Field Investigation on Thermal Responses of the Elderly to Outdoor Climate Shift in Autumn in Xining, China

Wuxing Zheng, Yingluo Wang, Yiwei Bai, Kaibo Wang, and Wanqin Li

***Abstract*—The increasing aging population in China leads to increase in the demand for various types of aged outdoor spaces. To improve living quality for elderly, a safe, convenient, comfortable, accessible, and livable environment system is going on creating for the elderly. Field investigation of thermal comfort was carried out in Xining, China in October, 2020 for a week in order to obtain thermal responses of the elderly to outdoor climate shift in autumn at high altitude. Typical climate characteristics of Xining in autumn and the subjective responses of the elderly were collected. The results showed that the thermal sensation of the elderly is mostly neutral, and most of the elderly feel that the environment is a little dry. Also, the elderly were more likely to expect higher ambient temperatures and higher or constant humidity. For outdoor activity space in autumn in Xining, the thermoneutral black globe temperature (t_g) of the elderly is about 16.10℃. The research results of this paper can provide reference for the design of outdoor thermal environment for the elderly in autumn in Xining, Qinghai.**

***Index Terms*—Thermal responses, the elderly, outdoor climate shift, Xining, China.**

I. Introduction

Comfortable thermal environment can guarantee people's physical and mental health, which is one of the goals pursued by environmental design. The elderly are usually less sensitive to environmental temperature shift while are weakened in ability of adaptation to the environment, showing different thermal adaptabilities from other age groups, such as the elderly have a higher thermal acceptance in hot environment [1] and less sensitive with vertical temperature difference [2]. Scholars worldwide are aware of this problem and have conducted studies on thermal comfort for the elderly in some countries and regions.

Outdoor space is an important place in the daily life of the elderly in China, thermal environment of which would affect the health of the elderly. China's climate types can be divided into five climate zones according to the average air temperature of the hottest and coldest months across the country. Xining, Qinghai is belonging to the severe cold region, but it is different from other severe cold region due to its significant climate characteristics at high altitude. Some domestic scholars begin to pay attention to the special human thermal adaptation model of plateau low-pressure environment whose neutral temperature of people is higher than that under normal pressure [3] due to the direct and important influence of atmospheric pressure on human thermal comfort in cold regions [4]. However, there is a lack of research on the thermal comfort of the elderly in plateau area with severe cold climate.

The fluctuation of temperature in a day in autumn is great, and the whole level of indoor thermal environment is low, which always make the elderly feel uncomfortable. Therefore, the elderly usually choose to have a rest and bask in the open space outside to maintain their comfort. The immune function of human is high in spring and summer and low in autumn and winter [5]. Thus, the elderly whose adaptation to climate shift is poor are prone to disease onset in these seasons, especially for the elderly in weak and those suffering from respiratory diseases and chronic diseases are more likely to relapse [6]. Thermal comfort evaluation of outdoor environment cannot follow the indoor thermal comfort theory [7]. Studies on outdoor thermal comfort of the elderly have just started in China at present, and various theoretical evaluation models are disjointed from experimental studies, lacking experimental studies [8]. Most studies on thermal comfort models of the elderly are focused on summer and winter, showing a lack of studies on autumn. Studies have shown that people's behavioral regulation, psychological expectation, and physiological regulation are different in different seasons, yet it is not clear how the elderly respond to autumn climate shift.

Therefore, this paper mainly selects Xining, Qinghai province, a severe cold region with plateau climate characteristics, to investigate the outdoor thermal comfort of the elderly in autumn.

II. Methods

A. The Climate of the Investigated Area

Xining, Qinghai belongs to the continental semi-arid climate of plateau which is a cold area in the division of building thermal climate. It has the characteristics of long

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sunshine duration and strong radiation, cold and long winter, cool and short summer, large diurnal temperature range and small annual temperature range. The annual average sunshine is 1939.7 hours, the annual average temperature is 7.6℃, the highest temperature is 34.6℃, the lowest temperature is -18.9℃, the average annual precipitation in the central city is 380 mm, evaporation is 1363.6 mm. The autumn in Xining is short and has low temperature, large temperature variation and dry air.

B. Investigation Methods

In October 2020, we conducted a thermal comfort field survey to test and questionnaire the daily outdoor activity environment of healthy elderly people over 60 years old in Xining city and its surrounding areas for a week. The research sites include six villages around Xining city. The research content includes objective thermal environmental parameters and subjective response to thermal comfort. Relative humidity, wind speed and black sphere temperature was measure and test respectively using HD32.3 thermal comfort instrument (Table I). From local meteorological stations, we collected real-time outdoor temperature. We used the Wenjuanxing system to prepare the thermal comfort questionnaire for the subjective thermal response investigation, including the basic information of the subjects (such as age, height, weight, clothing, etc.), human thermal sensation, wet sensation, and the satisfaction and expectation of the subjects to the hot and wet environment.

TABLE I: TECHNICAL PARAMETERS OF TEST INSTRUMENT

Instrument	Model	Measurement range	Accuracy
Thermal comfort instrument	HD32.3	Relative humidity: 0-100% Black globe temperature：-10-100℃ Wind speed：0.1-5m/s	±1.5%（0-90%） 0.1°C ±0.2m/s(0-1m/s) ±0.3m/s(1-5m/s)

III. RESULTS OF SURVEY

A total of 243 questionnaires were obtained, of which 52% were male and 48% were female. Other relevant background parameters of subjects are listed in Table II.

TABLE II: BASIC INFORMATION OF SUBJECTS

	Average age (years)	Average height (cm)	Average body weight (kg)
Minimum value	56	140	50
Maximum value	89	188	94
Average value	70.4	162.3	64.4
Standard deviation	6.3	8.1	9.9

A. Statistical Results of Thermal Environment Parameters

We selected October, as a typical month in autumn, to conduct on-site questionnaire survey on the elderly at rest for outdoor activities. Physical parameters of the outdoor environment of the elderly were measured at the same time. The measured data are shown in Table. III. The radiation temperature was calculated by air temperature, black sphere temperature and wind speed according to (1)[9]:

$$t_r = t_g + 2.4 \cdot v_a \cdot 0.5(t_g - t_a) \tag{1}$$

where t_r refer to radiant temperature(℃), t_g refer to black globe temperature(℃), v_a refer to wind speed(m/s), and t_a refer to air temperature(℃).

TABLE III: OUTDOOR THERMAL ENVIRONMENT PARAMETERS

	Air temperature(℃)	Radiant temperature(℃)	Wind speed(m/s)	Relative humidity(%)
Minimum value	8.2	8.6	0.00	19.0
Maximum value	24.9	31.4	1.99	74.1
Average value	15.3	17.5	0.31	35.9
Standard deviation	3.3	4.2	0.30	9.5

As can be seen from Table. III, there is a large difference in outdoor relative humidity in Xining in this survey, with a standard deviation of 9.5, a maximum of 74.1% and a minimum of 19.0%. The difference between air temperature and radiation temperature is large. The highest air temperature is 24.9℃, the minimum is 8.2℃, the standard deviation is 3.3. The maximum radiation temperature is 31.4℃, the minimum is 8.6℃, and the standard deviation is 4.2. The wind speed varies from 0m/s to 1.99m/s with a standard deviation of 0.3.

B. Clothing Thermal Resistance and Metabolic Rate

We investigated the metabolic rate and clothing thermal resistance of the elderly in the survey, and the data obtained are sorted out as shown in Table IV.

TABLE IV: INDIVIDUAL VARIABLES

	Metabolic rate(met)	Clothing thermal resistance(clo)
Minimum value	0.7	0.75
Maximum value	2.0	2.56
Average value	1.4	1.45
Standard deviation	0.44	0.32

As can be seen from Table. IV, the minimum metabolic rate of the elderly in this survey is 0.7 met, and the maximum is 2 met. The minimum thermal resistance of clothing is 0.75clo and the maximum is 2.56 clo. The standard deviations were small (0.44 and 0.32 respectively), and the mean values were 1.4 met and 1.45 clo respectively.

C. Subjective Reaction of the Elderly

1) Thermal sensation, acceptability and expectation

The thermal sensation, thermal acceptability and thermal expectation of the subjects were statistically analyzed according to ASHRAE55's 7 grades of thermal sensation scale (+3 hot, +2 warm, +1 slightly warm, 0 neutral, -1 slightly cool, -2 cool, -3 cold) and thermal acceptability (+1 completely acceptable, +0.01 just acceptable, -0.01 just unacceptable, -1 completely unacceptable) [10] and the results were shown in Fig. 1-(a), (b), and (c).

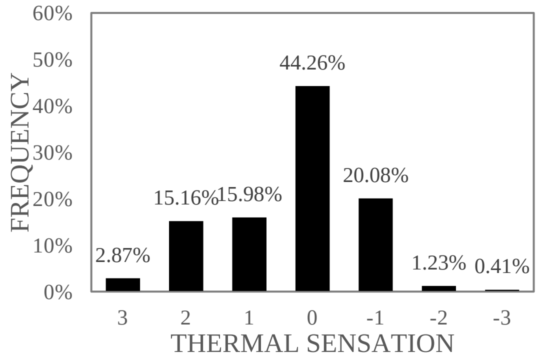

Fig. 1. (a). Frequency of subjects' thermal sensation distribution.

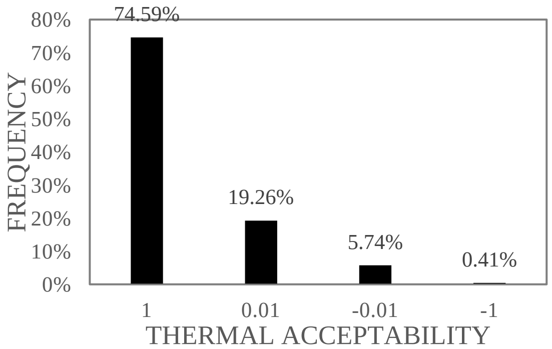

Fig. 1. (b). Frequency of subjects' thermal acceptability distribution.

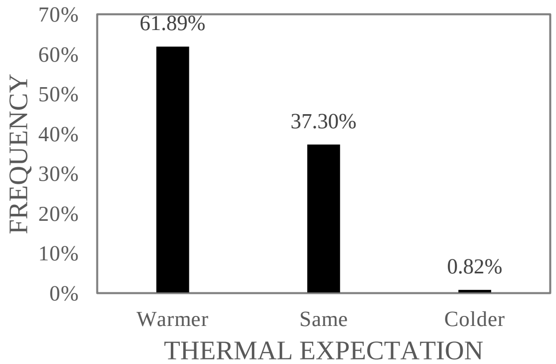

Fig. 1. (c). Frequency of subjects' thermal expectation distribution.

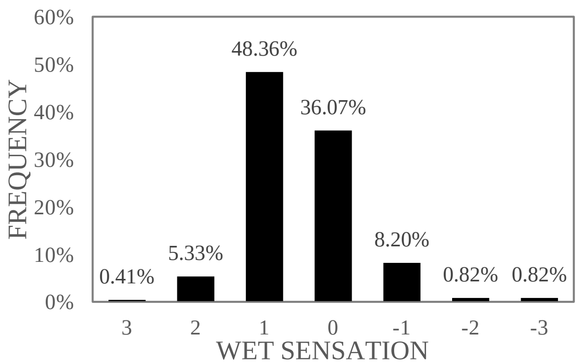

Fig. 2. (a). Frequency of subjects' wet sensation distribution.

As can be seen from the figures, the distribution frequency of thermal sensation was basically normal distribution, and nearly half of the subjects (44.26%) had neutral thermal sensation. The number of people whose thermal acceptability was completely acceptable (74.59%) far outnumbered those who felt just acceptable, just unacceptable or completely unacceptable. Far more people (61.89%) expected a warmer environment than (0.82%) expected a cooler environment, and 37.3% said they wanted the temperature to remain the same.

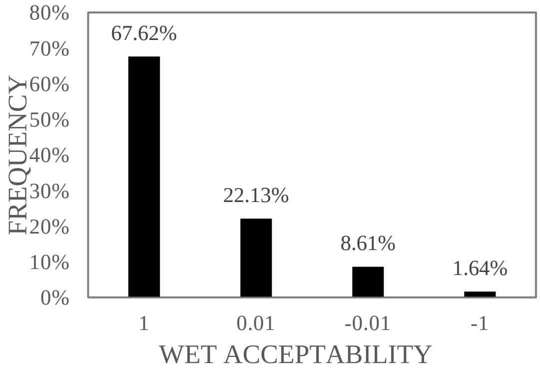

Fig. 2. (b). Frequency of subjects' wet acceptability distribution.

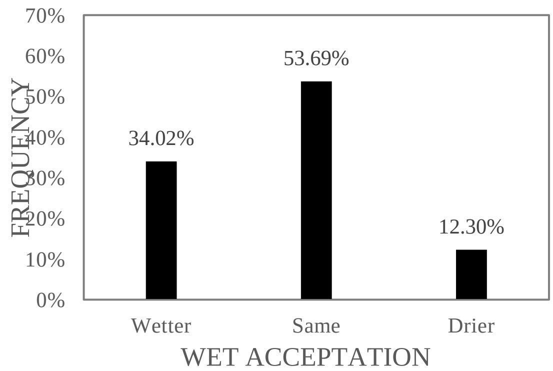

Fig. 2. (c). Frequency of subjects' wet expectation distribution.

2) *Wet sensation, acceptability and expectation*

The wet sensation, wet acceptability and wet expectation of the subjects were statistically analyzed according to ASHRAE55's 7 grades of wet sensation scale (+3 very dry, +2 dry, +1 a little dry, 0 neutral, -1 a little wet, -2 wet, -3 very wet) and wet acceptability (+1 completely acceptable, +0.01 just acceptable, -0.01 just unacceptable, -1 completely unacceptable) [10] and the results were shown in Fig. 2-(a), (b), and (c).

As can be seen from the figure, the distribution frequency of wet sensation is basically normal distribution, most people (48.36%) feel a little dry, 36.07% feel neutral. However, the majority of people (67.62%) think the wet environment is completely acceptable, far more than those who feel just acceptable, just unacceptable or completely unacceptable, and nearly half (53.69%) want the humidity to remain the same. Slightly more people (34.02%) wanted a wetter environment than those (12.3%) wanted a drier environment.

IV. Discussion

Outdoor temperature (t_a), black globe temperature (t_g), physiological equivalent temperature (PET) and subject thermal sensation (TSV) were analysed. Temperature frequency method (Bin method) was adopted, 0.5℃ was used as interval grouping, and the obtained data were processed. For outdoor temperature and black bulb temperature, the obtained figure was shown in Fig. 3-(a) and 3-(b), and the linear regression equation is obtained as shown in (2) and (3).

$$TSV = 0.1104t_a - 1.5437\left(R^2 = 0.3202, \ P < 0.05\right) \quad (2)$$

$$TSV = 0.0965t_g - 1.5539\left(R^2 = 0.3976, \ P < 0.05\right) \quad (3)$$

where t_a refer to air temperature (°C) and t_g refer to black globe temperature(°C).

Physiological equivalent temperature (PET) to evaluate the comfort of outdoor thermal environment quantitative index [11]. RayMan software was chosen for calculation of physiological equivalent temperature (PET). Input data of place, date and time, air temperature, wind speed, air humidity, the subjects' age, gender, height, weight, activity emphasized and clothing thermal resistance, then the PET value of each questionnaire was calculated. The obtained figure was shown in Fig. 3-(c). And the relationship between PET and thermal sensation voting of subjects was fitted, the linear regression equation was obtained as (4).

$$TSV = 0.0352PET - 0.6243\left(R^2 = 0.1757, \ P < 0.05\right) \quad (4)$$

where *x* refer to physiological equivalent temperature (°C), and *y* refer to thermal sensation.

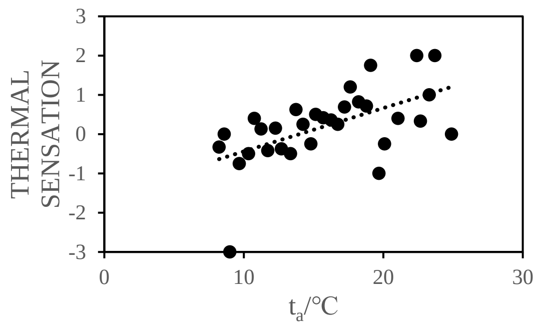

Fig. 3. (a). Linear regression diagram of thermal sensation and outdoor temperature(t_a).

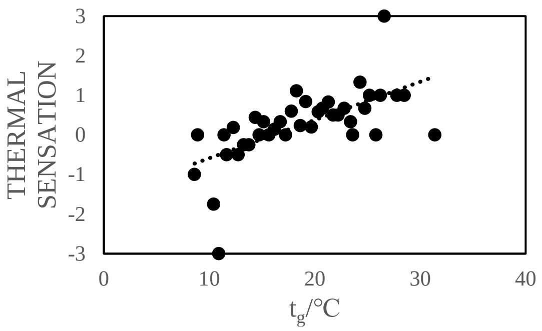

Fig. 3. (b). Linear regression diagram of thermal sensation and black globe temperature(t_g).

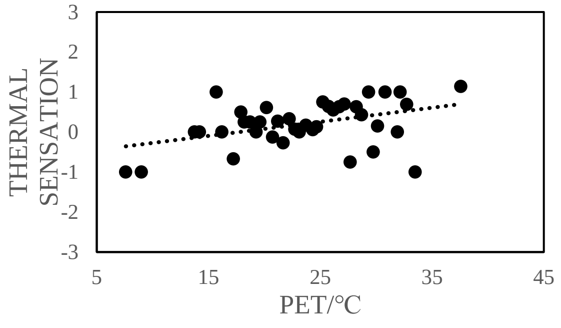

Fig. 3. (c). Linear regression diagram of thermal sensation and physiological equivalent temperature (PET)

It can be seen from (2), (3) and (4) that R² (0.3975) in (4) is greater than those in (2) and (3). Therefore, it can be concluded that t_g has the highest fitting degree with thermal sensation and can best reflect the changing law of thermal sensation among the three indicators of outdoor temperature, black globe temperature and physiological equivalent temperature. Black globe temperature was selected to study outdoor thermal comfort in autumn in Xining and to calculate thermal neutral temperature.

When the thermal sensation TSV=0, $t_g \approx 16.10$°C. That is, the outdoor thermal neutral t_g value of the elderly in autumn is 16.10°C. This temperature is the comfortable temperature for the elderly in outdoor activities, which can provide reference for the design of outdoor thermal environment in Xining.

V. Conclusion

In this paper, the rural area of Xining city, which belongs to the cold plateau area, was selected to conduct a survey on the physical parameters of outdoor objective thermal environment and subjective questionnaire of the elderly in autumn. The main conclusions are as follows:

(1) In autumn in Xining, the thermal sensation of the elderly is mostly neutral, and most people feel that the environment is a little dry.

(2) While most people thought the environment was perfectly acceptable, older people were more likely to expect higher ambient temperatures, higher or constant humidity.

(3) For outdoor activity space in Xining in autumn, black globe temperature was used to evaluate, and the thermal neutral black globe temperature of the elderly was calculated to be about 16.10°C.

The research results of this paper can provide reference for the design of outdoor thermal environment for the elderly in autumn in Xining, Qinghai. As this study is limited by sample size and trial period, the results obtained are for reference.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Wuxing Zheng conducted the research and revised the paper; Yingluo Wang and Wuxing Zheng wrote the original draft; Yiwei Bai and Kaibo Wang analyzed the data; all authors conducted the thermal comfort questionnaire survey; all authors had approved the final version.

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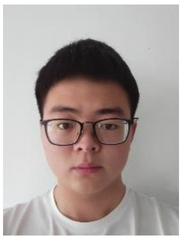

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