



**OPEN** **Field study of thermal comfort of the elderly in tree-shaded areas of urban parks in the cold area of China**

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Although extreme heat waves present a significant challenge to urban residents, the elderly in China prefer to go outdoors in summer. Shaded areas in parks may offer an ideal space for their outdoor activities. To assess the thermal adaptation of the elderly in open spaces during periods of high temperature, this study conducted an on-site test and survey for two groups, the elderly (aged 60 and above) and the non-elderly (aged below 60), in a park with tree-shaded areas in China. In total, 557 valid samples were collected, including microclimate parameters, visiting patterns, and subjective responses. Statistical analysis showed that the temperature-related parameters in shaded areas were significantly lower than those in open spaces. Among the elderly, 47.5% visited the park daily, and 33.6% chose to go out even when the temperature reached  $36.8 \pm 2.6$  °C. The thermal sensitivity of the elderly was significantly lower than that of the non-elderly. Both groups showed a high level of thermal acceptability at elevated temperatures with no significant difference. For the elderly, the standard effective temperature was 32.4 °C for 80% thermal acceptability, and 25.7 °C for 90% acceptability. The high acceptability might be attributed to psychological adaptation driven by their willingness for outdoor activities.

**Keywords** Thermal comfort, Psychological adaptation, The elderly, Park, Tree shade

According to data released by the National Bureau of Statistics of China, by the end of 2023, the elderly population aged 60 and above exceeded 296.97 million, accounting for 21.1% of the total population. Among them, 216.76 million were aged 65 and above, representing 15.4% of the total population. China has entered a moderately aging society and is the first country in the world to surpass 200 million elderly individuals, making it home to the largest elderly population globally. Moreover, the trend of aging continues to intensify.

After retiring, the elderly return to their families and communities with more free time. Most elders in China prefer to seek companions in parks or plazas where they can gather and, engage in social interactions and group activities<sup>1</sup>, such as dancing, playing cards, exercising, or chatting. These activities help them pass their free time, lift their spirits, and alleviate feelings of loneliness. Esther notes that social connections are a crucial factor in the choice of parks<sup>2</sup>. A survey by Lai of a park in Tianjin found that more than 75% of the occupants on weekdays were elderly individuals<sup>3</sup>. The elderly are the primary users of open spaces, and well-maintained open spaces can increase their physical health and well-being<sup>4</sup>. In fact, prolonged sedentary behavior indoors can also harm people's health<sup>5</sup>. Urban outdoor spaces, including community parks, street green spaces, and urban parks, provide excellent venues for the elderly. These spaces offer multiple benefits for the health and well-being of the elderly.

Due to the physiological and psychological particularities associated with aging, the elderly are often considered a special group that receives more attention and care. Therefore, the design and construction of urban outdoor spaces, such as parks and green spaces, are directly related to the well-being of the elderly.

## Literature review

Microclimate plays a significant role in shaping people's behaviors and usage of outdoor spaces<sup>6</sup>. Generally, the more comfortable an outdoor activity space is, the more likely people are to engage in outdoor activities. However, compared to the relatively stable and adjustable indoor thermal environment, the outdoor thermal

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environment is greatly affected by outdoor climate conditions. Air temperature, black globe temperature<sup>1</sup>, mean radiant temperature<sup>7</sup>, air humidity<sup>8</sup>, and wind<sup>5</sup> are key determinants of people's thermal comfort. Research by Zhang<sup>9</sup> confirmed that air temperature is the most influential factor affecting people's willingness to visit urban parks. A study<sup>10</sup> in Canada showed that when summer temperatures exceed 33 °C and spring and autumn temperatures surpass 29 °C, people begin to feel "too hot," leading to a decreased willingness to visit urban parks. Lai et al.'s<sup>3</sup> research indicated that the usage rate of the park reached a maximum when the thermal environment was approximately neutral and decreased as the thermal environment became hot or cold. In short, due to the variability of outdoor environments, outdoor thermal comfort is inherently complex.

According to reviews by<sup>11,12</sup>, Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Universal Thermal Climate Index (UTCI), and Standard Effective Temperature (SET) are the four commonly used thermal comfort indices for outdoor environment, in which PET is adopted most widely. Other indices, such as black globe temperature<sup>13</sup>, operative temperature, and Wet-Bulb Globe Temperature (WBGT) are also used for assessing thermal comfort. Taking PET as an example<sup>14</sup>, conducted a year-long outdoor study, and found a neutral PET of 28.6 °C. The acceptable comfort range was 19.1–38.1 °C, with a preferred temperature of 20.8 °C in Tempe, Arizona<sup>1</sup>. The annual thermal neutral PET of the elderly in Lhasa was 20.6 °C<sup>15</sup>. The neutral PET of the elderly in Xi'an was 13.2 °C, with a range of 3.1–23.2 °C in winter. The PET range of thermal acceptability for 90% of respondents was 10.9–25.9 °C, and the preferred PET was 14.4 °C. Another study, in China's cold regions, found that the outdoor neutral PET in winter was –0.5 °C<sup>16</sup>. It can be seen that thermal comfort levels vary depending on region and population.

Additionally, thermal comfort is influenced by factors such as age, clothing insulation, and education level. Both neutral PET and thermal sensitivity increase with age<sup>17</sup>. Education level and gender directly affect thermal perception in summer<sup>4</sup>. The availability of shade in summer and location expectations<sup>18</sup> also impact people's thermal comfort. Lin's<sup>19</sup> field study of parks in southern Taiwan found that in both cool and hot seasons, the number of people seeking shade increased with temperature to reduce thermal discomfort. Li's<sup>17</sup> survey of elderly park-goers in Changsha during midsummer revealed that moving to the shade provided by trees or buildings is the main thermal adaptation behavior of the elderly in the park during summer. Shaded areas create relatively cooler spaces and are a key factor in encouraging people to remain in parks during hot weather<sup>19</sup>. In pedestrian spaces<sup>17</sup> and street spaces<sup>20</sup>, trees serve as the principal shading strategy for open spaces, and can significantly improve outdoor thermal comfort in urban settings. In public squares, the elderly feel more comfortable in tree-shaded areas in summer and in open squares in winter. Psychologically, people also perceive green spaces as more conducive to achieving thermal comfort<sup>21</sup>. With hot summer climates, especially in the context of global warming and the increasing frequency of extreme weather, outdoor conditions often remain harsh with elevated temperatures. Shade from trees acts as an effective cooling tool in open spaces<sup>7</sup>, offering an excellent outdoor leisure area for the elderly.

## Objectives

Existing research has primarily focused on the thermal comfort characteristics of the elderly in indoor environments<sup>22,23</sup>. In recent years, although studies on outdoor thermal comfort for the elderly have increased, they mainly focus on high-density urban parks and parks in mega-cities<sup>24</sup>, often involving elderly individuals in more developed regions. In contrast, the elderly in small and medium-sized cities, influenced by economic conditions and lifestyle habits, may exhibit different thermal comfort levels and behaviors. In fact, besides major cities like Beijing, Shanghai, Guangzhou, and Shenzhen, as well as provincial capitals, small and medium-sized cities make up a significant portion of China, both in number and population. Since the elderly in these cities have fewer leisure activities, their demand for parks is even greater. Therefore, studying the thermal environment and thermal comfort of semi-open shaded spaces in the summer is crucial. Although there are studies on thermal comfort in shaded spaces, such as those created by trees or artificial structures<sup>24,25</sup>, research specifically focusing on the thermal comfort of the elderly in these shaded spaces remains limited.

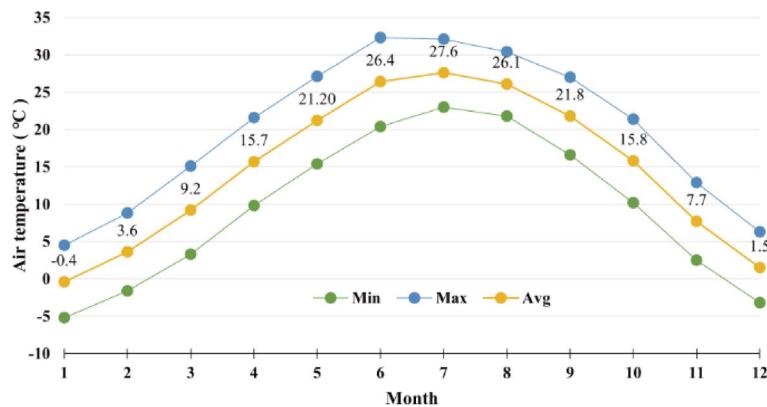
This study conducted thermal environment tests in both open and shaded spaces of People's Park in Anyang, a central city, along with surveys on thermal comfort and travel patterns among the elderly. The goal is to identify their thermal comfort characteristics and needs, providing guidance for developing 15-minute elderly care living circles, park planning, and green space design in small and medium-sized cities.

## Methods

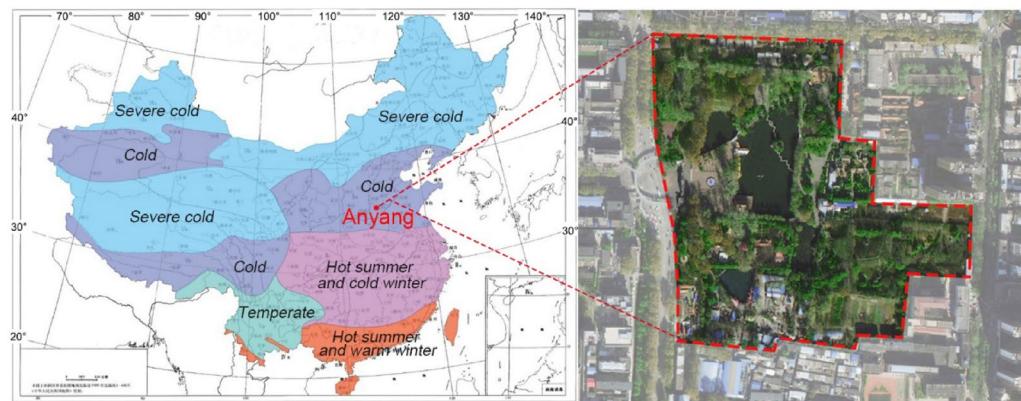
### Location and climate

This study was conducted in Anyang, China, which has an urban population of 1.5 million permanent residents and is classified as a medium-sized city. Anyang is located between 35°12' – 36°22' N and 113°37' – 114°58' E. Anyang is located in the central plains at the northernmost part of Henan Province and experiences a continental monsoon climate with distinct seasons, featuring both extreme cold and heat. According to Köppen-Geiger climate classification, Anyang is located in Cwa (monsoon-influenced humid subtropical climate)<sup>26</sup>. According to China's building climate zoning, Anyang falls within the cold climate zone<sup>27</sup>. The average annual temperature ranges from 12.7 °C to 13.7 °C, with the highest monthly average temperatures occurring between June and August. Southerly winds prevail in spring, summer, and autumn, while northerly winds dominate in winter. The city's annual average wind speed ranges from 1.7 m/s to 3.5 m/s (Fig. 1)<sup>28</sup>.

The survey site chosen for this study is People's Park, located in the center of Anyang City (Fig. 2). Compared with other parks in the city, the park has a long history. The park was established in 1955, and the trees within the park are quite old, with dense, healthy foliage. During the summer, they provide excellent shade for visitors. The tall trees in the park are mainly *Platanus acerifolia* Willd, which are large deciduous trees with a maximum diameter at breast height of 80 cm, a height of more than 30 m, and luxuriant branches and leaves. In addition,



**Fig. 1.** Typical Monthly Average Air Temperature.



**Fig. 2.** Survey Location (The satellite imagery is obtained from Baidu Maps (<https://map.baidu.com/>) and complies with any copyright requirements by Baidu Company (<https://map.baidu.com/zt/client/copyrightPc/index.html>)).

there are *privet*, *pine*, *cypress*, *willow*, *Prunus lannesiana*, etc. Moreover, the park's surrounding area is part of the older urban district, featuring mainly low-rise residential buildings and a significant elderly population.

### Time of survey

Based on typical meteorological data for Anyang, this survey was conducted to accurately assess the travel patterns and thermal comfort of the elderly under hot summer conditions. The survey began on June 27, 2023, and concluded on July 5, 2023, with no data collected on July 2 due to adverse weather conditions. There were 7 survey days in total. To align with the lifestyle habits of the elderly and ensure the health and safety of the surveyors, the survey was conducted from 6 AM to 11 AM, and from 3 PM to 7 PM. The midday period (11 AM to 3 PM) was excluded because the temperature was high during that time, and there were few visitors in the park.

### Respondents

Respondents were selected randomly, primarily targeting citizens sitting in shaded areas not exposed to direct sunlight, without deliberately fixing age, gender, or other demographics. A total of 589 questionnaires were collected, with 557 valid responses. Of these, 319 respondents were over 60 years old, accounting for 57.3%, and 244 were over 65, representing 43.8%. Respondents under 60 accounted for 238 responses, or 42.7% of the total.

### Measurements

#### Microclimate measurement

The measured thermal environment parameters in this study include air temperature (ta), globe temperature (tg), wind speed (v), and relative humidity (RH), which are the four key physical factors influencing human thermal comfort. The measurement instrument used was the HD32.3, which complies with the ISO 7726 standard in terms of range and accuracy, with its performance specifications listed in Table 1. The placement of measurement points followed ASHRAE Standard 55, with instruments placed near the respondents. For seated respondents, the instruments were set at a height of 0.6 m, and for standing respondents, at 1.1 m (Fig. 3a, b). Before the survey,

Measurement parameter	Range	Accuracy
Air Temperature	-10 to 80 °C	±0.2 °C
Relative Humidity	5 to 98%	±2% (15–90%) ±2.5% (Other ranges)
Wind speed	0.05 to 5 m/s	±0.05 m/s (0–0.99 m/s) ±0.15 m/s (1–5 m/s)
Globe Temperature	-10 to 100 °C	±0.2 °C

**Table 1.** Specifications and accuracy of instrument HD32.3.



**Fig. 3.** Filed survey (a), (b) Questionnaire survey, (c), (d) Environmental parameter test.

the test instruments were switched on for approximately 20 min in advance, and the questionnaire was started after the instruments had stabilized. In addition, to compare the physical environmental parameters between shaded and unshaded spaces, two instruments were placed in the shade and in the open area respectively to continuously record meteorological data during the survey period (Fig. 3c, d).

#### Questionnaire survey

The survey questionnaire consisted of two parts. The first part covered visiting patterns, including questions such as whether the respondent comes to the park daily, the reasons for visiting the park, the usual time of day they leave home, and whether hot weather affects their decision to come to the park (Fig. 4).

The second part pertained to thermal comfort. It included personal information (such as gender, age, height, and weight), clothing details, and activities performed in the 20 min before the interview and during the interview. Thermal and humidity sensations, wind perception, thermal comfort, thermal acceptability, thermal preference, and airflow preference were recorded in the second part of the questionnaire. Respondents' clothing type was recorded in detail during the survey, and the total insulation of clothing was determined by the sum of the individual values listed in ASHRAE Standard 55. The metabolic rate was determined based on current and previous 20-minute activity levels.

Considering the hot climate, a nine-point extended scale from ISO 15,001 (ISO, 2002) was used for the thermal sensation rating, including very cold (-4), cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2), hot (+3), and very hot (+4). The humid sensation adopted a 5-point scale, including dry (-2), slightly dry (-1), neutral (0), slightly humid (+1), and humid (+2). Additionally, the thermal acceptability scale recommended by Wyon et al., includes clearly unacceptable (-1), just unacceptable (-0.01), just acceptable (+0.01), and clearly acceptable (+1). The questionnaire was written in Chinese, and the Chinese wording for the scale degrees from the Chinese national standard GB/T 18,977 (AQSIQ, 2003) was used. Respondents checked the appropriate boxes according to their actual conditions, and if they had difficulty, the surveyors assisted with filling out the forms.

#### Survey procedure

The on-site survey was conducted by university student volunteers. Upon arriving at the park, the surveyors first selected a shaded area to conduct thermal environment tests under tree cover, with data recorded at 5-second intervals. The location was typically under or near a tree, with adjustments made based on sunlight exposure to ensure that the measured conditions reflected a shaded environment. Subsequently, the surveyors selected an open area for thermal environment testing. They then began looking for respondents situated in shaded areas to conduct the thermal comfort questionnaire, while simultaneously conducting thermal environment tests. To avoid the influence of recent activity, respondents who had just entered the shaded area were not asked to complete the questionnaire.

## Investigation on the influence of hot weather on travel behavior in parks in summer

1. Just got here?  
yes a short while a long time
2. How did you get here?  
walk cycle bus
3. Do you come here every day?  
yes usually sometimes pass by
4. What is the most important factor in choosing this location? (Multiple choices are allowed)  
there is shade nice and cool good natural ventilation many people and lively  
close to home this is the only one park nearby
5. How far is it from here to your home?  
within 15 minutes on foot within 30 minutes on foot within 45 minutes on foot  
more than 45 minutes on foot
6. What time do you usually go out?  
 Morning: around 5 o'clock around 6 o'clock around 7 o'clock around 8 o'clock  
around 9 o'clock around 10 o'clock other time
   
 Afternoon around 5 o'clock around 5 o'clock around 5 o'clock around 5 o'clock  
around 5 o'clock other time
7. What is the main reason for coming to the park? (Multiple choices are allowed)  
exercise stroll play with others there are many people and lively cool other
8. Does the hot weather not affect your coming here?  
no a little yes

Date of survey: \_\_\_\_\_ Time of survey: \_\_\_\_\_

Measuring point: \_\_\_\_\_ Investigator: \_\_\_\_\_

**Fig. 4.** Questionnaire about visiting patterns in parks in summer.**Statistical analysis**

To better study the thermal comfort characteristics of the elderly, this research divided the respondents into two groups: the elderly (those aged 60 and over) and the non-elderly (those under 60). An independent sample t-test was used to test the environmental differences between shaded and unshaded spaces. Linear regression was adopted to derive the relationships between the thermal sensation vote (TSV) and SET, humidity sensation vote (HSV) and RH, and percentage dissatisfied (PD) and SET. Covariance analysis was used to test the significant differences between various regression lines. In this study, the SET is defined under the ideal standard environment characterized by a radiation temperature that is roughly equal to the air temperature, a relative humidity of 50%, a metabolic rate consistent with the real environment, and standard clothing insulation and air velocity that vary with the metabolic rate, aligned with correct standard environment in SET definition in<sup>29</sup>.

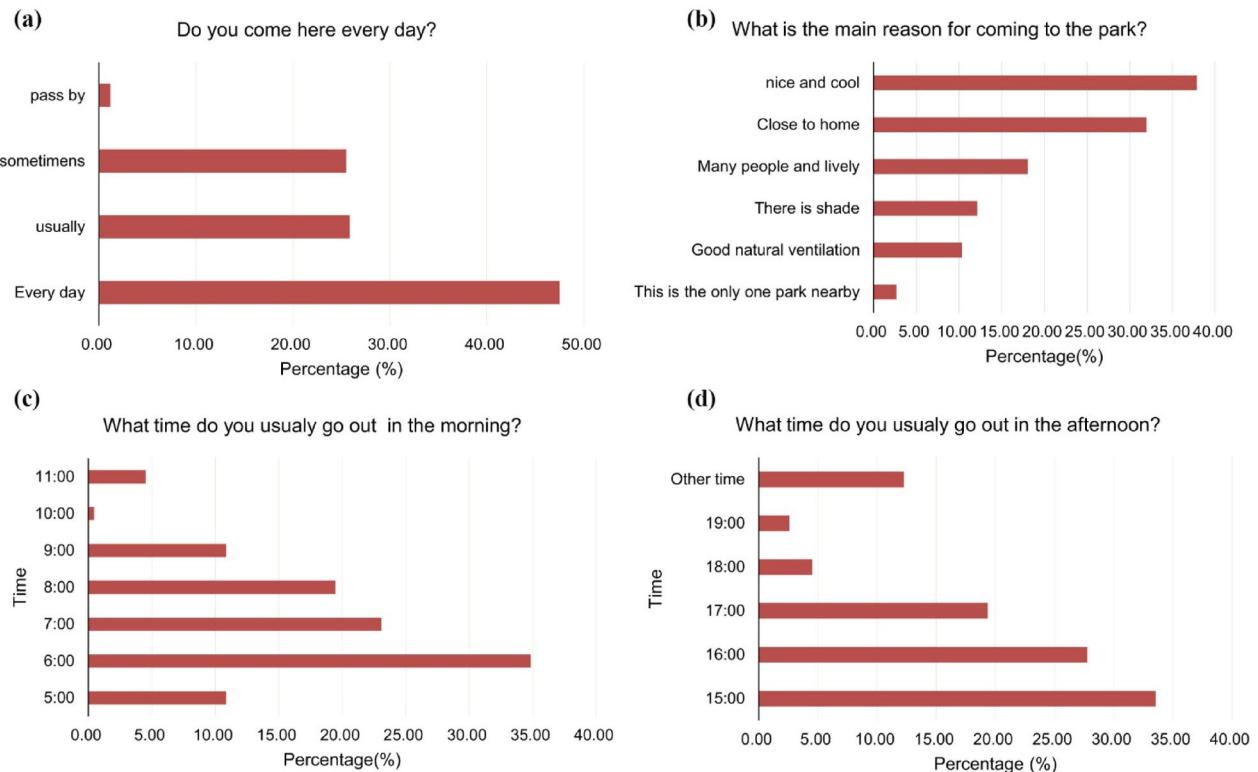
Due to the large volume of on-site data, the “bin” method was repeatedly used in this study to ensure that the sample analysis more accurately represented the majority. Specifically, the data were divided into bins by operative temperature in 0.5 °C steps, and the values of the variables were averaged for each bin to analyze the averages by their weighted sample size. All statistical analyses were conducted using SPSS v 22.0 software (IBM, New York, NY, US), and all differences were accepted as significant at a 0.05 level.

**Results****Microclimate's parameters**

Table 2 presents the thermal environment parameters for shaded and unshaded open spaces during the survey period. According to one-way analysis of variance (ANOVA), significant differences were found between the meteorological parameters under shaded and unshaded conditions. The air temperature, globe temperature, and mean radiant temperature under shaded conditions were significantly lower than those under unshaded conditions, showing that the cooling effect of trees on the microclimate of the park was evident. The RH under shaded conditions was higher than that under unshaded conditions, resulting from the transpiration of the trees.

	Air temperature (°C)	Globe temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Mean radiant temperature (°C)
Shade	30.6 ± 2.8*	30.8 ± 3.0	57.8 ± 19.7	0.40 ± 0.38	31.3 ± 3.5
Unshaded	35 ± 4.7	39.1 ± 6.5	41.6 ± 18.9	0.67 ± 0.49	48.0 ± 12.4
P value	<0.001	<0.001	<0.001	<0.001	<0.001

**Table 2.** Meteorological parameters in shaded and open spaces. Note: \* Mean ± standard deviation.



**Fig. 5.** Results of visiting patterns to the park.

The wind speed under shaded conditions was lower than the one under unshaded conditions because the wind was blocked by the trees weakening the airflow in the shaded area.

### Visiting patterns

The results of the questionnaires showed that 47.5% of respondents visited the park daily, while 25.9% visited usually, accounting for a total of 73.4% (Fig. 5a), indicating a high level of attachment and demand for the park among the elderly. 53% of elderly respondents lived within a 15-minute walking distance from the park, while a few were 45 min or more away. However, some respondents reported that they cycled to the park to shorten their travel time.

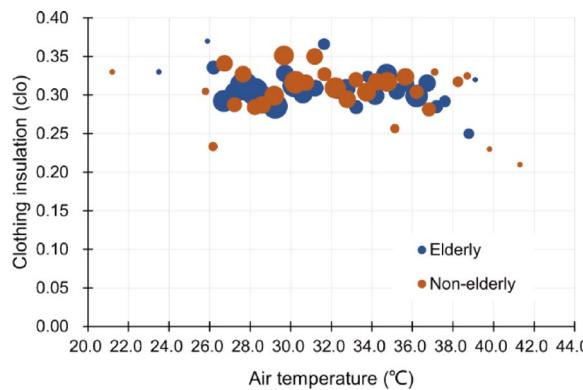
The main reasons attracting the respondents to visit the park, as shown in Fig. 5b, included cooler temperatures (37.9%), proximity to home (32.0%), and the lively atmosphere with many people (18.0%).

Regarding morning departure times, a majority of respondents left between 6 AM (34.8%) and 7AM (23.1%) when the temperature was relatively low. In the afternoon, 33.6% of the respondents departed at 3 PM, and 27.7% at 4 PM (Fig. 5c, d).

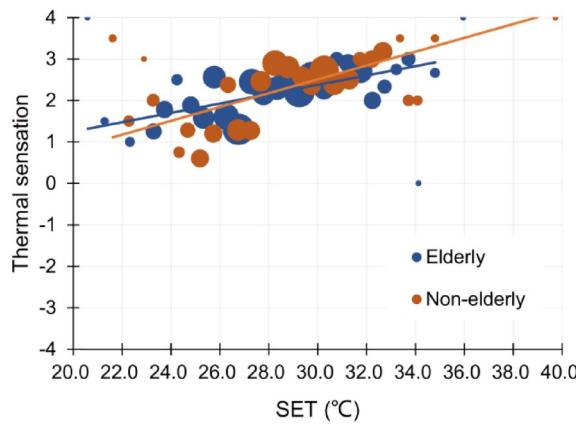
### Subjective responses

#### Clothing insulation

In summer, the weather is hot, and people commonly wear light clothing (such as short-sleeve shirts, shorts, and sandals). The clothing thermal resistance values, as shown in Fig. 6, reveal that regardless of changes in air temperature, the thermal resistance values remain relatively constant, staying slightly above 0.3 clo. There was no clear trend of adjusting clothing to meet thermal comfort. The average clothing insulation for the elderly (aged 60 and over) was  $0.31 \pm 0.07$  clo, while for the non-elderly (aged under 60), it was  $0.31 \pm 0.09$  clo. There was no significant difference between the two groups (t-test,  $p=0.391$ ).



**Fig. 6.** Clothing insulation changes with air temperatures.



**Fig. 7.** The relationship between the thermal sensations and the SET.

#### Thermal sensation

A linear relationship was observed between TSV and SET for both the elderly (aged 60 and over) and the non-elderly (aged under 60), as shown in Fig. 7. The regression equations were obtained as follows:

$$TSV = 0.113SET - 1.014(R^2 = 0.332) \text{ (Elderly)} \quad (1)$$

$$TSV = 0.167SET - 2.502(R^2 = 0.411) \text{ (Non-elderly)} \quad (2)$$

The thermal sensitivity, namely, the slope of the regression line, was  $0.113 \text{ } ^\circ\text{C}^{-1}$  for the elderly and  $0.167 \text{ } ^\circ\text{C}^{-1}$  for the non-elderly, which means that for each  $1 \text{ } ^\circ\text{C}$  increase in SET, thermal sensation increased by 0.113 and 0.167 units of scale for the elderly and the non-elderly, respectively. A significant difference was found between the slopes of the two regression lines (analysis of covariance,  $p < 0.001$ ), indicating that the thermal sensitivity of the elderly is significantly lower than that of the non-elderly.

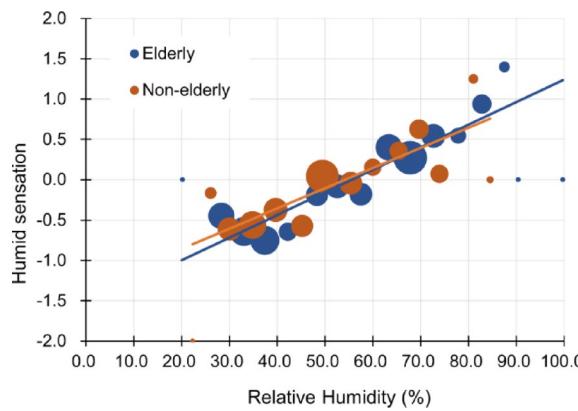
#### Humidity sensation

A linear relationship was also observed between HSV and RH, as shown in Fig. 8. For both the elderly (aged 60 and over) and the non-elderly (under 60), humidity sensation increases as RH rises, showing a strong linear relationship between HSV and RH. The regression equations were obtained as follows:

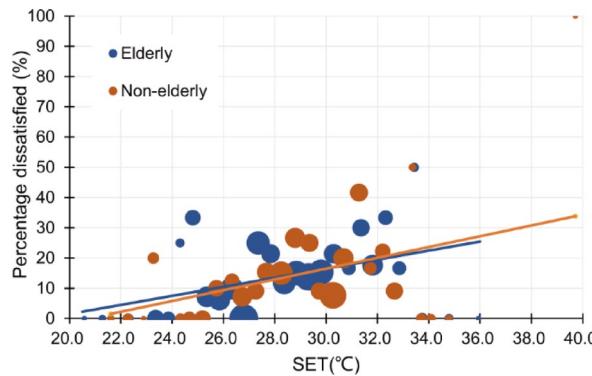
$$HSV = 0.028RH - 1.557(R^2 = 0.846) \text{ (Elderly)} \quad (3)$$

$$HSV = 0.025RH - 1.356(R^2 = 0.697) \text{ (Non-elderly)} \quad (4)$$

The humidity sensitivity, namely, the slope of the regression line, was  $0.028 \text{ RH}^{-1}$  for the elderly and  $0.025 \text{ RH}^{-1}$  for the non-elderly; that is, for each 1% increase in RH, humidity sensation increased by 0.028 and 0.025 units of scale for the elderly and the non-elderly respectively. A significant difference was found between the slopes of the two regression lines (analysis of covariance,  $p = 0.011$ ). This indicates that the humidity sensitivity of the elderly (aged 60 and over) is significantly higher than that of individuals under 60.



**Fig. 8.** The relationship between the humidity sensations and the RH.



**Fig. 9.** Percentage dissatisfied changes with SET.

Based on the regression equations, the neutral RH for humidity sensation was determined to be 55.6% for the elderly, and 54.2% for the non-elderly. This means that the elderly and the non-elderly felt neither dry nor humid at RH levels of 55.6% and 54.2% respectively.

#### Percentage dissatisfied

The number of votes for thermal acceptability below 0 was calculated for each temperature range, and the proportion of votes for thermal acceptability below 0 to the total votes was defined as the percentage dissatisfied (PD). A linear relationship was observed between the percentage dissatisfied and SET, and the result of the regression analysis is shown in Fig. 9. The percentage dissatisfied increases as SET rises. The regression equations were obtained as follows:

$$PD = 1.496SET - 28.41 (R^2 = 0.169) \text{ (Elderly)} \quad (5)$$

$$PD = 1.783SET - 37.01 (R^2 = 0.183) \text{ (Non-elderly)} \quad (6)$$

At the same temperature, there was no significant difference in the PDs between the elderly and the non-elderly (analysis of covariance,  $p=0.342$ ). According to Eq. (5), for the elderly, the SET value corresponding to 80% thermal acceptability was 32.4 °C, and for 90% acceptability, it is 25.7 °C. According to Eq. (6), for the non-elderly, the SET value corresponding to 80% thermal acceptability was 32.0 °C, and for 90% acceptability, it was 26.4 °C.

#### Thermal and airflow preference

Table 3 summarizes the proportion of various thermal and airflow preferences at different SETs. In general, a large proportion of the respondents expected the temperature to decrease and the airflow to be strong. Regardless of whether the SET was high or low, the respondents preferred a cool environment with a greater expectation of lower temperatures. Even when the SET was below 26 °C in some situations, those respondents still predominantly expected a lower temperature. The higher the temperature was, the larger the proportion of respondents expecting a cooler environment was. Consistent with the temperature preference, there was a high expectation of stronger airflow, regardless of the level of SET, indicating that enhanced ventilation was desired to improve the thermal comfort of the respondents.

SET (°C)	Number	Thermal preference			Airflow preference		
		Warmer	No change	Cooler	Stronger	No change	Lighter
20.5–21.0	1	0	0	100%	100%	0	0
21.0–21.5	2	0	50%	50%	50%	50%	0
22.0–22.5	3	0	66.67%	33.33%	33.33%	66.67%	0
23.0–23.5	8	0	25%	75%	62.50%	37.50%	0
23.5–24.0	9	0	22.22%	77.78%	100%	0	0
24.0–24.5	4	0	25%	75%	100%	0	0
24.5–25.0	9	0	22.22%	77.78%	88.89%	11.11%	0
25.0–25.5	14	0	42.86%	57.14%	100%	0	0
25.5–26.0	16	0	37.50%	62.50%	87.50%	6.25%	6.25%
26.0–26.5	20	0	50%	50%	70%	25%	5%
26.5–27.0	30	0	53.33%	46.67%	76.67%	23.33%	0
27.0–27.5	20	0	10%	90%	90%	10%	0
27.5–28.0	14	0	35.71%	64.29%	71.43%	28.57%	0
28.0–28.5	17	0	11.76%	88.24%	64.71%	35.29%	0
28.5–29.0	20	5%	5%	90%	80%	20%	0
29.0–29.5	29	3.45%	20.69%	75.86%	51.72%	48.28%	0
29.5–30.0	26	7.69%	11.54%	80.77%	73.08%	23.08%	3.85%
30.0–30.5	14	0	28.57%	71.43%	78.57%	21.43%	0
30.5–31.0	6	0	16.67%	83.33%	83.33%	16.67%	0
31.0–31.5	10	20%	20%	60%	70%	10%	20%
31.5–32.0	17	0	23.53%	76.47%	64.71%	17.65%	17.65%
32.0–32.5	9	0	22.22%	77.78%	66.67%	33.33%	0
32.5–33.0	6	0	16.67%	83.33%	83.33%	16.67%	0
33.0–33.5	4	0	0	100%	75%	0	25
33.5–34.0	6	0	0	100%	100%	0	0
34.0–34.5	1	0	100%	0	0	100%	0
34.5–35.0	3	0	0	100%	66.67%	33.33%	0
35.5–36.0	1	0	0	100%	100%	0	0

**Table 3.** Proportion of various thermal and airflow preferences for different temperature.

## Discussion

### Shade, parks, and thermal environment

According to the microclimate measurement data, the thermal environment parameters related to temperature in the shaded areas were significantly lower than those in unshaded, open spaces. This is consistent with Zhang's findings<sup>30</sup>, which showed that trees had insignificant cooling effects in unshaded areas despite being nearby. Lin<sup>31</sup> studied the impact of trees on air temperature in a park in Taipei and found that air temperatures under the canopies were 0.64 to 2.52 °C lower compared to nearby unshaded open spaces. As part of urban green infrastructure, trees can provide significant cooling through shading and transpiration. The canopy is the most important thermal regulating element<sup>32</sup>, depending on the leaf area index and canopy coverage, contributes the most to cooling at midday<sup>33</sup>.

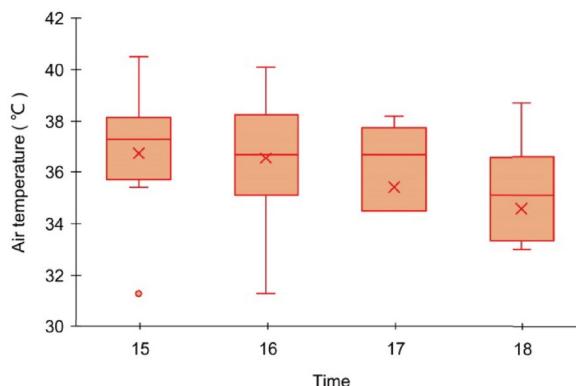
As global warming continues, even in cold regions, summer temperatures are rising and the summertime becomes longer. Therefore, the arrangement of trees should be emphasized to meet the needs for shading and cooling in park design. An optimal design with better shading provided by trees can accommodate the outdoor activities of the elderly and improve their well-being. According to a study<sup>24</sup> deciduous tree shading is considered the optimal shading design, meeting the requirements for thermal comfort. In summer, their lush foliage provides ample shade, while in winter, their fallen leaves allow sunlight to reach the ground, fulfilling the thermal environment requirements for different seasons.

### Psychological thermal adaptation

#### Visiting patterns and psychological adaptation

According to the survey, apart from the relatively comfortable morning hours, 33.6% of elderly individuals chose to go out at 3 PM. As shown in Fig. 10, during the survey period, the average air temperature at 3 PM in Anyang was  $36.8 \pm 2.6$  °C. Despite the extremely high temperatures, which led to discomfort of outdoor individuals, the elderly were still willing to visit the park. This shows that even extreme heat did not deter them from going to the park, reflecting the significant role of their needs. Their needs influenced thermal acceptability, where psychological factors played a key role.

As early as 2003, Nikolopoulou<sup>34</sup> showed that although microclimatic parameters strongly influence thermal sensation, they cannot fully account for the wide variation between objective and subjective comfort evaluations;



**Fig. 10.** Air temperature in the afternoon during the investigation period.

psychological adaptation seems to be increasingly important. The psychological adaptation here is mainly based on expectations.

The visiting pattern survey of the elderly highlights the important role of parks in their daily lives. Therefore, in urban planning and design, special attention should be given to the allocation and design of parks, and it is essential to create 15-minute park living circles to meet the daily needs of the elderly.

#### *Thermal preference and psychological adaptation*

A comparison of thermal sensation, thermal acceptability, and thermal preference between the elderly and the non-elderly revealed no significant differences. Both groups showed a preference for cooler environments and enhanced ventilation. This is consistent with the research of<sup>35</sup>, which indicates that environmental expectations are also an aspect of psychological adaptation.

According to the study<sup>17</sup>, age affects thermal perception. However, our study did not find any significant impacts caused by age. Psychological needs and adaptation could be possible explanations for the lack of significant impacts by age in our study. The objective existence of hot weather is a factual reality. However, the recreational pursuit of visiting a park diverges from the imperative nature of professional responsibilities, where attendance is mandatory, as it presents a range of discretionary options. If one cannot accept the heat, they can choose not to go out. Since the decision to visit the park has been made, it indicates a mental acceptance of the high temperatures. Therefore, from this perspective, psychological adaptation may be a significant influencing factor on demand.

#### **Limitations and future work**

The duration of the on-site survey in this study was relatively short. Although the results align with common sense, some bias may still exist. Additionally, grouping individuals under 60 into a single category, compared to the elderly group over 60, involves a large age range, which could affect the comparison between the two groups. In future research, the sample size can be increased, and age groupings can be made more precise. Activities in parks are diverse, and this study focused on the thermal comfort and adaptation of elderly individuals in shaded areas, with most respondents either sitting or standing. However, activities in parks are varied. For example, according to the survey, dancing is popular among visitors, especially elderly women. Future studies should be expanded to include other activities, such as dancing, to assess thermal comfort and adaptation in different scenarios.

#### **Conclusion**

This study investigated the visiting patterns of the elderly and the non-elderly during the summer in a park located in the cold area of China. The thermal environment parameters of shaded areas and open areas in the park were measured and a subjective thermal perception survey for both the elderly and non-elderly was conducted. A total of 7 days of microclimate data were recorded and 557 valid questionnaires were collected. Based on statistical analysis, the conclusions of this study are summarized as follows:

- The outdoor temperature was high in the cold area of China during summer, and the on-site tests revealed that the thermal temperature-related parameters in shaded spaces were significantly lower than those in open spaces, making shaded areas ideal for outdoor activities in summer.
- A majority of the elderly (47.5%) visited the park daily, and over half of them (53%) lived within a 15-minute walking distance from the park, while a few were 45-minutes or farther away.
- Approximately one third of the elderly (33.6%) chose to visit the park at 3 PM, even when the outdoor temperature reached  $36.8 \pm 2.6$  °C. This shows that parks play a crucial role in the daily lives of the elderly in the cold area of China during summer and psychological adaptation based on needs play an important role.
- There was no significant difference between the elderly and the non-elderly in terms of clothing thermal resistance. Regardless of changes in air temperature, the thermal insulation remained approximately 0.31 clo in the cold area of China during summer.

- The thermal sensitivity of the elderly was significantly lower than that of the non-elderly, while their sensitivity to humidity was significantly higher. The neutral RH for the two groups was 55.6% for the elderly and 54.2% for the non-elderly, respectively.
- For the elderly, the SET value corresponding to 80% thermal acceptability was 32.4 °C, and for 90% acceptability, it was 25.7 °C. For the non-elderly, the SET values were 32.0 °C for 80% acceptability and 26.4 °C for 90%. There was no significant difference between the two groups, displaying high thermal acceptability at elevated temperatures. The plausible reason for this is the psychological adaptation driven by their needs.
- Both groups, the elderly and non-elderly, demonstrated a preference for a cooler environment and enhanced ventilation regardless of the level of SET.

The findings of this study will offer valuable guidance for the development of 15-minute elderly care living circles, as well as for the planning of parks and the design of green spaces in small and medium-sized cities.

## Data availability

Data will be made available on request. If you would like to request the data from this study, please contact the first author Zhongjun Zhang by email (zhongjun@ayit.edu.cn).

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## Author contributions

Zhongjun Zhang: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Project administration. Yaqian Wang: Writing – review & editing, Investigation. Zhaoji Wu: Writing–review & editing, Visualization, Validation, Conceptualization.

## Declarations

### Competing interests

The authors declare no competing interests.

### 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.

### Ethics declarations

The study received approval from The Anyang Institute of Technology. All methods were conducted in accordance with relevant guidelines and regulations. The human-related experiments consisted solely of a questionnaire survey. All participants were fully informed about the purpose of the survey and consented to the use of their data exclusively for this study. The participants depicted in Fig. 3 were informed and agreed to the publication of the figure in an online open-access journal.

### Additional information

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