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Seasonal Study of Human Physiological Parameters and Thermal Sensation in Cold Regions

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Abstract

To investigate the seasonal effects of physiological parameters on human thermal response in a cold environment. The research subjects in this study were 32 college students from a university in Jiaozuo city. The subjects' subjective evaluation, physiological parameters, and indoor and outdoor environmental parameters were all tested. Summer skin temperature was significantly higher than in other seasons, according to the findings. The change in skin temperature was more stable in the summer, and the ankle temperature was the lowest of all seasons. There was a significant positive correlation between thermal sensation and average skin temperature and heart rate in different seasons, but seasonal climate change had no effect on thermal sensation sensitivity to these two changes. The preceding studies investigated the seasonal influence mechanism of physiological factors on human thermal sensation in the real-world built environment.

Keywords

Cold Region; Thermal Sensation; Physiological Parameters; Seasonal Variation.

1. Introduction

The current building thermal environment standards mostly regulate the comfortable conditions in summer and winter from the perspective of behavioral regulation[1], rather than from the perspective of physiological or psychological seasonal changes of human body[2]. However, with the development of thermal comfort research, the close relationship between indoor thermal neutral temperature and outdoor air temperature is gradually revealed. One of the important characteristics of outdoor air temperature change is the seasonal change of climate, so the seasonal change of climate also has the possibility of affecting the thermal response of human body. At the moment, most field studies on the influence of seasonal variation in human thermal comfort focus on the influence of transitional season[3-4], non-transitional season[5-6], annual[7-8] environmental parameters, and behavioral regulation on human thermal response, while ignoring the influence of physiological factors on seasonal variation in human thermal response.

Physiological research serves as a link between thermal environmental parameters and human subjective thermal response, as well as providing mechanical interpretation for experimental results of human subjective thermal response[9]. In recent years, researchers both at home and abroad have studied human thermal comfort by focusing on various physiological parameters. Foreign researchers have investigated the effects of physiology on thermal comfort from various perspectives, including rectal temperature[10], body temperature regulation[11], skin temperature[12-14], and so on. Similarly, many domestic researchers are investigating how physiological factors influence the human body's thermal response. Lin[15] investigated the physiological heat adaptation of subjects

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from the south and the north, discovering that subjects from the south had higher average skin temperature, respiration rate, and blood volume, while subjects from the north had lower heart rate and heart rate variability. Wang[16] studied male thermal physiological parameters and psychological thermal response in the summer and discovered that subjects with cool preferences had higher average skin temperature and heart rates than those with warm preferences. According to the research of the aforementioned scholars on the influence of physiological parameters on human thermal response, future research on thermal comfort should not ignore the role of physiological thermal adaptation, but the majority of current research on physiological factors on human thermal response is concentrated in the artificial climate laboratory. There is generally a difference between the thermal response of the human body in the actual building and the steady-state performance in the artificial climate laboratory, according to a large number of field investigations[17]. People in the actual built environment are not passive recipients of the thermal environment, but rather active participants. People will eliminate the negative effects of the thermal environment through behavioral adaptation, physiological adaptation, psychological adaptation, and other means in order to meet their thermal comfort needs in the current thermal environment.

As a result, the purpose of this study is to investigate the seasonal influence of physiological factors on human thermal response in the actual built environment of cold regions throughout the year. A one-year field survey was conducted at a university in a cold area to monitor the physiological parameters and psychological subjective thermal response of the subjects in this paper. The research objectives are as follows: 1) analyze the seasonal variation trend and seasonal rule of physiological parameters in different seasons; 2) establish the relationship between physiological factors and human thermal response in the actual built environment; 3) investigate whether the relationship between physiological factors and human thermal response is affected by climate seasonal variation.

2. Methods

2.1 Brief of the Field Study

For the field investigation, a construction physics laboratory at a university in a cold area was chosen, and the one-year field investigation was planned in accordance with the actual building operation mode. The study lasted from September 2017 to August 2018. The experiment was repeated every two weeks to avoid excessive concentrations of environmental parameters during the research period. Because the survey is being conducted in a cold region, the climate is characterized by cold winters, with an annual average temperature of 12.8-14.8°C. As a result, central heating is used in the winter (from mid-November to mid-March the following year), and natural ventilation is used in the other seasons.

2.2 Respondents

Table 1. Subject basic information

	Age	Height(cm)	Weight(kg)	BMI(kg/m^2)
Min.	19	153.00	45.30	16.40
Max.	22	185.00	81.30	25.50
Mean	20.50	169.00	60.20	21.10
SD	0.76	8.02	10.94	2.62

To avoid gender, age, and other factors influencing the final experimental results, a total of 16 girls and 16 boys were recruited to form the test group through strict subject screening. The subjects chosen are all junior students who have been in school for two years and have demonstrated some adaptability to the local climate. Table 1 displays the subjects' basic information. During the experiment, the subjects will sit in a chair and only complete simple questionnaires. As a result, the subjects'

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metabolic rate is estimated to be 1.2 Met. There is no uniform dress code for subjects in order to make the study more realistic.

2.3 Field Survey

2.3.1 Environmental Parameters Measurements

Measuring outdoor environmental parameters and indoor environmental parameters are examples of objective physical factors. The PC-4 portable automatic weather station is primarily used to collect outdoor environmental parameters (such as outdoor air temperature and relative humidity). Indoor environmental parameters (such as air temperature, relative humidity, and air velocity) were measured at the study site using measuring instruments. Table 2 displays the specific models and detailed information of measuring instruments.

2.3.2 Physiological Parameters Measurements

Skin temperature was chosen to study the seasonal changes of skin temperature with climate, according to the theory of autonomous physiological adaptation of the human body. To study the effects of seasonal climate changes on subjects, heart rate was chosen as a physiological indicator. Skin temperature was measured using a nine-point method, namely the forehead, back, forechest, upper arm, forearm, hand, thigh, calf, and ankle, taking into account the rationality of the test data and the feasibility of field testing. Table 2 displays the specific models and detailed information of measuring instruments.

Table 2. Information of the instruments

Instrument	Model	Measurement content	Operation range	Accuracy
Indoor thermal comfort and air quality tester	JT-IAQ	t_a	0 to 60 ℃	±0.2 ℃
		t_g	0 to 120 ℃	±0.5 ℃
		RH	0 to 100 %	±1.5 %
		v_a	0.06 to 2.5 m/s	±(0.03 m/s + 2%)
Automatic meteorological station	PC-4	t_a	-40 to +70 ℃	±0.1 ℃
		RH	0% to 100 %	±5 %
Multichannel temperature heat flow tester	LP184-JTNT-A	Skin temperature	-20 to +85 ℃	±0.2 ℃

2.3.3 Questionnaire Survey

The questionnaire primarily consists of thermal sensation voting, and the thermal sensation voting scale uses the ASHRAE 55 scale method to record subjects' subjective cold and heat sensations[1]. Table 3 shows the subjective thermal response scales used in the study.

Table 3. Subjective thermal sensation voting scales

Voting scale	-3	-2	-1	0	1	2	3
Thermal sensation	Very cold	Cold	Slightly cold	Neutral	Slightly warm	Warm	Hot

3. Results

3.1 Thermal Environments

Fig. 1 depicts the monthly average outdoor environmental parameters during the survey period. As shown in the graph below, outdoor air temperature is highest in summer, lowest in winter, and in the

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middle of the year in spring and autumn. The annual variation pattern is as follows: spring and summer are rising, while autumn and winter are falling. According to the law of change, the annual outdoor air temperature can be divided into two stages: rising (spring and summer season) and falling (autumn and winter season).

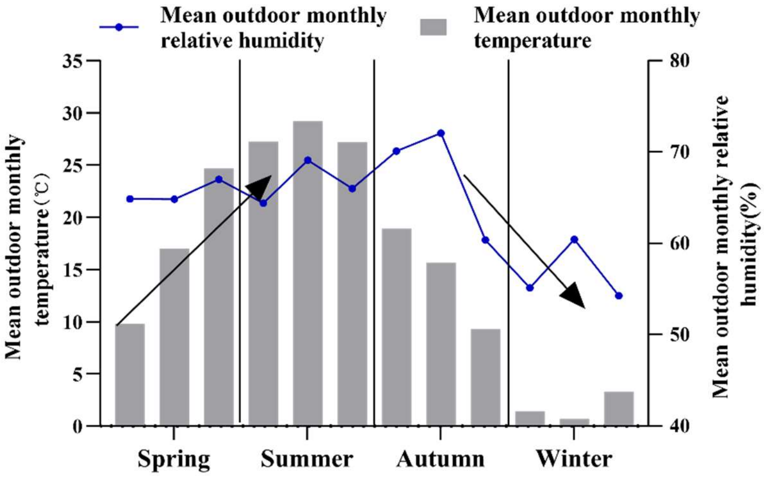

Fig. 1 Outdoor environmental parameters

Table 4 displays indoor environmental parameters for each season of the year. The seasonal variation of average indoor air temperature is similar to that of outdoor air temperature, with the highest value (29.45°C) in summer and the lowest value (18.50°C) in winter, with the spring and autumn seasons in between. Furthermore, due to the cold region where the survey was conducted, the centralized heating mode was used in winter to meet people's thermal comfort needs, resulting in significantly lower indoor relative humidity (36.92%) than in other seasons. The average wind speed varies by season, with summer having the highest (V =0.40m/s) and autumn and winter having the lowest (V =0.01m/s). To meet their thermal comfort needs in the summer, people can adjust the indoor thermal environment by opening windows and ventilating. Similarly, during the autumn and winter seasons, people reduce indoor heat loss by closing Windows, resulting in almost zero indoor wind speed.

Table 4. Indoor environmental

	Indoor environmental			
		Air temperature(°C)	Relative humidity(%)	Wind speed(m/s)
Spring	Mean	21.22	68.24	0.02
Summer	Mean	29.45	66.79	0.40
Autumn	Mean	19.03	63.97	0.01
Winter	Mean	18.50	36.92	0.01

The independent sample T test of environmental parameters in different seasons reveals that there are significant differences in indoor air temperature, indoor relative humidity, and outdoor air temperature between seasons (all P values less than 0.05), indicating that the three have seasonal variation rules.

3.2 Thermal Environments

The thermal resistance distribution of subjects' clothing in different seasons was also recorded during the investigation period, as shown in Fig. 2. The thermal resistance of clothing in summer and winter

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is 0.34 clo and 1.19 clo, respectively, which differs from the standard value of clothing stipulated in national standard (summer: 0.50 clo, winter: 1.0 clo), but is closer to the standard thermal resistance value of clothing in spring and autumn (spring: 0.53 clo, autumn: 0.95 clo). For each season, clothing thermal resistance was tested using an independent sample T test, and it was discovered that there were significant differences between seasons: winter significantly greater than the rest of the season, and summer significantly greater than the remaining three seasons, the subjects completely the change rule of clothing thermal resistance is affected by seasonal climate change, and negatively correlated with seasonal climate change law. During the survey period, the average indoor air temperature in spring and autumn was 21.22°C and 19.03°C, respectively, with a temperature difference of only 2.19°C between the two seasons. However, the average thermal resistance of clothing in autumn was 0.42 clo higher than in spring, indicating that thermal resistance of clothing differed significantly under similar environmental conditions. In the seasonal climate change cycle, the ascending and descending periods begin in spring and autumn, respectively. Spring and autumn are more sensitive to thermal and cold stimuli, respectively, after cold and heat adaptation. As a result, people will modify their clothing to better adapt to the impact of seasonal changes in ambient temperature in order to meet their own thermal comfort needs.

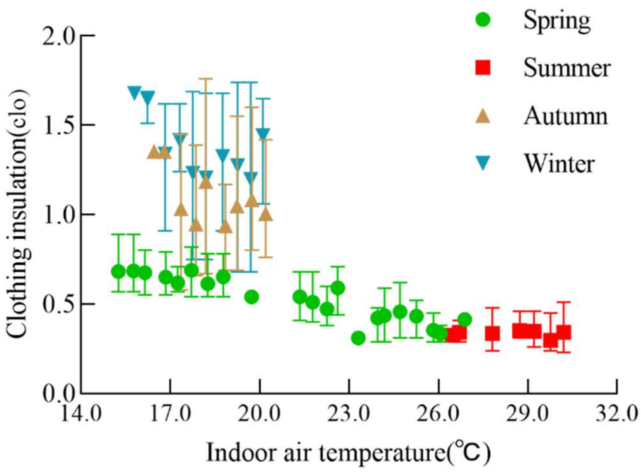

Fig. 2 Clothing thermal resistance

3.3 Thermal Sensation

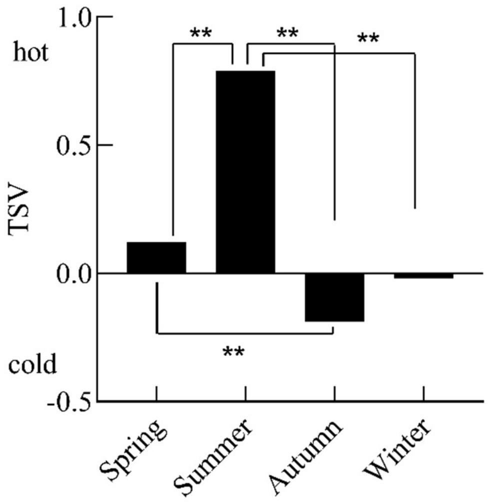

Fig. 3 Thermal sensation

Fig. 3 depicts the thermal sensation voting frequency distribution of subjects in different seasons throughout the year. On the overall thermal sensation of subjects in different seasons of the year, an

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independent sample T-test analysis was performed. The overall thermal sensation did not differ significantly between autumn and winter (P =0.079) or winter and spring (P =0.051). In autumn and winter, the average difference in indoor air temperature was only 0.53°C. As a result, there may be no discernible difference in human thermal sensation between seasons. There is no discernible difference in thermal sensation between winter and spring, implying that human thermal sensation lags in cold environments. However, there are significant seasonal differences, with indoor air temperature in summer being significantly higher than in other seasons. Spring is the first season of the "rising period", and autumn is the first season of the "falling period". There are significant differences in thermal sensation between the two seasons, which are influenced by the direction of climate seasonal change.

3.4 Physiological Parameters

3.4.1 Skin Temperature

Fig. 4 depicts a statistical analysis of local skin temperature and overall average skin temperature of subjects in different seasons. The average skin temperature of subjects was higher in the summer than in the other seasons. As a result, the skin temperature difference test revealed that there were significant differences between summer and other seasons (all P values were less than 0.05), and the skin temperature of different parts in summer was significantly higher than the corresponding parts in other seasons. When the fluctuation rate of skin temperature at different parts of the body in different seasons is compared, it is discovered that the fluctuation rate of skin temperature at different parts of the body in summer is less than that in other seasons. People wear fewer clothes in the summer and are more likely to adjust their heat balance through air convection and heat conduction. The temperature of the skin fluctuates similarly in the spring and winter, with the highest temperature in the core part (back and chest) and the lowest temperature in the ankle part. The skin temperature in the ankle part is the lowest in the local skin temperature in each season because it is at the end of the blood system.

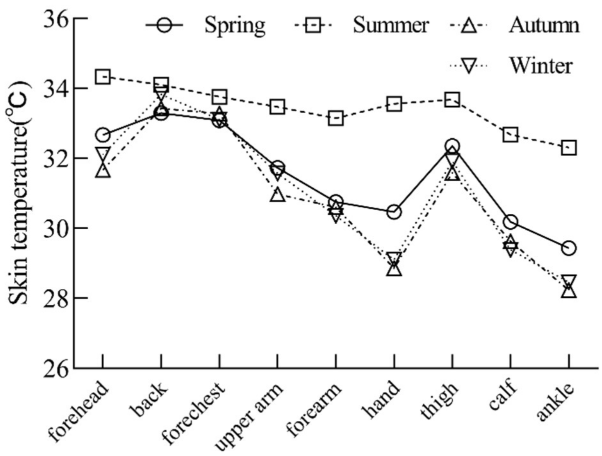

Fig. 4 Skin temperature

3.4.2 Heart Rate

Previous research has shown that the heart rate of subjects changes significantly with environmental conditions, and that the heart rate accelerates as the environmental temperature rises. Fig. 5 depicts statistically the heart rates of subjects recorded during the investigation. The minimum heart rate in each season was 60 beats per minute, but the mean values were 76.47 beats per minute in spring, 78.57 beats per minute in summer, 74.98 beats per minute in autumn, and 77.47 beats per minute in winter, respectively. The average heart rate in the transition season (spring and autumn) was lower than in the non-transition season (summer and winter), and the difference test revealed a significant difference (P = 0.001). To investigate whether there is a difference in heart rate between seasons, an independent sample T test was used to test the difference in heart rate between seasons throughout

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the year, and the test results revealed that: There are significant differences in heart rate between adjacent seasons, but there is no difference between non-adjacent seasons, indicating that the change in heart rate between seasons is affected by seasonal climatic changes.

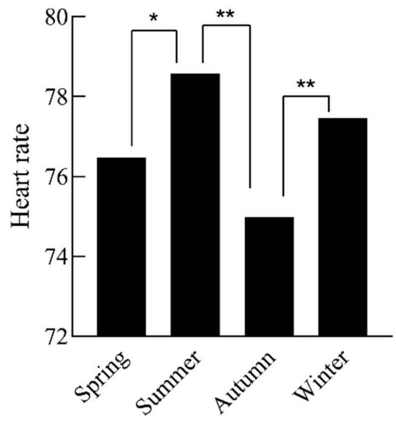

Fig. 5 Heart rate of all seasons

4. Discussion

The findings of the preceding study indicate that seasonal changes in climate can have an effect on people's physiological parameters. So, how does the relationship between physiological parameters and thermal sensation change with the seasons? And how will it be affected by seasonal climate changes? The problems mentioned above will be discussed and analyzed in this chapter.

4.1 Seasonal Effects of Skin Temperature on Thermal Sensation

The temperature frequency method was used to group average skin temperature at 0.50°C in different seasons of the year, and the weight linear regression of thermal sensation and average skin temperature was obtained, as shown in Fig. 6.

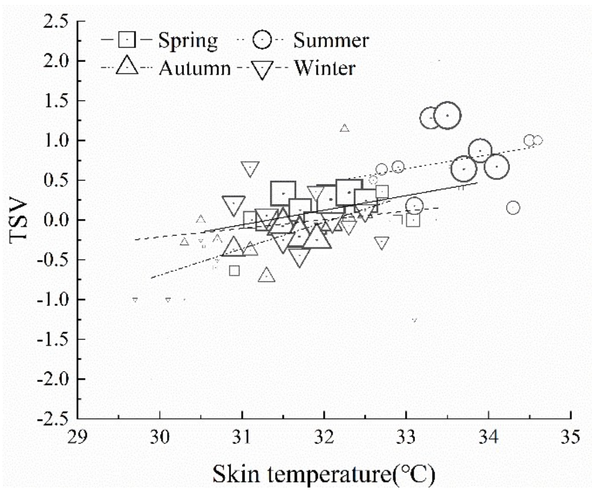

Fig. 6 Skin temperature and thermal sensation

There was a significant linear correlation between human thermal sensation and average skin temperature in different seasons of the year (all P values were less than 0.05), which means that within a certain range of healthy skin surface temperature, human thermal sensation would increase as average skin temperature increased in different seasons. Zhang[18] observed a linear relationship between average skin temperature and thermal sensation when the average skin temperature in the artificial climate laboratory was 29 to 34°C, but the skin temperature range obtained in this paper in

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the actual built environment was approximately 0.65°C higher (29.7 to 34.6°C). Chen et al.[19] discovered a link between human skin temperature and thermal sensation in hot and humid environments. In the climate laboratory, Wang et al.[20] discovered a good linear relationship between average skin temperature and thermal sensation. Skin temperature and thermal sensation were found to have a significant relationship.

By using thermal sensation between the four seasons throughout the year and the average skin temperature differences between the slope and intercept of the inspection formula, it was discovered that the slope between each season does not exist a significant difference (P value greater than 0.05), indicating that in the actual construction environment, body feel with the average temperature change of skin sensitivity is not affected by seasonal climate change. When the intercept difference test is applied to different seasons, it is discovered that some seasons have significant differences (P spring and summer =0, P spring and autumn =0.003, P summer and autumn =0, P summer and winter =0), while others do not (P spring and winter =0.209, P autumn and winter =0.289). There is a significant difference between summer and other seasons; in the heat environment, people will increase their heat resistance after physiological adaptation adjustment, lowering the thermal neutral skin temperature of the human body.

4.2 Seasonal Effects of Heart Rate on Thermal Sensation

Fig. 7 depicts the relationship between average heart rate and average thermal sensation in four seasons of the year. Under the premise of considering the influence of heart rate weight on human thermal sensation, it was discovered that there was a significant positive correlation between average thermal sensation and heart rate in all four seasons of the year (all P values were less than 0.001), which was consistent with good linear relationship between thermal sensation and heart rate obtained in the artificial climate laboratory. The difference test of the slope and intercept of the relationship between heart rate and thermal sensation among the four seasons revealed that there was no significant difference in the slope among the four seasons throughout the year (P values were all greater than 0.05), indicating that seasonal climate change had no effect on the relationship between heart rate and thermal sensation. As a result, heart rate can be regarded as one of the indicators for predicting human thermal sensation. Furthermore, the intercept difference test of the relationship between heart rate and thermal sensation revealed that the intercept was significantly larger in summer than in other seasons (all P values were less than 0.05). It has been demonstrated that in a relatively hot environment, people's heart rates increase, and that body temperature can be regulated by increasing blood circulation. The heart rate in summer is significantly higher than in other seasons in the same thermal sensation. In a hot summer environment, an appropriate increase in heart rate can help with physiological self-regulation and avoid physiological discomfort caused by high body temperature.

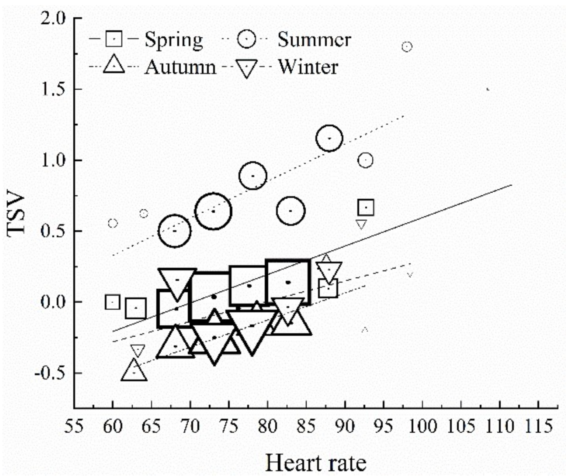

Fig. 7 Heart rate and thermal sensation

5. Conclusion

1) From spring to summer, the annual seasonal variation of outdoor temperature showed an upward trend from cool to warm, and a downward trend from warm to cool from autumn to winter. Indoor environmental parameters (indoor temperature, relative humidity) and clothing thermal resistance differed significantly from season to season, indicating that both were influenced by seasonal climate change.

2) The skin temperature at different parts of the body was significantly higher in summer than in other seasons, and the fluctuation rate of skin temperature at different parts of the body was lower in summer, and the ankle temperature was the lowest in all seasons. There was a significant difference in heart rate between adjacent seasons, but not between non-adjacent seasons, and the change rule of heart rate was affected by seasonal climate change.

3) There were significant positive correlations between average skin temperature, heart rate, and thermal sensation in different seasons of the year, but seasonal climate change had no effect on thermal sensation sensitivity.

References

[1] ASHRAE STANDARD 55-2017 Thermal Environmental Conditions for Human Occupancy[S]. Atlanta: ASHRAE, 2017.

[2] Zhang Yufeng, Wang Jinyong, Chen Huimei. Human thermal comfort research in hot-humid area of China (3) - Comparison between winter and summer[J]. Heating Ventilating & Air Conditioning, 2012, 42(02): 66-70.

[3] Jin Guohui, Zhang Dongjie, Shen Qiang, et al. Residential Thermal Comfort in Western Agricultural and Pastoral Areas of Inner Mongolia in Shoulder Season[J]. Building Science, 2017, 33(06): 41-47.

[4] Xing Kai, Shao Yu, Sun Huixuan. Thermal Comfort of Office Buildings During Transitional Seasons in Severely Cold Regions[J]. Architectural Journal, 2017, (03): 118-122.

[5] Li Kunming, Zhang Huawei, Zhao Lihua, et al. Study on the Outdoor Thermal Comfort of Residential Areas of Hot and Humid Areas in Different Seasons[J]. Building Science, 2019, 35(06): 22-29+162.

[6] Liu Hong, Wu Yuxin, Li Baizhan, et al. Seasonal variation of thermal sensations in residential buildings in the Hot Summer and Cold Winter zone of China[J]. Energy and Buildings, 2017, 140: 9-18.

[7] Zheng Wuxing, Yang Liu, Song Xiaoji, et al. Various levels of adaptation in four seasons of a year in cold climatic zone of China[J]. Heating Ventilating & Air Conditioning, 2015, 45(11): 80-85.

[8] Lin Yufan, Yang Liu, Zheng Wuxing, et al. Physiological adaption and subjective sensation in cold acceptable environment zone between male college students of southern and northern of China[J]. Journal of Civil and Environmental Engineering, 2018, 40(04): 55-62.

[9] Zhang Yufeng, Zhao Rongyi. Effect of local exposure on overall human response :a review[J]. Heating Ventilating & Air Conditioning, 2005, (02): 25-30+34.

[10] Amit Druyan, Itay Ketko, Ran Yanovich, et al. Refining the distinction between heat tolerant and intolerant individuals during a Heat tolerance test[J]. Journal of Thermal Biology, 2013, 38(8): 539-542.

[11] Damien Fournet, Lindsey Ross, Thomas Voelcker, et al. Body mapping of thermoregulatory and perceptual responses of males and females running in the cold[J]. Journal of Thermal Biology, 2013, 38(6): 339-344.

[12] Lisje Schellen, Marcel G.L.C. Loomans, Martin H. de Wit, et al. Effects of different cooling principles on thermal sensation and physiological responses[J]. Energy and Buildings, 2013, 62: 116-125.

[13] João Carlos Bouzas Marins, Alex Andrade Fernandes, Sergio Piñonosa Cano, et al. Thermal body patterns for healthy Brazilian adults (male and female)[J]. Journal of Thermal Biology, 2014, 42: 1-8.

[14] Jacquot Christel M C, Schellen Lisje, Kingma Boris R, et al. Influence of thermophysiology on thermal behavior: the essentials of categorization[J]. Physiology & behavior, 2014,128(10): 180-187.

[15] Lin Yufan, Zheng Wuxing, Yang Liu. Physiological regulatory responses and subjective sensations of human in thermal adaptable threshold zone[J]. Heating Ventilating & Air Conditioning, 2019, 49(12): 91-97.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202202_8(2).0029

[16] Wang Lijuan, Wang Peng, Chen Wenzhou, et al. Study on the different thermal preferences of male in summer[J]. Journal of Xi'an Polytechnic University, 2020, 34(06): 27-32.

[17] Cao Bin, Huang Li, Ouyang Qin, et al. Human thermal adaptation in real building environment (1) - Comparison between air-conditioned and non-air-conditioned public building[J]. Heating Ventilating & Air Conditioning, 2014, 44(08): 74-79.

[18] Zhang Hui. Human thermal sensation and comfort in transient and non-uniform thermal environment. PhD thesis, University of California at Berkeley, 2003.

[19] Chen Huimei, Zhang Yufeng, Wang Jinyong, et al. Human thermal comfort research in hot-humid area of China (1): experimental methods and results[J]. Heating Ventilating & Air Conditioning, 2010, 40(3): 83-88.

[20] Wang D, Chen G, Song C, et al.Experimental study on coupling effect of indoor air temperature and radiant temperature on human thermal comfort in non-uniform thermal environment[J]. Building & Environment. 2019, 65: 106387.