PRIMARY STUDY ON ADAPTIVE THERMAL COMFORT BASED ON LIFE STYLE IN CHINA

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1. Introduction

The existing thermal comfort standard are obtained mostly based on steady-state heat balance, in fact, culture, lifestyle, climate, social, psychological and behavioral adaptations have an impact on human thermal comfort (Runming Yao et al, 2009). Numerous studies show that indoor thermal comfort has a direct relationship with outdoor climate change, life style and thermal experiences. The differences of preferences to the indoor environment should be taken with zones, climates and life style. Over the past decade, Europe and the U.S. have developed adaptive thermal comfort standards (EN15251 and ASHRAE55) for natural ventilating buildings in summer, and the comfort operation temperature in winter is rigor and little difference with the air conditioning environment. In rural areas and the lower and middle reaches of Yangtze River, traditional heating methods or local heating by air conditioning are solved the heating problem in residential houses which are free-running building. The research for adaptive comfort operation temperature using the adaptive comfort principles is very limited, so this paper analyzes differences between indoor thermal environment in free-running buildings in typical climate in winter in China and adaptive thermal comfort standards by exploring the relevance of indoor environment and adaptive thermal comfort operation temperature and means of questionnaire and measured data done by the student of DUT during the winter.

2. Heating methods and indoor thermal environment with areas in China

As seen in Fig. 1 China, with a vast territory and a large population, has five climate zones: hot summer & warm winter, hot summer & cold winter, cold and severe cold. In winter, from December to February, the areas where mean monthly outdoor temperature is below -10 ℃ covers around 20% of national territory, where the temperature is -10℃~0℃ is accounting for about 45%, where the temperature is 0℃~10℃ occupies about 18%, so the buildings in 80% above of land need take variety of methods to heat. Besides the city in the north of Yellow river are district heating areas in China, in other regions the traditional heating methods , such as Chinese kang, hot wall, burning cave, stove and local air conditioning for heating are took(Fig. 2). In order to adapt to cold weather, people take some simple and effective methods, as seen in Fig. 3 sandwich wall design in north wall, tightness with plastic film and solar wall are some ways for warming in winter in severe cold areas. The basic status of indoor thermal environment that varies greatly in winter is shown in Fig. 4, and the thermal environment should not be comfortable because of too low indoor temperature. Questionnaire survey shows the people long living in the environment, especially the elderly, aren't fond of indoor environment of too high indoor temperature, such as higher than 16℃. Because of great difference in temperature between local heating and adjacent space, it is vulnerable to common cold and discomfort when residents go frequently in and out spaces. There are differences in preferences to the indoor environment between southerners and northerners, for example, southerners are more sensitive to humidity and expect the indoor temperature is higher than 20℃, relatively northerners are more sensitive to temperature, and like opening window to ventilate. Analysis indicated the diversity of lifestyle cause differences in adaptive thermal comfort.

Fig.1: Climate zoning and outdoor temperature profile in winter in China

(a) Yaodong (b) Chinese kang (c) Stove

Fig.2: Some Heating method in rural areas

(a) Sandwich wall design in north wall (b) Tightness with plastic film (c) Solar wall

Fig. 3: Some ways for warming in severe cold areas in winter

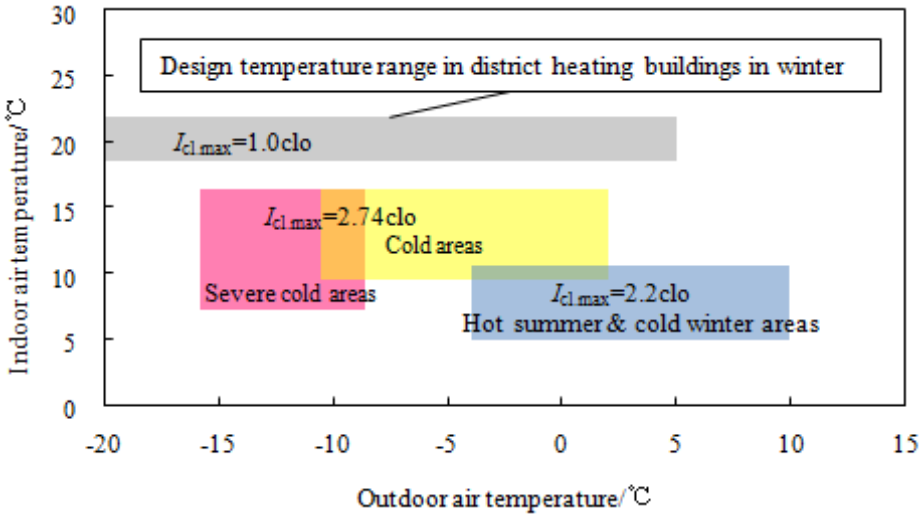


Fig.4: Indoor air temperature in non district heating areas

3. Survey Study on indoor climate in free running buildings in winter in China –short literature review

In China, there are hot, warm and cold climate zones from south to north, and because of the diversity of zones, climates, customs and habits, economic developments, ability of economy bearing between north and south may cause the difference of acclimation and psychological expectation. Especially for in non air conditioning buildings, its requirements for indoor environment are not so strict as office buildings. As Table 1 showed many Chinese scholars began to focus on indoor thermal environmental in the non air conditioning building by means of field survey. Seen from Table 1, investigation objects mostly are natural ventilating buildings in hot summer & cold winter areas, and the research issues include: 1) various impact factors of thermal comfort in natural ventilated environment were researched, 2) behavioral adjustment people are used to were investigation by statistics in naturally ventilated buildings 3) basing on the heat adaptation of the theory of natural ventilation environment, thermal adaptive model and thermal comfort zones were founded. The field survey results show the mean indoor temperature is about 8 ℃ when the mean outdoor temperature is 5 ℃ in naturally ventilated buildings in hot summer & cold winter areas. The reference (Xiangzha Fu,1999) calculated the thermal performance of an example residential unit in critical heating regions of China by means of the effective heat transfer coefficient, the results show that the envelope structure of existing houses is inadequate to maintain the minimum indoor temperature of 10℃. In cold and severe cold areas, the mean indoor temperature is about 10 ℃ when the mean outdoor temperature is -10 ℃ in rural buildings integrated Chinese Kang and stove. The mean indoor temperature for natural ventilating buildings in hot summer & warm winter areas is 15℃, relatively higher.

In addition, the indoor thermal comfort survey results show that: clothing insulation is 1.37~2.74clo and the acceptable thermal comfort lowest temperature is 9℃ in rural non district heating buildings in winter, and clothing insulation is 1.37~2.74clo and the acceptable thermal comfort lowest temperature is 9℃ in the buildings in hot summer & cold summer areas, the acceptable thermal comfort highest temperature is 30℃ in summer.

4. Questionnaire survey

To further understand climate adaptability of human beings from different climate zones to thermal comfort in China, 384 questionnaire sheets and liquid thermometers were distributed to students of DUT specialize in HVAC from almost all of the climatic zones in China. The indoor temperature in the morning, midday and evening were record. The period of survey is from Jan. to Feb. 2011, and the number of valid respondents is about 375. The summary of the questionnaire survey is showed in Table 2, and investigating areas cover

rural and urban areas throughout the country. The respondents are 8~85 years old. Indoor thermal environment, thermal sensation and adaptive behavioral adjustment methods, and so on are investigated.

Tab. 1: Survey measurement in free running buildings in China

Areas	Building type	Survey time	Ondoor temp. range/℃	Iutdoor temp. range/℃	Clothing insulation /clo	Acceptable temp.	Reference
Severe cold areas	Rural houses	2007/4/ 24~25	5.59~22.71 (14.6)*	18.71~22.7 0 (20.25)			Xiping Zhao, 2008
Cold areas	Natural ventilating buildings	1998/7/1	-	26~31 (28.6)	0.31	ET*<30	Yizai Xia, 1999
	Natural ventilating buildings	2003/8 /9~8/17	-	16.6~32.4 (23.2)	-	-	Jing Liu, 2005
	Yaodong building	2000/1/ 11	8.3-11.3	-10.4-10.4	-	-	Jiaping Liu, 2011
	Rural houses	2009/12 ~2010/1	-2.5~1.5 (0.4)	1~13.1 (5.2)	1.37~2.74 (1.98)	9~15.8 (11.6)	Qiang Yang, 2010
Hot summer & cold summer	Natural ventilating buildings	2000& 2001 summer	-	27-33.5	-	ET*<30	Xiuling Ji, 2011
	Classroom	2005/4~ 2006/5	Summer 21~39	Winter 22.2~38.2	0.26		Jing Liu, 2007
			Winter 4.8~14.4	Winter 8.8~15.5	1.39		
	Non distract heating buildings	2008/12 ~2009/3	-3.5~24.2 (5.7)	4~14.5 (9.9)	0.82~2.2 (1.41)	11.2~16.8 (13.6)	Junge Li, 2008
	Natural ventilating buildings	2006 winter	6.19~11.28 (8.66)	-	1.16~2.89 (2.15)	8.41~ 15.65	Jie Han, 2009
		2007 summer	26.6~31.6 (30.12)	-	0.09~0.43 (0.31)	15.65~ 30.14	
	Rural houses	2000/1/ 11	-1.7~10.8	6.1-22.3	1.1~1.9	>10.9	Li Huang, 2011
Hot-humid area	Natural ventilating buildings	2008/5~ 2009/5 winter	-	8~20	-	-	Yufeng Zhang, 2010

* The values in parentheses are average in Tab.1

Tab. 2: Summary of the questionnaire survey

Climate zones / Region	Hot summer & warm winter	Hot summer & cold winter	Cold	Severe cold	Total
Rural	20	55	47	19	141
Urban	20	89	62	53	234
Total	40	144	119	72	375

4.1 Indoor climate in winter and heating /cooling methods

From measured results (Fig.5), we can see that the indoor temperature of the residential buildings without district heating systems in hot summer & winter cold areas is below 10℃. The northern areas of yellow river is hot summer & warm winter, the indoor average temperature is above 10 ℃, close to the 15 ℃. The

average room temperature with district heating buildings is about 19 ℃. Heating methods in different areas are shown in Figure 6, we can find that the urban housing in cold and severe cold areas in winter have mainly taken district heating systems, while the rural residential buildings use kang and stove for heating. More than half of the rural houses in hot summer & warm winter and hot summer and cold winter areas don't take any heating measures, while 40% of the urban housings use the air conditioning for heating.

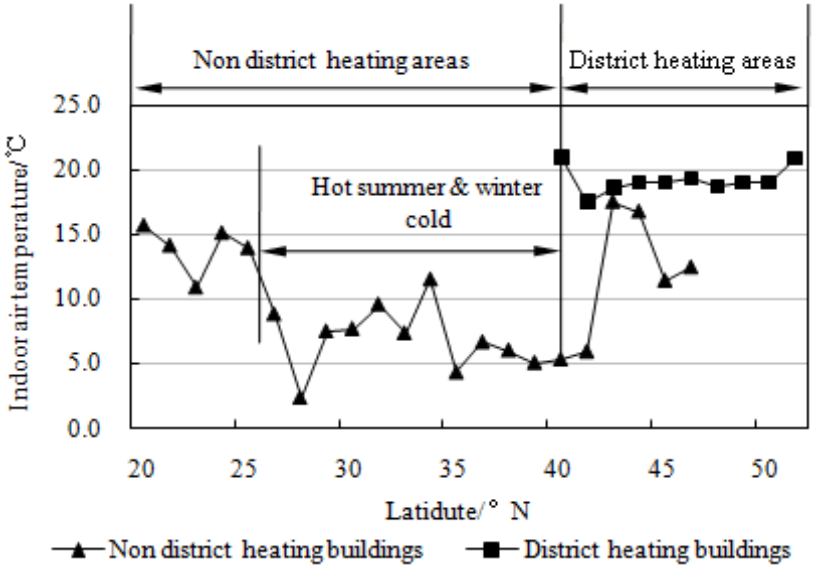


Fig 5: Indoor temperature in winter

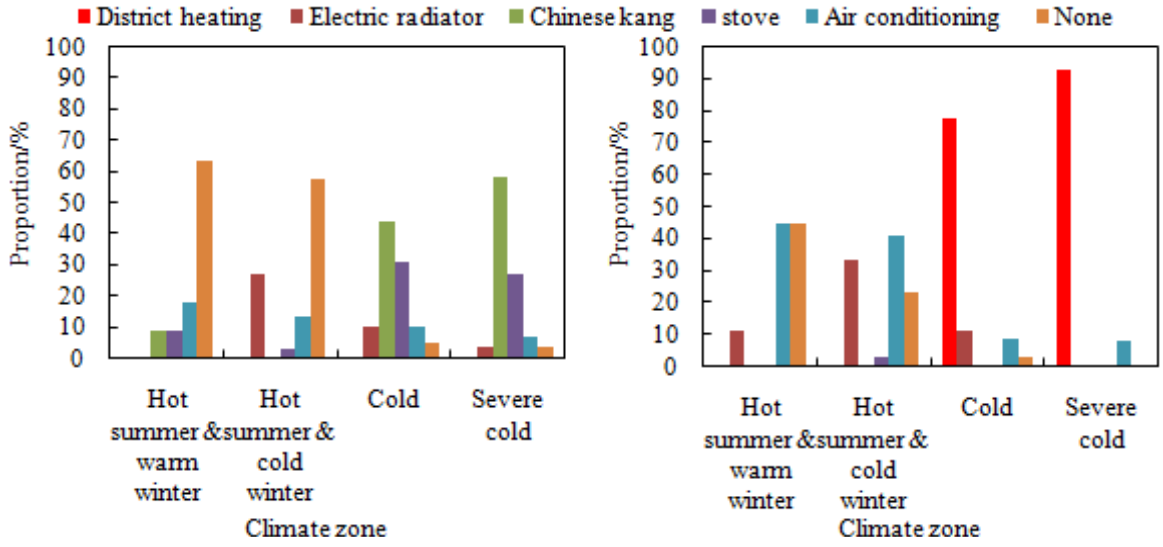
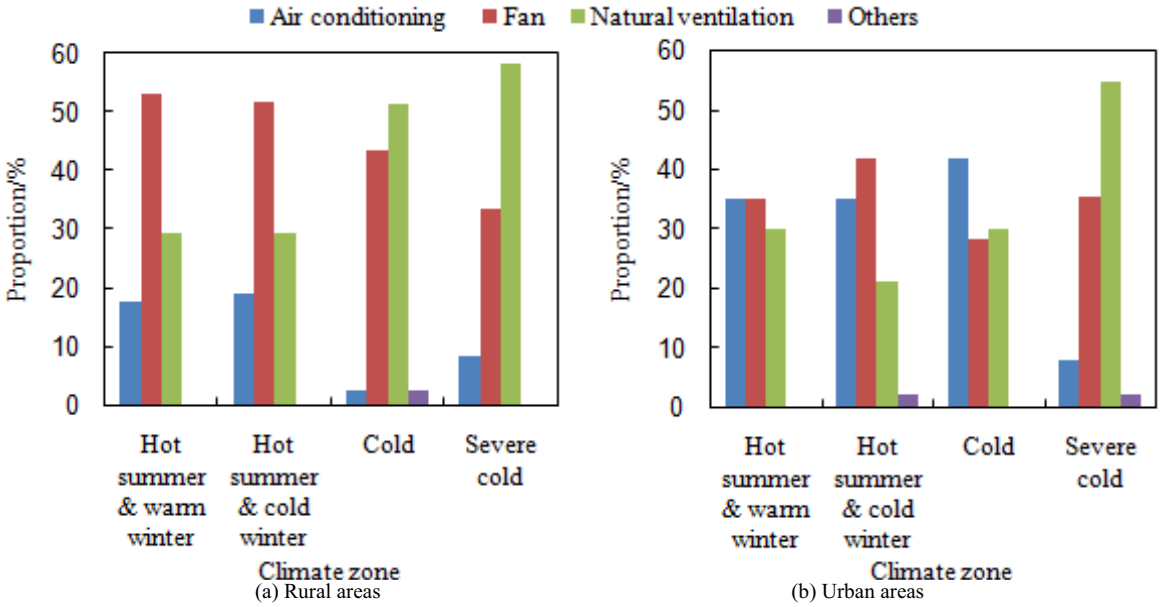


Fig. 6: Heating methods in rural houses in winter

Fig. 7 shows the cooling methods in summer.In the rural, natural ventilation and fans is the main cooling methods, the proportion is higher than the proportion of the use of air conditioning, and in the urban, apart from the severe cold areas, air conditioning is the main cooling way and its proportion is higher than in the rural. In general, natural ventilation and fans is the main cooling methods in the whether rural or urban, and there are two reasons why it isn't air conditioning, on the one hand, because of economic reasons for taking into account the cost of installing and running air conditioning, on the other hand, because of the large temperature difference between the air-conditioned room and outdoor made person feel very uncomfortable in the hot summer.In one word, people prefer to using natural ventilation, hope to closing to nature.

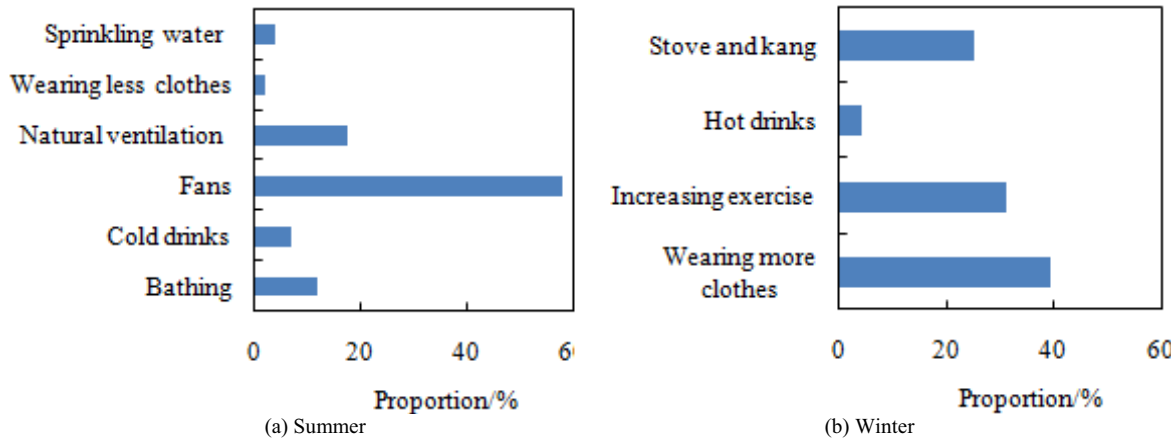


(a) Rural areas (b) Urban areas

Fig.7: Cooling methods in summer

4.2 Naturally conditioned methods

The concept of adaptive thermal comfort can be described as: when a change occurs causing thermal discomfort, people react in such a way that their thermal comfort is reestablished. This description refers to behavioral adaptation, physiological adaptation and psychological adaptation. Behavioral adaptation is one of the most direct and effective adjustment methods. Fig.8 shows behavioral adjustment methods in winter. We can see that increasing clothing is the most important adjustment methods, and its proportion is 39%. It has found that the largest clothing insulation can be 2.89clo, and as the reference (ASHRAE, 2004) described: the optimum operating temperature will decrease 6℃ when clothing insulation increase 1clo. 31% of the people by slight movement such as shaking feet and jumping, to adapt to indoor low temperature environment, in addition, 25% of people can take the local heating methods, and some people can also take hot drink to resist the bitter cold of the winter, such as people in the northeast rural often drink liquor when they are eating, because it can accelerate blood circulation to make people feel warm. In summer, indoor wind speed is the large difference between air condition and natural ventilation buildings. In the thermal comfort standards, office environment is the main consideration. If the wind speed is too fast ,it will be easy to blew the paper and lead to dust, so indoor wind speeds of air conditioning building is provided must not exceed 0.25m /s, while the survey of residential housing showed that residents prefer to faster indoor wind speed in the summer .In summer, without air conditioning system, the percentage of using fan is 58%, the percentage of opening windows for natural ventilation is 17%. The adjustment methods are to ensure body cooling needs by increasing indoor wind speed. Others include bath, cold drinks and wearing less clothing.



(a) Summer (b) Winter

Fig.8: Behavioral adjustment methods in winter

4.3 Prefer indoor climate

The adaptive thermal comfort theory emphasizes the differences in preferences of thermal environmental between among different population. The preferences are associated with one's experience of thermal environment and economic income, including health factors. In the investigation, it was studied whether constant temperature is good for health or not, acceptable temperature range.

4.3.1 Thermostatic indoor climate is good for health or not

For the question that "Do you think constant temperature environment is good for body", the statistical results is shown in Figure 9. Whether in the rural or urban residents, two-thirds of people think that constant temperature environment is bad for human health, and their reasons are: immunity decline, ability decline to adapt to the environment; the reason why people think it is good for health is that constant temperature environment is more comfortable.

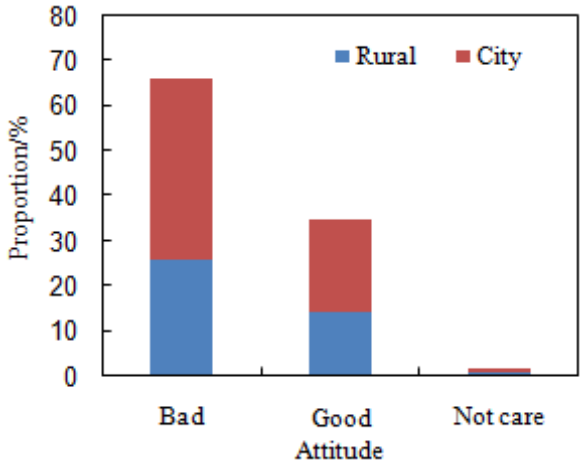


Fig.9: The attitude toward constant temperature indoor environment

4.3.2 Most unacceptable indoor climate

When the indoor temperature is in comfortable temperature range in winter, the people are not very strict to the humidity requirements. But when the indoor temperature is too low, the magnitude of humidity has a greater impact on human thermal sensation. The first indoor environment of that respondents can not stand (shown in Figure 10) is wet, the following is dry. The coastal city in the hot summer & warm winter areas have outdoor high humidity ,so dew condensation in the inner wall is common phenomenon when outdoor temperature decreases in winter, while people feel wet-cold and uncomfortable in the residential building without heating measures in the hot summer & cold winter areas where it's low temperature and high humidity in outdoor. It's too dry in the residential buildings in the northwest and wiht district heating.

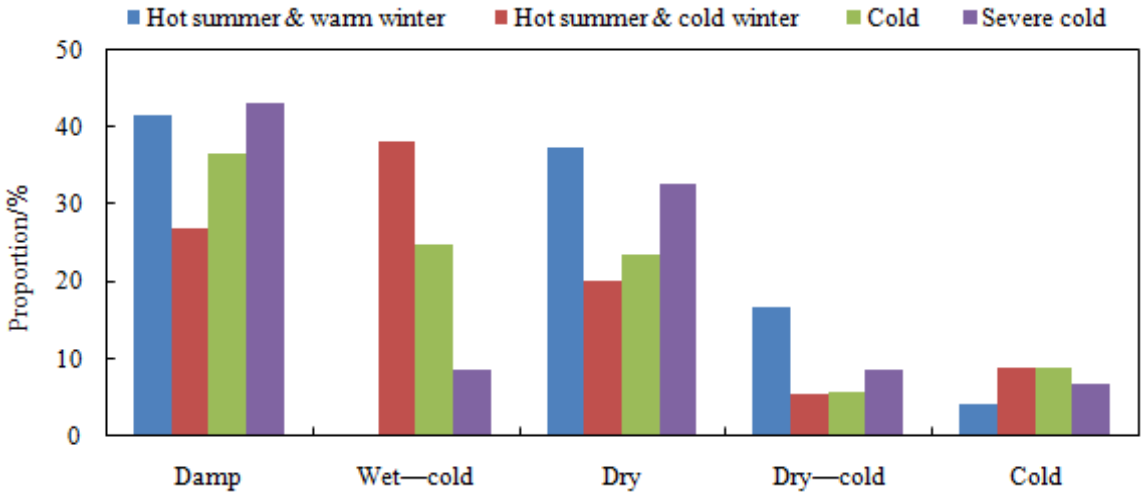


Fig.10: Unacceptable thermal and humidity indoor environment in winter

4.3.3 The Effect of climatic zones and age on thermal preferences

Fig. 11 and Fig. 12 show respectively the cumulative probability that people can not tolerate the minimum temperature in winter and maximum temperature in summer. Using the eq. 1, as seen in Table 3 the limits of average indoor temperature that people can not tolerate in different climatic regions are calculated.

$$T = \sum p_i \cdot T_i \qquad \text{(eq. 1)}$$

Where: T_i is indoor temperature, ℃; p_i is probability of the corresponding temperature.

In winter, the expectations to the indoor temperature of persons living in the cold and severe cold areas is higher than in the hot summer & cold winter areas and hot summer & warm winter areas. Because of the difference of heating methods, the indoor temperature is higher in the previous two climate areas, and the persons chronically live and are used to the thermal environment. In summer, the acceptable temperature in the hot summer and warm winter areas is higher about 4 ℃ than in the severe cold areas. Obviously, the people living in hot climate areas for a long time have a stronger tolerance capacity to hot.

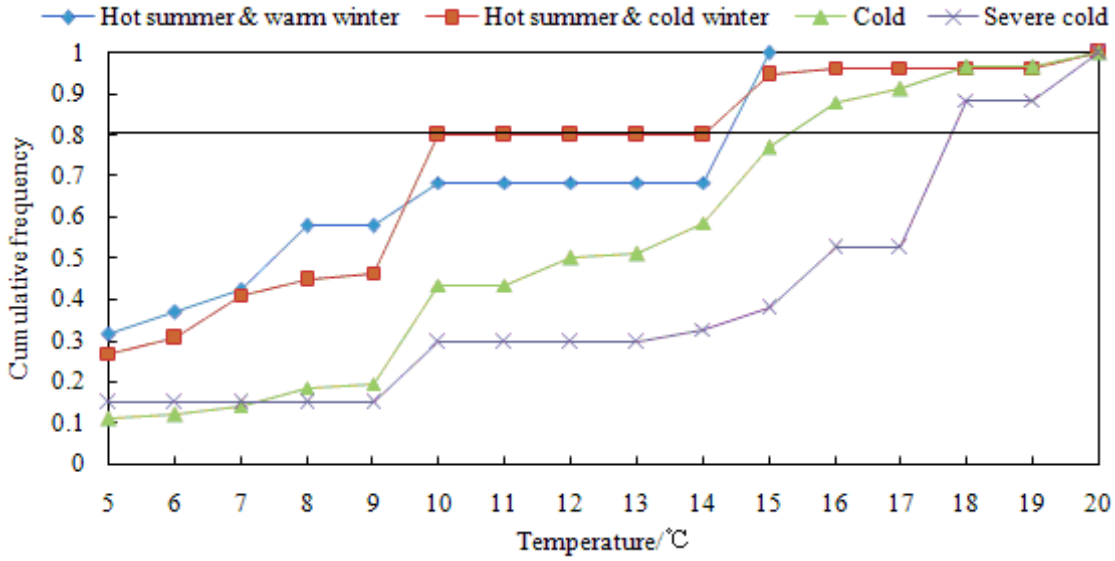


Fig.11: The cumulative frequency of acceptable air temperature in winter

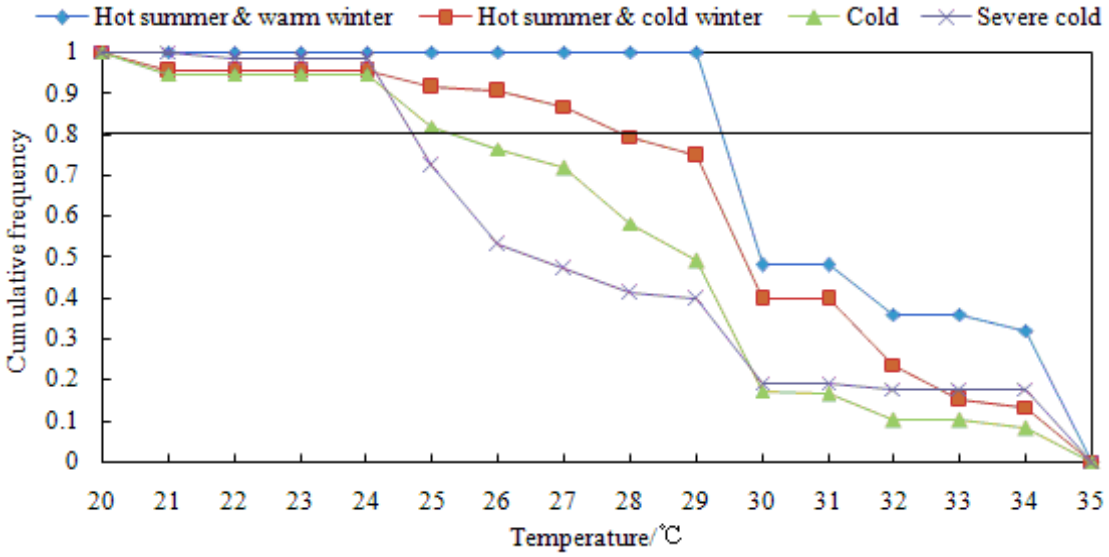


Fig.12: The cumulative frequency acceptable highest air temperature in summer

Tab. 3: Limits of average indoor temperature that people can not tolerate in different climatic regions

Areas	Unacceptable average minimum temperature in winter/℃	Acceptable minimum temperature over 80% of residents in winter/℃	Unacceptable average maximum temperature in summer/℃	Acceptable minimum temperature over 80% of residents in summer/℃
Severe cold	14.3	17.5	28.4	24.5
Cold	12.3	15.2	28.6	25.0
Hot summer & cold winter	9.1	13.5	30.3	28.0
Hot summer & warm winter	9.3	14.3	32.0	29.5

To analyze the differences of preferences to thermal environmental among different age, statistical analysis on acceptable temperature of different age groups in the survey sample is carried out is shown in Figure 13. The difference of acceptable temperature in different ages is 1.56 ℃ in winter and is 0.8 ℃ in summer, the preferences to the thermal environment have little difference.

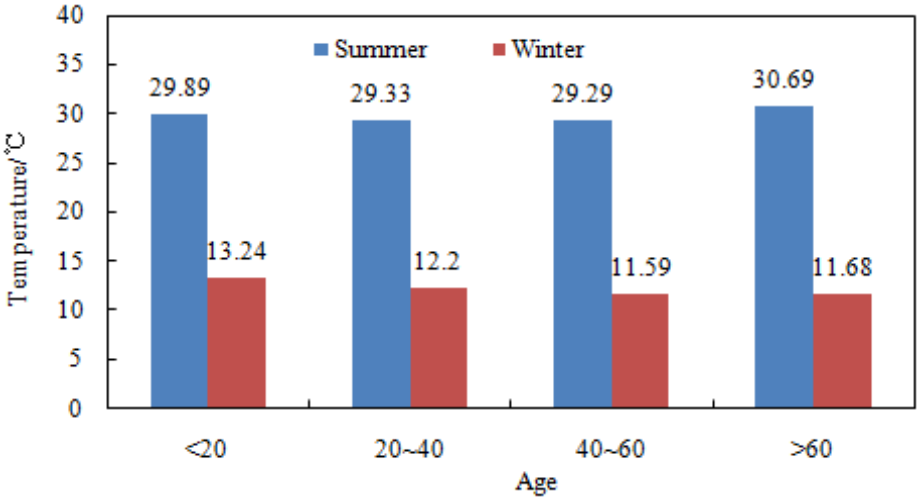


Fig. 13: Acceptable limit mean temperature for different ages

Tab. 4: Age distribution of respondents

Age	<20	20~40	40~60	>60	Undefinite
Number	55	123	137	58	2

4.3.4 Analysis of differences in thermal neutral temperature between urban and rural

There are great differences in lifestyles and indoor thermal environment between urban and rural. In order to analyze whether these differences will affect the preferences of the thermal environment, regression analysis and linear fitting of mean thermal sensation against mean air temperature for the buildings in the database of cold areas was carried out as Fig.14 showed. Let be MTS=0, thermal neutral temperatures are obtained , and for rural buildings is 17.8℃， and for city buildings is 19.8℃ which is 2℃ higher than rural building. This is due to quality of life for the rural relatively is low although peasants' living standard have been raised, and peasants have been used to indoor low temperature environment because they chronically live the thermal environment, meanwhile, peasants aren't fond of indoor too high indoor temperature environment because they preferentially wear thick clothes in order to go frequently in and out spaces. If it is assumed that subjects' thermal sensation vote is -0.5 ⩽ MTSV ⩽ 0 in winter is acceptable thermal comfort temperatures range, acceptable thermal comfort temperature range for rural buildings in winter is 13.9 ℃~17.8 ℃, relatively for city buildings is 16.2 ℃~19.8 ℃.

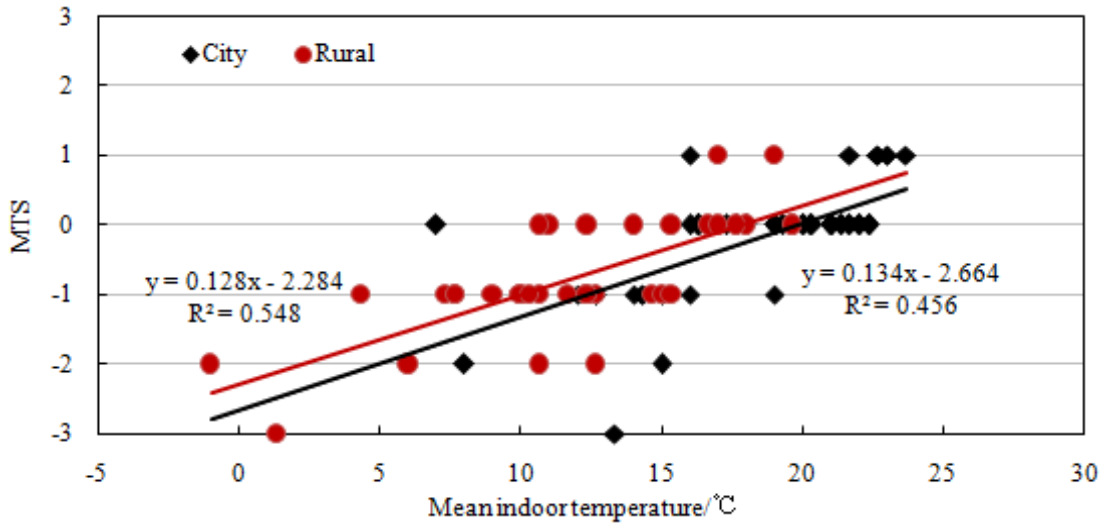


Fig. 14: Differences in mean thermal sensation against mean air temperature in the urban and rural

5. Conclusions

,Adaptive thermal comfort based on life style and heating methods in china is studied., through analysing the indoor thermal environment in the natural regulation buildings in China different climate zones and using the results of questionnaires during winter vacation by the students of DUT and the measured data. In this paper, the main conclusions are followed:

(1) The indoor temperature of the residential buildings without district heating systems in the hot summer and winter cold areas is below 10℃. the northern areas of yellow river is hot summer & warm winter, the indoor average temperature is above 10 ℃, closing to the 15 ℃. The average room temperature with district heating buildings is about 19 ℃.

(2) In winter the urban housing in the cold and severe cold areas have mainly taken district heating systems, while the rural residential buildings primarily use kang and stove for heating. More than half of the rural residential buildings in hot summer & warm winter and hot summer and cold winter areas don't take any heating measures, while 40 percent of the urban housings use the air conditioning for heating.

(3) To keep out the cold in winter, the main behavioral adjustment methods are wearing more clothes and doing some exercise, this can be attributed to the changes of clothing insulation and metabolism. And in summer, indoor wind speed is changed mainly through the electric fan and natural ventilation to meet the comfort requirements. And these parameters have very strict rules for the current standard. In the resident building, the behavioral adjustment methods can increase the acceptable temperature range

(4) If a comfort thermal environment and people's endurance for the environment want to be described in detail, cultural factors in connection with the people's age, clothes, food, rest habits and lifestyle need to be fully understood, also thermal experience that has been habituated in indoor and outdoor must be understood. And these influence factors have close relationship with outdoor climate. The studies on preferences to the thermal environment show that the indoor thermal environment which people in the different climate zones prefer has a big difference, also there is a difference between urban and rural areas, and in winter hot neutral temperature of city residents is 2℃ higher than rural areas, but relatively age has a little effect on the preferences

(5) Acceptable temperature in the different climate zones has been obtained: the hot summer and warm winter areas：14.2~29.5℃, the hot summer and cold winter areas：13.5~28.3℃, the cold areas：15.2 ~ 25.5℃, the severe cold area:7.5 ~ 24.8℃.

6. Acknowledgements

Support from Ph.D.Program Foundation of Ministry of Education of Chin (20100041110002) is greatly appreciated.

7. Reference

Runming Yao, Bauizhan Li, Jing Liu, 2009. A theoretical adaptive model for thermal comfort - Adaptive predicted mean vote. Building and Environment. 44(10): 2089-2096.

Xiangzha Fu, 1999. Conditions for determining the energy consumption standard in the Changjiang River Basin. Sichuan Building Science. Heating Ventilating & Air Conditioning. 29(6): 14-17.

Xiping Zhao, Xiuming Feng, 2008. The diagnoses for indoor thermal and humidity environment of village residence in Songyuancity in Jilin province. Sichuan Building Science. 34(5): 217-220

Yizai Xia, Rongyi Zhao, Yi Jiang, 1999. Thermal comfort in naturally ventilated houses in Beijing. Heating Ventilating & Air Conditioning. 29(2): 1-5

Jing Li, Wenqin Li, Fusheng Gao, Jingxin Li, Jinfeng Shi, 2005. Measurement and analysis of ondoor environment of Harbin in summer. Environmental Science and Management. 30(6): 105-107.

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

Jiaping Liu, Lijuan Wang , Yasuko Yoshino, Yanfeng Liu, 2011. The thermal mechanism of warm in winter and cool in summer in China traditional vernacular dwellings. Building and Environment. 47: 1709-1715

Xiuling Ji, Baoguo Wang, Shuyan Liu, Zizhu Dai, 2004. Study on thermal comfort in non-air-conditioned Buildings in Jiangsu and Zhejiang Provinces. Transactions of Beijing Institute of Technology. 24(12): 1110-1113.

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

Junge Li, 2008. A thermal comfort field survey in residential buildings in hot-summer and cold-winter area [M]. Shanxi: Xi'an University of Architecture and Technology.

Jie Han, 2009. Thermal Comfort Model of Natural Ventilation Environment and Its Application in the Yangtze Climate Zone. Hunan: Hunan University.

Li Huang, Yingxin Zhu, Bin Cao, 2011. Field survey of indoor thermal comfort in rural housing of northern china in heating season. Journal of Southeast University. 26(2): 169-172.

Yufeng Zhang, Jinyong Wang, Huimei Chen, JunZhang, Qinglin Meng, 2010. Thermal comfort in naturally ventilated buildings in hot-humid area of China, Building and Environment. 45: 2562-2570.

ASHRAE STANDARD 55-2004, Thermal Environmental Conditions for Human Occupancy.