed 24 June 2023).
[38] P. Kumar, A. Sharma, Study on importance, procedure, and scope of outdoor thermal comfort –A review, Sustain. Cities Soc. 61 (2020), 102297, https://doi.org/10.1016/j.scs.2020.102297.
[39] J. Li, R. Sun, L. Chen, Identifying sensitive population associated with summer extreme heat in Beijing, Sustain. Cities Soc. 83 (2022), 103925, https://doi.org/10.1016/j.scs.2022.103925.
[40] S. Chindaphol, J. Blair, P. Osmond, D. Prasad, Determining the metabolic rate of the Thai elderly, Chiang Mai Univ. J. Nat. Sci. 16 (2017), https://doi.org/10.12982/cmujns.2017.0004.
[41] 14:00-17:00, ISO 10551:2019, ISO. (n.d.). https://www.iso.org/standard/67186.html (accessed September 29, 2023).
[42] 14:00-17:00, ISO 7730:2005, ISO. (n.d.). https://www.iso.org/standard/39155.html (accessed September 29, 2023).
[43] L. Zhang, D. Wei, Y. Hou, J. Du, Z. Liu, G. Zhang, L. Shi, Outdoor thermal comfort of urban park—a case study, Sustainability 12 (1961) (2020), https://doi.org/10.3390/su12051961.
[44] E. Johansson, S. Thorsson, R. Emmanuel, E. Krüger, Instruments and methods in outdoor thermal comfort studies – the need for standardization, Urban Clim. 10 (2014) 346–366, https://doi.org/10.1016/j.uclim.2013.12.002.
[45] P.H. Gobster, Urban parks as green walls or green magnets? Interracial relations in neighborhood boundary parks, Landsc. Urban Plann. 41 (1998) 43–55, https://doi.org/10.1016/S0169-2046(98)00045-0.
[46] D. Wang, G. Brown, Y. Liu, The physical and non-physical factors that influence perceived access to urban parks, Landsc. Urban Plann. 133 (2015) 53–66, https://doi.org/10.1016/j.landurbplan.2014.09.007.
[47] F. Bahriny, S. Bell, Patterns of urban park use and their relationship to factors of quality: a case study of tehran, Iran, Sustainability 12 (2020) 1560, https://doi.org/10.3390/su12041560.
[48] X. He, W. Gao, R. Wang, D. Yan, Study on outdoor thermal comfort of factory areas during winter in hot summer and cold winter zone of China, Build. Environ. 228 (2023), 109883, https://doi.org/10.1016/j.buildenv.2022.109883.
[49] J. Qiu, J. Yang, M. Lu, Y. Chen, Y. Yang, W. Cao, K. Meng, Y. Chen, J. Zhang, C. Xu, L. Yi, X. Guo, Y. Wang, X. Liu, Y. Yan, H. Li, Q. Zhuo, W. Zhao, L. Feng, B. E. Ainsworth, Chinese Compilation of Physical Activities in healthy adults aged 18-64: categories and metabolic intensities, Sports Med. Health Sci. 4 (2022) 160–171, https://doi.org/10.1016/j.smhs.2022.06.004.
[50] W. Zhao, L. Cong, Physical activity evaluation: metabolic equivalent intensity levels and evaluation of different physical activity, J. Hyg. Res. (2004) 246–249.
[51] H.-W. Chow, C.-H. Ho, Does the use of outdoor fitness equipment by older adults qualify as moderate to vigorous physical activity? PLoS One 13 (2018), e0196507 https://doi.org/10.1371/journal.pone.0196507.
[52] E.W. Shaw, Thermal Comfort: analysis and applications in environmental engineering, by P. O. Fanger, 244 pp, DANISH TECHNICAL PRESS, Copenhagen, Denmark, 1970. Danish Kr. 76, 50, R. Soc. Health J. 92 (1972) 164–164, https://doi.org/10.1177/146642407209200337.
[53] Urban heat island and differences in outdoor comfort levels in Glasgow, UK | SpringerLink, (n.d.). https://link.springer.com/article/10.1007/s00704-012-0724-9 (accessed June 24, 2023).
[54] K. Tsuzuki, T. Ohfuku, Thermal sensation and thermoregulation in elderly compared to young people in Japanese winter season. https://www.semanticscholar.org/paper/THERMAL-SENSATION-AND-THERMOREGULATION-IN-ELDERLY-Tsuzuki-Ohfuku/39fce2574cb25ce80c5e498aefc40cad6b9df5e0, 2002. (Accessed 24 June 2023).
[55] Standard 55 – Thermal Environmental Conditions for Human Occupancy, (n.d.). https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy (accessed June 24, 2023).
[56] G.R. Jones, C. Brandon, D.P. Gill, Physical activity levels of community-dwelling older adults are influenced by winter weather variables, Arch. Gerontol. Geriatr. 71 (2017) 28–33, https://doi.org/10.1016/j.archger.2017.02.012.
[57] L. Chen, Y. Wen, L. Zhang, W.-N. Xiang, Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai, Build, Environ. Times 94 (2015) 644–653, https://doi.org/10.1016/j.buildenv.2015.10.020.
[58] N.P. Aspvik, H. Viken, J.E. Ingebrigtsen, N. Zisko, I. Mehus, U. Wisløff, D. Stensvold, Do weather changes influence physical activity level among older adults? – The Generation 100 study, PLoS One 13 (2018), e0199463, https://doi.org/10.1371/journal.pone.0199463.
[59] C.-H. Lin, T.-P. Lin, R.-L. Hwang, Thermal comfort for urban parks in subtropics: understanding visitor's perceptions, behavior and attendance, Adv. Meteorol. 2013 (2013), e640473, https://doi.org/10.1155/2013/640473.
[60] J. Huang, C. Zhou, Y. Zhuo, L. Xu, Y. Jiang, Outdoor thermal environments and activities in open space: an experiment study in humid subtropical climates, Build. Environ. 103 (2016) 238–249, https://doi.org/10.1016/j.buildenv.2016.03.029.
[61] S. Racinais, S. Cocking, J.D. Périard, Sports and environmental temperature: from warming-up to heating-up, Temp. Multidiscip. Biomed. J. 4 (2017) 227–257, https://doi.org/10.1080/23328940.2017.1356427.
[62] Y. Wang, Z. Ni, Y. Peng, B. Xia, Local variation of outdoor thermal comfort in different urban green spaces in Guangzhou, a subtropical city in South China, Urban For. Urban Green. 32 (2018) 99–112, https://doi.org/10.1016/j.ufug.2018.04.005.
[63] M. Nikolopoulou, N. Baker, K. Steemers, Thermal comfort in outdoor urban spaces: understanding the human parameter, Sol. Energy 70 (2001) 227–235, https://doi.org/10.1016/S0038-092X(00)00093-1.
[64] C. Buonocore, R. De Vecchi, V. Scalco, R. Lamberts, Influence of recent and long-term exposure to air-conditioned environments on thermal perception in naturally-ventilated classrooms, Build. Environ. 156 (2019) 233–242, https://doi.org/10.1016/j.buildenv.2019.04.009.
[65] W. Liu, Y. Zhang, Q. Deng, The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate, Energy Build. 128 (2016) 190–197, https://doi.org/10.1016/j.enbuild.2016.06.086.
[66] Y. Mei, L. Xu, Research on seasonal thermal neutral temperature in west lake scenic area of Hangzhou, China, Int. J. Environ. Res. Publ. Health 19 (2022), 14677, https://doi.org/10.3390/ijerph192214677.
[67] H. Jin, B. Wang, B. Han, Study on environment regulation of residential in severe cold area of China in winter: base on outdoor thermal comfort of the elderly, Sustainability 11 (2019) 6509, https://doi.org/10.3390/su11226509.
[68] Y. Mao, K. Han, Exploration on outdoor thermal comfort of urban parks: cases of two urban parks in Chengdu, Urban. Archit. 20 (2023) 87–91, https://doi.org/10.19892/j.cnki.csjz.2023.10.24.
[69] N. Pot, R. Keizer, Physical activity and sport participation: a systematic review of the impact of fatherhood, Prev. Med. Rep. 4 (2016) 121–127, https://doi.org/10.1016/j.pmedr.2016.05.018.
[70] T.B. Turrisi, K.M. Bittel, A.B. West, S. Hojjatinia, S. Hojjatinia, S.K. Mama, C. M. Lagoa, D.E. Conroy, Seasons, weather, and device-measured movement behaviors: a scoping review from 2006 to 2020, Int. J. Behav. Nutr. Phys. Activ. 18 (2021) 24, https://doi.org/10.1186/s12966-021-01091-1.
[71] F. Aljawabra, M. Nikolopoulou, Influence of hot arid climate on the use of outdoor urban spaces and thermal comfort: do cultural and social backgrounds matter? Intell. Build. Int. 2 (2010) 198–217, https://doi.org/10.3763/inbi.2010.0046.
[72] I. Maras, M. Buttstädt, J. Hahmann, H. Hofmeister, C. Schneider, Investigating public places and impacts of heat stress in the city of Aachen, Germany, ERDE, J. Geogr. Soc. Berl. 144 (2013) 290–303, https://doi.org/10.12854/erde-144-20.
[73] M. Du, B. Hong, C. Gu, Y. Li, Y. Wang, Multiple effects of visual-acoustic-thermal perceptions on the overall comfort of elderly adults in residential outdoor

environments, Energy Build. 283 (2023), 112813, https://doi.org/10.1016/j.enbuild.2023.112813.
[74] K.K.-L. Lau, C.Y. Choi, The influence of perceived aesthetic and acoustic quality on outdoor thermal comfort in urban environment, Build. Environ. 206 (2021), 108333, https://doi.org/10.1016/j.buildenv.2021.108333.
[75] Seasonal effects of urban street shading on long-term outdoor thermal comfort, Build. Environ. 46 (2011) 863–870, https://doi.org/10.1016/j.buildenv.2010.10.017.
[76] P. Cohen, O. Potchter, A. Matzarakis, Human thermal perception of Coastal Mediterranean outdoor urban environments, Appl. Geogr. 37 (2013) 1–10, https://doi.org/10.1016/j.apgeog.2012.11.001.
[77] T.-P. Lin, Thermal perception, adaptation and attendance in a public square in hot and humid regions, Build. Environ. 44 (2009) 2017–2026, https://doi.org/10.1016/j.buildenv.2009.02.004.
[78] The role of personal control of the environment in thermal comfort and satisfaction at the workplace - ProQuest, (n.d.). https://www.proquest.com/docview/303806654?pq-origsite=gscholar&fromopenview=true (accessed June 24, 2023).
[79] G. Brager, G. Paliaga, R. de Dear, Operable Windows, Personal Control and Occupant Comfort, 2004. https://escholarship.org/uc/item/4x57v1pf. (Accessed 24 June 2023).
[80] Y. Tian, B. Hong, Z. Zhang, S. Wu, T. Yuan, Factors influencing resident and tourist outdoor thermal comfort: a comparative study in China's cold region, Sci. Total Environ. 808 (2022), 152079, https://doi.org/10.1016/j.scitotenv.2021.152079.
[81] M. Nikolopoulou, K. Steemers, Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energy Build. 35 (2003) 95–101, https://doi.org/10.1016/S0378-7788(02)00084-1.
[82] G.S. Brager, R.J. de Dear, Thermal adaptation in the built environment: a literature review, Energy Build. 27 (1998) 83–96, https://doi.org/10.1016/S0378-7788(97)00053-4.
[83] M. Nikolopoulou, N. Baker, K. Steemers, THERMAL COMFORT IN URBAN SPACES: DIFFERENT FORMS OF ADAPTATION, 1999.
[84] T. Stathopoulos, Pedestrian level winds and outdoor human comfort, J. Wind Eng. Ind. Aerod. 94 (2006) 769–780, https://doi.org/10.1016/j.jweia.2006.06.011.
[85] H. Leng, Y. Zhang, Q. Yuan, Study on thermal comfort of urban parks in cold regions based on improving the physical activity level of the elderly——subjective perception and objective monitoring, Build. Sci. 39 (2023) 81–89+204, https://doi.org/10.13614/j.cnki.11-1962/tu.2023.04.11.