

Article

Understanding Outdoor Cold Stress and Thermal Perception of the Elderly in Severely Cold Climates: A Case Study in Harbin

Xiaoyun He ^{1,2}, Long Shao ^{1,2}, Yuexing Tang ^{1,2,*} and Liangbo Hao ^{1,2}

¹ School of Architecture and Design, Harbin Institute of Technology, Harbin 150001, China

² Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry of Industry and Information Technology, Harbin 150001, China

* Correspondence: 21b934029@stu.hit.edu.cn

Abstract: This study collected data through microclimate monitoring, surface temperature measurements, and questionnaire surveys, and used indicators, such as the universal thermal climate index (UTCI), surface temperature (T_s), and wind chill temperature (t_{WC}), to determine the thermal comfort threshold of the elderly in severely cold climates and evaluate their cold stress. The results indicated that (1) the neutral UTCI (NUTCI) for elderly individuals in winter was 13.3 °C, and the NUTCI range was from 1.4 to 25.2 °C; (2) the intensity of elderly individuals' physical activity affected the magnitude of risk of whole-body cooling, with duration-limited exposures corresponding to 0.5, 3.3, and over 8 h for light, moderate, and vigorous activity levels, respectively; (3) the t_{WC} in all four spaces was below −10 °C, potentially inducing discomfort or even frostbite in the elderly; (4) for a 10 s touch, the maximum T_s (−17.2 °C) of stone was lower than the numbness threshold (−15.0 °C), while that (−15.1 °C) of steel materials remained below the frostbite threshold (−13 °C), posing risks for the elderly during physical activity. This study's results will provide valuable insights and theoretical references for the landscape design of urban park activity spaces for elderly individuals in cold climate regions.

Keywords: cold stress; outdoor thermal perception; severely cold climates; the elderly; universal thermal climate index (UTCI); urban park



Citation: He, X.; Shao, L.; Tang, Y.; Hao, L. Understanding Outdoor Cold Stress and Thermal Perception of the Elderly in Severely Cold Climates: A Case Study in Harbin. *Land* **2024**, *13*, 864. <https://doi.org/10.3390/land13060864>

Academic Editors: Amos Darko, K. Venkatachalam, Baojie He, Siliang Yang and Ali Cheshmehzangi

Received: 16 May 2024

Revised: 9 June 2024

Accepted: 13 June 2024

Published: 15 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

According to the World Health Organization's 2021 report, the population aged 60 and above in China is projected to reach 28% of the total population within the next 20 years because of increased life expectancy and declining birth rates, positioning China as one of the fastest aging countries globally [1]. In fact, the extended lifespan not only presents opportunities for the elderly and their families but also holds developmental prospects for society overall. However, the extent of these opportunities and contributions largely hinges on elderly health [2].

Individual health encompasses being in a state of good physical health, which involves avoiding obesity, cardiovascular diseases, and type 2 diabetes [3–5]. It also involves maintaining good mental health and avoiding anxiety, stress, and depression [6–9]. Research indicates that urban green spaces within open urban areas have beneficial effects on individuals [10]. They provide an environment for people to meet and engage in social activities, preventing feelings of loneliness [11,12]. Additionally, engaging in physical activities in green spaces reduces the incidence of non-communicable diseases, such as obesity, cardiovascular diseases, and diabetes [5,13–16]. Participation in physical activities of moderate to vigorous intensity among the elderly may potentially attenuate cognitive decline [17], reduce the risk of dementia [18], and even lower mortality [19].

The health benefits of engaging in 150 min of moderate to vigorous physical activity per week have been well established [20]. However, the activity levels of the elderly often fall short [19]. This is partly attributed to the deterioration of outdoor environments

caused by climate change. Increasingly severe heatwaves and the urban heat island effect progressively affect citizens' physical health and quality of life [21–25]. Heatwaves and associated heat stress can increase the incidence of mortality rates in the human population [26]. During the summer, the elderly are more susceptible to the effects of extreme high temperatures, and they often appear in community spaces with less outdoor heat [27,28]. When the universal thermal climate index (UTCI) exceeds 39 °C, the activity of the elderly decreases substantially [29]. As evidenced by a study on thermal and acoustic comfort in Madrid, noise pollution and extreme temperatures in dense urban areas pose significant health risks to older adults. Approximately 73% of the respondents are at risk of heat stress in winter and summer. Strategies to reduce environmental risks for the elderly in public places in winter and summer urgently need to be studied [30]. Similarly, research exploring the relationship between the spatiotemporal distribution of tourists and thermal conditions in areas with hot summers and cold winters showed that women and the elderly are more sensitive to thermal changes than other groups [31].

The outdoor thermal environment substantially influences residents' attendance and activities in urban open spaces [32–35]. Well-designed open spaces with favorable thermal comfort are crucial in enhancing space utilization, promoting physical activity and social interaction, improving urban livability, and ultimately contributing to public health [36–38]. Elderly individuals constitute a significant user group of urban parks, and comfortable and safe open spaces within parks have been shown to enhance their physical and mental well-being [39]. Consequently, to enhance outdoor thermal environments and alleviate heat stress, researchers are focusing on identifying factors influencing thermal perception and comfort in the elderly. Yao et al. [40] unveiled gender differences in thermal sensation and established the neutral physiologically equivalent temperature range for elderly individuals in outdoor activity spaces in Lhasa City during winter and summer. Yung et al. [33] found differences in the impact of personal, physical, social, and psychological factors on Hong Kong elderly people's thermal perception in winter and summer. They suggested that greater emphasis should be placed on mitigating summer heat stress in outdoor spaces. Peng and Maing [41] revealed four main factors affecting the use of leisure space by Hong Kong elderly residents: average radiant temperature (T_{mrt}), air temperature (T_a), green plants and outdoor seating, and proposed age-friendly design strategies to cope with the hot climate. Ma et al. [39] determined the thermal comfort threshold for elderly individuals in cold regions. Through a comparative study of various meteorological factors and thermal comfort in different landscape spaces, they proposed optimal design strategies for open spaces suitable for the elderly.

Thermal comfort of the elderly in outdoor environments is of increasing concern. Existing research focuses on revealing the influencing factors of thermal comfort in the elderly and determining the thermal comfort threshold, with the aim of reducing the heat stress experienced by the elderly. The climate background of these studies concentrates on hot and cold regions, with less attention given to severe cold regions. China's severe cold regions are characterized by long and harsh winters. A study on college students showed that exposure to severe cold weather can induce physiological reactions such as trembling and a runny nose on the face, while hand exposure could cause pain and numbness in the skin. These localized exposures might reduce overall thermal comfort [42]. Prolonged exposure to cold environments could lead to overall body cooling and a decrease in core body temperature, with wind exposure and contact with cold objects intensifying cooling [43]. Shao et al. [44] revealed the cold stress experienced by children in outdoor activity spaces in severe cold climates and determined their thermal comfort threshold. A field study in Harbin demonstrated that the elderly were better able to adapt to severe cold weather conditions [45]; although, similar to children, the elderly were also a vulnerable group. Severe cold weather conditions may also negatively affect their outdoor activities and even cause physical damage such as frostbite. However, there is a scarcity of systematic evaluations of thermal comfort and cold stress for the elderly in extremely cold climate conditions.

To clearly address the challenges faced by the elderly in outdoor activity spaces under extremely cold climatic conditions, this study selected four open spaces and conducted spatial microclimate measurements and a questionnaire survey targeting the elderly population within a city park in Harbin. Therefore, this study aims to (1) explore the factors affecting the thermal perception of the elderly in winter; (2) identify the thermal comfort thresholds for the elderly in extremely cold climates; (3) quantify the levels of cold stress experienced by elderly individuals in Harbin city park; (4) explore the thermal adaptation behaviors employed by the elderly to cope with extreme cold conditions. Based on these findings, the study will provide valuable insights and theoretical references for the landscape design of urban park activity spaces for elderly individuals in cold climate regions.

2. Materials and Methods

2.1. Study Site

The onsite investigation and meteorological data measurements were conducted in a city park located in Harbin, Heilongjiang Province, China ($126^{\circ}38'58''$ E, $45^{\circ}45'30''$ N). Harbin's high latitude, coupled with cold winds from Siberia, results in severely cold winters. This climate makes Harbin famously known as China's "Ice City", celebrated for its spectacular winter festivals, including the renowned Harbin International Ice and Snow Sculpture Festival. Figure 1 illustrates the meteorological data for Harbin spanning the period from 1991 to 2021. The lowest cumulative monthly average temperature was registered in January, reaching -18.5°C , with the nadir of January's average temperature recorded at -24.4°C . Additionally, the highest cumulative monthly average temperature was observed in July, peaking at 23.1°C , and the zenith of July's average temperature was 27.4°C . The cumulative monthly average relative humidity (RH) ranged from 44–74%, exhibiting elevated humidity levels during the cold and hot seasons compared with the transitional seasons [46].

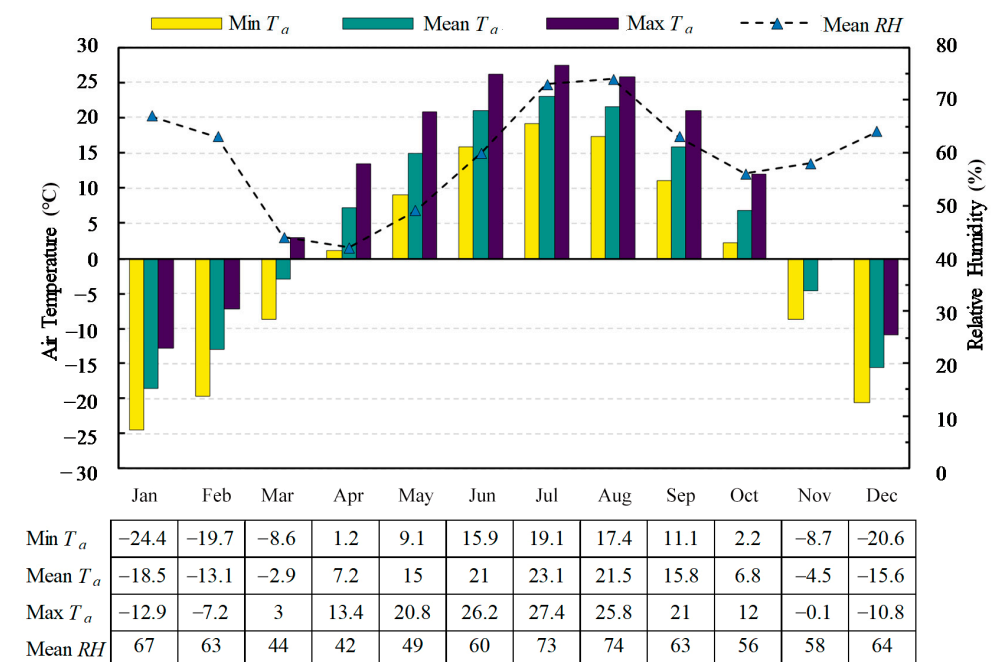


Figure 1. Monthly mean/maximum/minimum air temperature (T_a) and mean relative humidity (RH) in Harbin from 1991 to 2021.

Positioned within the central business district of the Nangang District in Harbin, the park is situated amidst a bustling commercial center and encompasses open squares, lawns, and diverse landscape features. Additionally, the park offers a diverse range of outdoor activity spaces, such as table tennis courts, badminton courts, and fitness equipment,

making it a popular destination for elderly individuals seeking recreational activities. This popularity among the elderly population, coupled with the park's variety of landscape elements and facilities, provides a rich context for studying thermal comfort and adaptation behaviors in outdoor spaces. In this study, four spaces were selected considering variations in winter landscape elements, sky view factor (SVF), and types of activities for the elderly (Figure 2).

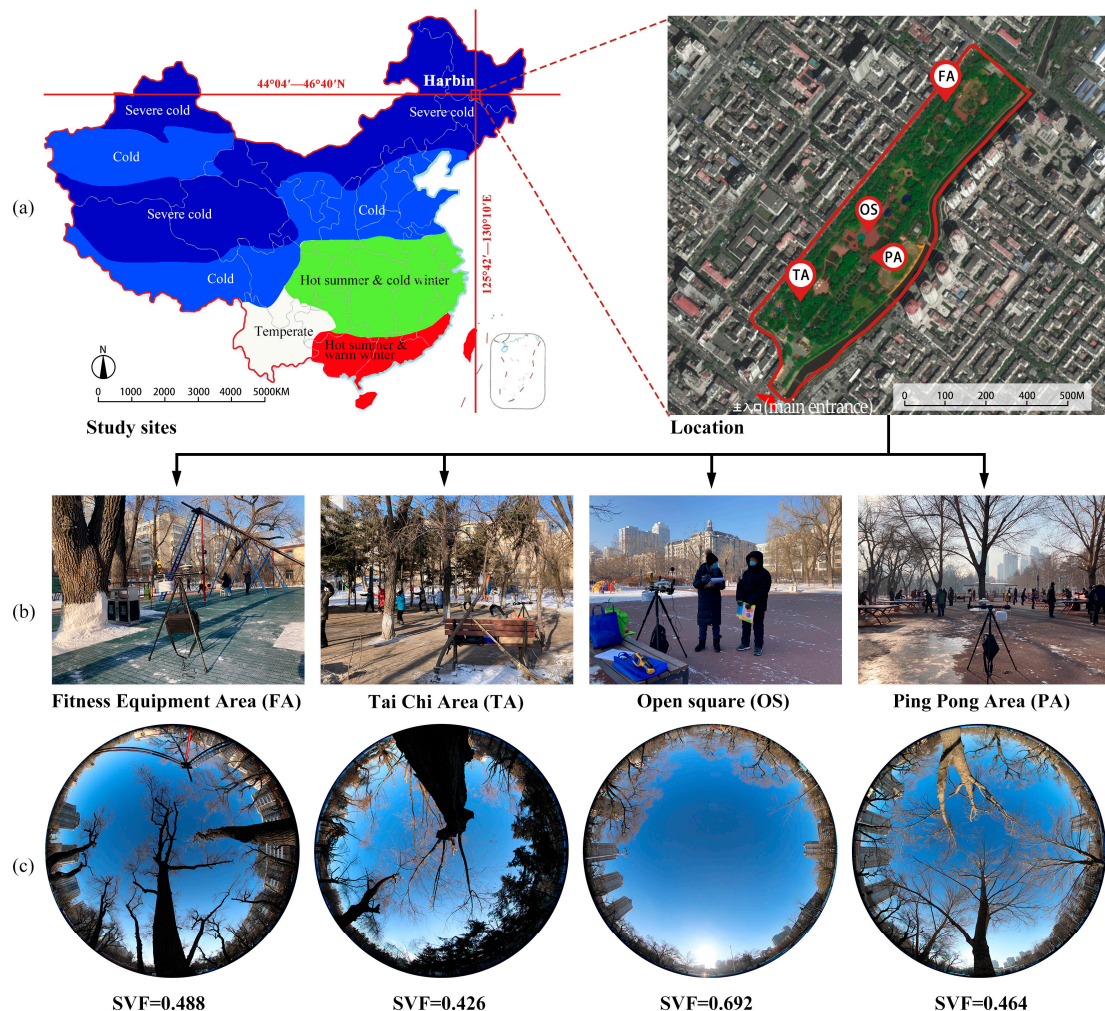


Figure 2. Site location and measurement spaces: (a) site location; (b) photos of open spaces; (c) winter fisheye photos.

The fitness equipment area (FA) is furnished with sports and fitness equipment, such as rings and horizontal bars, with the ground surface covered with PP court tiles. The predominant plant landscape consists of deciduous trees, and the SVF in winter is 0.488. This area was selected due to its popularity among elderly individuals for engaging in diverse fitness activities using equipment. The Tai Chi area (TA), distinguished by predominantly evergreen pine trees, exhibits the smallest SVF among all spaces at 0.426. This grass-covered area is specifically dedicated to Tai Chi activities for the elderly, chosen to represent shaded and sheltered activity spaces. The open square space (OS), notable for the absence of planted vegetation, stands out from other spaces with the largest SVF (0.692). This space serves as a venue for elderly individuals engaging in physical activities, such as square dancing, walking, and standing conversations. The selection of this area aimed to capture the microclimatic conditions of open and exposed spaces. Lastly, the ping pong area (PA), characterized by tall deciduous plants and asphalt paving, possesses an SVF

of 0.464. Activities in this area predominantly involve playing table tennis and standing around for observation. This area was included to reflect activity spaces with tall plants and hard surfaces.

2.2. Data Recording and Collection

The onsite investigation for this study was conducted on the 9th, 11th, 12th, 13th, 14th, 16th, and 20th of January 2022, the coldest winter month in Harbin. The investigation included meteorological measurements and recordings, measurements of material surface temperatures (T_s), and a questionnaire survey specifically designed for the elderly.

2.2.1. Meteorological Parameters and T_s

Meteorological parameters were acquired through a self-constructed small weather station (Figure 3 and Table 1). Throughout the experiment, key meteorological variables—including T_a , RH , wind speed (V), solar radiation (G), and globe temperature (T_g)—were recorded at one-minute intervals. Considering the relatively high latitude of Harbin and the diminished daylight hours in winter, the investigation period on experimental days was designated from 8:30 to 15:30 Beijing time.



Figure 3. Meteorological measurements.

Table 1. Technical details of meteorological equipment.

Instrumentation	Parameter	Range	Accuracy	Resolution Ratio
HOBO onset U23-001	T_a	−40–70 °C	±0.21 °C	0.001 °C
	RH	0–100%	±2.5%	0.001%
Kestrel 5500	V	0–40 m/s	0.1 m/s	0.1 m/s
Delta HD 32.2	T_g	−30–120 °C	±0.1 °C	0.01 °C
Pyranometer TBQ-2	G	0–2000 W/m ²	≤±2%	1 W/m ²

Direct contact of exposed skin with cold surfaces can potentially decrease skin temperature, which may lead to pain, numbness, and frostbite. Different contact modes, such as finger touching and hand gripping, may pose varying cold risk levels [47]. To evaluate the potential risk of cold injury faced by the elderly when their hands contact landscape materials during winter, this study employed an infrared thermal imager (FLUKE TiR110, Fluke Corporation, Everett, WA, USA) to measure and record the T_s of various landscape materials at one-hour intervals (Figure 4).

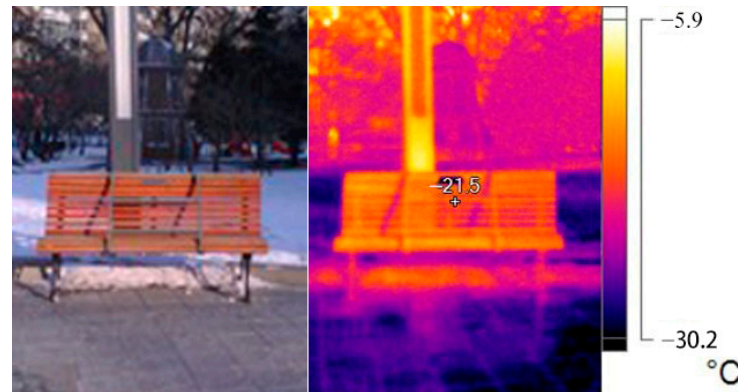


Figure 4. An infrared thermal image taken in area FA (17 January 2022).

2.2.2. Questionnaire Survey

During the microclimate measurements, simultaneous questionnaire surveys were administered, targeting elderly individuals participating in unrestricted activities within various spaces. Each questionnaire comprised three sections (Appendix A).

The first part included demographic information, such as sex, age, height, weight, clothing choices, and the primary activity within the preceding 20 min. The second section of the questionnaire solicited subjective evaluations of the thermal environment from the elderly, covering thermal perception and preferences for meteorological factors. The final section of the questionnaire prompted elderly participants to rank their thermal adaptation behaviors in extremely cold weather based on personal preferences. These behaviors included drinking hot water, adding clothing, exercising, and moving into sunshine.

2.2.3. Clothing Insulation and Metabolic Rate

The clothing of elderly participants was assessed using the clothing list specified in ISO 9920 [48]. Figure 5 illustrates the types of clothing worn by the elderly during winter in this survey, along with their corresponding clothing thermal resistance values.

The metabolic rate of the elderly is slower than that of young people, which may affect thermal sensation and comfort, leading to potential errors in experimental results [49,50]. Therefore, this study utilized the corrected metabolic rate of the elderly to assess the metabolic values associated with various physical activities, with a rate of 43.1 W/m² for men and 38.6 W/m² for women at 1 MET [39,51]. To investigate the impact of activity intensity on thermal perception in elderly individuals, this study categorized activity intensity based on the literature as follows: light <3.0 METs, moderate 3.0–5.9 METs, vigorous ≥6.0 METs [51–54]. Table 2 lists the common types of activities performed by the elderly during this survey period, along with their corresponding intensities.



Sundries:
☐ Gloves 0.05 ☐ Cap 0.01

Upper body:
☐ Underwear T-shirt 0.08 ☐ Underwear-Shirt, long sleeves, thermal 0.2
☐ Underwear-Shirt, long sleeves 0.25 ☐ Short sleeve 0.15 ☐ Vest 0.2
☐ Shirt 0.25 Jacket (☐ Thin 0.25 ☐ Thick 0.35 ☐ Fibre-pelt 0.4)
☐ Sweater (☐ Sleeveless 0.12 ☐ Thin 0.20 ☐ Thick 0.35) ☐ Down-vest 0.3
☐ Down jacket 0.55 ☐ Coat 0.6 ☐ _____ else.

Lower body:
☐ Underwear-Pants, long-legged, thermal 0.15 ☐ Underwear-Pants, long-legged 0.22
☐ Trousers (☐ Thin 0.15 ☐ Thick 0.24) ☐ Flannel 0.28
☐ Sweat pants 0.28 ☐ Trousers, fibre-pelt 0.4
☐ Winter dress, long sleeves 0.4 ☐ _____ else.

Feet:
☐ Shoes (☐ Thin-soled 0.02 ☐ Thick-soled 0.04) ☐ Boots 0.1 ☐ _____ else.
☐ Socks (☐ Thin 0.02 ☐ Thick & ankle 0.05 ☐ Thick & long 0.1) ☐ _____ else.

Figure 5. Simplified garment checklist (clo).

Table 2. The common types of activities performed by the elderly.

Levels	Activity Description	Code	METs	Modified Metabolic Value (W/m ²)	
				Male	Female
Light <3 METs	Sitting quietly, general	07021	1.3	56.03	50.18
	Standing, talking in person	09050	1.8	77.58	69.48
	Walking, very slow	17151	2.0	86.2	77.2
Moderate 3–5.9 METs	Tai Chi, qi gong, general	15670	3.0	129.3	115.8
	Sports spectator	15645	3.3	142.23	127.38
	Walking, moderate pace	17190	3.5	150.85	135.1
	Table tennis	15660	4.0	172.4	154.4
	Martial arts	15425	5.3	228.43	204.58
	Badminton, social	15030	5.5	237.05	212.3
	Skating, ice, 4 m/s or less	19020	5.5	237.05	212.3
Vigorous ≥6 METs	Bicycling, leisure	01019	5.8	249.98	223.88
	Running, 15 min/mile	12029	6.0	258.6	231.6
	Jogging, general	12020	7.0	301.7	270.2
	Tennis, general	15675	7.3	314.63	281.78
	General dancing	03031	7.8	336.18	301.08

2.3. Index for Assessing Outdoor Thermal Comfort

The assessment of thermal comfort in outdoor non-steady state environments commonly relies on multi-node thermal regulation models. Consequently, the UTCI was devised, building upon the “Fiala” multi-node model, to serve as a thermal comfort index. It assumes a constant walking speed of 4 km/h (1.11 m/s) and an internal heat production of 135 W/m² [55]. Furthermore, it integrates a clothing model that adjusts automatically to prevailing conditions [56]. UTCI values were calculated by inputting meteorological param-

eters, such as T_a (°C), RH (%), V (m/s), and T_{mrt} (°C), into RayMan Pro 2.1 software [57–59]. The T_{mrt} was calculated using Equation (1).

$$T_{mrt} = \left[(T_g + 273)^4 + \frac{1.10 \times 10^8 V^{0.6}}{\varepsilon D^{0.4}} (T_g - T_a) \right]^{\frac{1}{4}} - 273 \quad (1)$$

In Equation (1), D corresponds to the diameter of the black globe ($D = 0.05$ m), ε indicates the emissivity of the black globe ($\varepsilon = 0.95$).

2.4. Index for Assessing Cold Stress

2.4.1. Required Clothing Insulation (IREQ)

IREQ is a measure of the thermal stress presented by the combined effects of internal heat generation and heat exchange with the environment. It refers to the resultant thermal insulation of clothing required to maintain thermal balance under specified physiological strain standards. IREQ is measured in units of $\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$ and can also be expressed in clo ($1 \text{ clo} = 0.155 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$) [60].

By comparing the insulation value of clothing for elderly individuals with IREQ, the potential risk of overall body cooling under different activity levels can be assessed. However, IREQ is not a basic clothing insulation value (ICL) and cannot be directly compared with the I_{cl} from surveys. It is necessary to convert IREQ into the ICL. If $I_{cl} > ICL_{neutral}$, it indicates that the elderly individual is in a warm or overheated zone and clothing insulation should be reduced. If $ICL_{min} \leq I_{cl} \leq ICL_{neutral}$, it indicates that the elderly individual is in a moderate and comfortable zone, and no action is needed. If $I_{cl} < ICL_{min}$, it indicates that the elderly individual is in a cold or cooling zone, and clothing insulation should be increased, and the duration limited exposure (DLE) should be calculated. Here, $ICL_{neutral}$ and ICL_{min} are two critical values for ICL. $ICL_{neutral}$ is defined as the basic insulation value required to maintain heat balance under neutral conditions in the actual environment, that is, maintaining heat balance at the normal average body temperature level. ICL_{min} is defined as the minimum basic insulation required to maintain heat balance in the actual environment when the average body temperature is below the normal level. This level represents no cooling or minimal cooling. Similarly, there are two critical values for DLE: $DLE_{neutral}$, and DLE_{min} . $DLE_{neutral}$ is defined as the continuous exposure time to maintain heat balance at low physiological strain when the clothing insulation value is fixed. DLE_{min} is defined as the continuous exposure time to maintain thermal balance at high physiological strain, where the body continues to maintain heat balance through vasoconstriction of the skin and limbs when the clothing insulation value is fixed. IREQ, ICL, and DLE can be calculated using a computer program (<https://www.wold.eat.lth.se/Research/Thermal/TEL118ToolEn.html>, accessed on 10 December 2023). The specific method involves inputting measured meteorological data (T_a , RH , V , T_{mrt}) and providing basic information, such as metabolic rate and clothing insulation values, into the program [60–62].

2.4.2. Wind Chill Temperature (t_{WC})

During winter windy conditions, individuals experience a heightened perception of coldness beyond what the temperature alone indicates. This phenomenon, referred to as the wind cooling effect, is quantified by the t_{WC} [63]. It is a function of temperature and wind speed, calculated using Formula (2):

$$t_{WC} = 13.12 + 0.6215 \times T_a - 11.37 \times V_{10}^{0.16} + 0.3965 \times T_a V_{10}^{0.16} \quad (2)$$

In this study, wind speed is measured at ground level, so, when using the formula below, it should be multiplied by 1.5 to obtain V_{10} [60]. To assess the cold wind risk faced by elderly individuals in various locations at different times, the study calculated the t_{WC} for each space at one-minute intervals from 8:30 to 15:30.

3. Results

3.1. Descriptive Analysis

3.1.1. Participants' Attributes

A total of 477 valid questionnaires were collected. There were 174 women (36.5%) and 303 men (63.5%). The average clothing insulation value for elderly individuals in winter was 2.0 ± 0.2 clo, with a small difference between genders. Based on the revised metabolic rate, there was a significant difference in the average metabolic rates between women and men during the experimental period, with values of 148.6 ± 73.6 W/m² and 167.0 ± 77.2 W/m², respectively (Table 3).

Table 3. Characteristics of elder respondents.

Sex	Number	Age			Clothing Insulation (clo)			Metabolic Rate (W/m ²)		
		Mean $\pm$ SD	Min	Max	Mean $\pm$ SD	Min	Max	Mean $\pm$ SD	Min	Max
Women	174	69.2 $\pm$ 6.7	60	85	2.0 $\pm$ 0.2	1.5	2.4	148.6 $\pm$ 73.6	50.2	301.1
Men	303	70 $\pm$ 6.8	60	92	2.0 $\pm$ 0.2	1.3	2.6	167.0 $\pm$ 77.2	51.7	336.2
All	477	69.7 $\pm$ 6.7	60	92	2.0 $\pm$ 0.2	1.3	2.6	160.2 $\pm$ 73.6	50.2	336.2

3.1.2. Comparison of Meteorological Factors

Table 4 illustrates the average, maximum, and minimum values of meteorological factors across the four designated spaces over the testing period, based on hourly averaged values. Notably, OS exhibited the highest average wind speed at 1.2 m/s. This may be attributed to the absence of surrounding vegetation or structures, enabling the unimpeded flow of prevailing winds through this space. Additionally, both average T_g (-12.2 °C) and T_{mrt} (10.1 °C) of OS were highest compared with other areas. This phenomenon may be ascribed to the maximal SVF in OS, facilitating enhanced sunlight penetration and elevated G of 207.3 W/m². This surpassed G in other spaces, consequently increasing the radiation temperature within OS. Conversely, TA exhibited the lowest average T_g (-13.2 °C) and T_{mrt} (0.2 °C) among the designated spaces. This discrepancy might be linked to the predominantly planted evergreen cypress plants in this space obstructing sunlight. With an SVF of only 0.426, lower than other spaces, the average G in TA was the smallest (135.6 W/m²), consequently reducing the radiation temperature within this space.

Table 4. Measurements of meteorological variables among sites.

Site		T_a (°C)	RH (%)	V (m/s)	T_{mrt} (°C)	G (W/m ²)	T_g (°C)
FA	Average	-16.8 ± 3.2	54.2 ± 7.1	0.8 ± 0.3	2 ± 16.7	146.5 ± 100	-12.5 ± 5.5
	Max	-11.7	65.5	1.3	32.3	337.1	-1.9
	Min	-22.4	31.5	0.3	-21.1	29.9	-21.6
TA	Average	-16.3 ± 1.8	55.8 ± 7.7	0.9 ± 0.3	0.2 ± 10.7	135.6 ± 77.6	-13.2 ± 2.3
	Max	-13.7	64.5	1.5	19.0	299.7	-8.0
	Min	-20.2	21.5	0.6	-18.6	21.7	-18.0
OS	Average	-16.9 ± 3.1	54.8 ± 5.7	1.2 ± 0.3	10.1 ± 15.4	207.3 ± 111.1	-12.2 ± 4.6
	Max	-11.9	65.6	2.1	31.2	439.8	-4.8
	Min	-22.5	40.9	0.6	-22.3	33.2	-21.6
PA	Average	-16.6 ± 2	58 ± 5.3	1.1 ± 0.3	4.7 ± 13.8	145.2 ± 94.5	-12.8 ± 3.1
	Max	-13.2	69.2	1.9	33.8	389.4	-5.6
	Min	-20.8	40.8	0.3	-16.0	28.1	-19.5

3.1.3. Preference Vote for Meteorological Parameters

Approximately 60% of the elderly participants in the survey wished for the T_a to be higher, few wanted it to be lower, and even in severe cold weather, nearly 40% hoped that T_a will not change. This might be attributed to the long-term cold experience of these people who have a higher tolerance for low-temperature environments. Over 70% of the elderly participants believed that the RH did not need to change, more than 20% wanted RH to be higher, and almost no one wanted RH to be lower. In terms of the elderly participants' preference for V , almost no one hoped for a higher wind speed, about 60% hoped that the wind speed would not change, and nearly 40% hoped for a lower wind speed. More than 50% of the elderly participants hoped for G to be higher, and almost no one hoped for G to be smaller. This might be linked to the high latitude of Harbin, where the sun's altitude is low in winter and the daylight hours are short, making it impossible to receive enough sunlight (Figure 6).

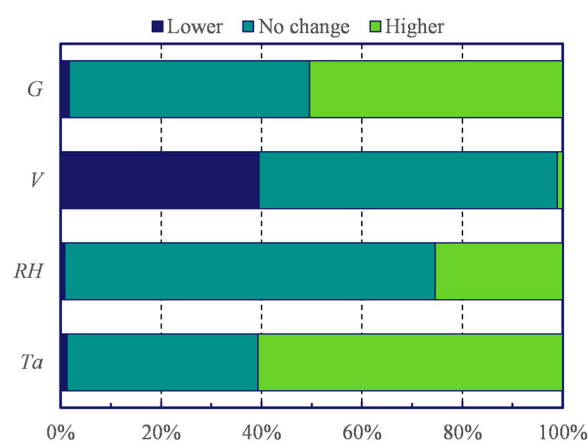


Figure 6. Meteorological parameter preference votes.

3.2. Factors Influencing Thermal Perception

3.2.1. Analysis of Factors Influencing Thermal Sensation Votes (TSV)

T_a , RH , V , and T_g are key factors influencing outdoor thermal comfort in urban open spaces [64]. To quantify the contribution of meteorological variables to thermal sensation in elderly individuals in China's severely cold regions, we conducted Pearson correlation analysis between these variables and TSV (Figure 7). T_a ($\rho = 0.15$) and T_g ($\rho = 0.14$) affected the TSV of elderly individuals during winter. Conversely, RH , V , and G did not exhibit a statistically significant influence.

In addition to meteorological factors, personal parameters and psychological adaptation influence outdoor thermal comfort [65]. Given the extended exposure of the participants to a severely cold climate, we explored the impact of personal parameters and psychological adaptation on thermal perception by conducting a Pearson correlation analysis between these variables and TSV (Figure 8). The results revealed that, among personal parameters, body mass index (BMI), sex, and clothing insulation did not exert an impact on TSV, whereas metabolic rate affected TSV ($\rho = 0.38$). Furthermore, there was a negative correlation between the TSV of elderly individuals and their preference votes for T_a and G . This suggested that, if the TSV were lower, elderly individuals would tend to prefer higher T_a and G . It is important to highlight that a strong correlation existed between the thermal comfort vote (TCV) and TSV of elderly individuals, indicating a substantial influence of thermal perception on their thermal comfort.

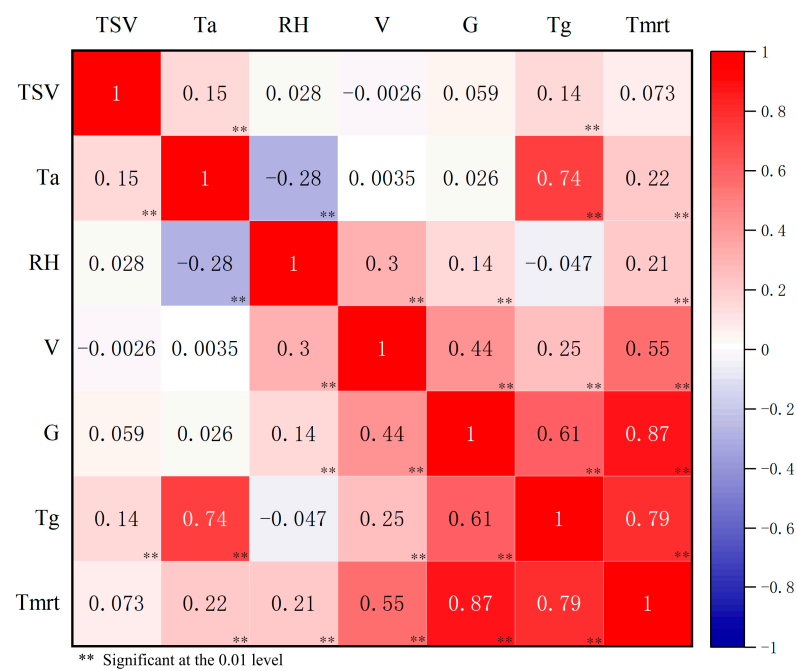


Figure 7. Pearson correlation statistics of thermal sensation votes and meteorological parameters.

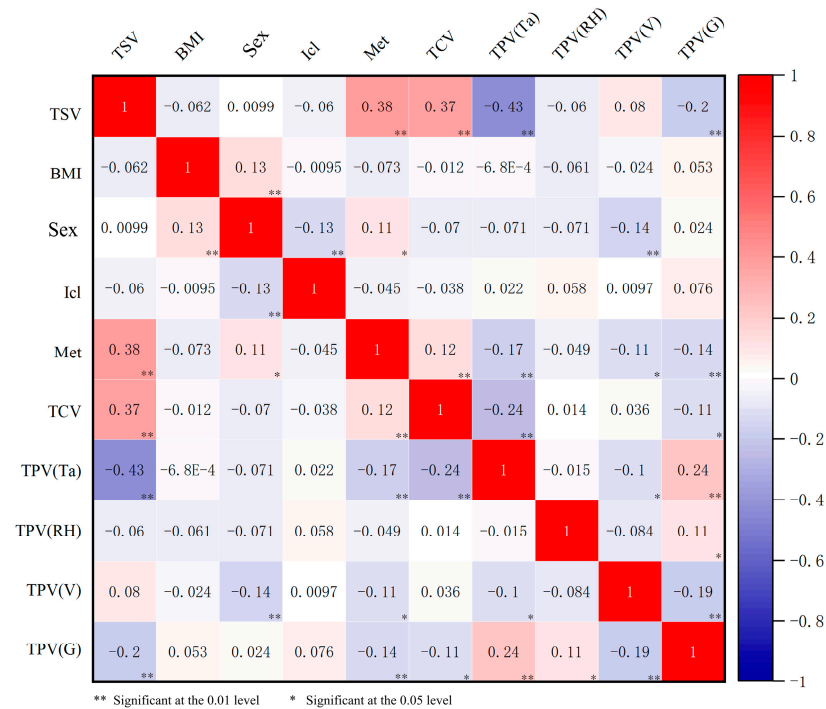


Figure 8. Pearson correlation statistics of thermal sensation votes and personal parameters.

3.2.2. Outdoor Physical Activity and TSV

This study defined physical activity intensity as follows: light < 3.0 METs, moderate 3.0–5.9 METs, vigorous ≥ 6.0 METs [52–54]. Figure 9 illustrates that elderly individuals who participated in moderate- and vigorous-intensity physical activities outnumbered those with light-intensity activity, potentially attributable to the fact that moderate- to vigorous-intensity activity generates more heat, aiding the body in resisting the cold. Elderly individuals with low-intensity activity primarily rated their TSV −2 and −3. Those engaged in moderate-intensity activity mainly rated their TSV −1 and 0, with −2 and −3 following closely, with only a few selecting 2 and −4. Elderly individuals who engaged in

vigorous-intensity activity primarily rated their TSV -1 and 0 . This result aligned with the Pearson correlation analysis, showing a correlation between TSV and activity intensity.

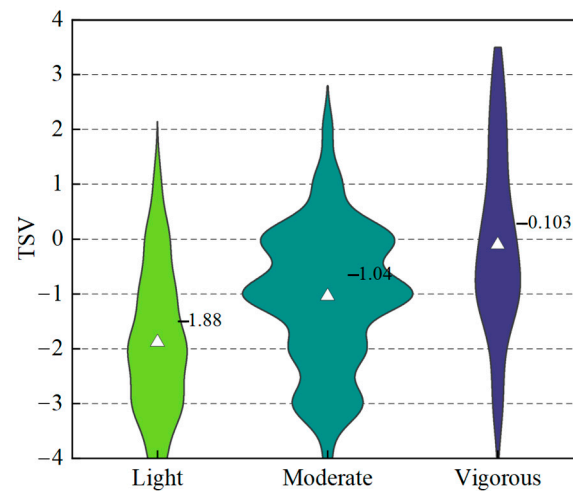


Figure 9. Thermal perception vote distribution for different intensities of physical activity.

3.3. Neutral UTCI (NUTCI) and Neutral UTCI Range (NUTCIR)

This study calculated the weighted mean TSV (MTSV) per $1\text{ }^{\circ}\text{C}$ UTCI interval for elderly individuals during the winter. The results of linear regression analysis indicated that UTCI significantly predicted MTSV, with $\beta = 0.629$, $t = 3.969$, and $p = 0.001$. UTCI could explain 39.6% of the variance in MTSV of elderly individuals. The regression line slope for the overall elderly individuals was 0.042, equivalent to a UTCI/MTSV ratio of $23.8\text{ }^{\circ}\text{C}$. For the female population, the regression line slope was 0.0423, corresponding to a UTCI/MTSV ratio of $23.6\text{ }^{\circ}\text{C}$, whereas for the male population, the slope was 0.471, resulting in a UTCI/MTSV ratio of $21.2\text{ }^{\circ}\text{C}$ (Figure 10 and Table 5).

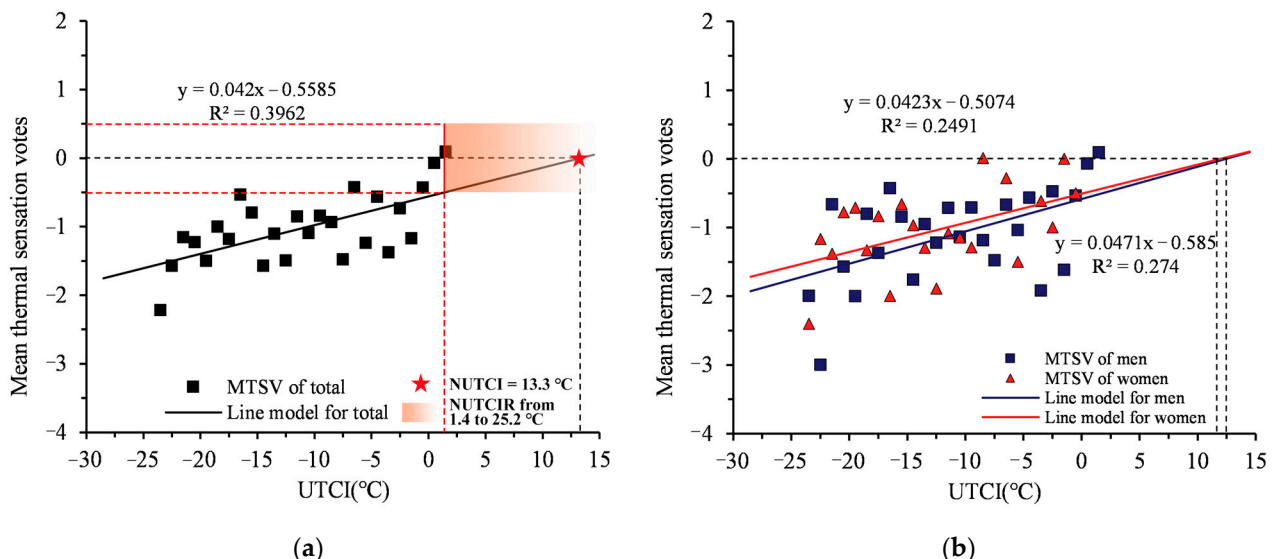


Figure 10. Correlation between UTCI and MTSV: (a) total, (b) women and men.

A neutral temperature is defined as a temperature at which individuals neither feel hot nor cold [66,67]. When MTSV = 0, the corresponding UTCI is NUTCI. Thus, the overall elderly population's winter NUTCI was $13.3\text{ }^{\circ}\text{C}$, while for women and men, it was $12.0\text{ }^{\circ}\text{C}$ and $12.4\text{ }^{\circ}\text{C}$, respectively. NUTCIR represents the temperature range corresponding to TSV between -0.5 and 0.5 . The overall elderly NUTCIR was $1.4\text{--}25.2\text{ }^{\circ}\text{C}$, and for women and

men, it was 0.2–23.8 °C and 1.8–23.0 °C, respectively. It is worth noting that almost no data points fell into NUTCIR in Figure 10a, that is, severely cold climate conditions made it difficult for the elderly to reach a neutral thermal state.

Table 5. Regression equation of MTSV and UTCI.

Regression Equation	β	R^2	t	P	F
$y = 0.042x - 0.5585$	0.629	0.396	3.969	0.001	15.750
$y = 0.0423x - 0.5074$	0.499	0.249	2.576	0.018	6.633
$y = 0.0471x - 0.585$	0.523	0.274	3.010	0.006	9.059

3.4. Outdoor Cold Stress

Thermal stress includes two types: cold stress and heat stress. Cold stress refers to substantial and occasionally unmitigable physiological strain resulting from climatic conditions when the body's heat exchange is equal to or too large to achieve heat balance. Cold stress is assessed based on the whole-body and local cooling of the body [60].

3.4.1. Whole-Body Cooling Assessment

For elderly individuals engaged in light-intensity activities, the average I_{cl} fell below ICL_{min} (2.0 clo < 4.4 clo), indicating that the clothing worn by them did not provide sufficient insulation to prevent body cooling. The risk of lowering body temperature increased with prolonged exposure, allowing for a maximum outdoor stay of only 0.6 h ($DLE_{min} = 0.6$ h). For those participating in moderate-intensity activities, the average I_{cl} ranged between ICL_{min} and $ICL_{neutral}$ (1.9 clo < 2.0 clo < 2.2 clo), suggesting that their clothing could provide adequate insulation, with thermal conditions ranging from “cool” to “neutral”. Elderly individuals who engaged in vigorous-intensity activities had an average I_{cl} greater than $ICL_{neutral}$ (2.0 clo > 0.9 clo), indicating that their clothing provided excessive insulation, potentially leading to sweating, and accelerating body cooling. Therefore, it is advisable for them to change into dry clothes promptly or enter a temporary rest area to restore body temperature and mitigate the potential risk of low body temperature [60]. The average winter I_{cl} for the total elderly individuals fell between ICL_{min} and $ICL_{neutral}$ (2.0 clo $\leq$ 2.0 clo < 2.4 clo), allowing for outdoor activities while maintaining body heat balance for up to 1.9 h.

Additionally, elderly individuals who engaged in different intensity activities exhibited the same clothing insulation, whereas the $DLE_{neutral}$ for those engaged in light-intensity activity was considerably shorter than for those involved in moderate-intensity activity (0.5 < 3.3 h). This indicated that the intensity of physical activity among older adults could influence the risk of whole-body cooling (Table 6).

Table 6. The risk corresponding to different activity intensities.

PA Levels	Metabolic Rate (W/m ²)	I_{cl} (clo)	$IREQ_{min}$ (clo)	$IREQ_{neutral}$ (clo)	ICL_{min} (clo)	$ICL_{neutral}$ (clo)	DLE_{min} (hours)	$DLE_{neutral}$ (hours)
Light	74.8 W/m ²	2.0	4.0	4.4	4.4	4.8	0.6	0.5
Moderate	152.5 W/m ²	2.0	1.6	2.0	1.9	2.2	>8	3.3
Vigorous	302.4 W/m ²	2.0	0.5	0.8	0.6	0.9	>8	>8
All	159.7 W/m ²	2.0	1.6	1.9	2.0	2.4	>8	1.9

3.4.2. Local Cooling Assessment

(1) Wind cooling

According to the wind chill temperature, the skin exposed to cold wind faces four levels of frostbite risk [63]. Figure 11 shows that the t_{WC} in the four spaces gradually increased over time but consistently remained below −10 °C. This implies that, throughout the investigation period, the elderly in these four spaces consistently faced at least a Level

1 cold risk (uncomfortably cold). Before 10:30, t_{WC} of certain time points in these spaces, especially OS, was below -24°C . This suggested that the elderly were exposed to a Level 2 cold risk during this period, potentially leading to frostbite. The distinctiveness of OS from other spaces could be linked to the lack of surrounding vegetation and buildings, which facilitated the penetration of cold wind. The average T_a was lower than in other spaces, and the wind speed was faster.

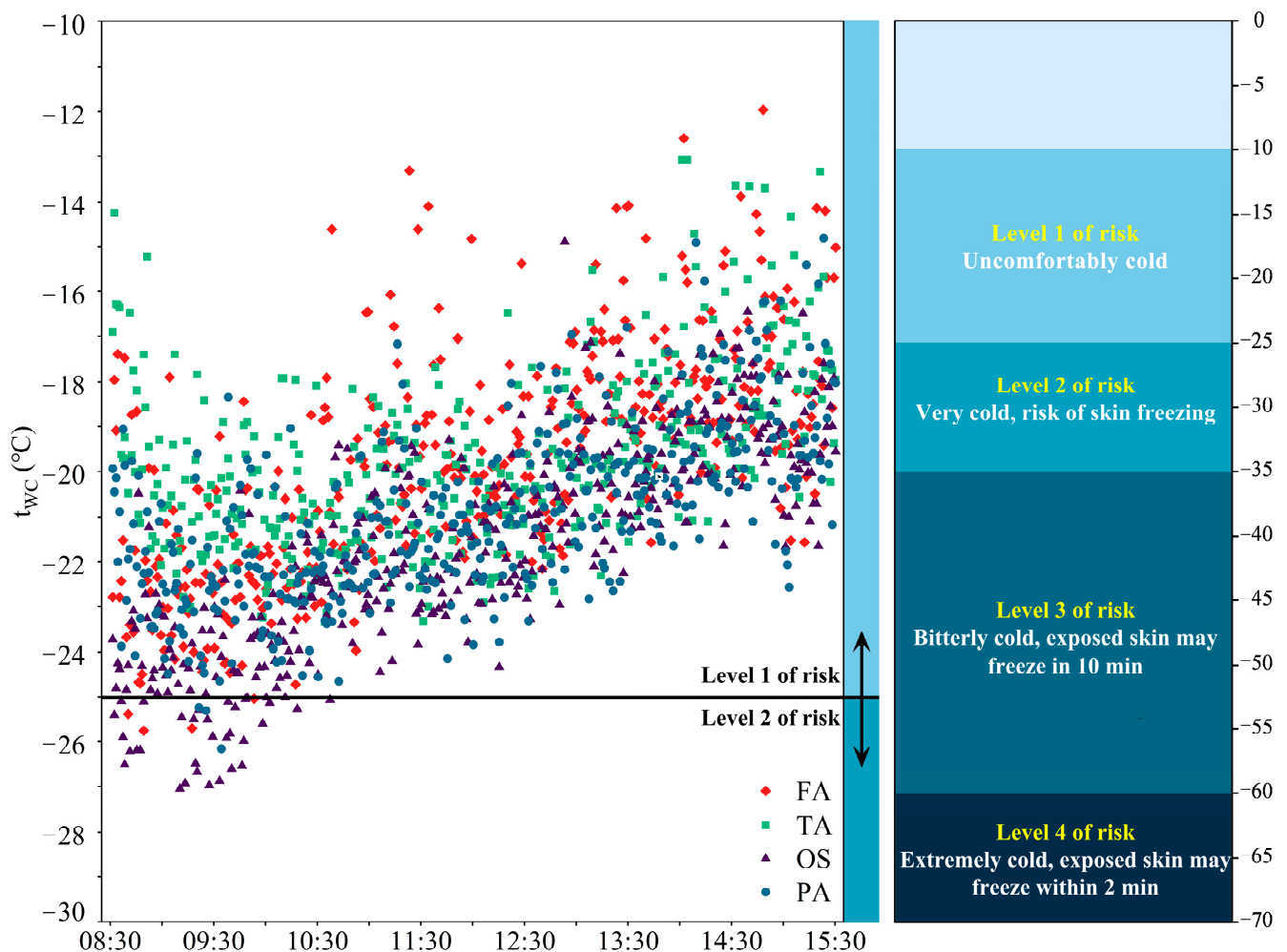


Figure 11. Daytime variation of wind chill temperature in four open spaces.

(2) Contact with cold surfaces

The potential cold risk stemming from direct exposure of bare skin to cold surfaces is contingent upon the duration and method of contact, as well as the material type and its T_s . Table 7 lists the cold risk thresholds for common materials [47]. Elderly individuals, when engaged in outdoor physical activities, may intentionally or unintentionally encounter cold surfaces. This study assessed the potential cold risk (Figure 12).

Table 7. Cold risk thresholds ($^{\circ}\text{C}$) for hand contact with different materials.

	Contact Period	Cold Risk	Aluminum	Steel	Stone	Nylon	Wood
Finger touching	10 s	Pain	>5	>5	4	−6	−10
		Numbness	3	−1	−15	−40	<−40
		Frostbite	−7	−13	−18	-	-
Hand gripping	100 s	Pain	−4	−7	−17	−33	<−40

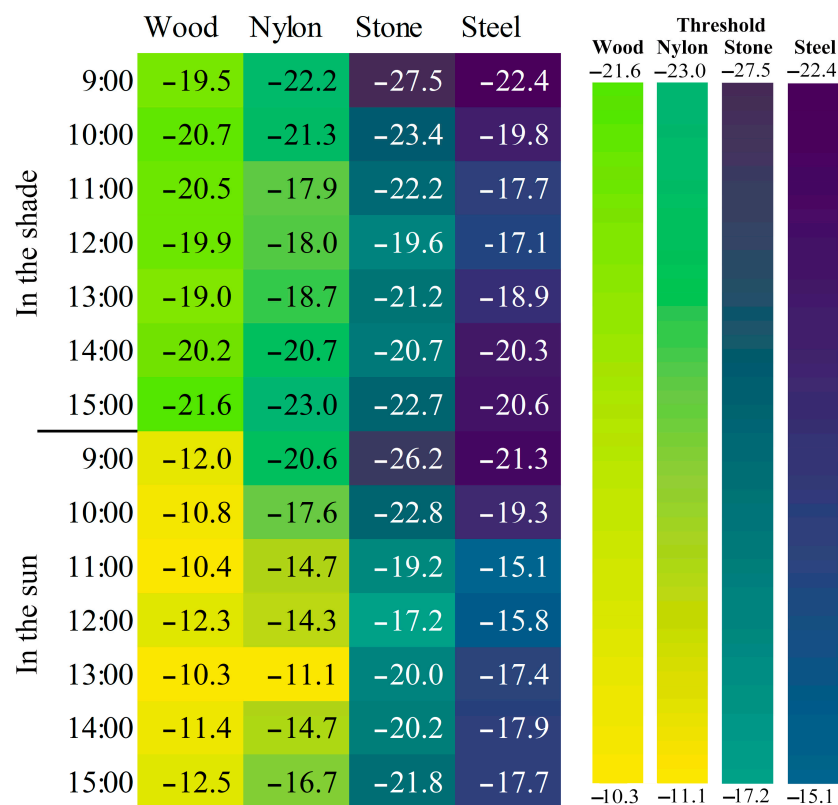


Figure 12. Different materials' T_s ($^{\circ}\text{C}$) and cold risk in the sun or shadow.

The T_s of a wooden seat in the sunlight remained consistently lower than the threshold of pain (-10°C) for finger contact with wood surfaces but was higher than the threshold of numbness ($<-40^{\circ}\text{C}$). Therefore, there was a risk of experiencing pain when fingers encountered the wooden seat. Similarly, there was a pain risk when fingers touched the surface of facilities made of nylon. When in sunlight, the average T_s of the stone was the highest at 12:00, reaching -17.2°C ; this was lower than the threshold of numbness when touched stone surfaces with fingers by 2.2°C . Measurements at other time points were below the threshold of frostbite (-18°C). Therefore, there was a risk of numbness or even frostbite if fingers touched the stone surface for more than 10 s. The T_s of steel remained consistently below the threshold of frostbite (-13°C) throughout the testing period. Thus, there was a risk of frostbite when fingers touched steel for more than 10 s. The T_s of these materials in the shade were lower than those in sunlight, which posed a more severe cold risk to elderly individuals' fingers.

Compared to finger touching, hand gripping poses a lower risk of cold exposure [41]. When elderly individuals engaged with steel handrails, the maximum T_s (-16.2°C) was lower than the pain threshold for a 100 s contact duration (-7°C).

3.5. Thermal Adaptation Behaviors

Preferences for thermal adaptation behaviors also provide insights for improving outdoor thermal comfort and heat stress in severely cold climates for elderly individuals. In winter, there was little difference in the thermal adaptation behavior preferences between genders among elderly individuals. The primary choice for women and men was often "moving to sunshine" ($P_{\text{women}} = 49.4\%$, $P_{\text{men}} = 46.3\%$), which aligned with the strong correlation between thermal perception and preference voting for G discussed in Section 3.1.3. The second preference was "exercising" ($P_{\text{Women}} = 28.7\%$, $P_{\text{Men}} = 28.5\%$). Additionally, women and men both considered "adding clothes" as their least preferred cold adaptation behavior (Figure 13). These results might be attributed to the fact that they wore enough clothing to cope with the severely cold climate conditions ($I_{\text{cl}} = 2.0$ clo).

In harsh thermal environments, blood vessels in the limbs begin to contract, limiting the amount of heat entering the limbs [68]. Increasing the thermal resistance of clothing slows down the cooling rate of the limbs but does not entirely impede it. Excessive clothing, therefore, not only hampers agility in physical activity but also does not completely prevent limb cooling [69].

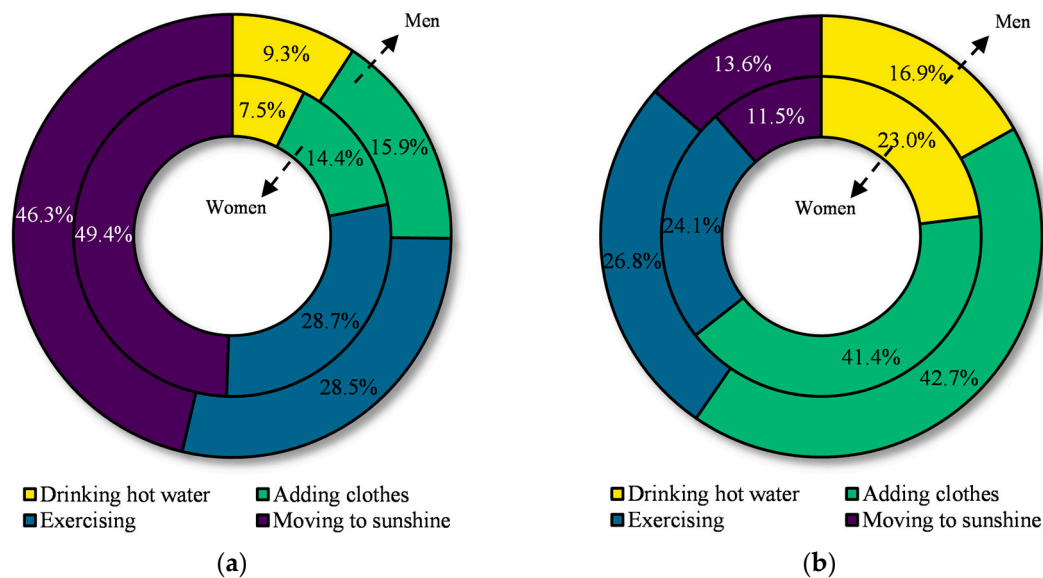


Figure 13. Preferred thermal adaptation behavior: (a) first choice, (b) last choice.

4. Discussion

4.1. Thermal Benchmarks

Compared with another study in Harbin, the NUTCI for elderly individuals in winter was higher in the current study ($13.3\text{ }^{\circ}\text{C} > 9.7\text{ }^{\circ}\text{C}$) [70]. This difference can be attributed to significant variations in participant age and metabolic levels between the two studies. Despite the similar climates of Harbin and Umeå, Sweden, the elderly NUTCI in Harbin was higher [71], likely influenced by seasonal differences and participant variations. Compared with Tianjin's study, the NUTCIR for elderly individuals in this study was broader [32]. This might be linked to Harbin being in a severely cold region of China with extremely cold winters and hot summers. Participants in this study exhibited diverse thermal experiences, contributing to a heightened tolerance for fluctuations in temperature (Table 8).

Table 8. The neutral UTCI and neutral UTCI rang in different studies.

City	Climate	Seasons	Population	NUTCI	NUTCIR	Analysis Methods
Harbin (this study)	Dwa	Winter	The elderly	13.3 °C	1.4–25.2 °C	LR, MTSV vs. UTCI bin 1 °C
Harbin	Dwa	Winter	Children	9.7 °C	2.3–17.1 °C	LR, MTSV vs. UTCI bin 1 °C
Umeå	Dfc	Summer	Mixed ages	14.4 °C	11.5–17.2 °C	LR, MTSV vs. UTCI bin 1 °C
Tianjin	Dwa/BSk	All	Mixed ages	17.5 °C	13.6–21.3 °C	LR, MTSV vs. UTCI bin 1 °C

4.2. Insights into Designing Urban Parks

With monthly average temperatures below $0\text{ }^{\circ}\text{C}$ from November ($-4.5\text{ }^{\circ}\text{C}$) to the following March ($-2.9\text{ }^{\circ}\text{C}$), Harbin's elderly population must endure a prolonged winter. As demonstrated in the introduction, ensuring that the elderly engage in activities in urban parks is crucial for their well-being. This study not only revealed the climate risks faced by this vulnerable group in severely cold climates, but also provided valuable insights into the age-friendly design of urban park open spaces in conjunction with the investigation into their thermal adaptation behaviors (Table 9).

Table 9. Challenges and insights into designing urban parks in severely cold climates.

Challenges	Analysis and Insights
1. The elderly who engaged in physical activities in the park faced the challenge of whole-body cooling. The $DLE_{neutral}$ for elderly individuals participating in activities of light, moderate, and vigorous intensities was 0.5, 1.3, and >8 h, respectively.	Analysis: The average T_a in all four spaces was below $-16\text{ }^{\circ}\text{C}$. The four spaces exhibited distinct landscape compositions, varied space types, and diverse themes, resulting in differences in the types of activities conducted. Insights: (1) It is advisable to strategically plan for the construction of temporary warming shelters. These shelters can serve as spaces for elderly individuals to take temporary breaks, change clothing, and restore body temperature. (2) Within different spaces in the park, install corresponding signage to remind elderly individuals to plan the type and the time of their activities.
2. The cold winds traversing through the park intensified the chilling effect on exposed skin. The t_{WC} in all four spaces was low, especially in OS, where elderly individuals faced a Level 1 or even a Level 2 cold risk.	Analysis: In OS, the average V reached up to 1.2 m/s, attributed to the minimal presence of vegetation and architectural coverage, allowing the wind to pass more freely. Adjusting the outdoor T_a is impractical, but mitigating the impact of wind can still effectively reduce t_{WC}. Insights: designers, when creating activity spaces, should consider incorporating features like camelback topography or structures and vegetation to block prevailing winter winds.
3. Cold surfaces of landscape materials, particularly metallic materials, in the park may lead to pain, numbness, and even frostbite on the fingers of elderly individuals.	Analysis: various landscape materials possess different physical characteristics, including thermal conductivity. Insights: (1) Designers should strive to avoid or minimize use of metal materials with high thermal conductivity. (2) Prominent warning signs such as “Please wear gloves to prevent frostbite” should be placed around landscape facilities and materials made of metal.
4. In severely cold climates, various spaces within the park failed to achieve thermal neutrality (NUTCIR) for elderly individuals.	Analysis: Adjusting the outdoor microclimates to achieve thermal neutrality of the elderly is impractical. Thermal adaptation behaviors of the elderly also provide ideas for design. Insights: (1) Designers should avoid planting tall deciduous trees on the southern side of activity spaces or consider using deciduous tree species instead of evergreen ones. (2) Landscape architects and planners should focus on providing more spaces where sunlight is freely accessible and offer a variety of exercise equipment or areas.

4.3. Limitations and Future Research

Our study has some limitations. Firstly, variations in temperature exist among different materials within the same space and among the same materials in different spaces. But we only measured surface temperatures of representative landscape materials. Therefore, future research should employ more advanced instruments or methods to comprehensively collect surface temperature data of on-site materials to assess their safety, thus enabling a more scientific selection of landscape materials for elderly activity venues. Secondly, our study revealed the thermal perception threshold and cold stress of the elderly during outdoor activities in severe cold climates through field surveys. Although we proposed a landscape design strategy for elderly friendly activity spaces in severe cold climate areas, its practical effects remain unverified. Future studies should include quantitative numerical simulations to validate the accuracy of these strategies.

5. Conclusions

In an extension of traditional thermal comfort assessments, this study employed various methods, including meteorological monitoring and subjective thermal perception surveys, to investigate the thermal comfort thresholds of elderly individuals and systematically evaluate thermal stress on elderly individuals in outdoor environments in severely cold climates. The principal conclusions could be drawn as follows:

- (1) Meteorological parameters affecting the TSV of the elderly in severely cold climates were T_a ($\rho = 0.151$) and T_g ($\rho = 0.144$). RH , V , and G did not affect the thermal sensation of elderly individuals during winter. Among personal parameters, BMI, gender, and clothing insulation had no significant effects on TSV, while metabolic rate was associated with TSV ($\rho = 0.380$).
- (2) The NUTCI for older women was slightly lower than for men ($12.0\text{ }^{\circ}\text{C} < 12.4\text{ }^{\circ}\text{C}$). The NUTCI for elderly individuals overall in winter was $13.3\text{ }^{\circ}\text{C}$, and the NUTCI_R was $1.4\text{--}25.2\text{ }^{\circ}\text{C}$.
- (3) The intensity of physical activity affected the whole-body cooling risk for elderly individuals. The DLE_{neutral} for light- and moderate-intensity physical activity levels was 0.5 h and 3.3 h, respectively. Elderly individuals engaging in vigorous-intensity activities should be cautious about preventing excessive clothing insulation, which may lead to sweating and more pronounced body cooling.
- (4) Wind chill and contact with cold surfaces were two crucial aspects of local cooling. The FA, TA, and PA consistently fell under a risk of level 1, according to the assessment of t_{WC} . Before 10:00, the OS fell under risk level 2. In severely cold climates, elderly individuals touching cold surfaces made of wood and nylon materials face a cold risk of experiencing pain. Contact with cold surfaces made of stone and steel poses a numbness and even frostbite risk.
- (5) In severely cold climates, appropriate thermal adaptation behaviors to mitigate cold stress primarily involved moving into sunshine ($P_{\text{Women}} = 35.5\%$, $P_{\text{Men}} = 48.3\%$) and exercising ($P_{\text{Women}} = 31.1\%$, $P_{\text{Men}} = 26.4\%$).

In conclusion, urban designers and landscape architects should consider the thermal comfort thresholds and thermal stress conditions of the elderly in severely cold climates. By implementing landscape optimization strategies, the thermal safety and comfort of urban park open spaces will be enhanced, ultimately contributing to the well-being of elderly individuals.

Author Contributions: X.H.: writing—review and editing, writing—original draft, visualization, validation, software, resources, methodology, investigation, formal analysis, data curation, conceptualization. Y.T.: resources, project administration, investigation. L.S.: supervision. L.H.: investigation. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 51908170. And The APC was funded by the Heilongjiang Province Philosophy and Social Sciences Planning Project, grant number 22SHB169.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Outdoor Thermal comfort questionnaire

Date: ____/____/____ Time: _____ Gender: ☐Male ☐Female
Age: _____ Height: _____cm Weight: _____kg
How many years have you lived here (Harbin): _____ year(s)

1、What are you wearing now? (multiple choice):

Sundries:
☐Gloves ☐Cap

Upper body:
☐Underwear T-shirt ☐Underwear-Shirt, long sleeves, thermal ☐Underwear-Shirt, long sleeves
☐Short sleeve ☐Vest ☐Shirt Jacket (☐Thin ☐Thick ☐Fibre-pelt)
Sweater (☐Sleeveless ☐Thin ☐Thick) ☐Down-vest ☐Down jacket
☐Coat ☐Other_____.

Lower body:
☐Underwear-Pants, long-legged, thermal ☐Underwear-Pants, long-legged
Trousers (☐Thin ☐Thick) ☐Flannel ☐Sweat pants
☐Trousers, fibre-pelt ☐Winter dress, long sleeves ☐Other_____

Feet:
Shoes (☐Thin soled ☐Thick soled) ☐Boots
Socks (☐Thin ☐Thick & ankle ☐Thick & long) ☐Other_____

2、Your current activity:

(1) Light intensity:
☐Sitting ☐Standing quietly ☐Standing, talking in person ☐walking, less than 3.2km/h
☐Dog sledding, passenge ☐Other_____

(2) Moderate intensity:
☐walking the dog ☐walking, 4.5–5.1 km/h ☐Playing table tennis
☐martial arts ☐Skating, less than 4m/s ☐Other_____

(3) Vigorous:
☐Basketball ☐General skating ☐Running ☐Other_____

3、How do you feel at this moment?

☐Very cold ☐Cold ☐Slightly cool ☐Cool ☐Neutral ☐Slightly warm ☐Warm ☐Hot ☐Very hot

4、What are you preference in regard to the following meteorological parameters?

Air Temperature	☐ Higher	☐ No change	☐ Lower	Solar Radiation	☐ Stronger	☐ No change	☐ Weaker
Relative humidity	☐ Wetter	☐ No change	☐ Drier	Wind Speed	☐ Stronger	☐ No change	☐ Weaker

5、Please describe your thermal comfort level:

☐Uncomfortable ☐Neutral ☐Comfortable

6、Your acceptable level for current thermal environment:

☐Unacceptable ☐Acceptable

7、In winter, when you feel cold outdoor, without returning indoors, you will:

Feeling cold: ☐Drinking hot water ☐Adding clothes ☐Exercising ☐Moving to sunshine

References

1. WHO. Caring for the Health of the Elderly in China. Available online: <https://www.who.int/news-room/feature-stories/detail/caring-for-the-health-of-the-elderly-in-china> (accessed on 2 June 2024).

2. WHO. Ageing and Health. Available online: <https://www.who.int/news-room/fact-sheets/detail/ageing-and-health> (accessed on 2 June 2024).

3. Liu, H.; Li, F.; Li, J.; Zhang, Y. The relationships between urban parks, residents’ physical activity, and mental health benefits: A case study from Beijing, China. *J. Environ. Manag.* **2017**, *190*, 223–230. [\[CrossRef\]](#) [\[PubMed\]](#)

4. Pietilä, M.; Neuvonen, M.; Borodulin, K.; Korpela, K.; Sievänen, T.; Tyrväinen, L. Relationships between exposure to urban green spaces, physical activity and self-rated health. *J. Outdoor Recreat. Tour.* **2015**, *10*, 44–54. [\[CrossRef\]](#)

5. Tamosiunas, A.; Grazuleviciene, R.; Luksiene, D.; Dedele, A.; Reklaitiene, R.; Baceviciene, M.; Vencloviene, J.; Bernotiene, G.; Radisauskas, R.; Malinauskiene, V.; et al. Accessibility and use of urban green spaces, and cardiovascular health: Findings from a Kaunas cohort study. *Environ. Health* **2014**, *13*, 20. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Mantler, A.; Logan, A.C. Natural environments and mental health. *Adv. Integr. Med.* **2015**, *2*, 5–12. [\[CrossRef\]](#)
7. Zhang, Y.; Van Dijk, T.; Tang, J.; van den Berg, A.E. Green Space Attachment and Health: A Comparative Study in Two Urban Neighborhoods. *Int. J. Environ. Res. Public Health* **2015**, *12*, 4342. [\[CrossRef\]](#) [\[PubMed\]](#)
8. Shackleton, C.M.; Blair, A.; De Lacy, P.; Kaoma, H.; Mugwagwa, N.; Dalu, M.T.; Walton, W. How important is green infrastructure in small and medium-sized towns? Lessons from South Africa. *Landsc. Urban Plan.* **2018**, *180*, 273–281. [\[CrossRef\]](#)
9. Gong, Y.; Palmer, S.; Gallacher, J.; Marsden, T.; Fone, D. A systematic review of the relationship between objective measurements of the urban environment and psychological distress. *Environ. Int.* **2016**, *96*, 48–57. [\[CrossRef\]](#)
10. Javadi, R.; Nasrollahi, N. Urban green space and health: The role of thermal comfort on the health benefits from the urban green space; a review study. *Build. Environ.* **2021**, *202*, 108039. [\[CrossRef\]](#)
11. Maas, J.; Verheij, R.A.; de Vries, S.; Spreeuwenberg, P.; Schellevis, F.G.; Groenewegen, P.P. Morbidity is related to a green living environment. *J. Epidemiol. Community Health* **2009**, *63*, 967–973. [\[CrossRef\]](#)
12. Dadvand, P.; Bartoll, X.; Basagaña, X.; Dalmau-Bueno, A.; Martinez, D.; Ambros, A.; Cirach, M.; Triguero-Mas, M.; Gascon, M.; Borrell, C. Green spaces and general health: Roles of mental health status, social support, and physical activity. *Environ. Int.* **2016**, *91*, 161–167. [\[CrossRef\]](#)
13. Dadvand, P.; Villanueva, C.M.; Font-Ribera, L.; Martinez, D.; Basagaña, X.; Belmonte, J.; Vrijheid, M.; Gražulevičienė, R.; Kogevinas, M.; Nieuwenhuijsen, M. Risks and benefits of green spaces for children: A cross-sectional study of associations with sedentary behavior, obesity, asthma, and allergy. *Environ. Health Perspect.* **2014**, *122*, 1329–1335. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Nielsen, T.S.; Hansen, K.B. Do green areas affect health? Results from a Danish survey on the use of green areas and health indicators. *Health Place* **2007**, *13*, 839–850. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Paquet, C.; Orschulok, T.P.; Coffee, N.T.; Howard, N.J.; Hugo, G.; Taylor, A.W.; Adams, R.J.; Daniel, M.J.L. Are accessibility and characteristics of public open spaces associated with a better cardiometabolic health? *Landsc. Urban Plan.* **2013**, *118*, 70–78. [\[CrossRef\]](#)
16. Shen, Y.-S.; Lung, S.-C.C. Can green structure reduce the mortality of cardiovascular diseases? *Sci. Total Environ.* **2016**, *566*, 1159–1167. [\[CrossRef\]](#) [\[PubMed\]](#)
17. van Gelder, B.M.; Tijhuis, M.A.R.; Kalmijn, S.; Giampaoli, S.; Nissinen, A.; Kromhout, D. Physical activity in relation to cognitive decline in elderly men. *Neurology* **2004**, *63*, 2316. [\[CrossRef\]](#) [\[PubMed\]](#)
18. de Bruijn, R.F.A.G.; Schrijvers, E.M.C.; de Groot, K.A.; Witteman, J.C.M.; Hofman, A.; Franco, O.H.; Koudstaal, P.J.; Ikram, M.A. The association between physical activity and dementia in an elderly population: The Rotterdam Study. *Eur. J. Epidemiol.* **2013**, *28*, 277–283. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Hupin, D.; Roche, F.; Gremeaux, V.; Chatard, J.-C.; Oriol, M.; Gaspoz, J.-M.; Barthélémy, J.-C.; Edouard, P. Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged ≥ 60 years: A systematic review and meta-analysis. *Br. J. Sports Med.* **2015**, *49*, 1262. [\[CrossRef\]](#) [\[PubMed\]](#)
20. Moore, S.C.; Patel, A.V.; Matthews, C.E.; Berrington de Gonzalez, A.; Park, Y.; Katki, H.A.; Linet, M.S.; Weiderpass, E.; Visvanathan, K.; Helzlsouer, K.J. Leisure time physical activity of moderate to vigorous intensity and mortality: A large pooled cohort analysis. *PLoS Med.* **2012**, *9*, e1001335. [\[CrossRef\]](#) [\[PubMed\]](#)
21. Emmanuel, R.; Krüger, E. Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK. *Build. Environ.* **2012**, *53*, 137–149. [\[CrossRef\]](#)
22. Martins, T.A.L.; Adolphe, L.; Bonhomme, M.; Bonneaud, F.; Faraut, S.; Ginestet, S.; Michel, C.; Guyard, W. Impact of Urban Cool Island measures on outdoor climate and pedestrian comfort: Simulations for a new district of Toulouse, France. *Sustain. Cities Soc.* **2016**, *26*, 9–26. [\[CrossRef\]](#)
23. Santamouris, M.; Ding, L.; Fiorito, F.; Oldfield, P.; Osmond, P.; Paolini, R.; Prasad, D.; Synnefa, A. Passive and active cooling for the outdoor built environment—Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. *Sol. Energy* **2017**, *154*, 14–33. [\[CrossRef\]](#)
24. Oliveira, S.; Andrade, H.; Vaz, T. The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. *Build. Environ.* **2011**, *46*, 2186–2194. [\[CrossRef\]](#)
25. Ghaffarianhoseini, A.; Berardi, U.; Ghaffarianhoseini, A.; Al-Obaidi, K. Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia. *Sci. Total Environ.* **2019**, *666*, 1327–1345. [\[CrossRef\]](#) [\[PubMed\]](#)
26. Montazeri, H.; Toparlar, Y.; Blocken, B.; Hensen, J.L.M. Simulating the cooling effects of water spray systems in urban landscapes: A computational fluid dynamics study in Rotterdam, The Netherlands. *Landsc. Urban Plan.* **2017**, *159*, 85–100. [\[CrossRef\]](#)
27. Li, X. Investigating the spatial distribution of resident's outdoor heat exposure across neighborhoods of Philadelphia, Pennsylvania using urban microclimate modeling. *Sustain. Cities Soc.* **2021**, *72*, 103066. [\[CrossRef\]](#)
28. Higuera, E.; Román, E.; Fariña, J. Guidelines for Healthier Public Spaces for the Elderly Population: Recommendations in the Spanish Context. In *Handbook of Quality of Life and Sustainability*; Martinez, J., Mikkelsen, C.A., Phillips, R., Eds.; Springer International Publishing: Cham, Switzerland, 2021; pp. 35–51.
29. Huang, J.; Chen, Y.; Jones, P.; Hao, T. Heat stress and outdoor activities in open spaces of public housing estates in Hong Kong: A perspective of the elderly community. *Indoor Built Environ.* **2022**, *31*, 1447–1463. [\[CrossRef\]](#)

30. Larriva, M.T.B.; Higuera, E. Health risk for older adults in Madrid, by outdoor thermal and acoustic comfort. *Urban Clim.* **2020**, *34*, 100724. [\[CrossRef\]](#)
31. Qin, H.; Cheng, X.; Han, G.; Wang, Y.; Deng, J.; Yang, Y. How thermal conditions affect the spatial-temporal distribution of visitors in urban parks: A case study in Chongqing, China. *Urban For. Urban Green.* **2021**, *66*, 127393. [\[CrossRef\]](#)
32. Lai, D.; Guo, D.; Hou, Y.; Lin, C.; Chen, Q. Studies of outdoor thermal comfort in northern China. *Build. Environ.* **2014**, *77*, 110–118. [\[CrossRef\]](#)
33. Yung, E.H.K.; Wang, S.; Chau, C.-K. Thermal perceptions of the elderly, use patterns and satisfaction with open space. *Landsc. Urban Plan.* **2019**, *185*, 44–60. [\[CrossRef\]](#)
34. Shooshtarian, S.; Rajagopalan, P.; Wakefield, R. Effect of seasonal changes on usage patterns and behaviours in educational precinct in Melbourne. *Urban Clim.* **2018**, *26*, 133–148. [\[CrossRef\]](#)
35. Martinelli, L.; Lin, T.-P.; Matzarakis, A. Assessment of the influence of daily shadings pattern on human thermal comfort and attendance in Rome during summer period. *Build. Environ.* **2015**, *92*, 30–38. [\[CrossRef\]](#)
36. Huang, Z.F.; Cheng, B.; Gou, Z.H.; Zhang, F. Outdoor thermal comfort and adaptive behaviors in a university campus in China's hot summer-cold winter climate region. *Build. Environ.* **2019**, *165*, 106414. [\[CrossRef\]](#)
37. Li, K.M.; Zhang, Y.F.; Zhao, L.H. Outdoor thermal comfort and activities in the urban residential community in a humid subtropical area of China. *Energy Build.* **2016**, *133*, 498–511. [\[CrossRef\]](#)
38. Lai, D.Y.; Liu, W.Y.; Gan, T.T.; Liu, K.X.; Chen, Q.Y. A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Sci. Total Environ.* **2019**, *661*, 337–353. [\[CrossRef\]](#) [\[PubMed\]](#)
39. Ma, X.; Tian, Y.; Du, M.; Hong, B.; Lin, B. How to design comfortable open spaces for the elderly? Implications of their thermal perceptions in an urban park. *Sci. Total Environ.* **2021**, *768*, 144985. [\[CrossRef\]](#) [\[PubMed\]](#)
40. Yao, F.; Fang, H.; Han, J.; Zhang, Y. Study on the outdoor thermal comfort evaluation of the elderly in the Tibetan plateau. *Sustain. Cities Soc.* **2022**, *77*, 103582. [\[CrossRef\]](#)
41. Peng, S.; Maing, M. Influential factors of age-friendly neighborhood open space under high-density high-rise housing context in hot weather: A case study of public housing in Hong Kong. *Cities* **2021**, *115*, 103231. [\[CrossRef\]](#)
42. Chen, X.; Xue, P.; Gao, L.; Du, J.; Liu, J. Physiological and thermal response to real-life transient conditions during winter in severe cold area. *Build. Environ.* **2019**, *157*, 284–296. [\[CrossRef\]](#)
43. Holmér, I.; Hassi, J.; Ikäheimo, T.M.; Jaakkola, J.J. Cold stress: Effects on performance and health. *Patty's Toxicol.* [\[CrossRef\]](#)
44. Shao, L.; He, X.; Tang, Y.; Wu, S. Outdoor Cold Stress and Cold Risk for Children during Winter: A Study in China's Severe Cold Regions. *Buildings* **2022**, *12*, 936. [\[CrossRef\]](#)
45. Jin, H.; Liu, S.; Kang, J. Thermal comfort range and influence factor of urban pedestrian streets in severe cold regions. *Energy Build.* **2019**, *198*, 197–206. [\[CrossRef\]](#)
46. China Meteorological Administration (CMA). Available online: <http://data.cma.cn/> (accessed on 10 December 2022).
47. ISO 13732-3; Ergonomics of the Thermal Environment—Methods for the Assessment of Human Responses to Contact with Surfaces—Part 3: Cold Surfaces. International Standard Organization: Geneva, Switzerland, 2005.
48. ISO 9920; Ergonomics of the Thermal Environment: Estimation of Thermal Insulation and Water Vapour Resistance of a Clothing Ensemble. International Standard Organization: Geneva, Switzerland, 2007.
49. Poehlman, E.T.; Arciero, P.J.; Goran, M.I. Endurance Exercise in Aging Humans: Effects on Energy Metabolism. *Exerc. Sport Sci. Rev.* **1994**, *22*, 251–279. [\[CrossRef\]](#) [\[PubMed\]](#)
50. Ma, T.; Xiong, J.; Lian, Z. A human thermoregulation model for the Chinese elderly. *J. Therm. Biol.* **2017**, *70*, 2–14. [\[CrossRef\]](#) [\[PubMed\]](#)
51. Chindapol, S.; Blair, J.; Osmond, P.; Prasad, D. Determining the metabolic rate of the Thai elderly. *Chiang Mai Univ. (CMU) J. Nat. Sci.* **2017**, *16*, 37–49. [\[CrossRef\]](#)
52. U.S. Department of Health and Human Services. 2008 *Physical Activity Guidelines for Americans: Be Active, Healthy, and Happy!* U.S. Department of Health and Human Services: Washington, DC, USA, 2008.
53. Niu, J.; Hong, B.; Geng, Y.; Mi, J.; He, J. Summertime physiological and thermal responses among activity levels in campus outdoor spaces in a humid subtropical city. *Sci. Total Environ.* **2020**, *728*, 138757. [\[CrossRef\]](#) [\[PubMed\]](#)
54. Ainsworth, B.E.; Haskell, W.L.; Herrmann, S.D.; Meckes, N.; Bassett, D.R.; Tudor-Locke, C.; Greer, J.L.; Vezina, J.; Whitt-Glover, M.C.; Leon, A.S. 2011 Compendium of Physical Activities: A second update of codes and MET values. *Med. Sci. Sports Exerc.* **2011**, *43*, 1575–1581. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Jendritzky, G.; de Dear, R.; Havenith, G. UTCI-Why another thermal index? *Int. J. Biometeorol.* **2012**, *56*, 421–428. [\[CrossRef\]](#)
56. Havenith, G.; Fiala, D.; Błażejczyk, K.; Richards, M.; Bröde, P.; Holmér, I.; Rintamaki, H.; Benshabat, Y.; Jendritzky, G. The UTCI-clothing model. *Int. J. Biometeorol.* **2012**, *56*, 461–470. [\[CrossRef\]](#) [\[PubMed\]](#)
57. He, X.; An, L.; Hong, B.; Huang, B.; Cui, X. Cross-cultural differences in thermal comfort in campus open spaces: A longitudinal field survey in China's cold region. *Build. Environ.* **2020**, *172*, 106739. [\[CrossRef\]](#)
58. Xu, M.; Hong, B.; Mi, J.; Yan, S. Outdoor thermal comfort in an urban park during winter in cold regions of China. *Sustain. Cities Soc.* **2018**, *43*, 208–220. [\[CrossRef\]](#)
59. An, L.; Hong, B.; Cui, X.; Geng, Y.; Ma, X. Outdoor thermal comfort during winter in China's cold regions: A comparative study. *Sci. Total Environ.* **2021**, *768*, 144464. [\[CrossRef\]](#) [\[PubMed\]](#)

60. ISO 11079; Ergonomics of the Thermal Environment: Determination and Interpretation of Cold Stress when Using Required Clothing Insulation (IREQ) and Local Cooling Effects. International Standard Organization: Geneva, Switzerland, 2007.
61. Holmér, I. Evaluation of cold workplaces: An overview of standards for assessment of cold stress. *Ind. Health* **2009**, *47*, 228–234. [[CrossRef](#)] [[PubMed](#)]
62. Farideh, G.; Keykavous, A.; Zahra, G.; Omran, A. Risk Assessment of Cold Stress in Petroleum Transfer Station in the Northwestern Regions of Iran: Subjective and Field Measurements. *J. Therm. Biol.* **2022**, *110*, 103335. [[CrossRef](#)] [[PubMed](#)]
63. ISO International Standard 15743; Ergonomics of the Thermal Environment-Cold Workplaces-Risk Assessment and Management. International Standard Organization: Geneva, Switzerland, 2008.
64. Liu, W.; Zhang, Y.; Deng, Q. The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate. *Energy Build.* **2016**, *128*, 190–197. [[CrossRef](#)]
65. Nikolopoulou, M.; Steemers, K. Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy Build.* **2003**, *35*, 95–101. [[CrossRef](#)]
66. ASHRAE Standard 55; Thermal Environmental Conditions for Human Occupancy. ASHRAE: Singapore, 2017.
67. Nikolopoulou, M.; Lykoudis, S. Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Build. Environ.* **2006**, *41*, 1455–1470. [[CrossRef](#)]
68. Romanovsky, A.A. Skin temperature: Its role in thermoregulation. *Acta Physiol.* **2014**, *210*, 498–507. [[CrossRef](#)] [[PubMed](#)]
69. Burse, R.L. Sex differences in human thermoregulatory response to heat and cold stress. *Hum. Factors* **1979**, *21*, 687–699. [[CrossRef](#)] [[PubMed](#)]
70. He, X.; Shao, L.; Tang, Y.; Wu, S. Improving children’s outdoor thermal comfort: A field study in China’s severely cold regions. *Urban Clim.* **2023**, *51*, 101620. [[CrossRef](#)]
71. Yang, B.; Olofsson, T.; Nair, G.; Kabanshi, A. Outdoor thermal comfort under subarctic climate of north Sweden—A pilot study in Umea. *Sustain. Cities Soc.* **2017**, *28*, 387–397. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.