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SPECIAL ISSUE: SUBJECTIVE APPROACHES TO THERMAL PERCEPTION

Outdoor thermal comfort and adaptive behaviors in the residential public open spaces of winter cities during the marginal season

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Abstract

In winter cities, outdoor seasons are highly valued due to the long cold winter. By improving the outdoor thermal environment during marginal seasons, outdoor seasons may be extended. Therefore, outdoor thermal comfort and adaptive behaviors during marginal seasons should be considered. Three representative residential public open spaces in Harbin, a typical winter city, were selected to conduct an empirical study. Meteorological measurements and rudimentary questionnaires were administered and observations were conducted to explore outdoor thermal comfort and adaptive behaviors. Three important conclusions were obtained from the survey. The result from the questionnaire surveys showed that users of public spaces generally believed that "warm" was comfortable during the spring marginal season of the winter cities. The 90% thermal acceptable physiologically equivalent temperature (PET) range, which was calculated using meteorological measurements and questionnaire results, was more than 10.2 °C for this time period in the winter cities. This threshold value was much lower than that of temperate and subtropical zones, indicating that the outdoor thermal comfort of users in the winter cities had regional characteristics. Moreover, users engaged in static vs. dynamic activities showed different sensitivities to thermal environments. The users' location selection showed a strong dependence on microclimate rather than on the activity-supported facilities; when microclimate conditions changed, users made accommodations by moving to sunny areas or performing other adaptive behaviors, and thus, space utilization changed. These findings can inform thermal comfort-oriented planning and design from the perspectives of micro-climate regulations, site planning, and activities in the residential public open spaces of winter cities.

Keywords Winter city · Marginal season · Residential public open spaces · Outdoor thermal comfort · Adaptive behaviors

Introduction

A cold climate is an ambient stressor characterized as being chronic, negatively valued, and physically perceptible (Campbell 1983), which may produce adverse effects in winter cities. The term "winter city" (or "northern city") usually refers to a city that has a long winter and a severe climate that negatively influences urban life (Liu 1998). Pressman, one of the founders of the Winter Cities Association and leader of the Winter Cities Movement from Canada, defines a city with a maximum daily temperature of below 0 °C during no fewer than 2 months in a year as a "winter city" (Pressman 1995). Winter cities are widely distributed in northern Asia, North America, northern Europe, and other high-latitude areas. In these harsh climates, many activities cannot be easily conducted outdoors in winter. Studies have shown that the time people spend indoors during the winter in these colder areas, especially those in subpolar regions, is approximately 90% (Pressman 1995). To mitigate the environmental stress, artificial environments for essential activities have been created that are free from the undesired weather, such as the "indoor cities", "underground cities", and "skyway cities" in North America (Gehl 1992). This approach may somewhat enrich urban life, but due to a lack of connection to the outside

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and to nature, it is criticized by many researchers (Nash 1987; Gehl 1992; Culjat and Erskine 1998).

People desire to be close to nature and to enjoy sunlight and fresh air. The "outdoor season," i.e., the period during which people can conduct outdoor activities without wearing heavy clothes, should be extended to reduce the extent of indoor isolation (Li 1994; Pressman 1996). Studies show that only when the temperature reaches a certain degree does the microclimate begin to influence behaviors (Li 1994). The "marginal season" is the time between the cold seasons and the season suitable for outdoor activities. Therefore, a desirable option would be to improve the "marginal season" environment to extend the outdoor season. Microclimate planning and design hold great potential to improve the thermal environment during this period. According to the results of a Norwegian study, the outdoor season can be extended by approximately 6 weeks by merely applying microclimatic planning and design principles (Culjat and Erskine 1998). Toronto increased the annual number of outdoor comfort days by 56 and prolonged outdoor time by 50% by increasing the number of wind and rain shelter facilities (Klinger 1991). However, the climate is unstable during the marginal season, which may improve or ruin users' experience of open spaces. Therefore, it is necessary to obtain a better understanding of the mechanism of how outdoor activities are facilitated or hindered by prevailing climatic conditions to reduce user discomfort. At the individual level, the underlying mechanism is a form of personal control and adaptability that relates to past thermal experience. Studies show that the neutral temperature of different European countries in autumn is higher than that in the spring due to the influence of the preceding season (Nikolopoulou and Lykoudis 2006). The expectations and thermal comfort demands changed with seasons in a year-long tracking experiment in Harbin (Chen et al. 2018). Winter cities feature severely long and cold winters, so the thermal perception in the spring marginal season can be expected to differ from that in other seasons due to the influence of the preceding season. Therefore, the spring marginal season in winter cities is worth studying.

Previous studies on this topic have primarily focused on urban public spaces, such as urban squares, parks, and waterfronts (Zacharias et al. 2001; Thorsson et al. 2004; Lin 2009; Nikolopoulou and Lykoudis 2007; Nouri et al. 2017; Qaid et al. 2018; Guo et al. 2018), and fewer studies have focused on residential public open spaces (Li et al. 2016; Liu et al. 2016). After a severe winter, an outdoor activity at short distance is the type of outdoor activity pursued by most residents in winter cities. At this time, residential public open spaces become the most popular outdoor places, as they host large numbers of outdoor activities. A European study found that due to the different demographic attributes of users and variation in spatial characteristics, residential public open spaces and urban public spaces show different trends of seasonal variation in the number of users (Nikolopoulou and Lykoudis 2007). Therefore, residential public open spaces should be studied.

Earlier studies have examined the relationships between microclimate and outdoor activities (Gehl 2001; Li 1994; Nagara et al. 1996; Mayer and Höppe 1987). Due to progress in climatology and biometeorological technology, a wide range of detailed analyses of microclimate and evaluations of outdoor thermal perception have recently been conducted (Zacharias et al. 2001; Thorsson et al. 2004; Eliasson et al. 2007; Thorsson et al. 2007; Knez et al. 2009; Lin 2009; Lin et al. 2012; Nikolopoulou and Lykoudis 2007; Lai et al. 2014; Gulyas et al. 2006; Tseliou et al. 2017). Outdoor thermal perception is a complex issue; the impacts of psychological adaptation and behavioral adjustment are the focus of thermal perception studies. In the context of urban planning, planners should focus not only on the objective indicators of microclimate but also on users' spatial perception of the thermal environment (Lenzholzer 2010) and how thermal comfort affects user adaptive behaviors and use of outdoor spaces (Chen and Ng 2012).

The literature related to thermal perception and adaptive behaviors during the marginal seasons in winter cities is sparse. This paper examines how outdoor thermal perception affects adaptive behaviors and space usage in residential public open spaces of winter cities during the spring marginal season and provides suggestions for improving outdoor thermal comfort, optimizing space utilization, and extending the outdoor season in winter cities.

Methods

Study sites

Harbin (44°04′N-46°40′N, 125°42′E-130°10′E), the capital city of Heilongjiang Province, China, features a monsoon-influenced, humid continental climate (Dwa) under the Köppen climate classification (Kottek et al. 2006). Harbin's climate background is shown in Fig. 1. Due to the Siberian high and its location above 45° north latitude, the winters in Harbin are

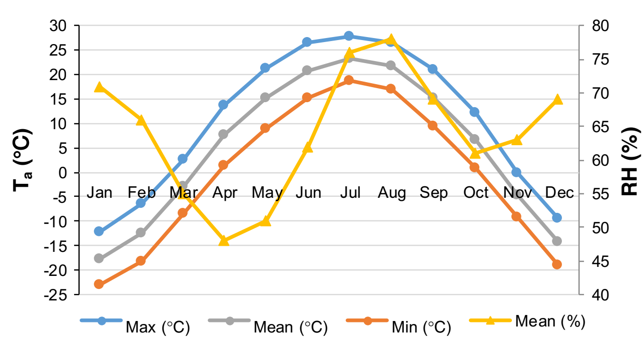

Fig. 1 The monthly average air temperature (T_a) (mean), maximum T_a (max), and minimum T_a (min) in Harbin over the 31 years from 1985 to 2016 and the monthly average relative humidity (*RH*) in Harbin over the 25 years from 1985 to 2010 (Source: China Meteorological Bureau website)

freezing cold; therefore, it exhibits all of the typical features of a winter city. This paper uses Harbin as a case study.

Multi-story residential communities are widely distributed in Harbin. To resist the severe winter climate, the layouts of these buildings are mainly enclosed, typical of the building layouts of winter cities; thus, they were selected for this study. By searching the Baidu map, 220 sites were selected from the Nangang, Daoli, Daowai, and Xiangfang districts where multi-story residential communities are concentrated. The public open spaces in these communities were mainly rectangular or irregularly or round-shaped with 5–7 stories. We chose three spaces (named A, B, and C) most representative of the characteristics of residential public open spaces in this winter city (Fig. 2). The three residential public open spaces exhibited the following characteristics: (1) they were all enclosed by multi-story buildings with 5–7 layers; the enclosed degree decreased from A to C; (2) A and B were rectangular in shape, whereas C was irregular in shape; and (3) the residential population densities were similar among the spaces (mean 354 individuals per hectare), and each space had sufficient activity space (more than 2500 m^2).

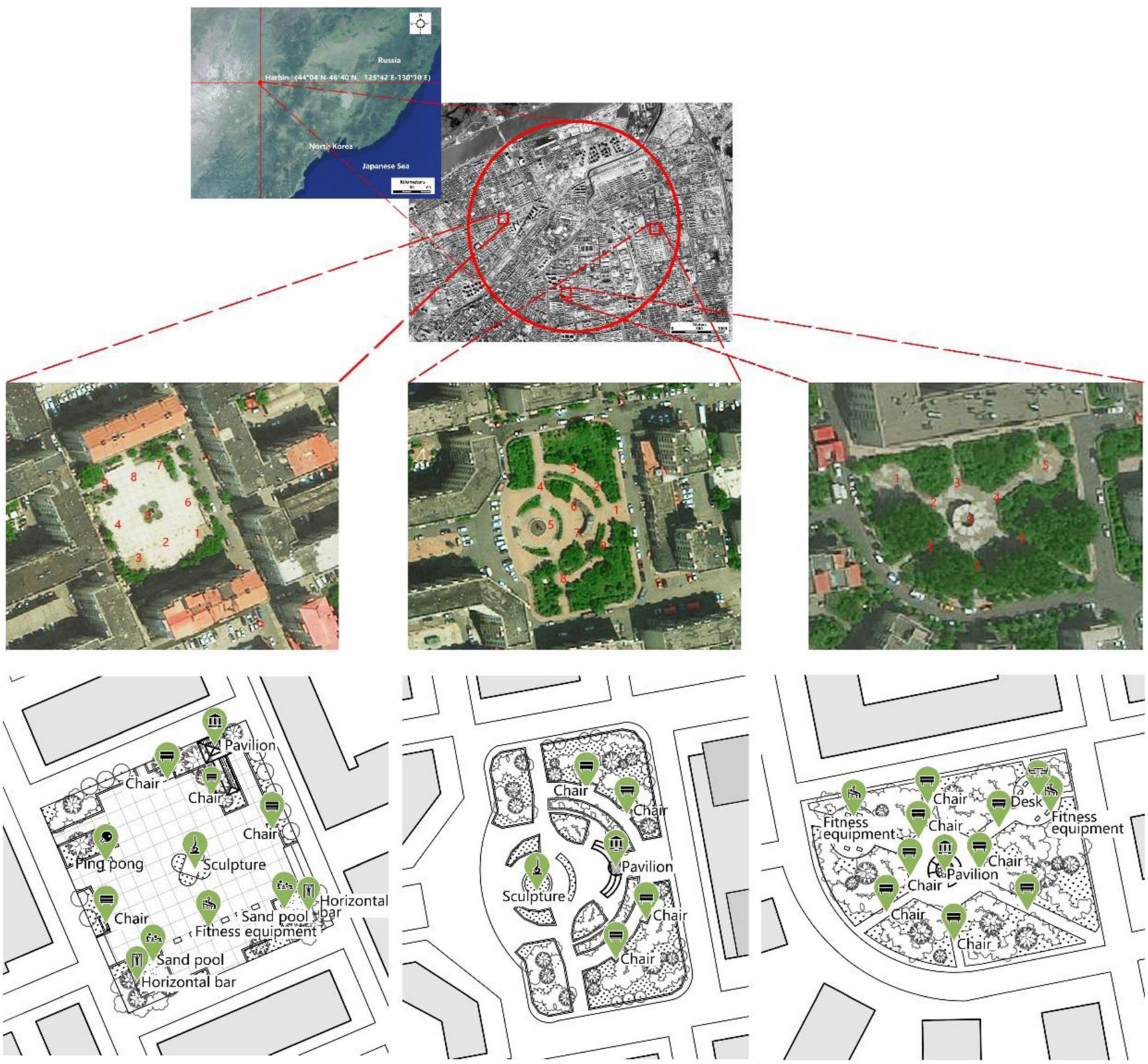

Fig. 2 Top: locations of study sites A, B, and C on the Baidu map. Middle: the plans of the study sites and the measurement points within them. Bottom: the distribution of activity-supported facilities (small icons denote the activity facilities, such as chairs, fitness equipment, and pavilions)

Field survey methods

According to the time period of the spring marginal season as calculated from the meteorological data of Harbin from the past 30 years (Leng and Jiang 2017) and actual weather conditions, the research days chosen were April 9th, April 10th, and April 12th of 2017. In consideration of the main daily activity times of users, the selected survey times were from 8:00 to 11:30 a.m. and from 13:00 to 18:00 p.m. each day.

Micro-meteorological measurements

Based on the spatial characteristics of the study sites, the distribution of the users, and the principle of maximum site coverage, nine sampling points were established at each site (Fig. 2). Three parameters were sampled every 10 s using a Testo 435-2 instrument: air temperature (T_a), relative humidity (*RH*), and wind speed (*V*). Five-minute averages were calculated, and microclimate indicators were recorded every half hour. Global radiation (*GR*) was sampled every minute using a JTR-05, and 5-min averages were calculated. The measurement height was 1.1 m above the ground, corresponding to the average height of the center of gravity for adults (ISO 7726 1998).

We selected the physiological equivalent temperature (PET) as the thermal comfort index, which was based on the MEMI thermal index of the Munich human body heat balance model. PET is defined as the air temperature in a typical indoor setting at which the human energy budget is maintained by the same skin temperature and sweat rate as those under the conditions to be assessed (Höppe 1984). This index has been widely applied in many climate regions, and it is applicable to the climatic conditions of our study area (Coccolo et al. 2016), which facilitates comparisons with previous results. To calculate PET, the Rayman model (Matzarakis et al. 2007, 2010) was adopted in this study.

Questionnaire surveys

We divided the investigation into two sections. Votes on outdoor thermal perception and outdoor thermal sensation were recorded in the first section. A total of 318 subjects were randomly selected from the study sites; 301 valid questionnaires were obtained from these subjects. A 5-point scale was adopted to record the variation in outdoor thermal perception and thermal sensation values. The second section employed a one-question survey to further examine thermal acceptability. The question was: "Do you think the present outdoor thermal environment is acceptable?" They have to select either "Yes" or "No". In this section, we targeted groups of users at different sampling points. The questionnaires were distributed and the users were asked to complete the questionnaires at the same time base. In this way, 16 groups of users were surveyed for the study and a total of 364 personal votes were collected in this section.

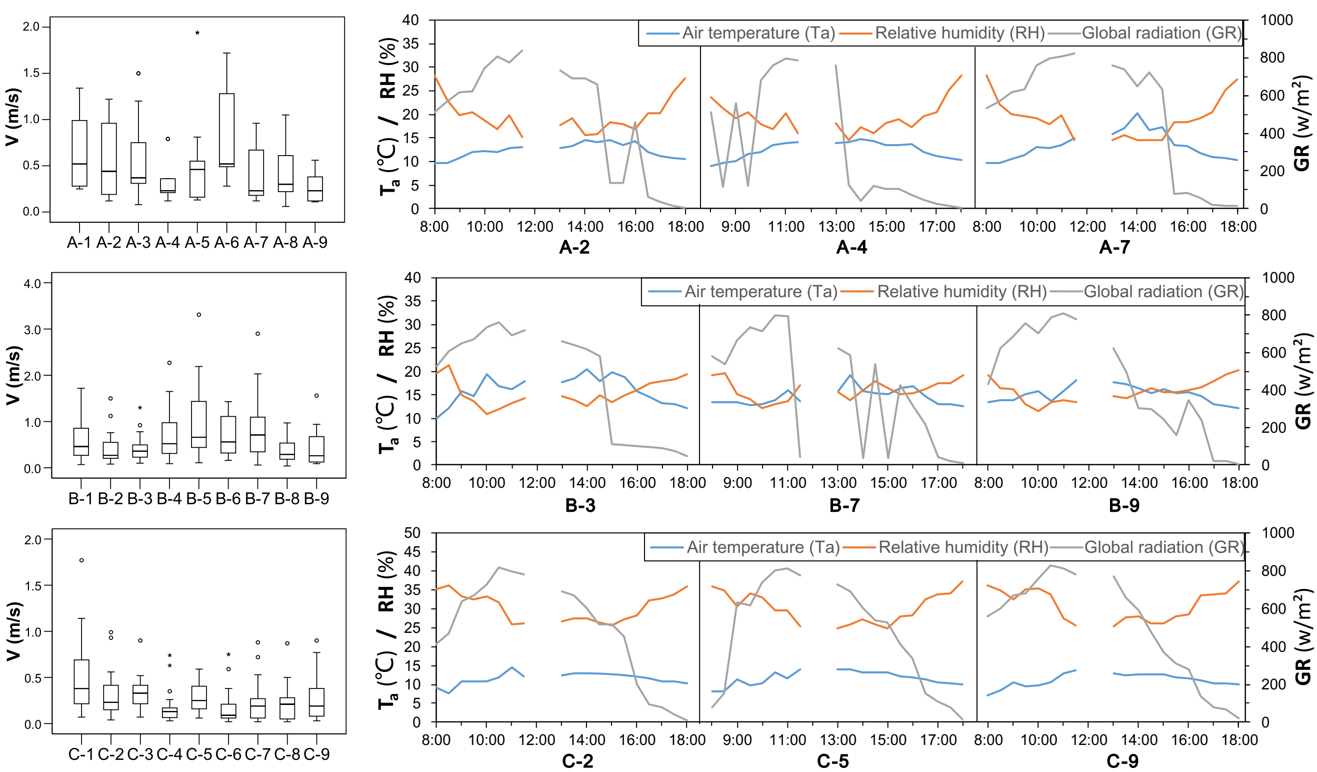

Fig. 3 *V* and T_a, *RH* and *GR* at the measuring points within the study sites during the survey periods (the average daylight hours value for this latitude at this time of year is 12 h 23 min)

Behavioral observations and annotations

In addition to collecting microclimate measurements, we captured photographs and recorded behavioral observations and annotations. The main observations included observations of (1) user number, (2) user motions, (3) user activity type, and (4) individual adaptive behaviors, such as sitting with chair pads, wearing hats, turning their backs to the sun, and changing the amount of clothing.

Results

The outdoor thermal environment

The *V* and T_a, *RH* and *GR* every half hour of the survey period at the points in sites A, B, and C are shown in Fig. 3 (each number following "A-", "B-", and "C-" represents the number of measuring points within that site).

V ranged from 0.1 to 3.5 m/s. The *V* at measuring points A-6, B-5, B-7, and C-1 was increased relative to that at the other points due to unsuitable building and planting layouts; for example, the *V* at point B-5 was influenced by a street canyon. The *V* at points A-4, A-9, B-2, B-3, B-8, C-4, and C-6 was decreased relative to that at the other points because of the presence of surrounding shading kiosks, rest corridors, or shrubs. T_a peaked at approximately 10:30 a.m. and 14:30 p.m. The duration of high T_a at points A-7 and B-3 was longer than that of the other points because these points were exposed to the sun for a long time and heat-absorbing materials, such as sand, leather, and iron were present in the pavement or facilities. The T_a at points A-4, B-7, and B-9 was lower than that at the other points because these points were shadowed by buildings or facilities for extended periods. The trends in *RH* were opposite those of T_a; this pattern was not unexpected given that these variables tend to be negatively correlated. The *GR* at each point varied greatly, mainly because buildings or trees intermittently blocked the sunlight.

Outdoor thermal perception

Comfortable thermal sensation

To understand outdoor thermal perception and the corresponding thermal sensation, we analyzed the thermal perception votes and the thermal sensation votes from the 301 valid questionnaires. The percentage distributions of the votes are shown in Table 1.

The results indicate that 37% of the users felt "comfortable" under "warm" conditions, whereas 16% reported "warm" as being "very comfortable." "Uncomfortable" and "very uncomfortable" were mainly associated with "cold" and "cool" (Table 1). The results illustrate that "warm" is closely associated with feeling comfortable in the spring marginal season.

Thermal perception range

To further evaluate the thermal comfort range of users in the winter city during the spring marginal season, microclimate measurements and surveys were conducted simultaneously. We surveyed 16 groups of users to ensure adequate variation in microclimate conditions for meaningful analysis. As most users were elderly users with similar attributes, all users were regarded as equivalent for convenience of calculation. Accordingly, the characteristics of users were standardized, and their attribute parameters were set as follows: height: 170 cm, weight: 70 kg, age: 60 years, sex: male, clothing insulation: 1.4clo, and metabolic rate: 80 W/m^2.

The ASHRAE Standard 55 specifies that when applying a high standard, acceptable thermal conditions must be acceptable by a minimum of 90% of the occupants in the space (i.e., ≤ 10% of the occupants consider the conditions unacceptable) (ASHRAE Standard 55 2004). To account for the thermal unacceptability of users in the spring marginal season, the thermal unacceptability ratings in different PET values were calculated; the results are plotted in Fig. 4. The large sample volumes distributed near the fitting curve show a good second-order polynomial relationship, from which we can

Table 1 The percentage distributions of thermal perception votes and thermal sensation votes

Thermal perception \ Thermal sensation	-2"cold"	-1 "cool "	0 "moderate"	+1 "warm"	+2 "hot"
-2 "very uncomfortable"	7%	1%	——	——	——
-1 "uncomfortable"	6%	4%	——	——	——
0 "moderate"	——	3%	7%	2%	——
+1 "comfortable"	——	2%	11%	37%	——
+2 "very comfortable"	——	1%	3%	16%	——

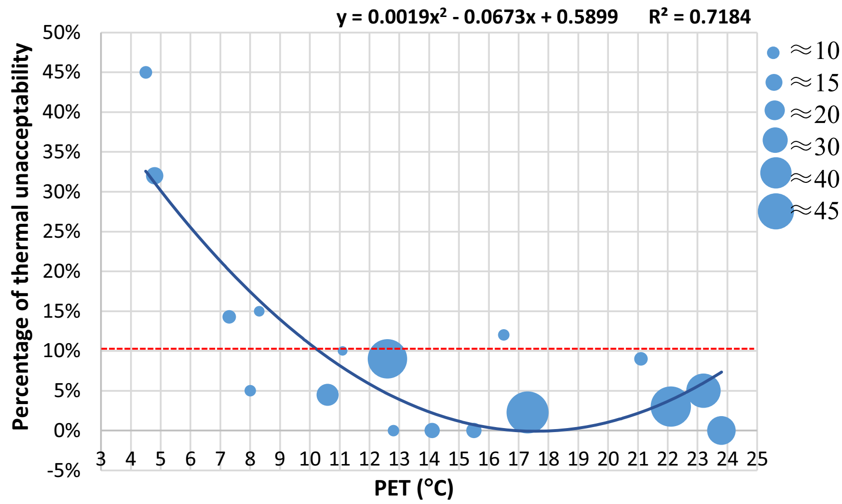

Fig. 4 Relationship between the thermal unacceptability rate and PET in the spring marginal season

determine that the 90% thermal acceptable range was more than 10.2 °C PET in the marginal season.

Adaptive behaviors

Attendance

To explore adaptive behaviors and the use of space, we constructed a map of the temporal-spatial distribution of user activities (Fig. 5) based on the behavioral observations and annotations above-mentioned. We recorded the spontaneous activities of users based on the photographs obtained and divided them into static (e.g., sitting, talking, and playing cards) and dynamic (e.g., walking and mild exercise) activities, and we excluded organized and regular activities. The numbers of users conducted static and dynamic activities were calculated for each point every half hour during the survey period within the study sites. Those points with a user population consistently less than 10 were excluded, so 12 sampling points were finalized from the total 27 sampling points, of which seven were dominated by static activities, and five were dominated by dynamic activities (Fig. 5).

To study the relationship between attendance and PET, we analyzed the data from each selected point separately. Figure 6 shows the correlation between the number of people performing static or dynamic activities and PET at the selected points. The relationships between the numbers of people at points A-6, A-7, A-8, B-1, B-2, B-3, and C-4, which were mainly dominated by static activities, and PET are shown on the left of the figure (with correlation coefficient (R^2) values ranging from 0.46 to 0.85, $p < 0.01$), whereas the corresponding relationships at points A-1, A-2, A-3, C-1, and C-5, which were mainly dominated by dynamic activities, are shown on the right of the figure (with R^2 values ranging from 0.18 to 0.34). The relationship between the number of people and PET was stronger for people performing static activities than for those performing dynamic activities, that is to say, the former were more sensitive to the thermal environment.

To study the reasons for the variation in sensitivity to the thermal environment, we examined the relationship between thermal sensation and PET for different activities (static and dynamic activities). Figure 7 shows that the TSV was higher for dynamic activities than for static ones at the same PET level. The deviation becomes less prominent as the PET increased. In addition, activity factors played a more prominent role under cold conditions. The results indicate that the variation in sensitivity to the thermal environment was due to the deviation in subjective thermal sensation between the different activities.

Space use

Comparison of the map in Fig. 5 with the distribution of activity-supported facilities (Fig. 2) revealed an inconsistency between design intention and actual use. The distribution of behaviors was not fully consistent with the locations of the corresponding activity-supported facilities, especially for static activities, which may reflect unique features of the Harbin climate. Therefore, we further explored how microclimate conditions affected the users' choice of location. People's decisions to stay or leave a given location may be closely associated with microclimate perceptions, experiences, and expectations (Huang et al. 2015). Accepting this premise, we controlled for the influences of confounding factors on user location selection. Two sampling points, B-2 and B-3 (Fig. 5), with similar facility conditions, greening environments and attractive view conditions were selected to conduct detailed behavioral observations, recording the number of users and the types of user activities and to collect microclimate measurements.

Fig. 5 The temporal-spatial distributions of users in the study sites

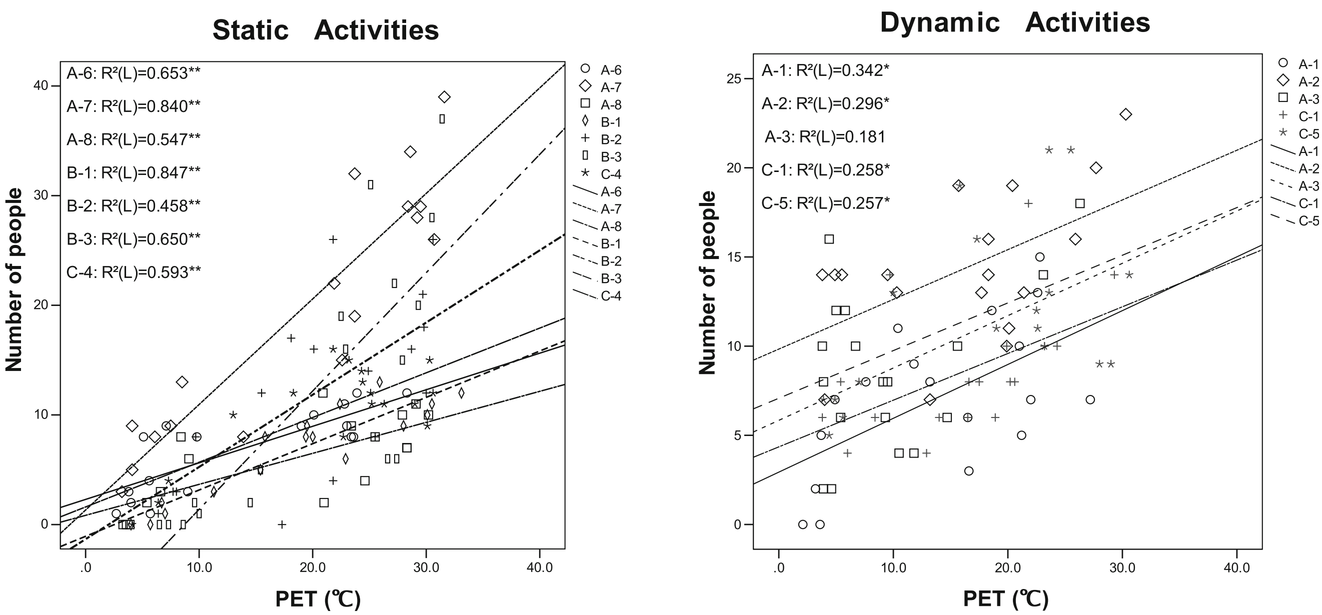

Fig. 6 Relationship between attendance and PET for static and dynamic activities (**$p < 0.01$, *$p < 0.05$)

The numbers of users at points B-2 and B-3 over time are shown in Table 2. Peak numbers at point B-2 were observed between 10:00 a.m. and 17:30 p.m., whereas those at point B-3 were observed between 8:00 a.m. and 15:00 p.m.

Figure 8 shows the microclimate conditions at points B-2 and B-3. The T_a and *GR* at point B-3 were higher than those at point B-2 from 8:00 a.m. to 10:00 a.m. During this time, users were clustered at point B-3, indicating that T_a and *GR* influenced the initial location selection of the users. The microclimate conditions from 10:00 a.m. to 15:00 p.m. were not significantly different between the two points; during this period, the number of users at point B-2 was approximately equal to that at point B-3. At approximately 15:00 p.m., point B-3 was shadowed, and *GR* decreased rapidly, which significantly reduced the number of users. Some of the users moved from point B-3 to B-2, which was still in the sun.

During the marginal season in winter cities, users show a strong tendency to move to the sunlight. We explored how this tendency affected the space utilization of users in the present study. The sun-filled regions at each site were defined as areas of "favorable microclimate conditions" and the shadowed areas were defined as areas of "poor microclimate conditions". By comparing the distribution map of the user behavior with both the locations of the activity-supported facilities and microclimate conditions, we found that the distribution of behaviors did not show a strong dependence on activity-supported facilities; in contrast, the distribution was closely related to the

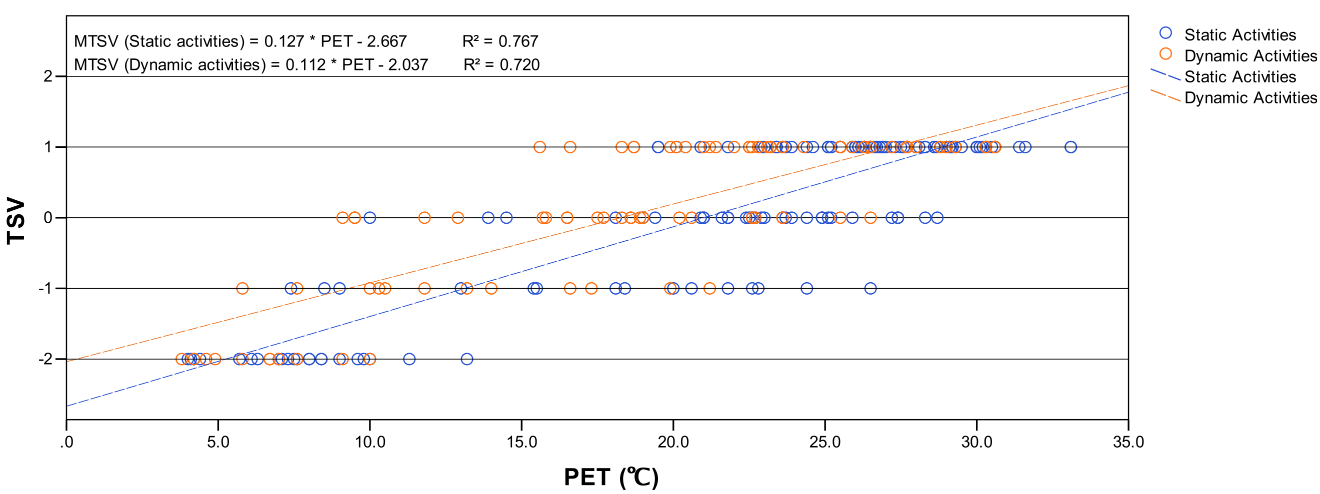

Fig. 7 Relationship between thermal sensation and PET for static and dynamic activities

Table 2 Numbers of users at points B-2 and B-3 over time

Time		8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00
Num.	B-2	0	0	1	2	12	16	18	14	—	—	8	16	36	26	21	17	12	8	3	3	1
	B-3	2	6	6	19	28	37	31	22	—	—	19	15	20	16	5	2	1	2	0	0	0

microclimate conditions. Based on this information, four typical modes of space use were designated for the marginal season in the winter city (Table 3).

Individual adaptive behavior

Behavioral adjustment is an effective method for adapting to unfavorable microclimate conditions. We carefully observed adaptive behaviors of individuals, such as using chair pads, wearing a hat, and turning their backs to the sun. Figure 9 presents the percentages of user adjustment behaviors. The data bordered by the blue box are the percentage distributions of adaptive behaviors against low temperature and high wind, whereas those bordered by the yellow box represent those employed to resist sun exposure and high temperature. The number of users resisting low temperature and high wind (sitting with chair pads, wearing a hat, and wearing heavy clothing) was higher than that resisting high temperature and sun exposure (turning their backs to the sun and moving to the shadows).

Discussion

Outdoor thermal perception

Users in winter cities feel comfortable when their own thermal sensation is "warm" during the spring marginal season. In the present study, the PET range for this period was higher than 10.2 °C. This threshold value is lower than temperatures that occur in temperate and subtropical zones, such as Rome (21.1 °C) (Salata et al. 2016), Taichung (21.3 °C) (Lin 2009), and Guangzhou(18.1 °C) (Li et al. 2016), but close to the threshold values of Glasgow (9 °C) (Kruger et al. 2013) and Tianjin (11 °C) (Lai et al. 2014). The "warm" feeling at the lower threshold was mainly due to the residents adjusting

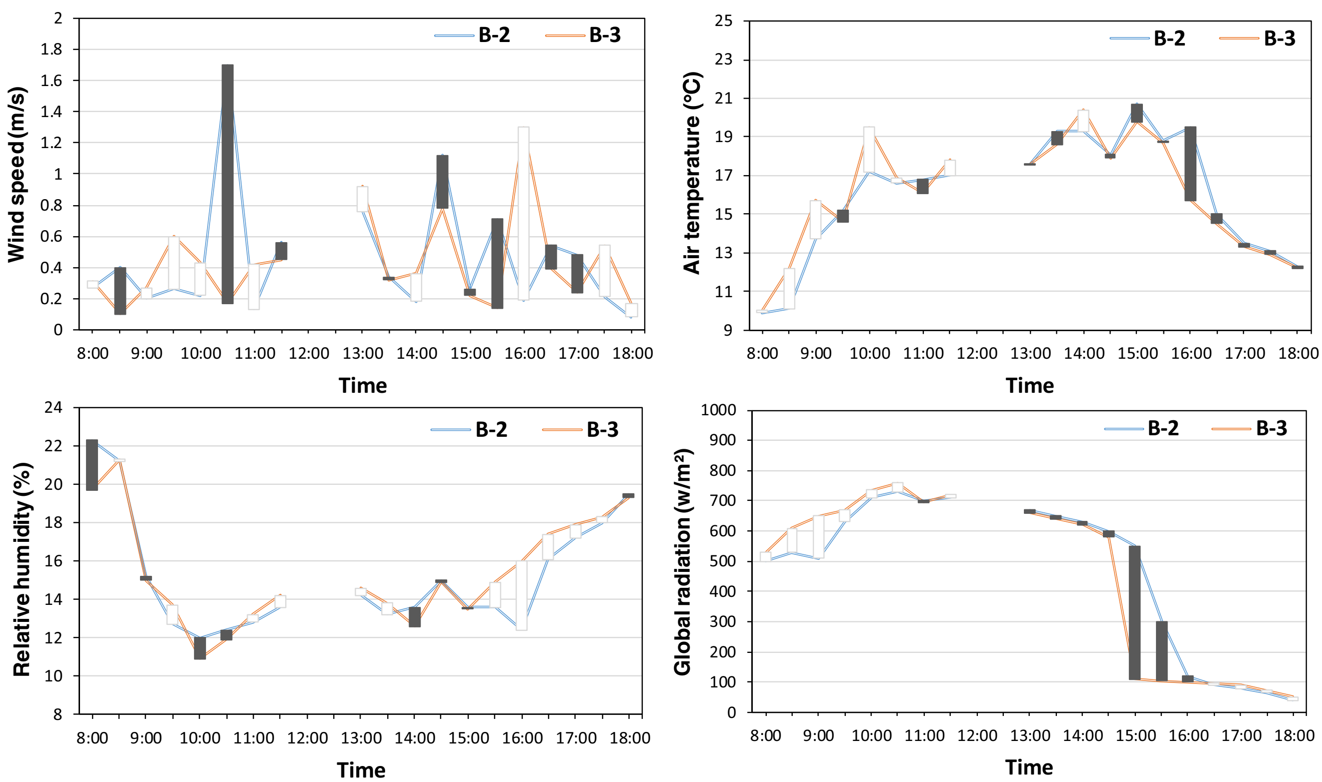

Fig. 8 The microclimate conditions at points B-2 and B-3 over time during the survey periods

Table 3 Four typical modes of space use. "+" represents "fine activity-supported" or "favorable microclimate conditions";"-" represents "lacking activity support" or"poor microclimate conditions"

	Activity support	Microclimate conditions	Space use
Mode I	+	+	Many users and a high utilization rate of facilities. The spaces are open and usually in the northern areas of the site with sufficient sunlight and deciduous plants.
Mode II	+	−	Corresponding activities cannot be performed, and the space and facilities are not in use. Plentiful rest places with roofs, such as pavilions.
Mode III	−	+	Most spaces are in the sun. Users spontaneously perform functional modifications to facilities or add new ones to support activities such as sitting, chatting and playing cards, e.g., converting a tree pond into a "seating" space.
Mode IV	−	−	Space with no users. The space is in shadow.

themselves to the thermal environment following the long period of cold and the harsh climates in the winter city.

Behavioral adaptations and the use of spaces

The residents showed strong adaptability to the thermal environment by adopting several adaptive behaviors. Consequently, some spatial phenomena were observed, such as changes in the vitality of a place, transformations of space use, and periods of non-use of space resources and facilities.

1. The success of public space design can be evaluated by the number of users (Carmona et al. 2003). Many researchers have demonstrated that the number of participants is influenced by the thermal environment (Thorsson et al. 2004; Eliasson et al. 2007; Nikolopoulou et al. 2001; Lin et al. 2013; Kántor and Unger 2010; Chen et al. 2015). This paper builds on these findings by examining the relationship between attendance and PET under different activities. The correlation between attendance and PET during static activity was found to be stronger than that during dynamic activity, which suggests differences in microclimate sensitivity among different activity types.
2. The perception of the microclimate environment affects the use of space. When engaging in outdoor activities, people choose to stay in a location based on their past thermal experiences of the current or similar spaces (Huang et al. 2015). After controlling for the variables of spatial function and activity-supported facilities, we found that T_a and *GR* had strong effects on user selection of spatial location, with *GR* being the decisive factor. During the marginal season of winter cities, the difference in radiation between sunlit and shadowed areas is pronounced. Relative to shaded areas, sunny areas are comfortable thermal environments for users. The tendency to use sunny areas indicates that the utilization rate of a space or facility is greatly influenced by the sun.
3. The adjustment behaviors to resist low temperature and wind during the marginal season indicated a demand for improved facilities. Individual behavioral adjustment is a simple and effective means for users to improve thermal comfort. Many studies have demonstrated a strong correlation between clothing quantity and PET; adjusting

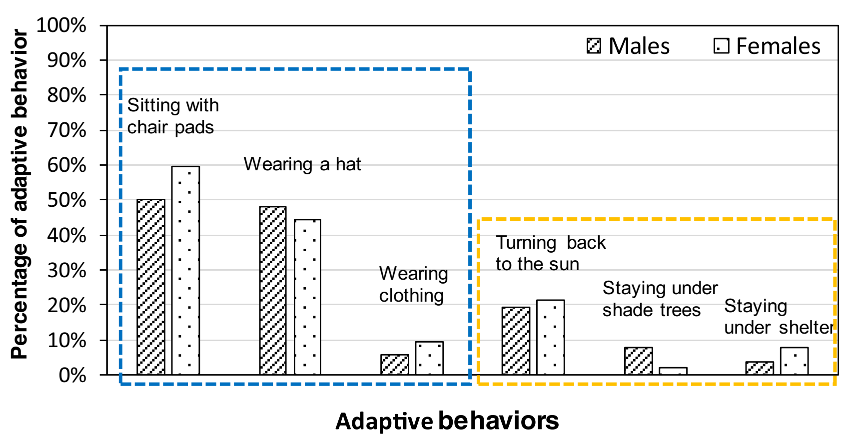

Fig. 9 Percentage distributions of adaptive behaviors by males and females

clothing based on environmental conditions is considered an effective adaptive behavior (Lin 2009; Yahia and Johansson 2013; Andrade et al. 2011). Sitting with chair pads, wearing a hat and other adjustment behaviors to resist low temperature and wind accounted for a much larger proportion of adjustment behaviors than did those adopted to resist high temperature/sun exposure, which revealed a demand during this period for both thermal insulation and wind-proof designs of the facilities.

Design considerations

The planning of public open spaces in urban residential areas of winter cities should be based on a full understanding of the outdoor thermal perception and adaptive behaviors of users.

1. Formulating microclimate control measures can effectively improve outdoor thermal comfort. For instance, San Francisco established design requirements for a new building to control its effects on the local microclimate; these requirements ensured that pedestrians experienced a positive sunlight and wind environment (Bosselmann et al. 1984). Similarly, microclimate control standards for cold climates should be set. The determination of user thermal comfort range during the marginal season can aid the planning and design of residential areas.
2. With regard to microclimate regulations, during the marginal season in winter cities, users tend to seek sunlight, consistent with the effect of sunlight on temperature compensation, as emphasized by Ulla Westerberg (Westerberg 1994). Therefore, sunlight conditions should be fully considered in design, especially the design of important activity areas. Appropriate building layouts and orientations should be established, and appropriate building heights should be set to avoid shaded outdoor spaces. The demand for shade during peak summer periods should also be considered.
3. With regard to site planning, the locations and areas of different functional spaces should be appropriately delineated. Since users engaged in static activities are more sensitive than are those engaged in dynamic activities to thermal comfort, facilities such as seating areas with desirable microclimates (sunny during the spring marginal season and shaded during peak summer periods) should be established. Dynamic activity areas or traffic areas can be placed in areas with poorer microclimate conditions.
4. With regard to supporting activities, establishing mobile facilities in the public spaces of residential areas can provide user flexibility in location choice according to microclimate conditions. We also recommend adding temporary facilities based on seasonal demand and providing resting facilities with rise-and-fall or removable roofs. In shaded areas windshield facilities, trees and heated seats should be added to encourage static activities. It is necessary to design and select materials with low thermal conductivity, such as wood fibers and recycled textile (Schiavoni et al. 2016), and to use warm colors such as yellowish and reddish hues (Wang et al. 2018) to allow facilities and buildings to meet the users' psychological needs of "warm."

It is necessary to enhance users' thermal comfort during the marginal season in winter cities to stimulate the vitality of a place, improve space utilization, and promote public spaces for neighborhood interaction. In addition, to promote use throughout the year, the needs of users during different seasons should be considered during the planning and design stages.

Conclusions

In this paper, users' thermal comfort and adaptive behaviors during the spring marginal season in a winter city were investigated. Users feel comfortable when their own thermal sensation is "warm." The calculated thermal comfort range was greater than 10.2 °C. The threshold value was lower than that of temperate and subtropical zones. Sensitivity to the thermal environment varies between activity types. Moreover, the use of public space in residential areas was highly influenced by microclimate conditions. For example, dependence on functional facilities decreased due to the strong tendency to move to the sunlight. Consequently, the usage of spaces changed. Therefore, planners and designers should locate activity-supported facilities based on microclimate conditions to stimulate the vitality of spaces and improve space utilization.

The influence of microclimate on user behavior is a complex topic that can be addressed at physiological, psychological, social, and behavioral levels. User behaviors are affected not only by the microclimate environment but also by demographic factors (gender, age), daily life habits, and other environmental factors, such as ambient noise levels and air quality. Moreover, due to the interference of human and instrument factors during the experiment, there may be a deviation in the experimental data. Therefore, in the next research phase, such factors will be considered and more detailed and continuous research will be conducted.

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