

Indoor Thermal Comfort Analysis of Office Buildings in Hot Summer and Cold Winter Region in China

Hong Liu, Baizhan Li, Wenjie Li, shenglan Jing

Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, Chongqing University, Chongqing, China ,Liuhong1865@163.com

ABSTRACT: The office buildings indoor environment in hot summer and cold winter region in China in 2007 was surveyed, for a example, the Chongqing's office buildings indoor environment conditions and subjective evaluation of the office staffs on indoor environment in winter and summer were analyzed. The relationships between Predicted Mean Vote (PMV) /Actual Mean Vote (AMV) and the office building indoor temperature were described and analyzed. It shows that the neutral temperature in office buildings is 20.7°C in winter and 24.5°C in summer. The range of acceptable indoor temperature were confirmed when the AMV were within ± 0.5 . This thermal comfortable analysis provides a basis for the establishment of buildings indoor environment standard in hot summer and cold winter region in China.

Key words: office building, indoor environment, PMV, AMV, neutral temperature

1. INTRODUCTION

Covering a wide range of land, China has diversified types of climates. The Chinese Civil Building Thermal Design Code (GB50176-93) [1] classifies China into 5 thermal regions: severe cold, cold, hot summer and cold winter, hot summer and warm winter, and warm. The research on buildings indoor thermal environment in different regions to find out the indoor thermal comfort controlling standards for different regions, beneficial for building energy efficiency design.

The main climate characteristics of hot-summer cold-winter region with high

temperature high humidity in summer and coldness and wetness in winter. This region's average temperature in the coldest month is 0-10°C, and average temperature in the hottest month is 25-30°C, with 0--90 days of daily average temperature ≤ 50 , and 40--110 days of daily average temperature ≥ 25 °C [1]. Chongqing is a typical city with hot summer and cold winter. Therefore, this study, targeting at Chongqing, through survey ways of questionnaires, focuses on Chongqing's office buildings indoor thermal comfort in winter and summer, thus providing support to establish standard for this region's buildings indoor thermal comfort.

2. DATA STATISTICS

This survey adopted the methods of site testing and questionnaires, targeting at the 12 regions inside Chongqing respectively in 2 seasons of 2007, the January to February, and the July to August. The questionnaire, based on the ISO7730 Standard assessment indexes, covers the object person's background, building construction time, building envelop structure, the winter heating methods & summer cooling methods, indoor people's habit of ventilation, people dressing habit, the subjective comments on indoor environment (indoor temperature, humidity, air velocity, etc). The site testing is mainly for fixing the building indoor and outdoor physical parameters, including air temperature, the comparative humidity, air velocity etc.

There are 1241 effective winter questionnaires and 1093 effective summer questionnaires, in which 60% are filled by male and 40% are filled by female. Over 90% of the objects are 20 to 50 years old, generally belong to workers inside office buildings. The target office buildings are diverse in feature, 80% are built in the 1990s or after, and 80% are built with single-layer frame and single-layer glass, which are poor in insulation and increase the demand for heating in winter and cooling in summer. According to the questionnaires, 82% of the buildings have heating equipment, and 92% have cooling air-conditioner, which implicates that most of the office building use heating and air-conditioning to improve indoor thermal comfort in this region.

According to statistics, 90% or above of all the surveyed people have the habit to open windows at some frequency, in which 50% are for fresh air. For those people who do not use heating and air-conditioning, 30%

of them want to get rid of stuffy indoor environment. About 60% of people do not use heating and air-conditioning for avoiding closing doors and windows when using heating and air-conditioning, which creates stuffy indoor environment. About 20% do not like the cold or hot air blowing when using heating and air-conditioning, and another 20% are for energy saving. It can be observed that the common purpose of opening windows is to increase the new air volume and enhance the indoor air quality by the natural ventilation. However, opening windows can increase energy use when using heating and air-conditioning. So air change to increase new air volume is the key for using heating and air-conditioning.

3. DISCUSSION

3.1 Subjective Satisfaction Degree Analysis based on Environmental Parameters

3.1.1 Winter

Table1 Environmental parameters in winter

Physical Parameters	Max	Min	Mean
Indoor Temp(°C)	24.9	14	17.9
Outdoor Temp(°C)	22.3	6.3	16.3
Indoor Humidity(%)	79.3%	23.3%	61.5%
Outdoor Humidity(%)	88.4%	36.6%	76.7%
Indoor air velocity (m/s)	0.35	0	0.03
Outdoor air velocity(m/s)	2.95	0	0.26

Table 1 shows the indoor/outdoor environmental parameters in winter.

Based on statistics, for the cold and wet winter, about 82% of the office buildings use different ways of heating. A small part of people not using heating adopt ways such as more clothes, hot drink and some exercises etc to increase thermal comfort.

Now it begins the analysis of subjective satisfaction of indoor thermal comfort by office workers using heating.

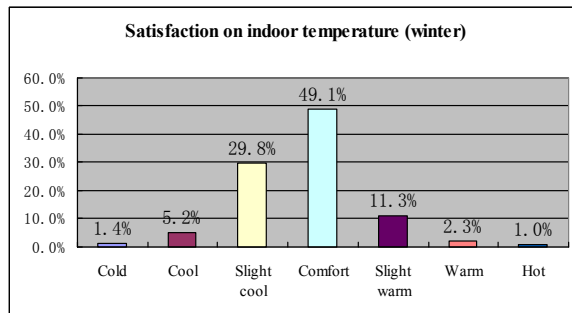


Figure 1 : Winter indoor temperature satisfaction assessment

Figure 1 exhibits the satisfaction assessment on indoor temperature. The site testing max-value of indoor temperature is 24.9°C, and the min-value is 14°C, the mean value is 17.9°C. 49.1% of the objects are satisfied.

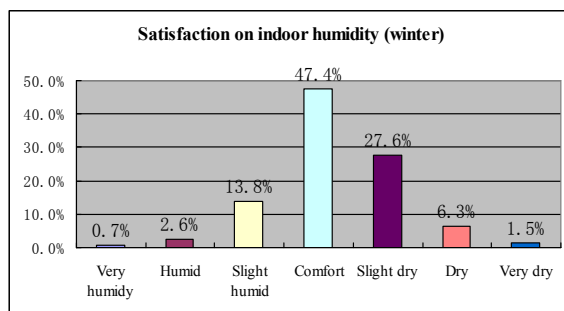


Figure 2 : Winter indoor comparative humidity satisfaction assessment

Figure 2 exhibits the satisfaction assessment on indoor comparative humidity. The site testing max-value is 79.3%, min-value is 23.3%, mean-value is

61.5%. 47.4% of the objects are satisfied with the comfort, and only 3.3% think humid and very humid. These data indicate that the use of heating equipment marked improvement in the indoor humid environment.

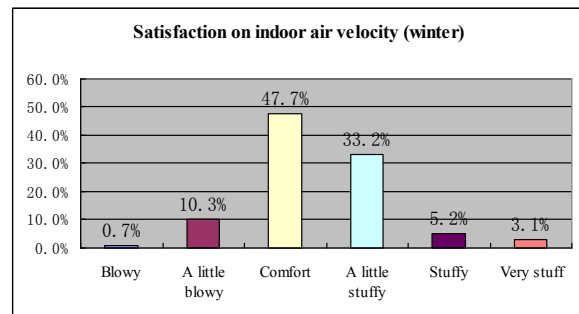


Figure 3 : Winter indoor air velocity satisfaction assessment

Figure 3 shows the satisfaction assessment of indoor air velocity. The site testing max-value of indoor air velocity is 0.35 m/s, and the mean value is 0.03m/s. 47.4% of the objects are satisfied, and 38% consider a little stuffy. Generally speaking, the indoor air velocity in office buildings is low, corresponding with the fact that over 90% objects often open their office windows. Therefore, people need the natural ventilation to relieve the problem of stuffy indoor air environment.

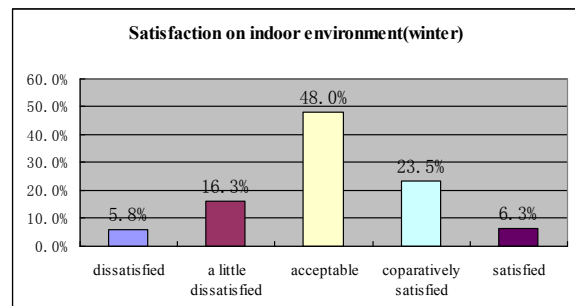


Figure 4: Satisfaction on General Indoor Environment in winter offices

Figure 4 shows the satisfaction assessment on the general indoor environment. it can be seen that for offices in winter the indoor mean temperature is 17.9°C, the mean comparative humidity is 61.5%, the mean air velocity is 0.03m/s, 29.8% of the people feel satisfied or comparatively satisfied with the general indoor thermal environment, 48% fell acceptable. Therefore, we can generalize that the office indoor thermal comfort is acceptable in the winter of Chongqing.

3.1.2 Summer

Table2 Indoor/Outdoor Environmental Parameters in Summer

Physical Parameters	Max	Min	Mean
Indoor Temp (°C)	34.1	23.6	28.1
Outdoor Temp(°C)	39.4	26.4	31.6
Indoor Humidity (%)	89.2%	35%	63.8%
Outdoor Humidity(%)	87.4%	33.3%	66.3%
Indoor air velocity(m/s)	1.02	0	0.13
Outdoor air velocity(m/s)	3.25	0.00	0.41

Table2 shows the indoor/outdoor environmental parameters in summer.

Based on the questionnaire, it is found out that, due to the heat and humidity in summer, above 92% of the office buildings use air conditioning and about 8% use electric fan or natural ventilation methods.

Now it begins the analysis of subjective satisfaction of indoor thermal comfort by office workers using air-conditioning in

summer.

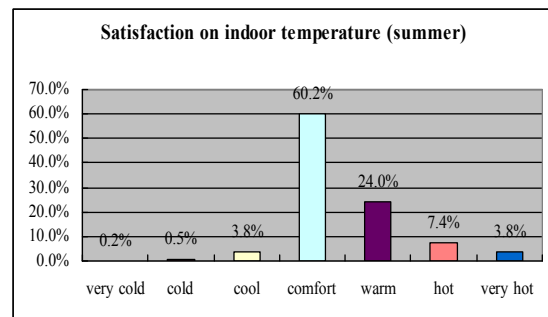


Figure 5: Summer indoor temperature satisfaction assessment

Figure 5 shows the summer indoor temperature satisfaction assessment. The site testing max-value of indoor temperature is 34.1 °C, and the min-value is 23.6 °C, the mean value is 28.1 °C. 60.2% of the objects are satisfied.

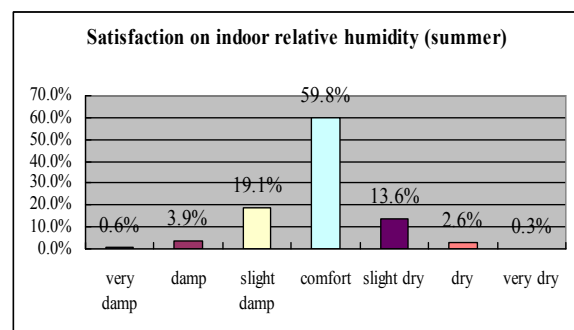


Figure 6: Summer indoor comparative humidity satisfaction assessment

Figure 6 shows the satisfaction assessment on indoor comparative humidity. The site testing max-value is 89.2%, min-value is 35%, mean-value is 63.8%. 59.8% of the objects are satisfied with the comfort. These data indicate that the use of air-conditioners marked improvement in the indoor humid environment. Figure 7 shows the satisfaction assessment of indoor air velocity. The site testing max-value of indoor air velocity is 1.02 m/s , and the

mean value is 0.13m/s. 28% of the objects are satisfied, and 64% consider a little stuffy and stuffy. This is mainly with the doors and windows closed when the air-conditioning.

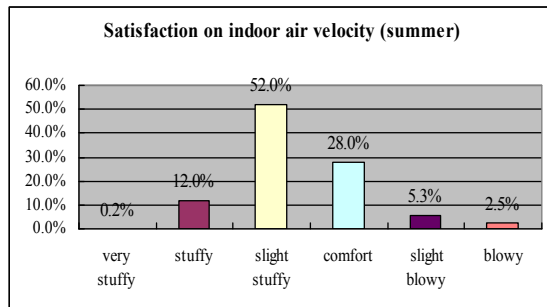


Figure 7: Satisfaction assessment of indoor air velocity in Summer

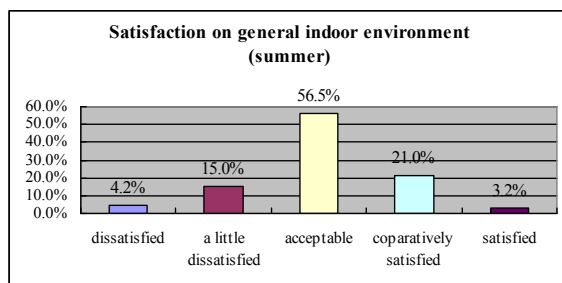


Figure 8: Satisfaction on general indoor environment in winter offices

Figure 8 shows the satisfaction assessment on the general indoor environment. it can be seen that for offices in summer the indoor mean temperature is 28.1°C, the mean comparative humidity is 63.8%, the mean air velocity is 0.13m/s, 34.2% of the people feel satisfied or comparatively satisfied with the general indoor thermal environment, 56.5% fell acceptable. Therefore, we can generalize that the office indoor thermal comfort is good acceptable in the winter of Chongqing.

3.2 Analysis of Indoor Thermal Comfort and Acceptable Temperature Scope

3.2.1 Comparison of PMV and AMV

The Predicted Mean Vote (PMV) used in ASHRAE55-2004^[2] and ISO7730^[3] is a kind of thermal comfort indicator^[4] based on Thermal Comfort Equation by Fanger, providing not the specific temperature degree, but the mean vote value of people towards the thermal comfort based on ASHRAE 7 levels of thermal assessment. And Actual Mean Vote (AMV) is the reflection of people's actual feelings towards thermal comfort^[5]. PMV and AMV classify the human feeling for indoor thermal environment into 7 levels: very hot, hot, a little hot, comfortable, cold, a little cold, very cold, corresponding with the values of -3、-2、-1、0、1、2、3.

We use parameters include indoor temperature, air velocity, comparative humidity, human metabolism rate and clothes thermal-resistance in the PMV calculation formula, and then draw the relationship between the PMV、AMV and indoor air temperature by way of Bin method, namely, making the middle temperature degree in each classified temperature scope as independent variable, the PMV and AMV of the object in each classified temperature scope as dependent variable, as Figure 9 and 10 show. Due to restriction of testing conditions, we suppose that the mean radiation temperature is the same with air temperature. Meanwhile, for the objects are always sitting in the offices, we use the value 1.2 as the human metabolism rate, and for almost same dressing code in summer, we use value 0.5 as the clothes thermal-resistance. The clothes thermal-resistance in winter is between 0.619 and 1.483, with mean value of 1.16.

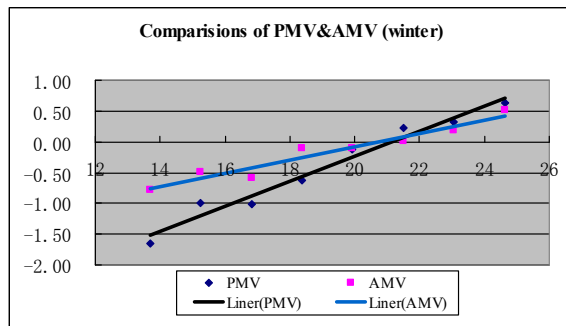


Figure 9: PMV/AMV changes indoor air temperature changes (winter)

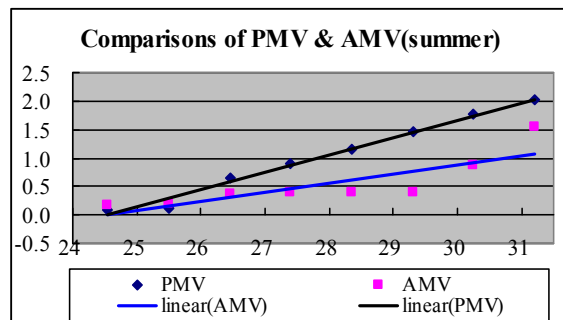


Figure 10: PMV/AMV change as indoor air temperature changes (summer)

It can be seen from the two figures that in winter and summer, both of the change of PMV and AMV have good linear relationship with the indoor temperature. This shows that the indoor temperature is the main factor of PMV and AMV.

It can be seen from the figures that PMV and AMV intersect at almost 0, that is to say, PMV and AMV indicate the same neutral temperature.

In order to compare with the PMV and AMV, the linear regression equations of PMV/AMV change as indoor air temperature changes show as follow, in winter:

$$PMV = 0.204t_{in} - 4.308 \quad (R^2 = 0.971)$$

$$AMV = 0.109t_{in} - 2.251 \quad (R^2 = 0.941)$$

in summer:

$$PMV = 0.305t_{in} - 7.496 \quad (R^2 = 0.986)$$

$$AMV = 0.162t_{in} - 3.989 \quad (R^2 = 0.684)$$

It can be seen that $PMV \leq AMV$ as $t_{in} \leq t_n$ in winter and $PMV \geq AMV$ as $t_{in} \geq t_n$ in

summer. This means that the surveyed office people can actually accept lower temperature than that of PMV model predict in winter and can actually accept higher temperature than that of PMV model predict in summer. This shows that people can make certain reactions and self-regulation to hot or cold uncomfortable environment, and this regulation is impacted by the climate, cultural backgrounds and living habits so that actually, people have difference expectation on satisfaction to the thermal comfortable environment comparing with PMV model. Therefore, AMV is more reasonable to confirm the range of acceptable temperature than PMV.

3.2.2 Confirmation of the acceptable temperature region and thermal comfort neutral temperature

When the temperature corresponding to the scope of $AMV = \pm 0.5$ is defined as an acceptable temperature range, the acceptable office temperature in winter is $16.1^\circ\text{C} - 25.3^\circ\text{C}$, the neutral temperature (namely $AMV=0$) is 20.7°C . In the acceptable temperature scope, the comparative humidity is 50%—80%, with air velocity ≤ 0.1 m/s. In summer, with the same way, we find out the acceptable office temperature in summer is $21.5 - 27.6^\circ\text{C}$, the neutral temperature (namely $AMV=0$) is 24.5°C . In the acceptable temperature scope, the comparative humidity is 40%—80%, with the winter air velocity ≤ 0.3 m/s.

4. CONCLUSION

Through survey on Chongqing office indoor thermal environment in the winter

and summer, it is found out that, due to the hot and humid summer and cold and wet winter, more and more people working in offices choose to use heating and air conditioning to improve indoor thermal comfort. Based on questionnaire, it is concluded that:

4.1 In this area, people have the habit to open windows. In order to save energy, indoor air exchange and fresh air volume increase should be focused when using heating and air conditioning.

4.2 The AMV can reflect human actual adaptability to hot or cold uncomfortable environment, thus more reasonable to be used to define the acceptable temperature range.

4.3 When $AMV = \pm 0.5$, the range of acceptable indoor temperature in winter is $16.1^{\circ}\text{C} - 25.3^{\circ}\text{C}$, in summer is $21.5 - 27.6^{\circ}\text{C}$. When $AMV=0$, office indoor neutral temperature in winter is 19.9°C and in summer is 24.5°C . In the range of acceptable indoor temperature, the comparative humidity in winter is 50%—80%, in summer is 40%—80%, the air velocity in winter is $\leq 0.1\text{m/s}$ and in summer is $\leq 0.3\text{m/s}$.

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