# Seasonal Rhythm of Human Thermal Adaptation for Chinese Youth in Cold Climate Zone

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***Abstract*—In order to obtain the relationship between climate seasonal change rhythm and the human thermal adaptation for Chinese youth in cold climate zone, a long-term thermal comfort field survey was conducted in campus buildings in Xi'an, China. A total of 1100 valid questionnaires were obtained, including indoor and outdoor thermal environment measurements and subjective questionnaires. The results showed that the sensitivities of TSV responding to indoor operative temperature in spring, summer, autumn and winter were 0.048, 0.284, 0.045 and 0.140, and the neutral temperatures were 19.5 ℃, 25.8 ℃, 25.4 ℃ and 16.5 ℃, respectively. Meanwhile, the clothing insulation varies with indoor operative temperature in four seasons were -0.066, -0.011, -0.081 and -0.036. The seasonal adaptive thermal comfort models were then established. It is pointed out that human thermal adaptation changes with a significant seasonal rhythm, the seasonal variation of human adaptation is not only related to the climatic characteristics of each season, but also related to the thermal experience provided by the previous season.**

***Index Terms*—Thermal comfort; Seasonal rhythm; Thermal adaptation; Chinese youth; Cold climate zone of China.**

## I. Introduction

Variation in thermal comfort requirements in different seasons would affect human adaptive behavior and thus has energy applications. Current comfort standards only specify design guidelines for summer and winter but not for swing seasons. However, for climates with distinct seasonal changes, swing seasons are the best time for natural or mix-mode ventilation while a large amount of energy could be saved if these free cooling could be used wisely. In order to provide such information, it is important to investigate comfort requirements in different seasons.

In the past 30 years, field studies in naturally ventilated buildings have been widely conducted and thermal adaptive models have been developed accordingly. Humphreys [1] established the foundation of thermal adaptation, namely, the physiological, behavioral and psychological ability to maintain comfort by adapting to changes in ambient thermal environment [2] under climate changes [3][4]. Based on a large number of on-site thermal comfort surveys, Humphreys [5], Nicol [6], de Dear [7], McCartney [8].etc., established the thermal comfort model and analyzed the linear relationship between outdoor temperature and indoor comfort temperature, their findings were included in ASHRAE 55 [9], EN 15251 [10] ,etc.

Field studies [11-17] also indicated lower neutral temperatures in summer than in winter (e.g. the winter neutral temperature in Beijing [11] was 21.8 ℃ compared to 26.8 ℃ in summer ), which was due to different physiological responses to caloric stimulation and corresponding adaptive adjustments. According to existing seasonal changes of thermal adaptability, a question whether human adaptation follows the changes of four distinct seasons (warm spring, hot summer, cool autumn, cold winter) in mid-latitude temperate monsoon climate zone was raised.

Long-term field studies by Goto [18] suggested that the sensitivities of TSV responding to indoor temperature in transitional seasons of spring and autumn in Japanese office buildings are stronger than that in winter and weaker than in summer. Zhang [19] conducted a research in the hot and humid climate region of southern China and found that TSV in summer is more sensitive than transitional seasons with the changes of SET*, while autumn is colder than spring in cooler regions. Based on systematic study of seasonal variations of thermal comfort in hot summer and cold winter zone in China, Liu [20] found stronger sensitivity of TSV following outdoor tem-

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perature changes in summer than in the other three seasons, with the value of winter being slightly stronger than spring and autumn.

Besides, a higher TSV in spring than in winter at the same temperature was indicated in comparison between two transitional seasons. China is a country with distinct climate patterns: the southern regions are hot and humid, with summer as its longest season and no heating in winter, while the northern regions are featured by temperate monsoon climate, with four distinct seasons and heating in winter. Cao [21] supported Goto's finding by revealed the diversity of thermal adaptation in transitional seasons, and found neutral temperature fell between summer and winter. Qu [22] investigated thermal adaptation in autumn in Xi'an, China, and proposed better adaptability in transitional seasons.

This study aims to discover the relationship between climate seasonal change rhythm and the human thermal adaptation for Chinese youth, and establish seasonal thermal adaptation models. A long-term fieldwork has been conducted in a temperature climate city in four seasons, and we need to 1) analyzed seasonal thermal adaptability, seasonal differences, and its reasons, 2) establish seasonal thermal adaptation models.

## II. Method

### A. General Climates

The field study was conducted in Xi'an China, which is located at latitude 34°15' and longitude 108°55', with an average altitude between 325m ~ 800m. It is a typical cold climate region with warm and semi-humid continental monsoon climate. According to the seasonal climate classification of China, Xi'an has four distinct seasons, with moderate rainfall in the whole year, and the maximum temperature is about 40 ℃, the lowest -8 ℃ or so. The general characteristics of the seasonal climate and the monthly main outdoor weather parameters (TMY) are shown in Table I.

TABLE I. The General Characteristics of the Seasonal Climate of Xi'an

| Season | Month included | Mean outdoor temperature [℃] | Mean relative humidity [%] | Climate characteristics |
|---|---|---|---|---|
| Spring | Mar., Apr., May | 14.8 | 66.1 | Warm and dry |
| Summer | June, July, Aug. | 26.0 | 68.0 | Hot and rainy |
| Autumn | Sept., Oct., Nov. | 14.4 | 72.8 | Cool and humid |
| Winter | Dec., Jan. Feb. | 1.0 | 65.0 | Cold and less snow/rain |

### B. Investigation Methods

The field thermal comfort surveys were carried out in the apartments and teaching buildings in the campus during four seasons. These buildings are running freely during spring, summer and autumn, and heating in winter. The surveys were conducted from March 2018 to June in 2019. The surveyed buildings contain 2 teaching building and 2 apartment buildings. Both subjective questionnaire surveys and objective on-site measurements were carried out. The general background information such as age, gender, weight and height of each participant was recorded, clothing insulation (Icl) and metabolic rate (MR) were estimated in accordance with ASHRAE 55 [9]. A summary is shown in Table II. The ASHRAE seven-point thermal sensation scale was adopted for this survey to quantify people's thermal sensation. The indoor air temperature, relative humidity, globe temperature and air velocity were measured and recorded using indoor thermal comfort data recorder. Outdoor air temperature and relative humidity were measured and recorded using temperature and humidity recorder. The accuracy of the above instruments are to meet the ISO 7726-2002 standard[23]. The instruments were positioned at a height of 1.1 m from the floor and close to the occupants, and data readings were recorded simultaneously during the questionnaire interview.

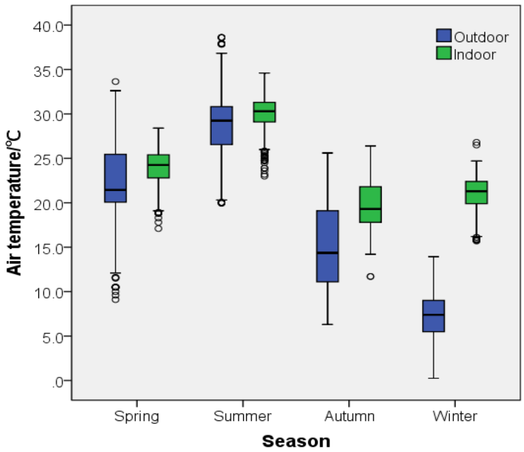
TABLE II. Background Information of Participants in Each Season

| Season | Sample size | Parameters | Min | Max | Mean | S.D. |
|---|---|---|---|---|---|---|
| Spring | 326 | Height[cm] | 152 | 193 | 170.6 | 8.5 |
| | | Weight[kg] | 41 | 101 | 62.1 | 11.3 |
| | | Age[yr] | 18 | 28 | 24.2 | 2.0 |
| | | MR[met] | 0.8 | 2.8 | 1.16 | 0.49 |
| | | $I_{cl}$[clo] | 0.19 | 1.45 | 0.63 | 0.27 |
| Summer | 209 | Height[cm] | 152 | 193 | 168.5 | 7.6 |
| | | Weight[kg] | 40 | 92 | 59.6 | 10.3 |
| | | Age[yr] | 18 | 28 | 23.8 | 1.8 |
| | | MR[met] | 0.8 | 3.8 | 1.24 | 0.66 |
| | | $I_{cl}$[clo] | 0.18 | 0.60 | 0.35 | 0.06 |
| Autumn | 300 | Height[cm] | 150 | 195 | 171.6 | 8.5 |
| | | Weight[kg] | 40 | 100 | 63.6 | 11.4 |
| | | Age[yr] | 17 | 26 | 22.7 | 2.3 |
| | | MR[met] | 0.8 | 2.8 | 1.29 | 0.74 |
| | | $I_{cl}$[clo] | 0.21 | 1.5 | 0.81 | 0.30 |
| Winter | 265 | Height[cm] | 152 | 188 | 168.7 | 7.4 |
| | | Weight[kg] | 40 | 90 | 59.5 | 10.1 |
| | | Age[yr] | 18 | 26 | 22.4 | 2.1 |
| | | MR[met] | 0.8 | 3.8 | 1.17 | 0.42 |
| | | $I_{cl}$[clo] | 0.33 | 1.9 | 0.76 | 0.32 |

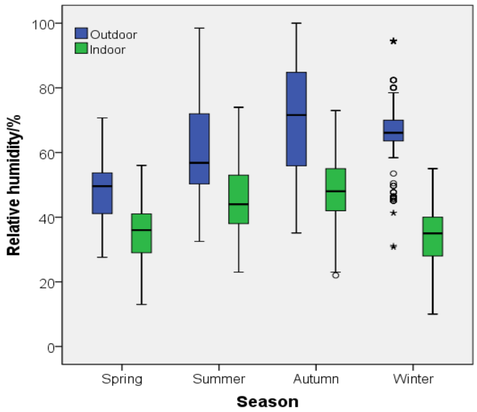
## III. Results and Analysis

### A. Seasonal Thermal Environment

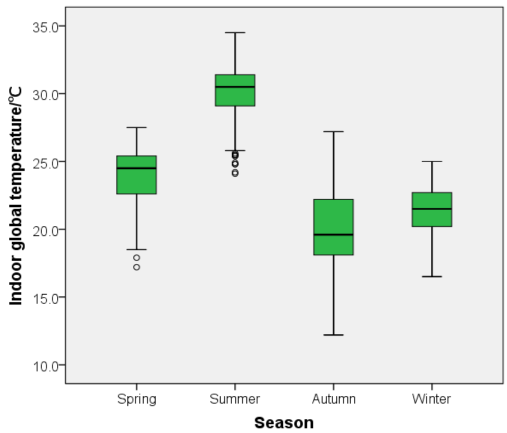
The indoor air temperature ($t_a$), relative humidity (RH), air velocity ($v$) and globe temperature ($t_g$), and outdoor air temperature ($t_{out}$) and relative humidity ($RH_{out}$) were measured in this study. The minimum, maximum, mean and standard deviation of each parameter were statistically analyzed. The results show that the outdoor temperature was generally distributed between -0.5 ℃ (in winter) and 37.9 ℃ (in summer), and the relative humidity between 29.6% (in spring) and 100% (in autumn). The indoor temperature was distributed between 11.6 ℃ (in autumn) and 34.5 ℃ (in summer), and the relative humidity was between 10.8% (in winter) and 74.2% ( in summer). The indoor air velocity was distributed at 0.01m/s (in spring, autumn and winter) and 1.55m/s (in summer), globe temperature in 11.8 ℃ (in autumn) and 34.7 ℃ (in summer). The seasonal results are shown in Fig.1 and Table III.



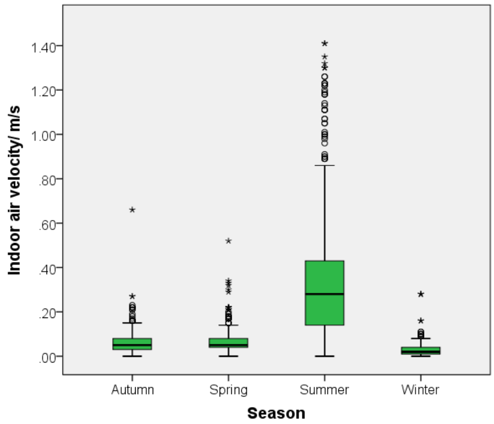

（a）Indoor & outdoor air temperature




（b）Indoor & outdoor relative humidity




（c）Indoor globe temperature




（d）Indoor air velocity

Figure 1. The seasonal distributions of thermal environmental parameters

TABLE III. SUMMARY OF THE SEASONAL THERMAL ENVIRONMENTAL PARAMETERS

| Season | Parameters | | Min. | Max. | Mean | S.D. |
|---|---|---|---|---|---|---|
| Spring | Indoor | $t_a$[℃] | 17.1 | 28.4 | 24.1 | 2.10 |
| | | RH[%] | 13.0 | 56.0 | 34.6 | 9.01 |
| | | $v$[m/s] | 0.01 | 0.56 | 0.08 | 0.06 |
| | | $t_g$[℃] | 17.2 | 26.5 | 23.8 | 2.03 |
| | Outdoor | $t_{out}$[℃] | 9.1 | 33.6 | 21.9 | 5.04 |
| | | $RH_{out}$[%] | 29.6 | 69.7 | 48.3 | 8.03 |
| Summer | Indoor | $t_a$[℃] | 23.0 | 34.5 | 30.1 | 1.92 |
| | | RH[%] | 23.0 | 74.2 | 45.3 | 9.18 |
| | | $v$[m/s] | 0.02 | 1.55 | 0.35 | 0.34 |
| | | $t_g$[℃] | 24.1 | 34.7 | 30.2 | 1.82 |
| | Outdoor | $t_{out}$[℃] | 20.9 | 37.9 | 28.6 | 4.01 |
| | | $RH_{out}$[%] | 31.9 | 99.1 | 60.7 | 16.1 |
| Autumn | Indoor | $t_a$[℃] | 11.6 | 26.4 | 19.8 | 2.97 |
| | | RH[%] | 22.0 | 73.0 | 47.6 | 9.73 |
| | | $v$[m/s] | 0.01 | 0.66 | 0.06 | 0.05 |
| | | $t_g$[℃] | 11.8 | 27.2 | 20.1 | 3.09 |
| | Outdoor | $t_{out}$[℃] | 7.1 | 25.3 | 14.5 | 4.09 |
| | | $RH_{out}$[%] | 37.7 | 100 | 71.0 | 16.9 |
| Winter | Indoor | $t_a$[℃] | 15.7 | 26.8 | 21.0 | 2.01 |
| | | RH[%] | 10.8 | 55.0 | 34.2 | 9.07 |
| | | $v$[m/s] | 0.01 | 0.28 | 0.03 | 0.03 |
| | | $t_g$[℃] | 16.5 | 25.0 | 21.3 | 1.89 |
| | Outdoor | $t_{out}$[℃] | -0.5 | 13.5 | 7.1 | 3.06 |
| | | $RH_{out}$[%] | 30.4 | 92.6 | 65.7 | 9.07 |

### *B. Seasonal Thermal Sensation and Neutral Temperature.*

According to BIN method [24], the indoor operative temperature was grouped at 0.5 ℃ and several bins were then created, the mean thermal sensation (TSV) and mean indoor operative temperature ($t_{op}$) in each bin were calculated and the relationship between them was established. TSV and $t_{op}$ has a strong linear relationship in four seasons, as shown in Fig. 2, and the linear regression equations are shown in Table IV.

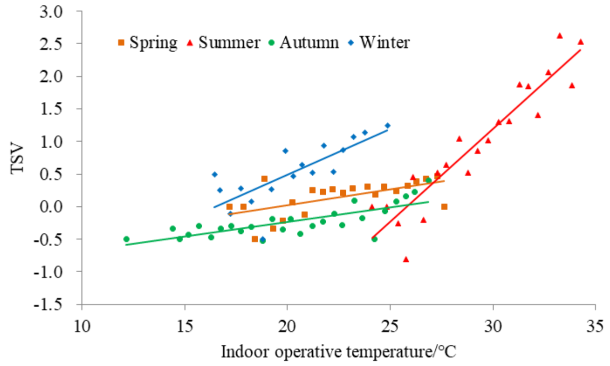



Figure 2. Seasonal TSV variations with indoor operative temperature

TABLE IV. SEASONAL LINEAR REGRESSION EQUATIONS OF TSV AND INDOOR OPERATIVE TEMPERATURE

| Season | Relationship between TSV and $t_{op}$ | | Neutral temperature/ ℃ |
|---|---|---|---|
| | Equations | $R^2$ | |
| Spring | $TSV = 0.048t_{op} - 0.94$ | 0.37 | 19.5 |
| Summer | $TSV = 0.284t_{op} - 7.32$ | 0.87 | 25.8 |
| Autumn | $TSV = 0.045t_{op} - 1.14$ | 0.57 | 25.4 |
| Winter | $TSV = 0.140t_{op} - 2.31$ | 0.60 | 16.5 |

The slopes of the equation indicate the sensitivity of human thermal sensation to temperature changes. The slopes are 0.048 in spring, 0.284 in summer, 0.045 in autumn and 0.140 in winter, respectively, indicating that TSV was highly sensitive to temperature change in summer, and less in spring and autumn. With the slopes being close, TSV in spring is higher than in autumn at the same indoor $t_{op}$. Comparing with spring and autumn, TSV at the same $t_{op}$ in winter is higher.

The neutral temperature for four seasons are shown in Table IV, which were 19.5 ℃, 25.8 ℃, 25.4 ℃ and 16.5 ℃ for spring, summer, autumn and winter, respectively, indicating that human thermal adaptability varies with seasons. Despite of the minor difference in mean outdoor temperature in transitional seasons of spring and autumn, it is interesting to note that thermal sensation is dominated by indoor $t_{op}$ instead of outdoor temperature. The neutral temperature for spring (19.5 ℃) is closed to that for winter (16.5 ℃), and neutral temperature for autumn (25.4 ℃) is closed to that for summer (25.8 ℃). This indicates that thermal experience in prior seasons may affect human thermal comfort in the seasons next.

### C. Seasonal Clothing Adaptation

Clothing adaptation is one of the most important ways to adapt to thermal environment and to maintain thermal comfort. Fig. 3 shows the distribution of clothing insulation in four seasons, the mean values in spring, summer, autumn and winter are 0.63clo, 0.35clo, 0.81clo and 0.76clo respectively. The seasonal clothing insulation ($I_{cl}$) variations with $t_{op}$ are shown in Fig. 4, and the linear regression equations of $I_{cl}$ and $t_{op}$ in four seasons are listed in Table V. The slopes of linear regression equations for spring, summer, autumn and winter are -0.066, -0.011, -0.081, and -0.036 respectively, indicating that $I_{cl}$ varies with indoor operative temperature in different seasons. There is a significant reduction in clothing level as $t_{op}$ increases from cool to warm temperatures in spring and autumn. In summer, a weak relation between $I_{cl}$ and $t_{op}$ was found because the limit of clothing adaptation when temperatures were higher than 26 ℃. For winter, despite the moderate slope, the tendency of changing $I_{cl}$ against $t_{op}$ was more close to that of spring and autumn.

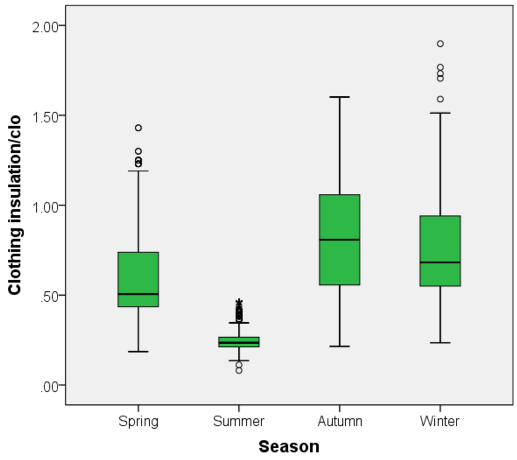



Figure 3. Seasonal distribution of the clothing insulation values

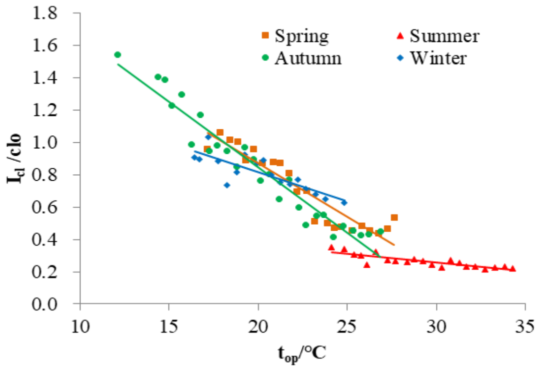



Figure 4. Seasonal clothing insulation variations with indoor operative temperature

TABLE V. SEASONAL LINEAR REGRESSION EQUATIONS OF CLOTHING INSULATION AND OPERATIVE TEMPERATURE

| Season | The linear regression equations | $R^2$ |
|---|---|---|
| Spring | $I_{cl} = -0.066t_{op}+2.19$ | 0.55 |
| Summer | $I_{cl} = -0.011t_{op}+0.58$ | 0.73 |
| Autumn | $I_{cl} = -0.081t_{op}+2.46$ | 0.94 |
| Winter | $I_{cl} = -0.036t_{op}+1.54$ | 0.70 |

### D. Seasonal Adaptive Thermal Comfort Model

According to ASHRAE55-2013 [9], the prevailing mean outdoor air temperature was calculated for each surveyed day, and the daily average of the neutral temperature of all subjects were also calculated using Griffiths method [25], that is, using the equation of $t_n = t_{op}$-TSV / G to calculate the neutral temperature, where G is Griffiths Constant, Nicol and Humphreys proposed to take 0.5 [26]. The seasonal adaptive thermal comfort models were subsequently established shown in Table VI and Fig. 5.

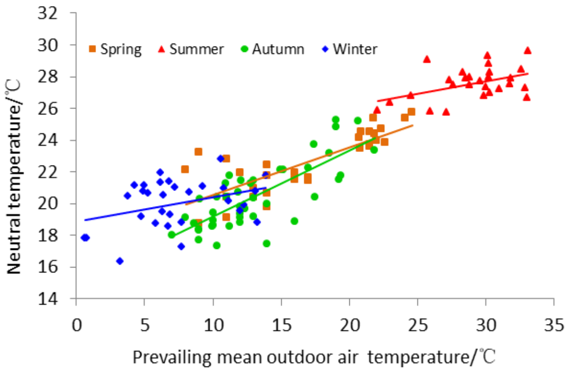



Figure 5. Seasonal and yearly adaptive thermal comfort models

TABLE VI. SEASONAL AND YEARLY ADAPTIVE THERMAL COMFORT MODELS

| Seasons | The linear regression equations | $R^2$ |
|---|---|---|
| Spring | $t_n = 0.31t_{out}+17.6$ | 0.63 |
| Summer | $t_n = 0.17t_{out}+23.0$ | 0.23 |
| Autumn | $t_n = 0.41t_{out}+15.0$ | 0.60 |
| Winter | $t_n = 0.16t_{out}+18.9$ | 0.15 |

The results show that slopes of the fitted equations in four seasons are different, with values being 0.31, 0.17, 0.41 and 0.16 for spring, summer, autumn and winter respectively. The slopes of spring and autumn are larger than summer and winter. Besides, indoor neutral temperatures have stronger correlation with outdoor air temperature in spring and autumn than in summer and winter, considering the determination coefficient $R^2$ in the equations. These findings suggest the seasonal characteristics of thermal adaptations and limited adaptability in summer and winter, which was accordant with the findings by Liu et al. [27] in Hot Summer and Cold Winter zone in China.

## IV. CONCLUSIONS

(1) The sensitivity of the human thermal sensation in spring, summer, autumn and winter was 0.048, 0.284, 0.045 and 0.140, and the neutral temperature was 19.5 ℃, 25.8 ℃, 25.4 ℃ and 16.5 ℃. Although the overall characteristics of the spring and autumn climate are the same, but the spring neutral temperature is closer to the winter, the autumn neutral temperature is closer to the summer, which may be due to the opposite direction of climate change between hot and cold, which provided a different seasonal thermal experience, behavioral and psychological adaptations.

(2) The sensitivities of clothing insulation varies with indoor operative temperature in four seasons were -0.066, -0.011, -0.081 and -0.036 respectively. The slopes of the linear regression equation for adaptive thermal comfort model was 0.31, 0.17, 0.41 and 0.16 in spring, summer, autumn and winter, respectively, which were caused by the seasonal behavioral and psychological adaptations.

(3) It can be concluded that there exists a strong relationship between climate seasonal change rhythm and the human thermal adaptation. The seasonal models can more accurately reflect the seasonal characteristics of dynamic climate, and can well reflect the seasonal human thermal adaptations.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Wuxing Zheng and Yu Liu conducted the research; Wuxing Zheng analyzed the data and wrote the paper; Yiming Zhang and Jin Wang carried out the field suvey; Seigen Cho and Yu Liu revised the paper; all authors had approved the final version.

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## REFERENCES

[1] M. A. Humphreys, "Field studies of thermal comfort compared and applied," *J. Inst. Heat. & Vent.Eng*, vol. 44, no. 1, pp. 5-27, 1976.

[2] M. A. Humphreys and J. F. Nicol, "Understanding the adaptive approach to thermal comfort," *ASHRAE Trans*, vol. 104, no. 1, pp. pp. 991-1004, 1998.

[3] G. S. Brager, R. J. de Dear, "Thermal adaptation in the built environment: a literature review," *Energy and Building*, vol. 27, no. 1, pp. 83-96, 1998.

[4] A. K. Mishra, M. Ramgopal, "Field studies on human thermal comfort d An overview," *Building and Environment*, vol. 64, pp. 94-106, 2013.

[5] M. A. Humphreys, "Outdoor temperatures and comfort indoors," *Building Research and Practice (Journal of CIB)*, vol. 6, no. 2, pp. 92-105, 1978.

[6] J. F. Nicol, I. A. Raja, A. Allaudin, et al, "Climatic variations in comfortable temperatures: the Pakistan projects," *Energy and Buildings*, vol. 30, no. 3, pp. 261-279, 1999.

[7] R. J. de Dear, S. B. Gall, "Developing an adaptive model of thermal comfort and preference," *ASHRAE Trans*, vol. 104, no. 1, 1998.

[8] K. J. McCartney, J. F. Nicol, "Developing an adaptive control algorithm for Europe: results of the SCATs project," *Energy and Buildings*, vol. 34, no. 6, pp. 623-635, 2002.

[9] ANSI/ASHRAE Standard 55. Thermal Environment Conditions for Human Occupancy; 2013.

[10] CEN. CEN Standard EN15251 Indoor environmental parameters for design and assessment of energy performance of buildings. Addressing indo or air quality, thermal environment, lighting and acoustics. Brussels: CEN, 2007.

[11] B. Cao, Y. Zhu, Q. Ouyang, et al, "Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing," *Energy and Buildings*, vol. 43, pp. 1051-1056, 2011.

[12] L. Yang, H. Yan, Y. Xu, et al, "Residential thermal environment in cold climates at high altitudes and building energy use implications," *Energy and Buildings*, vol. 62, pp. 139-145, 2013.

[13] H. B. Rijal, H. Yoshida, N. Umemiya, "Seasonal and regional differences in neutral temperatures in Nepalese traditional vernacular houses," *Buildings and Environment*, vol. 45, no. 12, pp. 2743-2753, 2010.

[14] B. Li, W. Yu, M. Liu, et al, "Climatic strategies of indoor thermal environment for residential buildings in Yangtze river region,

China," *Indoor Built Environment*, vol. 20, no. 1, pp. 101-111, 2011.
[15] A. A. de Paula Xavier, L. Roberto, "Indices of thermal comfort developed from field survey in Brazil," *ASHRAE Transactions,* vol. 106, no. 1, pp. 45-58, 2010.
[16] Z. Wang, L. Zhang, J. Zhao, et al, "Thermal comfort for naturally ventilated residential buildings in Harbin," *Energy and Buildings,* vol. 42, pp. 2406-2415, 2010.
[17] Z. Wang, "A field study of the thermal comfort in residential buildings in Harbin," *Buildings and Environment,* vol. 41, no. 8, pp. 1034-1039, 2006.
[18] T. Goto, T. Mitamura, H. Yoshino, et al, "Long-term field survey on thermal adaptation in office buildings in Japan," *Building and Environment*, vol. 42, pp. 3944-3954, 2007.
[19] Y. Zhang, J. Wang, H. Chen, et al, "Thermal comfort in naturally ventilated buildings in hot-humid area of China," *Building and Environment,* vol. 45, no. 11, pp. 2562-2570, 2010.
[20] H. Liu, Y. Wu, B. Li, et al, "Seasonal variation of thermal sensations in residential buildings in the hot summer and cold winter zone of China," *Energy and Buildings,* vol. 140, pp. 9-18, 2017.
[21] B. Cao. Research on the impacts of climate and built environment on human thermal adaptation. Beijing, PhD paper of Tsinghua University, 2012[In Chinese].
[22] W. Qu, H. Yan, L. Yang, et al, "Study on climate adaptation model for human thermal comfort in Xi'an in transition seasons," *Building Science*, vol. 30, no. 2, pp. 51-56, 2014[In Chinese].
[23] ISO 7726-2002, Thermal environments specifications relating to appliances and methods for measuring physical characteristics of the environment. Geneva: ISO, 2002.
[24] R. J. de Dear, E. Fountain Marc, "Field experiments on occupant comfort and office thermal environments in a hot-humid climate," *ASHRAE Trans*, vol. 100, no. 2, pp. 457-475, 1991.
[25] I. Griffths. Thermal comfort studies in buildings with passive solar features, field studies. UK: Report of the Commission of the European Community, ENS35 090; 1990.
[26] F. Nicol, M. Humphreys, "Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN15251," *Building and Environment,* vol. 45, pp.11-17, 2010.
[27] H. Liu, Y. Wu, B. Li, et al, "Seasonal variation of thermal sensations in residential buildings in the Hot Summer and Cold Winter zone of China," *Energy and Buildings,* vol. 140, pp. 9-18, 2017.



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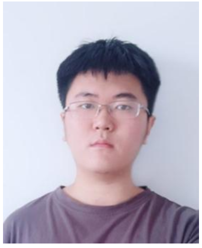
Asst. Prof. Zheng is a membership of Shaanxi Civil and Architectural Society. He won the second prize of science and technology for Shaanxi universities in 2019.



**Yiming Zhang,** born in Xi'an China in Apr. 1998, studied for a bachelor's degree at Northwestern Polytechnical University in Xi'an China since 2016, and his major is Architecture. He got a research project of Shaanxi University Student Innovation and Entrepreneurship Training Program in 2019, the Project name is 'Research on Indoor Environment Investigation and Green Development Strategy for Campus Apartment Buildings'. His current research interest is indoor thermal environment evaluation and thermal comfort.

**Jin Wang**, born in Shangluo, Shaanxi China in Jul. 1987, studied for a bachelor's degree at Tianjin University in Tianjin China from 2010, and obtained her master's degree in Architecture in Jan. 2013, and began her doctorate in Xi'an University of Architecture and Technology in Xi'an in Sep. 2017. The research fields are regionally suitable green building design standard, the passive design of rural buildings, the solar energy information system and design guides of solar energy application for the rural buildings.

She was offered a faculty position at Northwestern Polytechnical University in Xi'an China as a lecturer since Feb. 2014. Her current and previous research interests were evaluation system and construction planning in green community of northwest china. She obtained the national natural science foundation project for China youth in 2019, which focused on multi-objective optimization design of urban residence in the western solar enrichment area for schematic stage.

Ms. Wang won the second prize of science and technology for Shaanxi universities in 2019.

**Yu Liu,** born in Xi'an China in 1968, PhD in built environment, University of New South Wales, Sydnye, Australia, 2006; Mater of architecture at Xi'an University of Architecture and Technology in Xi'an, China, 1996. She is a PROFESSOR of architecture at the School of Mechanics, Civil Engineering and Architecture (SMCA), and DIRECTOR of the Sustainable Building and Environmental Research Institute (SBERI) in Northwestern Polytechnical University (NPU), Xi'an, China. She used to be vice dean of SMCA, visiting scholar at the University of Technology, Sydney (UTS), Australia and senior visiting scholar at the Royal Institute of Technology (KTH), Sweden. She has published 70 journal papers, 70 conference papers, 4 books, 2 textbook. Participated in the establishment of four regional green building design/assessment standards; owns 6 patents in the building design realm. Research interests include green, ecological and sustainable building & environmental design and assessment. Prof. Liu is a member of the Architects' Committee, the Architectural Society of China; a member of the Solar Building Committee, the Renewable Energy Society of China; a member of the Green Building and Energy Efficiency Committee, Green Building Council (ChinaGBC). She received more than 80 awards personally or through directing students, including: Second Prized of the 2019 Science and Technology Award of Universities in Shaanxi Province (1/11); Third Prize of the 2019 China construction Science and Technology Award (3/11); Best Presentation Award in the SBE 19 Seoul International Conference.

**Seigen Cho (Qingyuan Zhang)**, born in 1955, Doctor of Engineering at Kyushu University, Japan. The research areas are Architecture and building engineering, Architectural environment and Equipment. He is a PROFESSOR of Faculty of Urban Innovation Department of Urban Innovation in Institute of Urban Innovation in Yokohama National University. He has published more than 100 papers, such as 'Improvement of the hourly global solar model and solar radiation for air-conditioning design in China, Renewable Energy 2019(138), 1232-1238', 'Effect of building interface form on thermal

Hot-Humid Climates of Asia, Springer, 2018, ISBN: 9789811084645. His current research interests were Building Environmental Engineering, Building Equipment and Sustainability.

Prof. Cho won the highest honor of the architectural society of Japan in 2009, and received the best paper award of Journal of Asian Architecture and Building Engineering in 2006.