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Primary Exploration of Leisure Path Design along Songhua River by a Small Number of Sample Experiment, Considering Several Multiple Indexes

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Abstract: The waterfront park in northern China always has two parallel leisure pathways, a sunshine pathway and a tree-shaded pathway, which is attributed to the seasonal variations in water level. To provide some design suggestions according to the local characteristics of the waterfront park in northern China, this study selected six young volunteers to take part in an outdoor field experiment and a questionnaire survey in Stalin Park of Songhua River in Harbin, China. During the experiment, the volunteers' local skin temperature and core temperature were recorded, with their subjective responses recorded every 5 min, including thermal comfort, thermal sensation, thermal pleasure, and fatigue scale vote. This study found that, compared with the sunshine pathway, the tree-shaded pathway not only optimized people's outdoor thermal comfort and thermal pleasure, but also improved their fatigue scale vote experience. Some evidence showed that people's subjective response to the outdoor thermal environment might be influenced by physical factors (temperature, velocity, humidity, radiation, etc.) and may also be influenced by the surrounding landscape view (water, square, lawn, tree, etc.). The first piece of evidence is that, during the first 10 min, people's thermal sensation in the sunshine pathway group was high, but they kept voting for high thermal comfort, which may be due to the influence of the waterfront view on people's subjective response to thermal comfort. The second piece of evidence shows that people's overall thermal sensation was calculated by their local thermal sensation, looking at former research, with the voting results very different to the calculated results, which could be attributed to the influence of diversity landscape elements on people's subjective response to thermal sensation. Based on these results, some suggestions for the leisure pathway design along Stalin Park of Songhua River in Harbin, China, were given. The shaded device of the sunshine pathway should be designed in 15-min-walk intervals and accessible ways to the tree-shaded pathway should be added. The other facilities should be designed with 30 min walking distance on the tree-shaded pathway and 20 min walking distance to the sunshine pathway. Diversified landscapes should be designed for both the tree-shaded pathway and sunshine pathway, which could improve people's outdoor thermal comfort and the general subjective response to the environment. It is worth noting that the sample size of this study was small (6), and the participants were all homogenous young people (age, height, weight); thus, this study could be considered a preliminary work and the results and applicability have limitations.

Keywords: waterfront parks; leisure pathway; thermal comfort; fatigue scale vote; thermal pleasure

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1. Introduction

As the urban population increases [1,2], the demand for public open space in cities has also increased [3]. Many studies have proved that urban public open spaces are necessary,

as they benefit citizens' health and well-being [4]. On the one hand, public open space is an integral part of urban spaces and extends urban residents' lives, which promotes social interaction among urban residents [5]. On the other hand, public open spaces are beneficial for people to relax and relieve stress [6,7]. Therefore, how to reasonably design urban public open spaces, to ensure that they can effectively fulfil their role and improve comfort, as well as how to construct reasonable evaluation indexes to guide and provide feedback on these designs, have received a lot of attention from scholars [8–10].

The urban park is a critical component of urban public open spaces [11]. It helps promote people's physical and mental health [12], regulates the local microclimate [13], and maintains the city's image. Greenery in parks can also help reduce the urban heat island (UHI) effect [14,15], improve thermal comfort [16], reduce noise levels [17,18], absorb carbon dioxide [19], and improve air quality. In addition, studies have shown that the urban park was both a recreational and a stress-regulating place and was friendly to people of all ages [20]. Therefore, studies on the urban park, especially on the thermal environment, occupied an essential part of the studies on designing and evaluating public open spaces [21–23]. For example, Cheung et al. quantified the effects of nine parameters on the thermal environment of parks in summer. They pointed out that distance from the sea, shrub cover, tree cover, and sky view factors were critical influencing parameters, and recommended the development of large parks with good woody vegetation coverage to improve the urban microclimate in parks [24]. By examining human thermal comfort in different landscapes of Chengdu city parks, Wei et al. proposed that the Universal Thermal Climate Index (UTCI) was superior to the Physiological Equivalent Temperature (PET) for outdoor thermal comfort evaluation under specific conditions [25]. Kong et al. proposed building artificial shading devices such as pergolas and planting trees with a high canopy density to create large, shaded spaces. Ground coverings such as cement blocks, grass, stone slabs, and coconut mats were used to create an excellent human thermal environment, which was based on the micro-meteorological and human thermal sensation data measured in environments with different shading conditions and surface materials [26].

Urban waterfront parks, which combines the multiple advantages of green space, water body, and biodiversity, are typically representative of urban parks. Since the mid and late 20th century, with the worldwide boom in urban waterfront improvement and development, waterfront parks have been booming in many countries, including China [27,28]. In China, most of the urban waterfront parks were built by utilizing natural resources such as local rivers, streams, and lakes [29]. Since 1920, the number of waterfront parks has increased consistently. In addition, there is an obvious trend toward diversification of park scale and landscape facilities.

Based on the above results, the study on waterfront park design and evaluation is realistically meaningful and typical of urban open space studies. Previous studies on the comfort of urban parks have mainly focused on outdoor thermal comfort. Some studies used Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD), which were initially designed for indoor environments [30,31], to evaluate outdoor thermal comfort. However, outdoor open spaces are complex and dynamic [32,33], so the steady-state models used to analyze indoor thermal comfort are not applicable when evaluating thermal comfort in open spaces [34], especially spaces with complex landscape elements such as waterfront parks, where thermal comfort factors are more complex [35,36]. Some scholars have included micro-climate perception, environmental feature perception, and personal characteristics as additional predictor variables in thermal comfort prediction models and proved their reasonableness [37]. Not are only the outdoor thermal-comfort-influenced factors complex, people's perceptions of urban public open spaces are also diverse [38]. According to a study, people's overall comfort resulted from the interaction between multi-sensation stimuli from the environment [39]. In addition to the microclimate (e.g., temperature, wind speed, solar radiation, relative humidity), overall comfort is also influenced by psychological and behavioral factors [40]. Therefore, the use of a single thermal comfort index to guide the design of elements in the park is not comprehensive;

thus, it is necessary to introduce new evaluation indexes to enhance the diversity and reasonableness of the evaluation.

The traditional view in thermal comfort research is that thermal sensation is an index of a psychological state of satisfaction with the thermal environment. A state of "thermal comfort" and "thermal neutrality" (neither cold nor hot) is optimal for thermal sensation. Although many recent outdoor thermal comfort researchers have questioned this assumption of "neutrality" and proposed other indexes, such as preferred temperature and thermal acceptability, these concepts remain focused on subjects' ratings on traditional thermal sensation scales. In this article, we wanted an index that would be more descriptive of the subject's emotional state. Therefore, we cited the index of "thermal pleasure" proposed by Liu et al. [41]. In addition to the influence of subjective emotions, we found that visitors' activities in the park mainly included strolling, physical exercise, assembly activities, and sightseeing, which are inevitably accompanied by physical exertion and can easily make people feel fatigued. Fatigue is an essential self-protection mechanism for the human body, a signal that people urgently need to rest. It is also worth paying attention to recreational activities in the park. Therefore, we introduce fatigue scale vote as one of the indexes of the general subjective response to the environment.

In summary, this study took the human's thermal, physiological, and psychological experiences during outdoor recreation into account and selected three evaluation indexes: outdoor thermal comfort, thermal pleasure, and fatigue scale vote. The experiments were conducted by looking at the unique layout of two pathways of waterfront parks in northern China. Stalin Park is a typical case. By combining subjective votes and field measurements, we gained primary data, including body core temperature, local skin temperature, local and overall sensations, thermal comfort, fatigue scale vote, and thermal pleasure. We then compared and analyzed how the sunshine pathway and tree-shaded pathway influenced visitors' comprehensive experiences. The study results will serve as a supplement to the design concepts and principles of the waterfront parks and provide a theoretical basis for the landscape design and facility construction of the leisure pathway in the waterfront parks.

2. Materials and Methods

2.1. Location and Time

Harbin (45″41′ N 126″37′ E) is the capital city of Heilongjiang Province of China. It is located in the Dwa area, which means it is cold in the winter and hot in the summer (Figure 1).

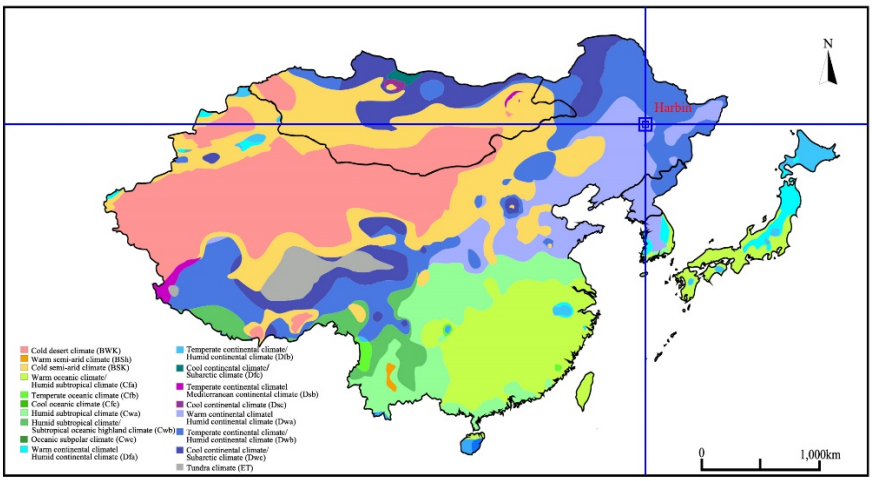


Figure 1. Location of Harbin in the Köppen–Geiger climate map of East Asia. Enhanced by the authors, derived from the Köppen–Geiger climate map in Wikipedia. The content of this website is licensed under CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/, accessed on 28 February 2022).

The study object of this paper is the park leisure pathway, and we selected Stalin Park in Harbin as the experimental field location. Stalin Park is located on the southern bank of the middle reaches of the Songhua River in Harbin. It represents an early waterfront park in northern China and is famous for its Russian style. The flood control memorial tower, the symbol of Harbin, is located in this park. Stalin Park is a famous scenic spot and also the park with the largest daily leisure crowd in Harbin [42].

As Harbin is located in the middle reaches of the Songhua River, the seasonal variations in water level in this section are significant [43]. To prevent floods, the revetment of the waterfront park on both sides of the Songhua River is designed to be a double-layer stepped slope protection section structure (Figure 2). There are three main recreational pathways on the structure's natural, two-level platform in Stalin Park. (The configurations of the sunshine and tree-shaded pathway in Stalin Park are shown in Figure 3). Steps connect the upper and lower levels of the park's two-level platforms, and the flood banks extend into the water.

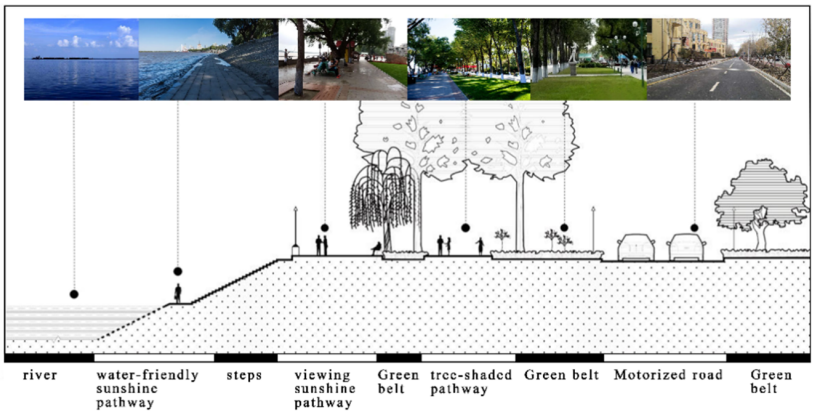


Figure 2. Section view of Stalin Park in Harbin.

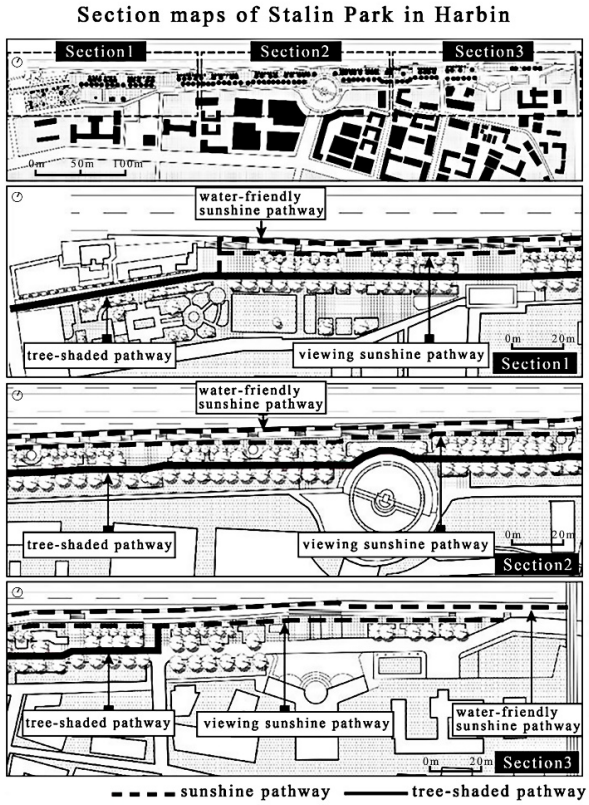


Figure 3. Plane view of Stalin Park in Harbin.

The water-friendly sunshine pathway in Stalin Park is located at the second-level platform with a lower level, which is exposed in the non-flood season and has no green space. Visitors walking here will be affected by direct sunlight. The viewing sunshine pathway is a transitional space with both traffic and viewing functions between the water-friendly sunshine pathway and the main road of the park, which is located at the first-level platform at a high level. The viewing sunshine pathway is shaded by greenery, where dry willow trees are only planted on one side to provide a transparent view of the river to pedestrians. As the main road of the park, the tree-shaded pathway is the main traffic evacuation area in the park, with tall trees planted on both sides. Two leisure pathways, the water-friendly sunshine pathway (hereinafter referred to as the sunshine pathway) and the tree-shaded pathway in Stalin Park, were selected as the specific experimental sites.

Harbin is located in the severe cold area, where the average maximum temperature is 28 °C in summer and the winter is long and cold. The historical minimum temperature of Harbin is −38 °C and the freezing time of Songhua River has even lasted for 137 days [44].

Due to the influence of climate, there are a lot of tourists in Harbin's parks along the river in summer, when tourism in Harbin peaks. Therefore, this study conducted the field experiments in summer to obtain more general sample data.

A date when the maximum daily temperature was close to 28 °C was selected for the experiment time, with the measured temperature data of the experiment day as follows: The average air temperature during the experiment on the water-friendly sunshine pathway group was 27.23 °C and the average air temperature during the experiment on the tree-shaded pathway group was 27.70 °C, both of which were close to Harbin's average summer maximum temperature of 28 °C. Therefore, the environmental climate on the test dates of this experiment had the typical climate characteristics of Harbin in summer.

2.2. Selection of Evaluation Indexes

As a waterfront park in northern China, Stalin Park has complex environmental elements, so a single evaluation index cannot accurately assess the impact of park design on human experience. Furthermore, a person's feelings in the urban outdoor environment are also affected by multiple factors and have a diversified nature. Therefore, it was necessary for this study to select multidimensional indexes to evaluate the impact of the design of leisure pathways in the waterfront park of Songhua River on visitors' experience.

2.2.1. Outdoor Thermal Comfort Index

People's perception of the thermal environment is affected by personal physiological sensations, surrounding environmental factors, thermal experience, etc. For example, if the outdoor environment contains a large area of green vegetation, the threshold of people's response to heat will be increased [45]. Therefore, the evaluation indexes of outdoor thermal environment should also cover a person's own subjective psychological feelings.

According to the definition of "thermal comfort" by ASHARE Standard 55-2020, "thermal comfort" is referred to as the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Thermal sensation is identified as a conscious subjective expression of an occupant's thermal perception of the environment, commonly expressed using the categories "cold", "cool", "slightly cool", "neutral", "slightly warm", "warm", and "hot" [46].

Therefore, this study chose overall thermal sensation and thermal comfort as evaluation indexes for outdoor thermal comfort.

2.2.2. Thermal Pleasure

In thermal comfort research, the traditional view is that thermal sensation is an index of the psychological state of satisfaction with the thermal environment–thermal comfort, and the "thermal neutral" state of being neither cold nor hot is the best thermal sensation. Liu et al. proposed a multi-dimensional semantic space for outdoor thermal affect that can more adequately reflect both descriptive information and the affective status of the

ambient outdoor environment [41]. This multi-dimensional semantic space of outdoor thermal impact contains affective dimensions and a descriptive dimension model. Affective dimensions contain two elements: thermal arousal and thermal intensity. Descriptive dimensions contain four elements: thermal sensation (temperature), humidity, wind speed, and solar radiation (sky). According to these models, a unidimensional thermal sensation scale is not capable of fully conveying the full picture of our thermal experiences, and thermal neutrality does not necessarily correspond with the optimal outdoor thermal environments. Thermal effect on both the pleasure and intensity dimensions does not consistently show a simple linear relationship with any single environmental parameter, but is impacted by diverse environmental factors under different climatic scenarios. In this study, we selected thermal pleasure as an index to describe subjects' emotional state during the whole process of walking on the pathway.

2.2.3. Fatigue Scale Vote

Generally speaking, fatigue is a subjective feeling of tiredness and exhaustion in humans.

In the medical field, fatigue describes a state involving both physical and psychological aspects of human beings. Physical fatigue is the temporary physical inability of muscles to perform optimally. Mental fatigue is a temporary inability to maintain optimal cognitive performance. Moreover, it is also described as a prominent disabling symptom in a variety of medical and neurologic disorders [47]. The fatigue scale (FS) is usually used to assist the study of the effects of specific diseases on the physiological and psychological states of patients [48,49].

In the field of a built environment, studies have shown that physical state will directly affect people's recreational experience and psychological state [50], so in this study, we used fatigue scale vote (FSV) as an index and defined it as an index to assess subjective feelings of fatigue during the whole process of walking on the pathway.

2.3. Introduction to the Experimental Process

In this study, we selected "outdoor thermal comfort", "thermal pleasure", and "fatigue scale vote" as the comprehensive evaluation indexes of the humanized design of the park. In this study, the sunshine pathway and the tree-shaded pathway in Stalin Park were taken as the research objects, and the physiological skin temperature and subjective evaluation data of each subject were obtained by a questionnaire survey and measurement.

Three local young men and three local young women were randomly selected in Stalin Park. The six people were in good health and had no undesirable hobbies, such as smoking and drinking. They were invited to participate as subjects in on-site experiments.

Questionnaire: The questionnaire survey mainly collected two forms of data. The first part recorded the experiment time and basic information of the subjects, such as gender, age, height, weight, etc. (Table 1 summarizes the subjects' statistical information). The second part collected the immediate feedback of subjects during the experiment by setting voting items, including local and overall thermal sensation, thermal comfort, fatigue scale vote, and thermal pleasure. (The questionnaire is shown in Figure 4).

Table 1. Statistical information of participants in the experiment.

Gender	Number of People	Age	Height (m)	Weight (kg)	BMI	Human Skin Surface Area (m^2)
Female	3	25 ± 5	1.65 ± 0.01	55 ± 4	22.20 ± 1.50	1.59 ± 0.05
Male	3	25 ± 5	1.79 ± 0.04	71 ± 4	22.45 ± 0.65	1.87 ± 0.07

Real-time skin temperature test: Apart from conducting questionnaire surveys, we also used the Omron cochlear temperature testing gun to measure and record subjects' core temperature and iButton to record the subjects' local skin temperature. According to the study of Joon-Ho Choi and Vivian Loftness, the most appropriate thermal sensation model study required at least eight measurement points to collect skin temperature data [51].

Combining previous studies and the "eight-point measurement" recommended by EN ISO 9886:2004 standard ergonomics, physiological measures of thermal strain were evaluated [52]. Therefore, ten parts (as shown in Figure 5), including forehead, neck, back, breast, upper arm, lower arm, hand, thigh, lower leg, and foot, were selected as the loci of local skin temperature of the human body. The skin temperatures of these loci were automatically monitored and recorded by iButton, and the measurement and recording period was 1 min. Figure 5 shows the instrument and layout of human partial skin temperature and body core temperature measurement.

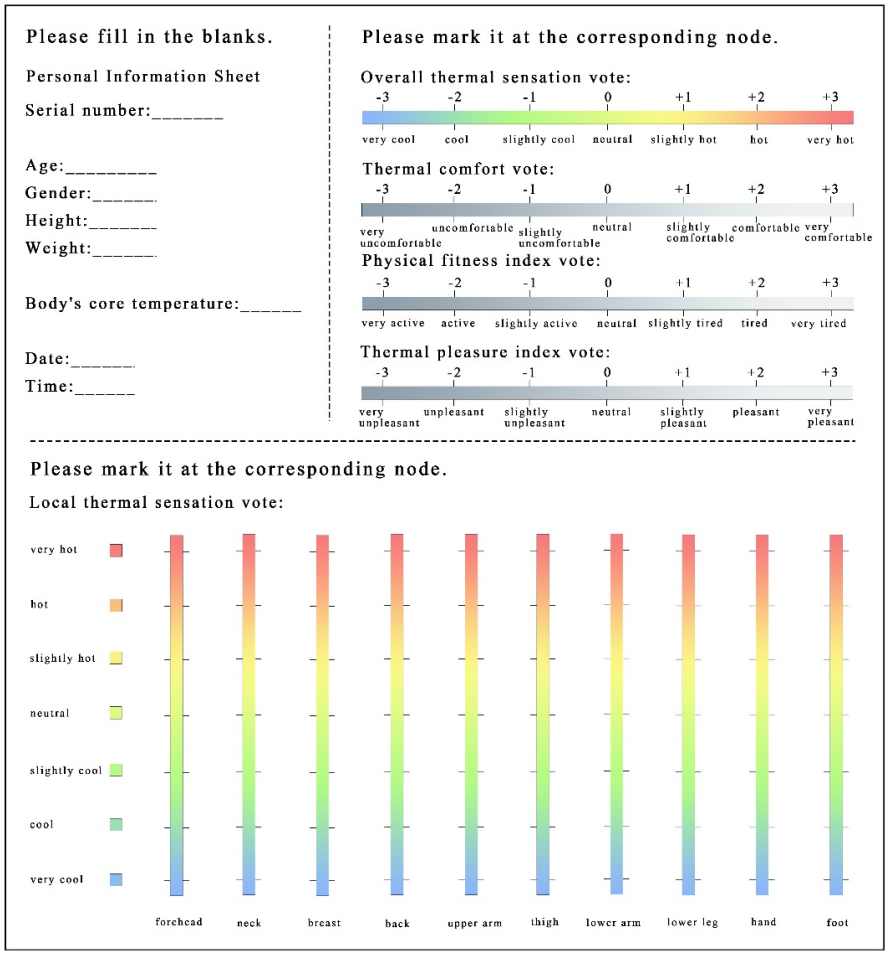


Figure 4. Questionnaire used for each participant in the experiment.

The main season for visiting Stalin Park is summer, with the largest visitor flow in June, July, and August [53]. During the peak tourism period, the pattern of visitors in the park is as follows:

- From 9:00 a.m. to 11:00 a.m.: the number of visitors begins to rise significantly.
- From 11:00 a.m. to 1:00 p.m.: the number of visitors remains stable or increases slightly.
- From 1:00 p.m. to 5:00 p.m.: the number of visitors increases significantly for the second time.

Moreover, more than 50% of visitors stay for 1~3 h [42].

To ensure the universality of the sample data, the experiment was conducted over two periods when the number of visitors was relatively concentrated: 10:00–12:00 and 12:30–14:30. Based on the transient research results of thermal comfort, Jim C.Y. proposed an improved method for an outdoor thermal comfort evaluation of "1-h acceptable thermal temperature range" [54]. Therefore, the experimental process of this study lasted for 2 h each time and the outdoor experiment lasted for 1 h.

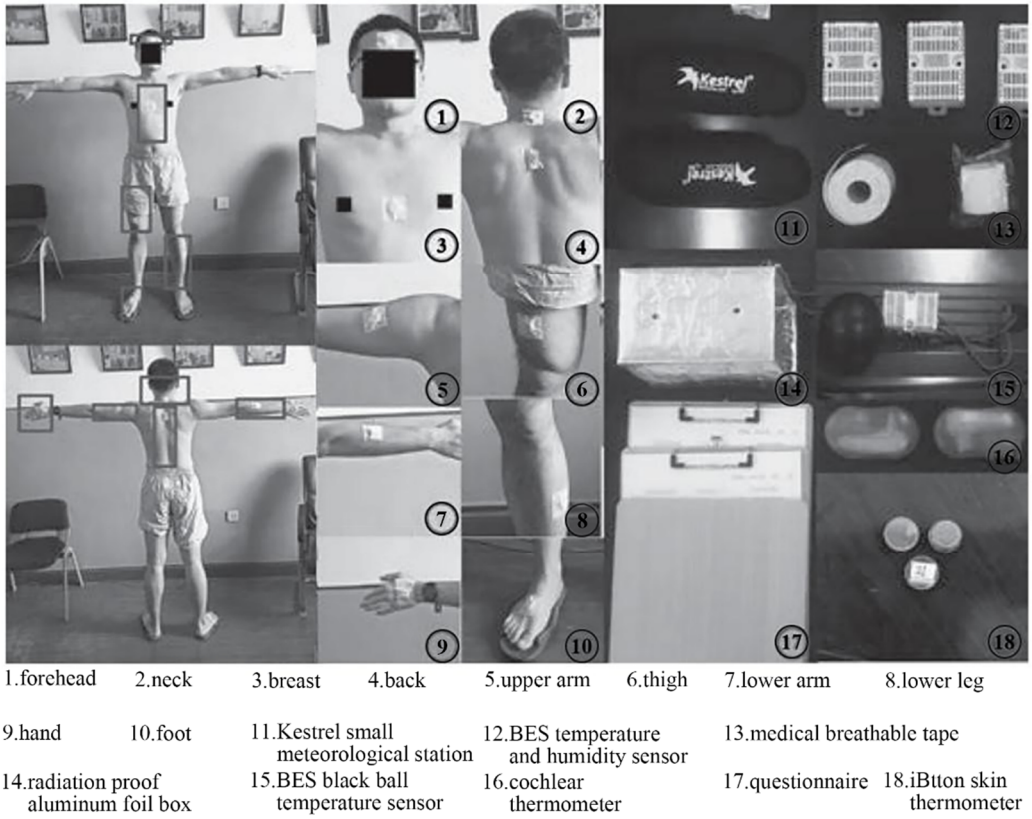


Figure 5. Partial skin temperature test point and experimental instruments.

In addition to climatic and psychological factors, clothing could also influence human thermal comfort. In summer, the dressing coefficient of people in Harbin is stable at 0.5 clo [55], so the uniform dressing coefficient of subjects in this experiment was 0.5 clo. Therefore, they were allowed to wear T-shirts, pants, and sneakers.

The single experimental process for each subject was divided into three stages (as shown in Figure 6):

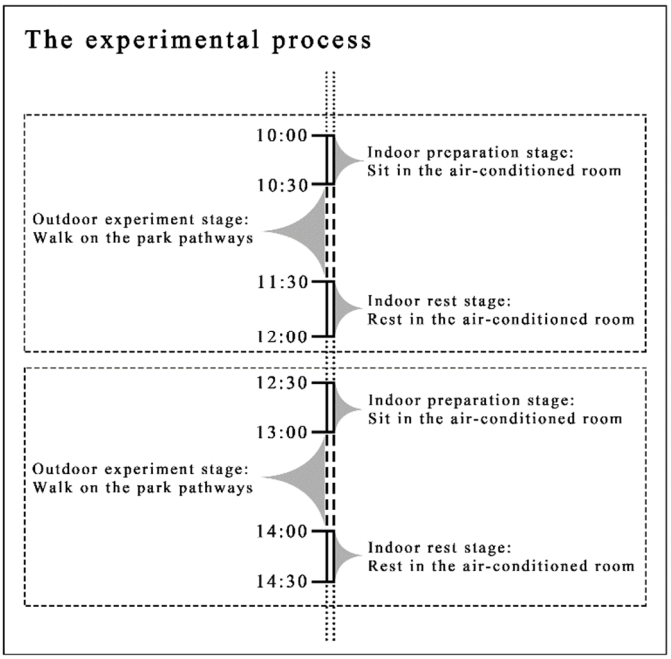


Figure 6. The experimental process chart.

1. Indoor preparation stage:

The subjects attached an iButton thermometer (show in Figure 5) to each part of the body and then sat quietly in an air-conditioned room for 30 min to ensure comfort in both their physical and mental conditions [56].

2. Outdoor experiment stage:

Each subject left the air-conditioned room and walked for 60 min on the sunshine pathway/the tree-shaded pathway, filling in the questionnaire every 5 min. According to their own feelings, they were subjected to an overall thermal sensation vote, thermal comfort vote, thermal pleasure vote, and fatigue scale vote.

3. Indoor recovery stage:

After the outdoor experiment, the subjects returned to the air-conditioned room, took off the iButtons, and departed.

2.4. Data Analysis

During the experiment, psychological data (thermal sensation, thermal comfort, thermal pleasure, and fatigue scale vote) were obtained by a subjective questionnaire, which was completed every 5 min. Skin physiological temperature was measured by iButton, with the instrument set to read the data every 1 min and stored automatically.

For psychological data, the arithmetic average was calculated according to the voting results of six samples to obtain the average values of thermal sensation, thermal comfort, thermal pleasure, and fatigue scale vote at each time node. Finally, these data were imported into SPSS software for regression curve fitting and correlation analysis among indicators.

For skin physiological data, we extracted the data of six samples from the stored data, found the arithmetic average of these data, and obtained the average value of each local surface temperature. Finally, these data were imported into SPSS software for analysis.

2.5. Statistical Test

We conducted paired-samples *t*-tests for the voted results of sunshine pathway and tree-shaded pathway groups, with the specific results placed in supplementary section Table S1. The results showed that the differences between the data of the two groups, including thermal sensation, thermal comfort, fatigue scale vote, and thermal pleasure, were statistically significant.

3. Results

3.1. Overall Thermal Sensation and Thermal Comfort

As shown in Figure 7, the overall thermal sensation of subjects in the tree-shaded pathway group was stable and remained at around −0.5 for an extended time. The correlation between overall thermal sensation and walking time was weak. At about 40 min, people's overall thermal sensation vote began to rise but remained within a moderate range.

Differing from the results of the experiment on the tree-shaded pathway group, the overall thermal sensation vote of subjects in the sunshine pathway group showed a positive linear correlation with walking time, and continued to rise with the time (as shown in Figure 7). During the first 30 min, people's overall thermal sensation vote remained at about 1 (slightly hot); after 30 min, it began to rise and reached 2 (hot) at 45 min.

In Figure 7, TSV (r), TSV (s), and T, respectively, represent the overall thermal sensation value voted by subjects in the sunshine pathway group, overall thermal sensation voted value by subjects in the tree-shaded pathway group, and the walking time.

Generally, during the whole 60 min of the experiment, the average overall thermal sensation vote of subjects in the tree-shaded pathway group was less than or equal to 0 (neutral). The average overall thermal sensation vote of subjects in the tree-shaded pathway group was −0.33 (slightly cool), which was 1.56 voted units lower than those in the sunshine pathway group.

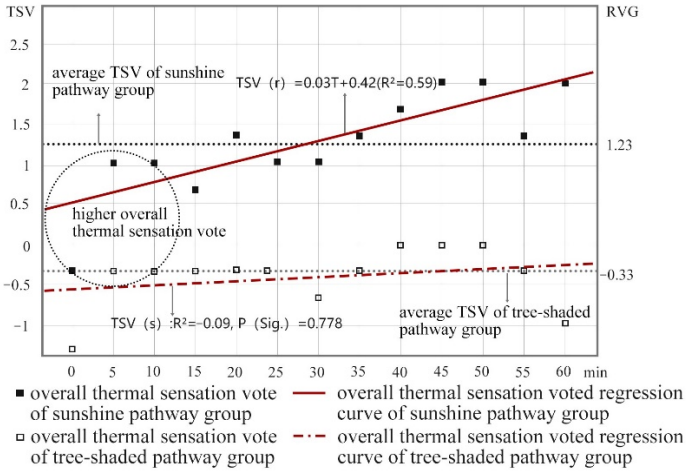


Figure 7. Voted overall thermal sensation of sunshine pathway group and tree-shaded pathway group.

The results of the real-time skin temperature test showed that the core temperatures of subjects in both the sunshine and tree-shaded pathway groups increased with walking time and the average core temperature of subjects in the sunshine pathway group was slightly higher than that of the tree-shaded pathway group, which fits well with the results of the thermal sensation vote. However, with the increase in walking time, the local skin temperatures of subjects in the sunshine pathway group increased, while the local skin temperatures of subjects in the tree-shaded pathway group decreased to different degrees.

These results suggested that, compared with the sunshine pathway, the tree-shaded pathway could effectively reduce the core temperature and local skin temperatures of each part of the human body and play a significant role in providing a cool walking space for people to enjoy their leisure time along the river.

Detailed statistics of the average core temperature and local skin temperatures of each part of the subjects' body are shown in Figure S1 for completeness but are not presented within the paper, as superior methods are used to display our conclusions.

The thermal comfort vote of subjects in both sunshine and tree-shaded pathway groups showed a negative linear correlation with walking time (Figure 8). With an increase in time, people's thermal comfort declined.

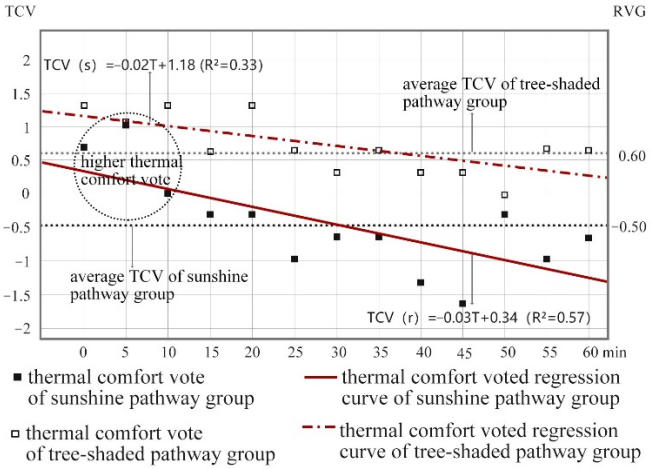


Figure 8. Voted overall thermal comfort of sunshine pathway group and tree-shaded pathway group.

In Figure 8, TCV (r), TCV (s), and T, respectively, represent the thermal comfort value voted by subjects in the sunshine pathway group, the thermal comfort value voted by subjects in the tree-shaded pathway group, and the walking time.

As shown in Figure 8, in the whole experiment, the thermal comfort vote of subjects in the tree-shaded pathway group remained within the comfort zone (TCV > 0), with an average thermal comfort vote of 0.6 (slightly comfortable). Nevertheless, after 15 min, subjects' thermal comfort vote dropped to the uncomfortable range (TCV < 0) and declined to −1.67 at 45 min. The average thermal comfort vote during the whole experiment of the sunshine pathway group was −0.5 (slightly uncomfortable), which was 1.1 voted units lower than the tree-shaded pathway group.

Based on the results of the overall thermal sensation vote and thermal comfort vote, both the average vote values of thermal comfort and overall thermal sensation of subjects in the sunshine pathway group were relatively high in the first 10 min, but the average thermal comfort vote rapidly declined after 10 min, which was speculated to be caused by the influence of the waterfront landscape. It should be noted that, in the first 10 min, there was a high degree of agreement between thermal comfort voting results and thermal pleasure voting results, which indicated that landscape elements may affect people's subjective judgment of the thermal environment by influencing their thermal pleasure.

Zhao song Fang proposed and used the local–overall thermal sensation prediction model in 2018 [57], which is shown in Formula (1):

$$\mathrm{MTSV} = 0.21\mathrm{TSVhead} + 0.61\mathrm{TSVupper} + 0.19\mathrm{TSVlower} \quad (1)$$

In Formula (1), MTSV is the overall thermal sensation vote; $\mathrm{TSV_{head}}$ is the thermal sensation vote of the human head, including the forehead and neck; $\mathrm{TSV_{upper}}$ is the thermal sensation vote of the upper part of the body, including the breast, back, upper arm, lower arm, and hand; $\mathrm{TSV_{lower}}$ is the thermal sensation vote of the lower part of the body, including the thigh, lower leg, and foot. The constants 0.21, 0.61, etc., are the weight coefficients of each part, calculated using the following method in Formula (2).

$$a_{ul} = \frac{A * p_l * a_{skl}}{\sum_l \mathrm{A} * p_l * a_{skl}} \quad (2)$$

In the formula, $\mathrm{a_{ul}}$ is the weight coefficient of each local part of the body; A is the area of the human skin surface, $\mathrm{m^2}$; $\mathrm{p_l}$ is the density of cold receptors, per $\mathrm{cm^2}$; $\mathrm{a_{skl}}$ is the weight coefficient of local parts in area skin surface. Both $\mathrm{p_l}$ and $\mathrm{a_{skl}}$ are known constants. The calculated weights of each part are shown in Table 2 [57].

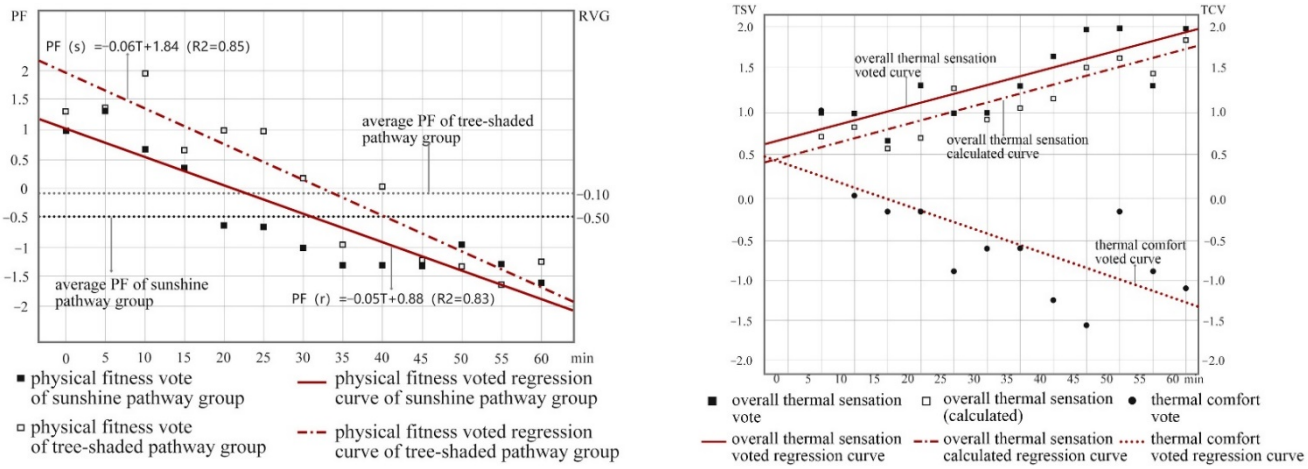
Table 2. Calculated weights of each part [57].

Body Part	Forehead	Neck	Breast	Back	Upper Arm	Lower Arm	Hand	Thigh	Lower Leg	Foot
Coefficient	0.5	0.5	0.41	0.32	0.105	0.105	0.06	0.51	0.36	0.13

The voted local thermal sensation values of each part of the human body investigated by the questionnaires were included in Formula (1) to calculate the overall thermal sensation voted value at each time note. Figure 9 shows a comparison between the calculated scatter plot regression curve and the voted scatter plot regression curve.

The overall thermal sensation result of the sunshine pathway group in the practical experiment closely fits the existing theoretical model, while the overall thermal sensation voted result of the tree-shaded pathway group in the practical experiment was significantly lower than the existing theoretical model. As the overall thermal sensation is subjective and, compared with the tree-shaded pathway, the landscape around the sunshine pathway was more simple, it could be inferred that the diversified landscape design and activity scenes around the tree-shaded pathway may help improve people's comprehensive experience of the environment. Therefore, people's overall thermal sensations may not only be affected by local thermal sensations, but also by outdoor physical thermal environmental factors

(temperature, velocity, humidity, radiation, etc.), as well as the landscape elements designed in the environment (square, lawn, trees, etc.).



(**a**) (**b**)

Figure 9. (**a**) Voted overall thermal sensation, calculated overall thermal sensation, and thermal comfort of tree-shaded pathway group. (**b**) Voted overall thermal sensation, calculated overall thermal sensation, and thermal comfort of sunshine pathway. Voted overall thermal sensation, calculated overall thermal sensation, and voted thermal comfort of tree-shaded pathway group and sunshine pathway group.

3.2. Fatigue Scale Vote

There was a high negative linear correlation between the fatigue scale votes of subjects in both sunshine and tree-shaded pathway groups and walking time.

In Figure 10, FSV(r), FSV(s), and T, respectively, represent the fatigue scale vote value voted by subjects in the sunshine pathway group, fatigue scale vote value voted by subjects in the tree-shaded pathway group, and the walking time.

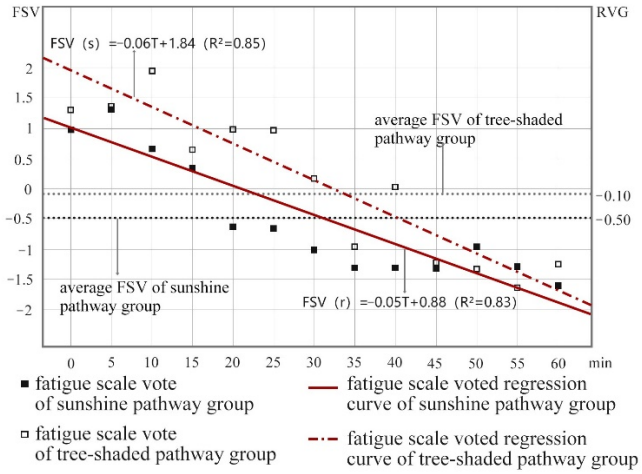


Figure 10. Fatigue scale votes of sunshine pathway group and tree-shade pathway group.

The longer people walked, the lower their fatigue scale vote was and the more tired they felt (Figure 10). In the first 20 min of the experiment in the sunshine pathway group, people felt energetic (FSV > 0) but then began to feel tired (FSV < 0). The average fatigue scale vote value for the whole process was −0.5. People felt energetic (FSV > 0) in the first 30 min of the experiment in the tree-shaded pathway group but then began to feel tired. The average fatigue scale vote value for the whole process was −0.1.

In general, in the first 30 min, the fatigue scale vote of subjects in the tree-shaded pathway group was significantly higher than those in the sunshine pathway group. As time went by, after 50 min, the fatigue scale vote values of subjects in both sunshine and tree-shaded pathway groups were almost the same, declining to the range of −1.5~−2.

The experimental results showed that the tree-shaded pathway could not only effectively reduce the overall thermal sensation and improve the thermal comfort of the walking crowd, but it could also make people feel less tired while walking compared with the sunshine pathway. It was speculated that, when people were walking in the tree-shaded pathway, the physiological metabolic expenditure which caused physical fatigue, such as sweating (water loss), was lower than when walking on the sunshine pathway. In addition, the environmental landscape elements in the tree-shaded pathway may help alleviate psychological fatigue.

3.3. Thermal Pleasure

As shown in Figure 11, there was a negative linear correlation between the thermal pleasure votes of both tree-shaded and sunshine pathway groups and walking time.

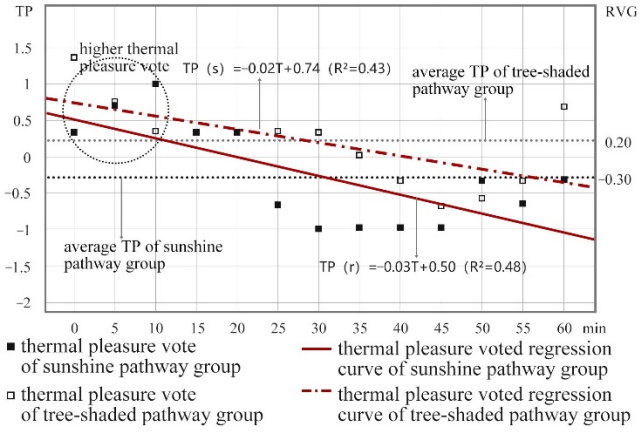


Figure 11. Voted thermal pleasure of sunshine pathway group and tree-shaded pathway group.

In Figure 11, TP(r), TP(s), and T, respectively, represent the thermal pleasure value voted by subjects in the sunshine pathway group, thermal pleasure value voted by subjects in the tree-shaded pathway group, and the walking time.

During the first 20 min of the experiment in the sunshine pathway group, the subjects' thermal pleasure remained positive. It then significantly increased and was higher than that of the tree-shaded pathway group in the first 10 min. After 20 min, the thermal pleasure of subjects in the sunshine pathway group declined to the negative range. In the first 30 min of the experiment in the tree-shaded pathway group, subjects' thermal pleasure remained stable (0.3). It then began to decline and fell to the negative range after 35 min.

The thermal pleasure of subjects in the sunshine pathway group was lower overall than those in the tree-shaded pathway group, and remained slightly unpleasant (−1) for a long time. Finally, the average thermal pleasure of subjects in the sunshine pathway group was 0.5 voted units lower than those in the tree-shaded pathway group.

In general, this result closely fits the voted results of subjective feelings of overall thermal sensation, thermal comfort, and fatigue scale vote. However, it should be noted that, at the beginning of the experiment, the thermal pleasure of subjects in the sunshine pathway group was higher than those in the tree-shaded pathway group, and then rapidly declined, presumably due to the hydrophilicity of the sunshine pathway. The experimental results showed that people's thermal pleasure was influenced by complex factors.

According to the results of the thermal sensation and thermal comfort votes, people on the tree-shaded pathway maintained cool and comfortable levels for 60 min, while the vote of people on the sunshine pathway dropped below 0 and entered uncomfortable levels when walking for more than 15 min.

4. Discussion

4.1. Overall Thermal Sensation and Thermal Comfort

According to the results of the thermal sensation vote and thermal comfort vote, people on the tree-shaded pathway remained at cool and comfortable levels for 60 min, while the vote of people on the sunshine pathway dropped below 0 and entered uncomfortable levels when walking for more than 15 min.

Therefore, the designer could refer to the 15-min walking radius, and add shading facilities or accessible walkways to the tree-shaded pathway to improve pedestrians' thermal comfort on the sunshine pathway and enhance the leisure experience in Stalin Park in summer.

Comparing the voted overall thermal sensation and overall thermal sensation calculated by local thermal sensation, it was found that the two results fitted well with each other in the sunshine pathway group, but the overall thermal sensation value voted by the tree-shaded pathway group were much lower than the calculated value. Through comparing the objective variables of the two experimental groups, we inferred that, because thermal sensations are people's subjective response to the environment, the diversified landscape on the tree-shaded pathway may lead to lower thermal sensations.

According to this result, the designer should create rich and diversified landscapes to improve people's thermal comfort when designing recreational pathways.

4.2. Fatigue Scale Vote

People were less likely to feel tired when walking on the tree-shaded pathway. In the first 30 min, the fatigue scale vote of subjects on the tree-shaded pathway was significantly higher than those on the sunshine pathway. After 50 min, the fatigue scale vote levels of subjects in the two pathway groups were nearly equal. Subjects on the tree-shaded pathway began to feel tired at 30 min, while subjects on the sunshine pathway began to feel tired at 20 min. Finally, the average fatigue scale vote of subjects on the tree-shaded pathway was 0.4 units higher than that of those on the sunshine pathway.

According to the fatigue scale voting results, the length of the tree-shaded pathway should not exceed 30 min walking distance; otherwise, some measures should be taken to improve the pedestrians' fatigue scale vote. The sunshine pathway should not be more than 20 min walking distance, or some measures should also be taken.

The layout of the recreation facilities at Stalin Park is shown in Figure 12, while in Figure 13, 62 chairs are arranged along the tree-shaded pathway in a zonal distribution. In terms of the continuity, the layout could meet the requirement of 30 min walking distance but could only accommodate 186 people simultaneously at most, which is not enough when the number of people walking in Stalin Park in summer is considered. A total of 26 squares are set as landscape nodes along the pathway, including 12 sculpture squares and flower bed squares, which were built as landscape markers, and 14 event squares. The designer should consider adding rest seats and spaces, as well as creating some concentrated rest spaces to improve the capacity of the recreation place.

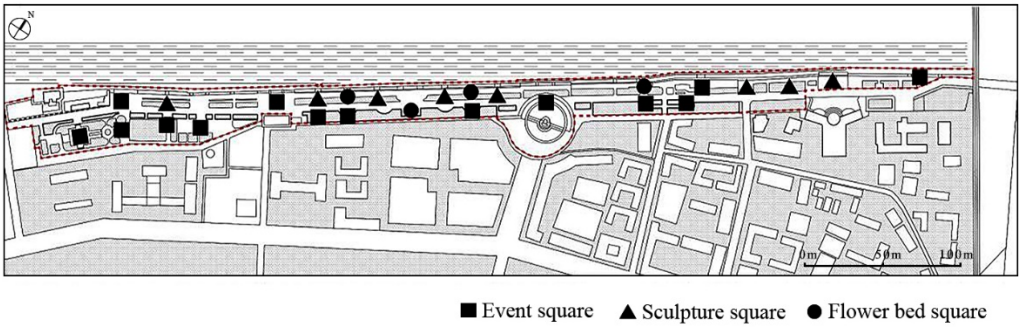


Figure 12. Types and location of leisure square in Harbin's Stalin Park.

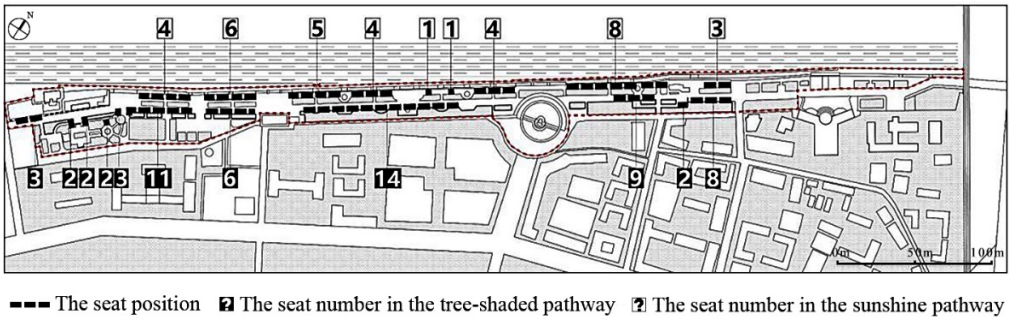


Figure 13. Number and location distribution of rest facilities in Harbin's Stalin Park.

A total of 36 seats in the sunshine pathway are arranged linearly along the river, which meet the requirements of 20 min walking distance according to the layout continuity. However, the seats could only accommodate 108 people resting at the same time, which means that the sunshine pathway faced the same problem of a lack of rest space as the tree-shaded pathway. Because the sunshine pathway is linear space and the seats' arrangement is relatively continuous, the design of rest facilities on the sunshine pathway should consider the combination of the addition of concentrated rest spaces and sunshade viewing facilities.

4.3. Thermal Pleasure

Initially (approximately the first 10 min), the sunshine pathway group voted for higher thermal comfort and thermal pleasure while their thermal sensation was higher, which indicated that people's thermal comfort not only related to thermal sensation but to the whole environment. Based on the analysis of the environmental elements surrounding the sunshine pathway, we concluded that the waterfront landscape could improve people's overall experience, including their thermal pleasure.

This result showed that the hydrophilicity of the sunshine pathway could effectively improve people's thermal pleasure. Therefore, a certain number of sunshade viewing facilities should be added to the sunshine pathway to meet people's multiple thermal comfort and river-view needs.

4.4. Limitation

This study conducted a small-sample-size experiment, comprising only six subjects. Admittedly, to a certain extent, experiments with a small sample size may have uncertainties in relevant calculation estimates. However, the preparation of an outdoor thermal comfort experiment in a dynamic environment is complicated and the whole experiment requires a lengthy time, which makes it difficult to carry out a large-sample experiment. For example, in this study, the whole experiment for each participant lasted for about 2 h and the preparation work was very complicated.

The subjects in this study were all young people of a similar age, height, and weight. In previous studies on thermal comfort or outdoor thermal environment, the research objects were mostly young people of a similar age, height, and weight. According to our considerations, due to the limits of small sample numbers, the influence of factors such as age, height, and weight should be avoided. This may explain why researchers always choose young people as participants in this research field.

Most previous studies in the field of the dynamic thermal environment selected young people as the research objects, which led to limitations. Therefore, it is necessary to expand the sample size and select different population groups for the experiment, according to age, height, and weight. Combined with former studies, this study could benefit retrospective future research in this field.

5. Conclusions

The waterfront park along the Songhua River in Harbin is typical to northern China, which always has both a sunshine pathway and a tree-shaded pathway due to the consideration of flood seasons. This work studied people's subjective responses to the sunshine pathway and the tree-shaded pathway, including outdoor thermal comfort, fatigue scale vote, and thermal pleasure. The main findings are as follows:

1. At the very beginning (about 10 min), although the thermal sensation of the sunshine pathway group was higher than that of the tree-shaded pathway group, people still voted for higher thermal comfort and thermal pleasure when walking on the sunshine pathway, which indicated that thermal comfort not only relates to thermal sensation but also the whole environment. In this case, the waterfront view should improve people's general feelings, including thermal comfort.
2. Comparing the voted overall thermal sensation and overall thermal sensation calculated by local thermal sensations, it was found that the two results fitted well with each other in the sunshine pathway group but the voted overall thermal sensation in the tree-shaded pathway group was much lower than the calculated result. This result showed that people's overall thermal sensation is not only influenced by both local thermal sensation and the physical environmental influencing factors, but is also influenced by the environment design. As thermal sensation is people's subjective response to the environment, the diversified landscape on the tree-shaded pathway led to lower thermal sensations.
3. Compared with the sunshine pathway, the tree-shaded pathway led to lower thermal sensations, lower fatigue scale vote, higher thermal comfort, and higher thermal pleasure.
    - The average thermal sensation of the tree-shaded pathway group was −0.33, which was 1.56 lower than that of the sunshine pathway group;
    - The average thermal comfort of the tree-shaded pathway group was 0.6, which was 1.1 higher than that of the sunshine pathway group;
    - The average fatigue scale vote of the tree-shaded pathway group was −0.1, which was 0.6 higher than that of the sunshine pathway group;
    - The average thermal pleasure of the tree-shaded pathway group was 0.2, which was 0.5 higher than that of the sunshine pathway group.
4. According to the results, some suggestions were provided for the pathway design to improve people's subjective response to the environment. The shaded device of the sunshine pathway should be implemented at 15-min-walk intervals, or accessible ways to the tree-shaded pathway should be designed. The rest facilities should be designed according to a 30-min walking distance on the tree-shaded pathway and a 20-min walking distance on the sunshine pathway. Diversified landscape should be designed for both the tree-shaded pathway and sunshine pathway, which could improve people's outdoor thermal comfort and the general subjective response to the environment. The mechanism of how visible design influences people's thermal comfort and fatigue has not been revealed in this study, and only the phenomena was detected; to make a further step for this, a method that enables those design factors to be measured and analyzed is necessary [58].

In this study, thermal comfort, fatigue scale vote, and thermal pleasure were selected as the evaluation indexes; the sunshine pathway and tree-shaded pathway in Stalin Park in Harbin were taken as the research objects. Throughout the field experiment, the different responses of subjects on the two pathways to the outdoor environment were obtained, including thermal sensation, thermal comfort, thermal pleasure, and fatigue scale vote. Through the analysis of the experimental data, qualitative and quantitative results were presented and, based on the results, some rational suggestions were presented for the design of recreation sunshade facilities for the recreational pathways in city parks along the river in Harbin. This study also had limitations, and it is recommended to expand the sample size and select different population groups for experiments according to age, height,

and weight. Combined with previous studies, this study could benefit future retrospective research in this field.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos13081165/s1, Figure S1: Core temperature and local-skin temperature; Table S1: Results of paired-sample T test on thermal sensation; Table S2: Results of paired-sample T test on thermal comfort; Table S3: The results of unary linear regression on TSV(r); Table S4: The results of unary linear regression on TSV(s); Table S5: The results of unary linear regression on TCV(r); Table S6: The results of unary linear regression on TCV(s).

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