Proceedings of 7th Windsor Conference: ***The changing context of comfort in an unpredictable world*** Cumberland Lodge, Windsor, UK, 12-15 April 2012. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

The Chinese Evaluation Standard for the Indoor Thermal Environment in Free-running Buildings

Baizhan Li [1*], Runming Yao [2], Qinqing Wang[3], Yangang Pan[4]， Wei Yu[1]

[1]. Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, Chongqing University, Chongqing 400045, P. R. China
[2]. School of Construction Management and Engineering, the University of Reading, Whiteknights, PO Box 219, Reading RG6 6AW, UK
[3]. China Academy of Building Research, Beijing 100013, P. R. China
[4]. China Architecture Design & Research Group, Beijing 100044, P. R. China

Corresponding author: baizhanli09@gmail.com

Abstract
Designing for indoor thermal environmental conditions is one of the key elements in the energy efficient building design process. This paper overviews the investigation of thermal comfort conditions in China and relevant energy efficiency issues. A development of the Chinese evaluation standard for indoor thermal environments based on intensive field and laboratory studies has been introduced. Over 20,000 subjects participated in the field study for the different climate zones in China and over 500 subjects have been involved in laboratory studies. International standards such as the ASHRAE55, ISO7730, DIN EN Standards have been reviewed. The research findings reveal that there is a need for updating the Chinese thermal comfort standard based on local climates and people's habitats. This paper introduces in detail the requirements for the thermal environment for heated and cooled buildings and free-running buildings for different climate zones in China.

Keywords: indoor thermal environment, adaptive thermal comfort, Chinese standard, Adaptive Predicted Mean Vote (aPMV) model , climate zones in China

1. Introduction

China has a diverse climatic character, as a result, five climate zones have been classified for the purpose of building design: the very Cold zone, Cold zone, Hot Summer and Cold Winter zone, Hot Summer and Warm Winter zone, and Mild zone (GB50178-93 1993) (see Fig. 1). There is little guidance on indoor temperature settings; therefore it is usually dependent on occupants' preferences. There has been a greatly increasing trend in energy consumption for heating and cooling buildings. Due to the pressures of building energy efficiency and reduction of carbon emission, in 2007, China's State Council issued an ordinance (Guobanfa 2007) that requires the indoor air temperature setting of air conditioners to be no lower than 26℃ for cooling during the summer in offices.

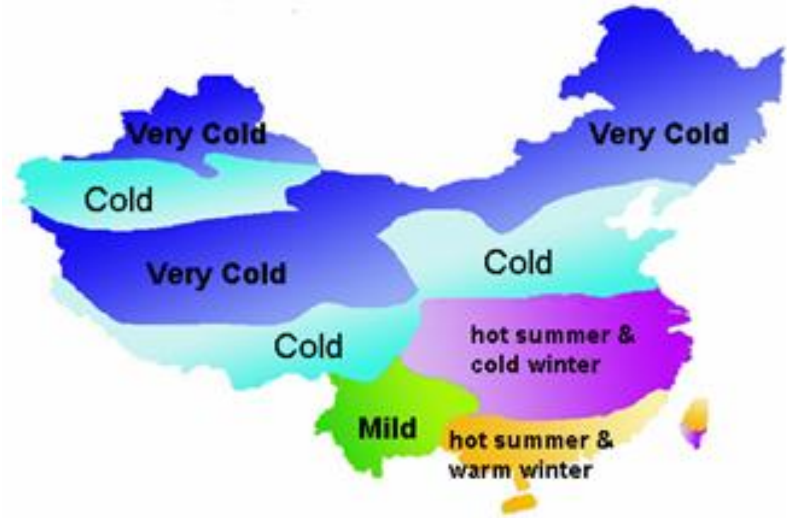

Figure 1: Five climate zones for building design in China

2. International thermal comfort standards

Thermal comfort standards determine indoor thermal environmental conditions and the energy consumption by a building's environmental systems; therefore they play an important role in building sustainability. International standards such as ISO 7730 (ISO7730 1994) and the ASHRAE Standard 55-92 (ANSI/ASHRAE55-1992 1992) define comfort zones by applying Fanger's Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) method, which is based on steady-state, human body heat balance theory (Fanger 1970). The thermal comfort standard has been challenged by the claim that energy saving will be achieved by switching from the traditional PMV-PPD-based comfort standard to an adaptive comfort standard (de Dear and Brager 2002). Thereafter, an Adaptive model for the thermal Comfort assessment has been updated to the ASHRAE Standard 55 (ANSI/ASHRAE55-2004 2004) and the International Organization for Standardization 7730 was also updated in 2005 (ISO7730 2005). The latest version of ISO 7730 (ISO7730 2005) considers the adaptations of occupants and includes the method for the long-term evaluation of general thermal comfort conditions. They recommended that thermal comfort conditions are presented in terms of three categories: A, B and C, respectively. The level of category that should be applied is determined by the individual country or contract between client and designer (Olesen 2004). The Chartered Institution of Building Services Engineers' Guide A (CIBSE-Guide-A 2006) provides the adaptive thermal comfort approach and presents the corresponding adaptive thermal comfort temperature ranges based on the outdoor running mean temperature for offices. Table 1 lists design criteria for thermal comfort in office workplaces.

Table 1: Thermal comfort criteria for offices

Thermal Comfort Standard	Recommended Values			
ASHRAE Standard 55	80% Criteria		-0.85<PMV<+0.85	
	90% Criteria		-0.5<PMV<+0.5	
ISO 7730	Category	PPD	Summer (°C)	Winter (°C)
	A	PPD<6%; -0.2<PMV<+0.2)	24.5 ± 1.0	22.0 ± 1.0
	B	(PPD<10%; -0.5<PMV<+0.5)	24.5 ± 1.5	22.0 ± 2.0
	C	(PPD<15%; -0.7<PMV<+0.7)	24.5 ± 2.5	22.0 ± 3.0
CIBSE Guide A	Air-conditioned Building	PPD<10%; -0.5<PMV<+0.5)	Summer (°C)	Winter (°C)
			22-24	21-23

The international comfort standards, such as the ASHRAE standards and the International Standards Organization (ISO), are almost all based on North American and northern European subjects (Olesen and Parsons 2002; ISO7730 2005). Do these standards apply to environments where conditions vary? Can international standards be applied directly in the China context? Extensive literature reviews in respect of thermal comfort studies in China have been conducted.

3. Thermal comfort study in China

In the last decade, nationwide thermal comfort studies have been carried out in China in different types of buildings and different climate zones, including laboratory and field studies(Mao, Liu et al. ; Wang 2006; Liu, Lian et al. 2007; Yang and Zhang 2008; Han, Yang et al. 2009; Liu, Xiaolei Ma et al. 2009; Tan, Li et al. 2009; Wenjie Li, Li et al. 2009; Li, Li et al. 2010; Li, Tan et al. 2010; Wang, Zhang et al. 2010; Cao, Zhu et al. 2011; Wang, Zhang et al. 2011). The common findings are that there are discrepancies between real thermal sensation and the predicted thermal sensation, especially for naturally ventilated buildings. It was found that the Chinese people have a broader range of tolerance of thermal stress. The PMV model overestimates/underestimates thermal sensations in summer and winter respectively in free-running buildings. As a result, the guidance on thermal environment design based on the PMV-PPD concept could lead to excessive use of energy for improving indoor thermal environments. Chinese people are very active in adapting the indoor thermal environment by behavioral adaptation, in particular those who live in hot and humid climate areas. The previous thermal experience and psychological expectations also play a role in adapting thermal environments in real situations in China. There was no heating/cooling policy in the south area, therefore people from this area are more tolerant of thermal discomfort. However the situation could change due to the gradually improved indoor thermal environment as a result of the economic affordability of energy in recent years. Figure 2 shows the indoor thermal environment in buildings in the south and north of China from a nationwide field study in fourteen major cities, including Harbin, Beijing, Xi'an, Chongqing, Chengdu, Changsha, Wuhan, Shanghai, Fuzhou and Guangzhou. From the figure we can see the worst conditions, with indoor temperatures of over 30℃ in summer and below 15℃ in winter, are in southern China. In recent years, air conditioning and electronic heating devices have become increasingly popular in south China due to an increased demand for improving living conditions. For example, the annual growth rate for sales of air-conditioners is about 20% (China 1994-2010) .

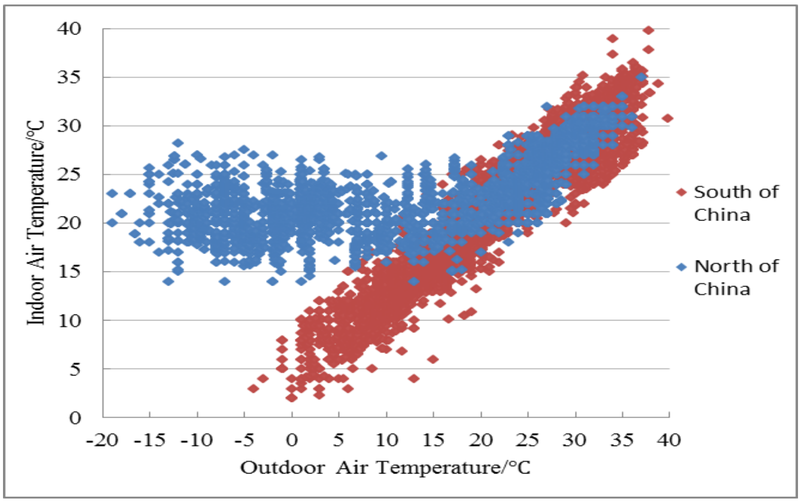

Figure 2: Indoor thermal conditions in China

Existing Standards

The existing relevant Chinese standards are listed in Table 2. They were mostly developed for environmental systems design and indoor environment evaluation purposes.

Table 2: **Existing standards** for the design and evaluation of indoor environments

Year	Name of the code	Purpose	Criteria	References	Other information
1985	Optimum temperature in an air-conditioned room GB/T 5701-85	Evaluation and design for civil buildings	Operative temperature		Replaced by GB/T 5701-2008
1993	Thermal Design Code for Civil Buildings GB50176-93	Thermo-technical design of civil buildings			
1998	Hot environments – Estimation of the heat stress on a working man, based on the WBGT index (wet bulb globe temperature) GB/T17244	An evaluation of the mean effect of heat on a man during a period representative of his activity	WBGT index (wet bulb globe temperature)		Equivalent to ISO7243:1989
2000	Moderate thermal environments - Determination of the PMV and	Evaluation and design for civil	PMV-PPD Operative	ISO7933-1989	Equivalent to ISO7730:1994

	PPD indices and specification of the conditions for thermal comfort GBT18049-2000	buildings	temperature	GB/T17244 - 1998	
2003	Code for design of heating ventilation and air conditioning GB50019-2003	Design for HVAC of civil buildings	PMV-PPD Indoor temperature	GB/T 18049-2000	Replaced by GB 50019-2011
2005	Design standard for energy efficiency of public buildings (GB50189-2005 2005)	Energy-efficient building design	PMV-PPD Indoor temperature		
2008	Thermal environmental conditions for human occupancy GB/T 5701-2008	Evaluation for the thermal environment in civil buildings	PMV-PPD Operative temperature	ANSI / ASHRAE 55 - 2004	.
2011	Code for design of heating ventilation and air conditioning GB 50019-2011	Design for HVAC in civil buildings	PMV-PPD Indoor temperature	GB/T 18049-2000 GB 50019-2003	

The standard 'Moderate thermal environments - Determination of PMV and PPD indices and specification of conditions for thermal comfort' (GB/T18049-2000 2000) was the first national standard specifically focusing on indoor thermal environments and thermal comfort. This standard is the equivalent application of ISO 7730-1994, which has been used for indoor thermal conditions and thermal comfort assessment of the conditions of healthy, seated people with standardized clothing insulation of 0.5clo in summer and 1.0clo in winter (GB/T18049-2000 2000).

The 'Design standard for energy efficiency of public buildings' (GB50189-2005 2005) is the guide to the energy efficiency design of the new, refurbished and extended public buildings to meet the 50% building energy consumption reduction target. It specifies the comfortable indoor design parameters for centrally-heated and air-conditioned spaces, respectively.

In 2008, 'Thermal environmental conditions of human occupancy' (GB/T5701-2008 2008) was released to replace the code 'Optimum temperature in air-conditioned rooms' (GB/T5701-1985 1985). This code specifies the acceptable operative temperature and relative humidity ranges for typical indoor spaces and provides the variable range of given environmental parameters which may cause local thermal discomfort. The dynamic indoor operative temperature was introduced as a function of the mean monthly outdoor temperature by considering the adaptations of occupants. This standard can be regarded as the equivalent application to ASHRAE 55-2004.

To summarize, the existing Chinese standards relevant to indoor environmental design and thermal comfort evaluation mainly adopt international standards based on the PMV-PPD indices. Few methods and research outcomes in the China context are included in these standards. As mentioned above, extensive research identified the discrepancies between the predicted PMV and actual thermal sensation AMV obtained from nationwide field studies carried out in China in recent years. Few methods of evaluating adaptive thermal comfort are introduced in those standards, although adaptive thermal comfort concepts are acknowledged. The new code 'Evaluation standard for indoor thermal environments in civil buildings' (Evaluation Standard thereafter) attempts to provide methods and guidance to assess indoor thermal comfort in line with the China context.

4. The new evaluation standard

4.1 General Information

Scope

This standard is suitable for the evaluation of the indoor thermal environment in residential and public buildings including offices, malls, hotels and classrooms for science and higher education, and is applicable to healthy adults.

The Evaluation Standard can take a room or area in a building as the assessment objective or may also take an entire building. A building is said to have reached a specified grade if over 90% of its rooms or areas reach the conditions of that grade.

Considering the different economic situations and the different application requirements of the buildings in different regions, this provision specifies that the indoor thermal environment in civil buildings should be classified according to whether a building has been heated and cooled or whether it is free-running. These two types of evaluation will comply with the requirements.

Contents

Data are collected from both field studies and climate chamber experiments. This standard emphasizes the evaluation of indoor thermal environments, takes into account vast regions, great climate diversity and significant sensation differences and comprehensively considers human adaptation. The evaluation method for the indoor thermal environment is suitable for heated, cooled and free-running buildings in different climate zones. The standard attempts to provide a concept and methodology to create an acceptable and energy-efficient indoor thermal environment. The main technical contents of this standard include:

1) General Provisions;
2) Terminologies;
3) Basic Requirements;
4) Requirements for Indoor Thermal Environments in Heated and Cooled Buildings;

5) Requirements for Indoor Thermal Environments in Free-running Buildings;
6) Measurement of the Basic Parameters of an Indoor Thermal Environment.

The heated/cooled buildings are equipped with and used mechanical heating and cooling systems. The indoor thermal environment assessment criteria mainly adopt PMV-PPD indices. Three categories: I, II and III, are introduced. In general, Category I represents ‘90% satisfactory’, Category II represents ‘75% satisfactory’, Category III represents ‘not acceptable’. Table 3 lists the PMV-PPD assessment criteria for the heated/cooled buildings. Due to the page limitations, this paper will focus on the indoor thermal environment in free-running buildings.

Table 3: Thermal comfort assessment criteria PMV-PPD

Thermal Comfort Standard	Recommended Values		
Evaluation standard for indoor thermal environments in civil buildings	Category	For heated and cooled buildings	
	I 90% satisfactory	PPD≤10 %	-0.5≤PMV≤+0.5
	II 75% satisfactory	10%＜PPD≤25 %	-1≤PMV＜-0.5 or +0.5＜PMV≤+1
	III Unacceptable	PPD＞25%	PMV＜-1or PMV＞+1

Compliance

The evaluation of an indoor thermal environment shall be divided into evaluation in the design stage and evaluation in the operation stage. The evaluation in the design stage is referred to here as "design evaluation" and the evaluation in the operation stage is hereinafter referred to as "operation evaluation”. The design evaluation shall be conducted after completion of the construction drawing of a building design. For the building applying for design evaluation, the following materials must be provided:

The appraisal documents from government and the relevant authorities, including project approval and planning license;

- Design and construction drawing documents including the relevant HVAC design specification, drawings and calculations;

- Construction appraisal certificates.

The process for a building’s operation evaluation should be taken after one year of the building coming into use. In addition to the above listed documents, construction acceptance certificates and the detailed information on the indoor thermal environment are required.

Evaluation methods for the thermal environment will be chosen depending on whether the calculation or graphical method is used. These will be described in section 5. If it poses difficulties with adopting the calculation and/or graphical methods, the survey method should be performed by an impartial third institution.

5. Thermal comfort assessment of free-running buildings

5.1 Calculation Method – Adaptive Predicted Mean Vote (aPMV)

Thermal environment refers to the circumstances comprising several physical factors such as air temperature and humidity, air velocity, solar radiation and the surface temperature of the surrounding objects. The indoor thermal environment is affected by the ambient conditions through the external and internal heat exchanges of a building. A building's thermal process has a dynamic status during the day and varies from season to season according to the external climate fluctuations. Passive environmental systems such as building envelope insulation, passive solar radiation, shading devices, natural ventilation and thermal mass, in conjunction with night ventilation, will play the role of regulator in achieving a comfortable indoor thermal environment. However, in some poor weather conditions normally in both summer and winter, passive systems are not capable of achieving a thermally comfortable environment. As a result, a mechanical system such as heating, cooling and air-conditioning is required. Good passive building designs can 'produce' the indoor thermal environment according to variations in the outdoor climate, meanwhile, it can prevent heat losses in winter and heat gains in summer thus reducing the burden on mechanical systems as far as possible. In China, during the spring and autumn seasons, many buildings are free-running (not heated or cooled). Occupants interact with environmental systems in order to achieve thermal comfort through adaptations (physiological, psychological and behavioral). The mechanism of achieving thermal comfort involves 'creation' and 'adaptation' behaviors from both environmental systems and people, as shown in Figure 3.

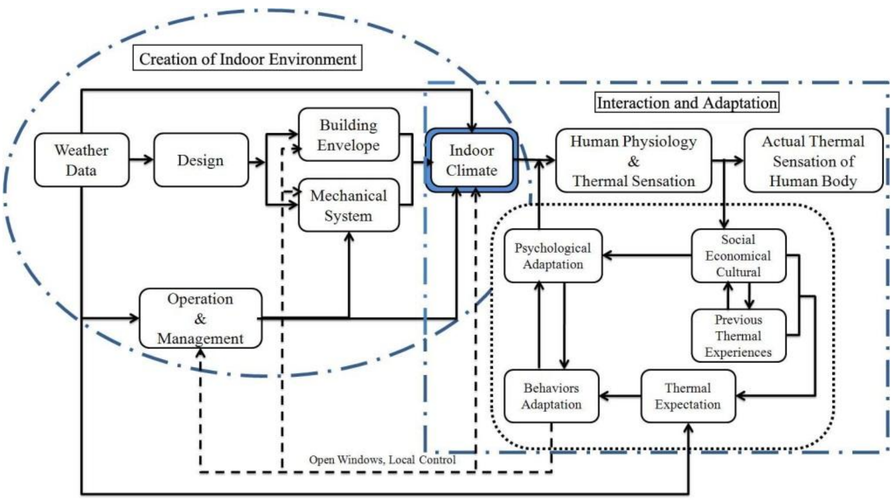

Figure 3: Mechanism of adaptive thermal comfort

The principle of adaptive thermal comfort is expressed as: if change occurs such as to produce discomfort, people react in ways which tend to restore their comfort (Nicol and Humphreys 2002). Recent research (Liu, Yao et al. 2011) carried out in free-running buildings in China demonstrates that occupants are active players in environmental control and their adaptive responses are driven strongly by ambient thermal stimuli and vary from season to season and from time to time, even on the same day. Thermal adaptation is a dynamic process of behaviors involving technological, personal and psychological adaptations in response to varied thermal conditions.

A theoretical adaptive model of thermal comfort based on the cybernetic engineering 'Black Box' theory, taking into account factors such as culture, climate and social, psychological and behavioral adaptations which have an impact on the senses used to detect the indoor thermal comfort, was proposed. This aimed to investigate the relationship between actual predicted mean vote and predicted mean vote (Yao, Li et al. 2009). The model is called the Adaptive Predicted Mean Vote (aPMV) model. The aPMV model explains, by applying the cybernetics concept, the phenomenon whereby the Predicted Mean Vote (PMV) is greater than the Actual Mean Vote (AMV) in free-running buildings, which has been revealed by many researchers in field studies. The equation for the aPMV has been proposed as follows:

$$aPMV = \frac{PMV}{1 + \lambda PMV} \quad (1)$$

Where, λ is the *adaptive coefficient*, which has a positive value when in warm conditions and a negative value when conditions are cool.

Equation (1) revealed the generic relationship of the Adaptive Predicted Mean Vote (aPMV) and the Predicted Mean Vote (PMV) in free-running buildings. This involves the adaptive coefficient, λ, which reflects a human's adaptive functions such as behavioral and psychological adaptation. When λ is equal to zero, the aPMV is equal to the PMV, which is the lab-based condition with no adaptive action. In warm conditions, that is when the PMV is greater than zero, the aPMV will be less than the PMV; in cool conditions, that is when the PMV is less than zero, the aPMV will be greater than the PMV. This model has explained the phenomenon whereby the discrepancy in the results between the field surveys and rational indices is based on the cybernetics concept. The empirical coefficient λ in warm and cool conditions can be derived by applying the least square method to the monitored onsite environmental data and the thermal comfort survey results. The detailed illustration of the method can be found in (Yao, Li et al. 2009).

Extensive field studies involving onsite environmental parameters monitoring and simultaneous thermal sensation surveys have been carried out in China from 2007 to 2011 in order to obtain the *adaptive coefficients*, *λ*, suitable for various regions in China. The empirical values obtained are listed in Table 4.

Table 4: Values of the adaptive coefficient λ

Climate zones \ Types		Residential buildings, Small department store, Lodge, Office	Meeting room, Classroom
Very cold, Cold **zones**	PMV ≥ 0	0.24	0.21
	PMV < 0	-0.50	-0.29
Hot summer and cold winter, Hot summer and warm winter, and Mild zones	PMV ≥ 0	0.21	0.17
	PMV < 0	-0.49	-0.28

The thermal environment evaluation grades I, II, III can be assessed according to the value of aPMV, which is illustrated in Table 5.

Table 5: Assessment Category for indoor thermal environments in free-running buildings

Category	**Assessment index**
I (90% satisfactory)	- 0.5 ≤ aPMV ≤ 0.5
II (75% satisfactory)	-1 ≤ aPMV < - 0.5 or 0.5 < aPMV ≤ 1
III (Unacceptable)	aPMV < -1 or aPMV > 1

5.2 Graphic Method

China is a large country with an area of about 9.6 million km^2. About 98% of its land area stretches between the latitudes 20°N and 50°N, from subtropical zones in the south to the temperate zones (including warm-temperate and cool-temperate) in the north. The northern area includes the Very Cold zone and Cold zone and the southern area includes the Hot Summer and Cold winter zone, Hot Summer and Warm Winter zone and Mild zone. The division between the southern and northern areas is determined by making reference to "Thermal Design Code for Civil Building" (GB50176-93 1993).

Graphics have been produced to provide information about the operative temperature zones based on the method of the adaptive model introduced in ASHRAE55-2004 (ANSI/ASHRAE55-2004 2004) and survey data from field studies and laboratory experiments in China. Operative temperature ranges for different climate zones have been produced. Figures 6 and 7 demonstrate the recommended indoor operative temperature ranges for free-running buildings in the Very Cold and Cold zones (Northern area) and in the Hot Summer and Cold Winter, Hot Summer and Warm Winter, and Mild zones (Southern area), respectively.

The upper and lower limits of indoor operative temperatures for category I which represent 90% satisfaction, are 18oC to 28oC respectively. Category II corresponds to 75%-90% satisfaction. The lower temperature limit of category II is 16oC, which is applicable to the case where people's clothing insulation in winter is thicker in the room; the upper limit of category II is 30oC, which is applicable to the environment where people's clothing insulation in summer is 0.5Clo or less, and the conditions for the local control of indoor air velocity are met and the indoor air velocity could be increased appropriately.

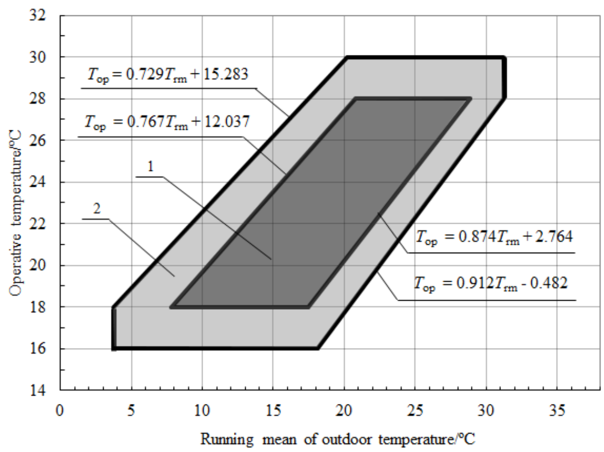

Figure 4: Range of the Indoor Operative Temperature of the Thermal Environment in Free-Running Buildings in the Very Cold and Cold Zones

1——the category I; 2——the category II

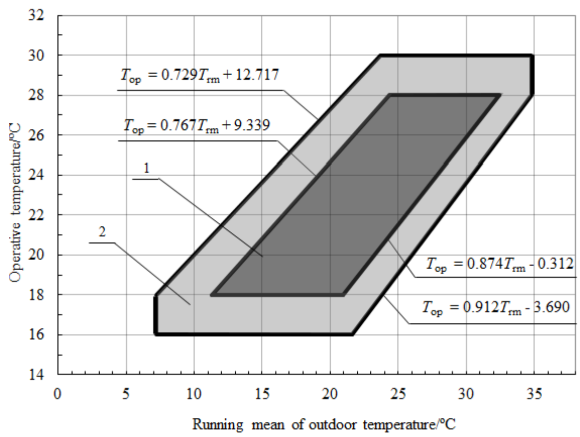

Figure 5: Range of the Indoor Operative Temperature of the Thermal Environment in Free-Running Buildings in the Hot Summer and Cold Winter Zone, the Hot Summer and Warm Winter Zone and the Mild Zone

1——the category I; 2——the category II

When using the graphical method to evaluate the thermal environment in free-running buildings, either Figure 4 or Figure 5 should be selected according to the zone where the building is located. The indoor operative temperature for different regions and different grades should be determined in line with Figures 4 and 5 according to the running mean outdoor temperature, which should be calculated according to formula 2 (Nicol and Raja 1996):

$$T_{rm} = (1-\alpha)(T_{od-1}+\alpha T_{od-2}+\alpha^2 T_{od-3}+\alpha^3 T_{od-4}+\alpha^4 T_{od-5}+\alpha^5 T_{od-6}+\alpha^6 T_{od-7}) \qquad (2)$$

Where,

T_{rm}—— running mean of outdoor temperature (°C);

A —— constant, recommended 0.8;

T_{od-n}—— daily mean outdoor temperature for n days ago (°C).

Conclusion

It is challenging to design and create an improved, comfortable and healthy indoor environment with minimum energy use. Indoor thermal environment evaluation can provide guidance in designing and operating a building to achieve comfortable and acceptable indoor thermal environments and energy efficiency. The existing Chinese indoor environment design codes and indoor thermal environment evaluation standards mainly adopt international standards such as ASHRAE and ISO, the methods of which are based on the PMV-PPD. Occupants' actual thermal sensations in real conditions in free-running buildings in China have been identified as different to those used to produce the international standards. Extensive field studies involving onsite indoor environment parameter monitoring and subjective surveys have been conducted in fourteen major cities covering different climate zones and building types to form the databases of the new evaluation standard for indoor thermal environments. For the heated/cooled buildings, three categories are used with modified ranges which are described in Table 3. The concept of adaptive thermal comfort has been introduced and three evaluation methods have been provided in the new evaluation standard for free-running building assessment. One is the calculation method based on the adaptive predicted mean vote (aPMV) model. Adaptive Coefficients, λ, for different climatic zones are provided in Table 4, which were obtained from extensive field studies. The second is the graphic method based on operative temperature criteria and the running mean outdoor temperature. Two categories - Category I with 90% and Category II with 75-90% satisfaction - are suggested for northern and southern areas in China, as illustrated in Figures 4 and 5. And the third one is the survey method.

The new evaluation standard classifies buildings into two types: 1) heated/cooled and 2) free-running. Different evaluation criteria have been provided for each. Current international comfort standards only cover building types of either air-conditioned or naturally-ventilated buildings. In reality in China, most civil buildings such as offices, education, and residential buildings operate their environmental systems in a dynamic way from season to season. Occupants' adaptive behavior in free-running buildings is a dynamic process affected by multiple factors such as the climate, culture and economics. Occupants maintain their thermal comfort dynamically and actively by means of environmental control strategies throughout the year. The new evaluation standard is easily used by designers, assessors and building users. It provides guidance on the implementation of the national energy efficiency policy.

Acknowledgement

The authors would like to thank their colleagues involved in this Standard Committee members Angui Li, Nan Li, Zhichao Wang, Xiaoling Zhang, Jianing Zhao, Guohui Feng, Qinglin Meng, Zhaojun Wang, Hong Liu and participants from Chongqing University Jie Zheng, Meilan Tan, Shenglan Jing, Zhenxing Jin, Yu Yang, Wenjie Li and Jing Liu. The authors are most grateful for the financial support for the fundamental research from the Natural Science Foundation (50838009) and the Ministry of Housing and Urban-Rural Development Foundation (2008-1-26). The authors would like to express their sincere appreciation to the international experts who provided useful comments with special thanks going to Michael Humphreys, Fergus Nicol, Ken Parsons, Jake Hacker, Atze Boerstra, Richard de Dear, Edward Arens and Hui Zhang.

References

ANSI/ASHRAE55-1992 (1992). ASHRAE Standard: Thermal Environmental Conditions for Human Occupancy. Atlanta, USA, American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.

ANSI/ASHRAE55-2004 (2004). ASHRAE Standard: Thermal Environmental Conditions for Human Occupancy. Atlanta, USA, American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.

Cao, B., Y. Zhu, et al. (2011). "Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing." Energy and Buildings **43**: 1051-1056.

China, N. B. o. S. o. (1994-2010). China's Statistics Almanac. Beijing, China Statistics Press.

CIBSE-Guide-A (2006). Environmental Design. London, CIBSE.

de Dear, R. J. and G. S. Brager (2002). "Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55." Energy and Buildings **34**(6): 549-561.

Fanger, P. O. (1970). Thermal comfort, analysis and application in environmental engineering. Copenhagen, Danish Technical Press.

GB50176-93 (1993). Thermal Design Code for Civil Buidling. M. o. C. o. China. Beijing, China Planning Press.

GB50178-93 (1993). Standard of climate regionalization for architecture. Beijing, China, Chinese Plan Pulication House.

GB50189-2005 (2005). Design Standard for Energy Efficiency of Public Buildings. Beijing, Ministry of Construction of the People's Republic of ChinaGeneral Administration of Quality Supervision, Inspection and Quarantine

GB/T5701-1985 (1985). Optimumtemperatureinair-conditioningroom. Beijing, National Bureau of Statistics of China, Chinese Standards(GB).

GB/T5701-2008 (2008). Thermal Environmental Conditions for Human Occupanc. Beijing, Standardization Administration of the People's Republic of China, SAC; General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, AQSIQ.

GB/T18049-2000 (2000). Moderate thermal environments-Determination of PMV and PPD indices and specification of conditions for the thermal comfort Beijing, General Administration of Quality Supervision, Inspection and Quarantine

Guobanfa (2007). State Council Announcement about strict compliance with air conditioning setting temperature in public buildings. C. S. Council. **42**.

Han, J., W. Yang, et al. (2009). "A comparative analysis of urban and rural residential thermal comfort under natural ventilation environment." Energy and Buildings **41**: 139-145.

ISO7730 (1994). Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Geneva, International Standard Organization.

ISO7730 (2005). Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Geneva, International Standards Organization.

Li, B., W. Li, et al. (2010). "Physiological Expression of Human Thermal Comfort to Indoor Operative Temperature in the Non-HVAC Environment." Indoor and Built Environment **19**(2): 221-219.

Li, B., M. Tan, et al. (2010). "Occupant's Perception and Preference of Thermal Environment in Free-running Buildings in China." Indoor and Built Environment **19**(4): 405-415.

Liu, H., Xiaolei Ma, et al. (2009). "Impact of summer office set air-conditioning temperature on energy consumption and thermal comfort." Journal of central south university of technology **16**(s1): 6-11.

Liu, J., R. Yao, et al. (2011). " Occupants' behavioural adaptation in workplaces with non-central heating and cooling systems." Applied Thermal Engineering **35**: 40-54.

Liu, W., Z. Lian, et al. (2007). "A neural network evaluation model for individual thermal comfort." Energy and Buildings **39**(10): 1115-1122.

Mao, X., H. Liu, et al. "Field study of thermal comfort and preferences in air-conditioned offices in Chongqing, P.R.China." Journal of central south university of technology **16**(s1): 43-48.

Nicol, J. F. and M. A. Humphreys (2002). "Adaptive thermal comfort and sustainable thermal standards for buildings." Energy and Buildings **34**(6): 563-572.

Nicol, J. F. and I. A. Raja (1996). Thermal comfort, Time and Posture: explanatory studies in the nature of adaptive thermal comfort. Oxford, UK, Oxford Brooks University.

Olesen, B. W. (2004). "International standards for the indoor environment." Indoor Air **14**(75): 18-26.

Olesen, B. W. and K. C. Parsons (2002). "Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730." Energy and Buildings **34**(6): 537-548.

Tan, M., B. Li, et al. (2009). "Field experiments on thermal comfort in university dormitories in Chongqing, China." Journal of central south university of technology **16**(s1): 55-61.

Wang, Z. (2006). "A field study of the thermal comfort in residential buildings in Harbin." Building and Environment **41**: 1034-1039.

Wang, Z., L. Zhang, et al. (2010). "Thermal comfort for naturally ventilated residential buildings in Harbin." Energy and Buildings **42**(12): 2406-2415.

Wang, Z., L. Zhang, et al. (2011). "Thermal responses to different residential environments in Harbin." Building and Environment **46**(11): 2170-2178.

Wenjie Li, B. Li, et al. (2009). "Thermal comfort in naturally ventilated indoor envionment in hot and humid climate zone in P.R.China." Journal of central south university of technology **16**(s1): 33-37.

Yang, W. and G. Zhang (2008). "Thermal comfort in naturally ventilated and air-conditioned buildings in humid subtropical climate zone in China." Int J Biometeorol **52**(385-398).

Yao, R., B. Li, et al. (2009). "A theoretical adaptive model of thermal comfort - Adaptive Predicted Mean Vote (aPMV)." Building and Environment **44**(10): 2089-2096.