Literature Review Based on Field Investigation of Indoor Thermal Comfort

Feng Yuan¹ and Yu Wang¹ *

¹ School of Energy and Safety Engineering, Tianjin Chengjian University, Tianjin, China

*Corresponding author: wy41523@126.com

Abstract. Factors such as cultural background, cognition level, local climatic conditions and socioeconomic conditions have not been involved or simplified in laboratory research, so field research can more realistically reflect various psychological reactions and behavioral performances. By analyzing and summarizing in the existing domestic thermal comfort field survey and research results to propose directions for further research on thermal comfort.

Keywords: Thermal Comfort, Experimental Research, Field Investigation, Thermal Adaptability

Preface
The thermal adaptation model is based on field investigations, emphasizing the use of large-scale data collection and statistical methods, considering the dynamic characteristics of the environment. This article focus on introducing the research methods and results, and point out the development trend.

1. Thermal comfort field survey theory

1.1 Research Theory
The representative views of adaptive thermal comfort theory are mainly two categories: modified PMV model and thermal adaptation model. Fanger and Toftum [¹] use an "Expectation factor" to modify the PMV model. Yao Running [²] established adaptive predictive thermal sensory voting model based on the black box theory. Tsinghua University [³,⁴] proposed multivariate linear regression to correct PMV* relationship. Humphreys and Nicol proposed a thermal adaptation model to explain the error between the actual thermal sensation in natural-adjusted buildings and the predicted thermal sensation [⁵,⁶].

1.2 Research methods
Artificial climate chamber and field research are two common methods to study thermal adaptation. Field survey has three steps: sample selection, data collection and data processing [⁷]. The minimum sample size under the accuracy of the physical parameters is emphasized [⁸]. Data collection includes environmental parameter measurements and subjective investigations. Data processing method is linear regression method through mathematical statistics. To form Y = a + b (x), the seven-point index of ASHRAE is used [⁹], the human thermal neutral parameter value can be obtained when Y = 0.
2. Research results

2.1 Results of Thermal Comfort Field Survey
The field investigation research of thermal comfort in China began in the early 1990s. The results of some thermal comfort field surveys are listed in Table 1.

| Researcher          | Year       | location   | Building type                | Neutral temperature / acceptable temperature range                                                                 |
|---------------------|------------|------------|------------------------------|---------------------------------------------------------------------------------------------------------------|
| Xia Yizai[10]       | 1998       | Beijing    | Residential building        | 26.7 °C/the upper limit of acceptable temperature for 80% of people is 30 °C                                  |
| Lu Fang et al.[11]  | 1999       | Tianjin    | Residential and office buildings | The measured neutral temperature is higher than the predicted neutral thermal PMV neutral temperature               |
| Wang Zhaojun[7]     | 2002       | Harbin     | Residential building        | 21.5 °C/18.0 ~ 25.5 °C                                                                                         |
| Chen Qizhen[12]     | 2004       | Shenyang   | Commercial Building         | 18.9. °C/16.6~21.3 °C                                                                                            |
| Zhang Yufeng et al.[13,14] | 2009-2010 | Guangzhou  | Dormitory and classrooms    | 24.6 °C/16.5 ~ 32.8 °C                                                                                            |
| Zhang Lin[8], Wang Zhaojun et al.[15] | 2010        | Harbin     | Residential building        | Thermal neutral temperature in summer is 23.7 °C; thermal neutral temperature before and after heating are 25.1, 20.4 °C |
| Jin Ling et al.[16] | 2011-2012  | East Guangdong | Farm house            | The neutral temperature and acceptable temperature are similar to the measured results of natural ventilation buildings in cities but different from urban air-conditioned buildings. |
| Ren Jing[17]        | 2013—2014  | Harbin     | Residential building        | The heat neutral temperatures are 24.3, 21.8, 22.9, 23.0, 24.0 °C in before heating period, initial heating period, middle heating period, end heating period and after heating period, respectively. |
| Guo Fei et al.[18]  | 2016       | Dalian     | Residential building        | The thermal neutral temperature of the elderly is 21.33 °C, which is lower than the non-elderly 22.99 °C/ 16.07 ~ 22.78 °C. |
| Wu Mengyun[19]      | 2019       | Shihezi    | Nursing home                | 29. 21 °C/24.09 ~ 31.14 °C                                                                                      |
| Ji Xiangfei[20]     | 2019       | Guangzhou  | Hospital                    | The acceptable temperature range for 80% of medical staff is 24 ~ 25.45 °C.                                      |
2.2 Research results and applications of adaptive models

Most of the domestic field studies follow the traditional methods of foreign field studies, and obtain the neutral temperature and acceptable temperature range of the city or region. In 2003, Yang Liu [21] established the relationship between neutral temperature and average outdoor temperature for the first time based on the actual questionnaire survey. The domestic field results are listed in Table 2.

| Researcher       | Year   | Year     | Location                        | Building type          | Thermal adaptation model |
|------------------|--------|----------|---------------------------------|------------------------|--------------------------|
| Yang Liu[21]     | 2003   |          | Beijing, Xi’an, Guangzhou, Shanghai and other places | Residential building   | Tn = 0.30Tout,m + 17.9   |
| Mao Yan[22]      | 2005   | Frigid areas | Hot summer and warm winter areas | Residential building   | Tn=0.12Tout,m +21.5;     |
|                  |        | Cold areas |                                      |                        | Tn=0.27Tout,m +20.0;     |
|                  |        | Hot summer and cold winter areas | Residential building   | Tn=0.33Tout,m +16.9;    |
| Yang Wei[23]     | 2006   | Changsha | Classrooms                      | Tn=0.25Tout,m+16.6     |
| Liu Jing[24]     | 2007   | Chongqing | Classrooms                      | Tn = 0.23Tout,m+16.9   |
| Yang Qian[25]    | 2010   | Xi’an    | Urban house                     | Tn=0.2125to+20.47716   |
|                  |        |          | Rural house                     | Tn=0.6301to+9.7972     |
| Wang Zhaojun[26] | 2011   | Harbin   | Residential building            | Tn=0.302Tout,m-6.506   |
| Ge Cuiyu[27]     | 2011-2012 | Turpan | Residential building            | Tn=0.28Tout, m+21       |
| Feng Jialiang[28] | 2014 | Guangzhou | Shopping mall                  | Tn=0.3178 Tout, m+15.479 |

Regarding the application of the thermal adaptation model, Feng Jialiang [28] designed an on-site investigation plan and conducted a field survey with a large-scale integrated shopping mall in Guangzhou, laying the foundation for the establishment of the mall's thermal comfort model. Wang Yan [29] proposed the construction process and method of functional quality house with thermal comfort requirements. The results of the ranking of the importance of human thermal comfort requirements and the prioritization of product functional characteristics were obtained.

2.3 Cutting-edge results of thermal comfort models

Regarding the wet and mass transfer in the thermal comfort model, its boundary conditions and equations are also more complicated. Du Chenqiu et al. [30] explored the effect of moisture in clothing on human thermal response, and revealed the negative hygroscopicity and hygroscopicity in the microenvironment of clothing in cold climates. Accurate analysis of the psychological effects in the establishment of thermal comfort models is still in the exploratory stage. Chen Yu et al. [31] proposed the seasonal behavior of people in the Chinese cultural background based on the 24 solar terms, and explored its potential impact on human climate adaptability. Regarding the proposal of the new model, Ji Wenjie et al. [32] used the data in the ASHRAE thermal comfort database and combined with the SET to establish a predicted thermal sensation PTS model.

3. Research directions
(1) Enrich the database for basic research. Personalized comfort conditions need to be studied to provide more personality for different types of population. Enrich the basic databases of different climate regions, different building types, and people with different characteristics to provide theoretical and data support for the formulation and improvement of building environmental standards.

(2) Improve the thermal adaptation model. Make the factors which affects thermal comfort more comprehensive and refined. New factors have been taken into consideration, such as combining adaptive behavior related to Chinese culture. Pay more attention to the microenvironment.

(3) The thermal comfort model is more closely related to product design and building energy consumption. It is necessary to start from the source of product design, fully consider the diversity and complexity of human thermal comfort requirements, and establish a mapping between thermal comfort requirements and product functional requirements to convert thermal comfort requirements to the product structure design process.

References
[1] Fanger P O, Toftum J. Thermal comfort in the future Excellence and expectation [C]//Conference Proceedings on Moving Thermal Comfort Standards into 21st Century. Windsor, UK, 2001:11-18.
[2] Running Yao, Baizhan Li, Jing Liu. A theoretical adaptive model of thermal comfort-Adaptive Predicted Mean Vote (aPMV)[J]. Building and Environment, 2009, 44: 2089-2096.
[3] Ouyang Qin. Study on dynamic characteristics of airflow and influencing factors in built environment[D]. Beijing: Tsinghua University,2005.
[4] Ouyang Qin, Dai Wei ,Zhu Yingxin. Spectral characteristics analysis of natural and mechanical wind in building environments [J]. Journal of Tsinghua University (Science and Technology) ,2005, 45(12): 1585-1588.
[5] Humphreys MA. Field studies of thermal comfort compared and applied [J]. J. Inst. Heat. & Vent. Eng., 1976, 44(1): 5-27.
[6] Nicol JF, Humphreys MA. Thermal comfort as part of a self-regulating system [J]. Building Research and Practice, 1973, 6 (3): 191-197.
[7] Wang Zhaojun, Fang Xiumu ,Lian Leming. Field experiments on occupant thermal comfort in Harbin [J]. Journal of Harbin Institute of Technology,2002(04):500-504.
[8] ZhangLin. Study on adaptation and thermal comfort of residents in Harbin [D]. Harbin Institute of Technology, 2010.
[9] ASHRAE. Thermal environment conditions for human occupancy: ANSI/ASHRAE Standard55—2010 [S]. Atlanta G A: American Society of Heating, Ventilating and Air – Conditioning Engineers, Inc., 2011: 3.
[10] Xia Yizheng, Zhao Rongyi, Jiang Yi. Thermal comfort in naturally ventilated houses in Beijing. Heating Ventilating & Air Conditioning,1999(2):1-5.
[11] Lu Fang, Tu Guangbei, Li Jingguang. Test and analysis of human thermal comfort in Tianjin in summer [C]. Proceedings of the 2000 National Annual Conference of HVAC and Refrigeration. Beijing: China Construction Industry Press, 2000: 636-639.
[12] Chen Qi zhen. Field survey and analysis of winter thermal comfort in Shenyang shopping malls [C]. National HVAC Refrigeration 2004 Annual Conference Summary (1). China Architectural Association HVAC Specialty Committee, China Refrigeration Society Air Conditioning Heat Pump Professional Committee: China Refrigeration Society, 2004: 37.
[13] Zhang Yufeng, Chen Huimei, Meng Qinglin. Field study on thermal comfort and adaptation in buildings with split air-conditioners in hot-humid area of China (1) :Thermal environment and perceptions [J]. Heating Ventilating & Air Conditioning, 2014, 44 (1) : 6-14.
[14] Zhang Yufeng, Chen Huimei, Meng Qinglin. Field study on thermal comfort and adaptation in buildings with split air-conditioners in hot-humid area of China (2) :Adaptive behaviors[J]. Heating Ventilating & Air Conditioning, 2014, 44 (1) : 15-23.
[15] Wang Zhaojun, Zhang Lin, Zhao Jianing, et al. Thermal comfort for naturally ventilated residential buildings in Harbin [J]. Energy and Buildings, 2010, 42(12): 2406-2415.

[16] Jin Ling, Meng Qinglin, et al. Indoor Environment and Thermal Comfort in Rural Houses in East Guangdong of China [J]. Journal of Civil and Environmental Engineering, 2013, 35(2): 105-112.

[17] Ren Jing. Field Study on Human Thermal Adaption at Residential and Office Buildings in Severe Cold Area [D]. Harbin: Harbin Institute of Technology, 2014.

[18] Guo Fei, Zhang Hezi. Comparative research on thermal adaptive model of elderly people and non-elderly people in naturally ventilated house [J]. Journal of Dalian University of Technology, 2016, 36(02): 147-152.

[19] Wu Mengyun, Jiang Shuguang, Dai Jin, Xu Xin. Investigation on summer thermal comfort of a nursing home in Shihaiji Xinjiang [J]. Journal of Shihezi University (Natural Science), 2019, 37(04): 445-451.

[20] Ji Xiangfei. Thermal Environment Parameters and Thermal Comfort in Hospital Obstetrics Clinic [D]. Guangzhou University, 2019.

[21] Yang Liu. Climatic Analysis and Architectural Design Strategies for Bio-climatic Design [D]. Xi’an: Xi’an University of Architecture and Technology, 2003.

[22] Mao Yan. Study on Climate Adaptability of Human Beings to Thermal Comfort in China [D]. Xi’an: Xi’an University of Architecture and Technology, 2006.

[23] Yang Wei. The Investigation of Thermal Comfort and Thermal Adaptation in Residential Buildings during the Summer Season of Hot Summer/Cold Winter Region [D]. Changsha: Hunan University, 2007.

[24] Liu Jing. Study on the Indoor Thermal Environment and Human Thermal Comfort In Natural Ventilation Building in Summer-Hot and Winter-cold Zone [D]. Chongqing: Chongqing University, 2007.

[25] Yang Qian. Study on the Indoor Thermal Comfort in the Cold Zone [D]. Xi’an: Xi’an University of Architecture and Technology, 2010.

[26] Wang Zhaojun, Zhang Lin, Zhao Jianing, et al. Thermal responses to different residential environments in Harbin [J]. Building and Environment, 2011, 46: 2170-2178.

[27] Ge Cuiyu, Yang Liu, Liu Dalong, He Wenfang, DU Xiaolei. Study on Passive Design Strategy Based on Human Thermal Comfort-taking Rural Housings in Turpan for example [J]. Building Science, 2013, 29(12): 66-71.

[28] Feng Jialiang. Thermal Comfort Research and Energy-saving Control Optimization in Air-conditioning Terminal of a Shopping Mall [D]. Guangzhou: South China University of Technology, 2014: 39-40.

[29] Wang Yan. Research on theory and method of air-conditioner energy saving design based on the thermal comfort [D]. Hefei University of Technology, 2015.

[30] Chen Qiu Du, Baizhan Li. Moisture in clothing and its transient influence on human thermal responses through clothing microenvironment in cold environments in winter [J]. Building and Environment, 2019, 150: 1-12.

[31] Chen Yu, Chen Bin, Zeng Chen, Wang Shibo, Zhang Xueyan. Correlative Analysis between Seasonal Behaviors and Climate Inadaptability [J]. Building Science, 2018, 34(02): 115-117+146.

[32] Ji Wenjie Cao Bin Zhu Yingxin. Development of a new thermal adaptive predicted model——PTS (predicted thermal sensation) model [J]. Heating Ventilating & Air Conditioning, 2019, 49(06): 39-45+73.