Evaluation of indoor environment quality of Urban Residential Buildings in Chongqing

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ABSTRACT: The field measurements and the questionnaire surveys of indoor environment in twenty urban residential buildings, which were held in October 2005 and December 2005 in Chongqing, are presented in the paper. The field measurements consist of thermal environment, indoor air quality, visual environment and acoustical environment in these buildings, while the questionnaire surveys reveal building characteristics, occupants' life styles and the subjective prediction of indoor environment. After analysing and comparing the results of objective tests and subjective surveys, the comprehensive evaluation of the study is drawn as follows: relative humidity is generally above 70% and some proper measures are required to remove the atmosphere moisture. 35% of residential buildings exceed the national standard of formaldehyde concentration. The toilets are severely polluted due to the too high ammonia concentration. However, the total occupant satisfaction is more than 80%, so the indoor air quality reaches the acceptable state.

Keywords: indoor environment, field measurement, questionnaire survey, residential building

1. INTRODUCTION

The main purpose of buildings is to provide a comfortable living environment for their occupants. This includes, among others, thermal, visual and acoustic comfort as well as indoor air quality [1]. Good indoor environment quality enhances occupant health, comfort and workplace productivity. In recent years, more and more people have started to recognize the importance of indoor air environment, especially when complaints about the indoor air quality increase annually with the spring up of the decoration of buildings [4].

Different from the hot humid climate in summer, it is always humid and cloudy with weak wind in autumn and winter in Chongqing. However, there is little research previously on the indoor environment quality of Chongqing in these seasons. Therefore, in order to obtain the comprehensive knowledge about the indoor environment situation of urban residential buildings, 20 residential buildings have been subjected to field measurement and 128 residents in Chongqing were surveyed by means of questionnaire from October to December in 2005. Through data processing and analysis, we could have much more understanding and comprehensive knowledge about the indoor environment situation of residential buildings in Chongqing in autumn and winter [4]. This paper mainly reports the investigation results of the actual status of indoor air environment.

2. Field measurement

The measurement was conducted on residential buildings in Chongqing from October 2005 to December 2005. Twenty residential buildings were selected to investigate in this field measurement in terms of different building ages and locations. The measurement consists of thermal environment, humid environment, visual environment, acoustic environment, and formaldehyde, Carbon dioxide, Carbon monoxide, ammonia, which was carried out in bedrooms, living rooms, kitchens and outdoors. The buildings under investigation have various characteristics. For instance, the oldest buildings have been lived for 12 years while the newly built just have completed decoration. Measurement spots vary from the bottom floor to 28th floor, and buildings' areas are between 60~140m2 with 7 street-side households and 13 non-street-side households. Therefore, the samples chosen can objectively reflect the real situation of the residential buildings. The instruments of measurement are listed in table1.

Table I: The instruments of measurement

Pollutants	Instruments	Accuracy
Formaldehyde	INTERCAN4160	±0.03ppm
CO_2	TSI IAQ-CALC 8762	±3%
CO	TSI IAQ-CALC 8762	±3%
Temperature	CLIMOMASTER 6531	±0.6℃
Humidity	CLIMOMASTER 6531	±0.6℃
Noise	TES 1352A	±1.5dB

2.1Indoor thermal and humid environment

According to the statistics, the changing tendency of the indoor dry-bulb temperature on the test days is showed in figure1. The outdoor temperature declined obviously after 16th November; meanwhile the indoor temperature is higher than outdoors.

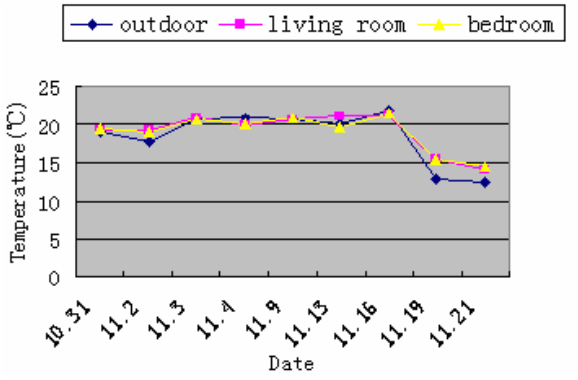

Figure 1: The temperature of outdoors, living room and bedroom in the typical days

From table2, we can find out that the indoor relative humidity in the residential buildings of Chongqing is rather high. It can maintain up to 70%, and a great deal of residential buildings' indoor relative humidity is over 80%, which goes against indoor comfort. Moreover, high air humidity could damp the floor, wall and even the surface of the furniture, which could result in the growth of bacteria. If we can dehumidify and keep the room dry, the indoor thermal and humid environment can be improved.

Table 2: The number of buildings at different relative humidity of outdoors, living room and bedroom

Relative humidity	Living room	Bedroom	Outdoors
60~80%	8 houses	8 houses	7 houses
>80%	12houses	12 houses	13houses

The comfort of human body refers to many different factors such as physiology, mentality and so on. The value of DI, named as an uncomfortable exponent, can be used to express the influence of the indoor relative humidity and wind velocity on body comfort [7]. The computing equation is

$$DI = 0.72(T_a + T_w) - 7.2\sqrt{V} + 40.6 \qquad [8]$$

T_a—dry-bulb temperature (℃), T_w—wet-bulb temperature(℃), v—wind velocity(m/s)

Generally speaking, when the value of DI is higher than 80, men will feel uncomfortable [8]. After computing the value of DI of the testing data, it can be concluded that the value of DI is between 65~70 from 31st October to 16th November, which indicates that the thermal environment during the period is comfortable. From 19th Nov, with the temperature dropping, DI value is about 56~60, which is comparatively comfortable. Table3 demonstrates the percentages of buildings at different DI value. In a word, the indoor thermal and humid environment of residential buildings in autumn and winter is comfortable.

Table 3: The percentages of buildings at different DI value

Value of DI	Percentages of buildings
71-75	5%
66-70	58%
61-65	11%
56-60	21%
51-55	5%

2.2 Indoor acoustic environment

Generally speaking, in residential buildings, daytime-noise around 55dB(A) was acceptable, or it will make people feel sick. The average sound level of indoor noise in urban residential buildings in Chongqing is 52dB(A), within regulated standards. The proportions of different ranges of sound level in living rooms are shown in figure2 below. It can be clearly seen that noise in 47% of the residential buildings are between 40 and 50dB (A) ,within which it is relatively quiet, so people will feel comfortable; 42% are 50-60dB, within which people feel it is slightly noisy; 12% are 60-70dB (A) , and most of these buildings are located in the downtown area or near the street.

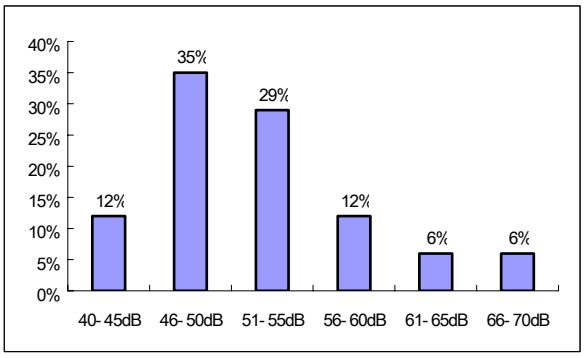

Figure 2: The proportions of different ranges of sound level in living rooms.

2.3 Indoor visual environment

The indoor visual environment not only relates directly with people's capability of identifying objects and working efficiency, but also relates with safety, comfort, convenience and appreciation of beauty. People's response to visual environment is both a physiological process and a psychological process.

Table5 is the ratio within the range of illuminance in living rooms and bedrooms. The percentage denotes the ratio of the total number of measured buildings within that illuminance. The mean

illuminance in living room is 195 lx while in the bedroom is 136 lx. The figure also shows that illuminance in 20% of bedrooms of residential building is below 30 lx, and 35% is above 150 lx; 5% of living rooms' illuminance is below 30 lx, 20% below 60 lx and 40% is above 150 lx. That relates with residents' living standards. Newly built constructions with good economical condition are of high illuminance while the old buildings with bad economical condition are of low illuminance. We can conclude that if designing follow the energy-conservation standards for lighting in residential buildings, we would have large energy conservation potential.

Table 4: The ratio within the range of illuminance in living rooms and bedrooms

Illuminance (lx)	bedroom	Living room
0-30	20%	5%
31-60	15%	15%
61-90	10%	20%
91-120	10%	10%
121-150	10%	10%
151-300	25%	20%
>300	10%	20%

2.4 Indoor air quality

2.4.1 Formaldehyde (HCHO) concentration

The results of indoor formaldehyde measurement are displayed in figure3. It shows the measured data of 20 households included living room, bedroom, among which households No.14- No.20 just recently moved into. It can be seen that about 30% of households of outdoor formaldehyde concentrations exceed the standard (0.1 mg/m3). About 35% of bedrooms' concentrations exceed the standard. Furthermore, the newly built residential buildings' formaldehyde is generally on the high rate. The volatile materials make the formaldehyde concentrations exceed the standard. The 19th household is the highest and the concentration of formaldehyde is up to 0.17mg/m3, nearly two times of the standard value. During the survey, it is found that the 19th household had recently completed interior decoration so that the materials are emitting formaldehyde, and its room ventilation is poor, which leads to higher concentrations of formaldehyde.

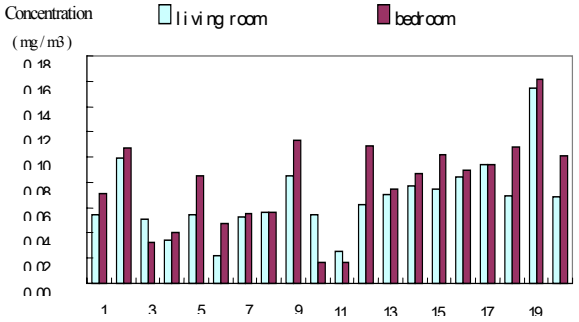

Figure 3: Formaldehyde concentration in living room and bedroom

Formaldehyde concentrations in living rooms are lower, and only a small number exceed the standard. In bedrooms, due to many wardrobes and cosmetics, the proportion of the indoor exceed-standard formaldehyde is larger. Outdoor formaldehyde concentrations change remarkably in different measurement spots. There are three houses whose outdoor formaldehyde concentrations exceed "Indoor Air Quality Standards" (GB/T 18883-2002), and eight houses whose outdoor concentrations even higher than its indoor. In addition to the influences of outdoor materials of the buildings and some indoor decorations, this phenomenon is a result of the slow diffusion of outdoor formaldehyde. And the slowness is caused by lower urban outdoor wind speed and the unreasonable complex layout.

2.4.2 Monoxide (CO) concentration

CO is mainly from the incomplete fuel combustion, industrial emissions, tail gas, cooking and smoking. With 20 samples, this research indicates that all the indoor CO concentrations meet the state standard (<=10mg/m^3). There are even some houses in which the CO concentrations are too thin to be measured. And for different rooms the values are different. For instance, the CO concentration in the kitchen is higher than others. The living room of one house also has a higher concentration because people in it were smoking during the time of measurement, thus human activity should be taken into account for the CO concentration.

2.4.3 Carbon dioxide (CO_2) concentration

Field measurement shows that the concentrations of most residences' outdoor CO2 (about 70%) are less than 100PPM. As for indoor, they are generally more than 100PPM, while 100-150 PPM accounts for about 52%. However, some old buildings' indoor concentrations are more than 200PPM, at a ratio of 20%. The differences caused by two factors: the number of indoor persons and the closeness of the rooms. In a word, the CO_2 concentrations live up to the state standard (1000PPM).

2.4.4 Ammonia (NH_3) concentration

The indoor NH_3 mainly comes from the concrete additive. However, since people in Chongqing seldom use it, most of the indoor NH_3 here is from human excreta. In addition, NH_3 can be produced by interior decoration material of additive and brightener, but those material can volatilize so fast that it will bring little harm to human being. NH_3 has bad odor, and when it reaches comparatively high concentration, it will sting men's nose and eyes etc. In a room with high concentration of NH_3, man will feel uncomfortable and his health will be in great danger if he lives there for a long time.

In this research, only the living rooms and toilets of House No.2, 3, 4, 5, 6, 7, 8, 11, 12 and 13 were selected to measure the NH3 concentration. As shown in Figure 4, the values are relatively higher, with a maximum 29 mg/m^3 (over standard). It also shows that the concentration in the toilet is higher than the living room remarkably. This is due to the excretion in the toilet, which can bring NH3. Most toilets in this research have no fans, so NH3 is hard to emanate. The GB/T 18883-2002 regulates that the average concentration of the NH3 per hour should not exceed 0.2 mg/m^3, but it greatly exceed that standard in Chongqing, which reflects serious pollution in toilets of residential buildings in Chongqing.

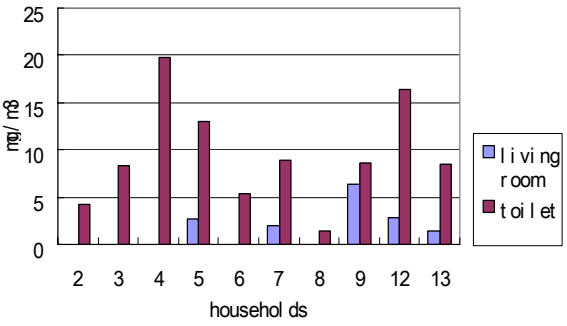

Figure 4: Ammonia concentration in living room and toilet

3. Results of questionnaire surveys

The assessment method can be divided into objective and subjective assessment. The objective assessment should test certain parameters, then the parameters can be compared with related sanitation standards to judge whether the indoor air quality is eligible. However, many investigations show that, sometimes although the indoor air parameters accord with the criterion and human body's physiological parameters have no obvious change, people inside still feel the air quality isn't agreeable. That was caused by hundreds of organic pollutants with low concentration, which is hard to test. From that we can see, subjective assessment is considered to be a significant factor to assess the indoor air quality [5].

In order to improve the evaluation quality and guarantee the accuracy, we designed the questionnaire according to the internationally used subjective assessment table, together with the specific situation in Chongqing. The contents of this questionnaire survey include the personal information of occupants, indoor air quality, overall indoor environment and health condition of occupants [2]. For this assessment, a total of 140 questionnaires were distributed to the residents and 88.28% of them (128 respondents) completed and returned. Among them, 62.19% are male, while the others are female. Table6 displays the percentages of different age range of the respondents. Based on data statistical analysis, following results have been found [4].

Table 5: The percentages of age range of the respondents.

Age range	Percents
less than20	7.21%
20-30	59.87%
30-40	14.63%
40-50	7.32%
50-60	8.53%
more than 60	2.44%

3.1 The evaluation of indoor air quality

Subjective assessment of indoor air quality (IAQ) shows the unacceptable rate is 10.98% (Figure 1). The main unacceptable reason for air quality is the bad air, such as air choke, uncirculated, and smelly. For instance, over 20% of the occupants claim that there is regular disagreeable odor in the house. The frequently emerged odor is from the volatile organic compounds and the activities of the occupants. According to ASHARE Standard 62-1999, the definition of acceptable indoor air quality in ventilation is "In the air, there are no pollutant reaching the harmful concentration which is set by authority, and most people inside feel satisfied (>80%)." Thus, we could know that the indoor air quality of the residential buildings in Shaping District has reached the acceptable state, for the indoor satisfaction degree accords with the requirement of standard.

Furthermore, it is concluded that keeping windows open can greatly improve the indoor air quality. Although the outdoor air coming into the house through the windows without filtering would bring the dust and pollutants, it can reduce the age of air, better the ventilation and exchange the fresh air at the same time. According to the investigation, 96.34% of all the residents preferred to open the windows of their houses. More than half of the residents kept the windows open for at least 12 hours each day. However, 66.7% of the residents, who couldn't accept the indoor air quality in their rooms, rarely opened the windows in their daily lives. They closed the windows more than 18 hours every day. So the opening hours of windows for air exchange may also affect indoor air quality of buildings. The indoor air quality has particular relationship with the windows' opening or closing.

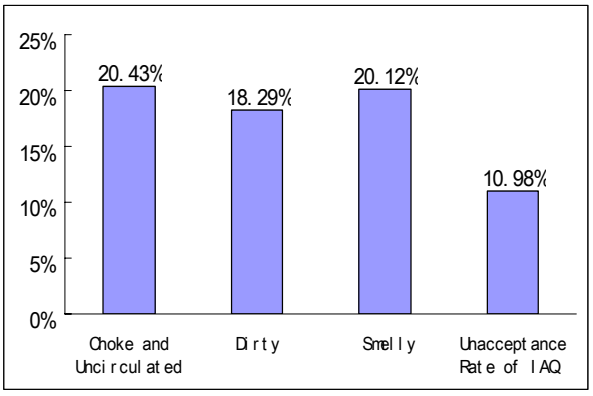

Figure 5: Residents' sense degree of indoor air quality (%)

3.2 The evaluation of overall indoor environment quality

From figure 6, we can analysis the influence of each indoor environmental component on indoor environment quality (IEQ) in urban residential buildings. The satisfaction degree of the five major components and overall IEQ is rated on a five-point scale. For each parameter, the occupant is asked to assess its quality over a continuum from 1 to 5, where the values of 1 and 5 represent the quality in terms of 'very poor' and 'excellent', respectively. Dissatisfaction refers to the percents of the occupants who rate the parameter as 1 or 2.

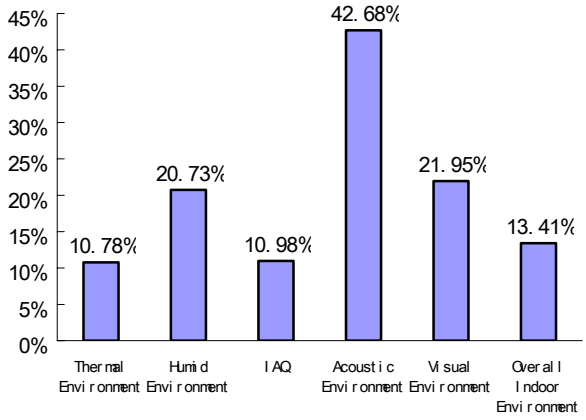

Figure 6: Residents' dissatisfaction degree to indoor environment (%)

The indoor acoustic environment exerts the greatest influence. Its unsatisfied rate is as high as 42.68 %, which ranks the top and become a main contradiction of indoor environment quality. In the ranking, visual environment follows acoustic environment, then followed by humid environment, indoor air quality and thermal environment. This result has close correlation with the autumn and winter weather in Chongqing. As far as we know, it is fairly common to be cloudy and rainy for the whole two or three weeks during that special period in Chongqing, which could obviously affect residents' visual and humid environment. To indoor air quality, thermal, humid and visual environment, though they are all of flexibility in testing result, their acceptable rate is greatly different from the others. That reflects residents' adaptability are different in different environments, meanwhile the influence of indoor environmental component on comfort parameter is also quite different. The dissatisfaction degree of overall indoor environment quality is low, which demonstrates though the parameter of some rooms is above the normal range of comfort, residents still could judge their satisfaction with their overall views of the indoor environment.

3.3 Result of Sick Building Syndrome investigation

In the last 20 years, a large number of office workers have complained of a similar set of symptoms, commonly known as the Sick Building Syndrome (SBS). The World Health Organization has defined the SBS as "an increase in the frequency of building occupant reported complaints associated with acute non-specific symptoms (eyes, nose or throat irritation, headache, fatigue, nausea) in non-industrial environments that improve while away from the building" [3]. Now the syndrome is getting more epidemic than before, it has emerged in developing countries, such as China, and may become a global environmental health problem for People in future [6].

Figure 7 displays the result of Sick building syndrome of this investigation. The sense degree of those syndromes is rated on a five-point scale. For each parameter, the occupant is asked to assess its quality over a continuum from 1 to 5, where the values of 1 and 5 represent the quality in terms of 'not at all' and 'very much', respectively. The syndrome frequency refers to the percents of the people with certain syndrome.

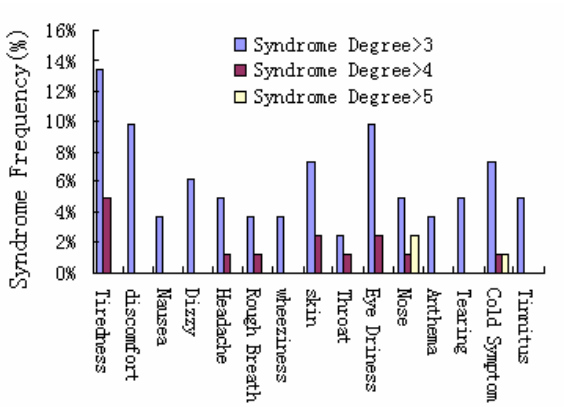

Figure 7: Syndrome degree and frequency of different SBS

The syndromes of "tiredness", "discomfort", "skin irritating allergy", "cough" and "eye dryness" are comparatively reflected strong, while other syndromes are comparatively weak. From the analysis of SBS syndrome frequency we can see that the frequency with different syndromes is reflected with great difference. Take "cough" and "nose provocation" for example, some people turn out serious syndrome, but the frequency is low. If the syndrome degree above 4

is considered serious, the biggest syndrome frequency “tiredness” is only 4.88%. Other syndrome frequencies are below 2.5%, and the frequency with syndrome degree above 3 is less than 15%. According to the definition of WHO, if we take syndrome frequency of 20% as a standard of healthy building, the urban residential buildings in Shaping District, Chongqing could be regarded as healthy buildings. In addition, the investigation demonstrates that only 14.6% of the occupants claimed that the syndromes are caused by indoor air quality.

4. CONCLUSION

Although the thermal comfort of residents was fairly good in Chongqing in autumn and winter, indoor relative humidity in a large number of residential buildings’ exceeds the state standards of China. So some proper measures are required to remove the atmosphere moisture. About 30% of buildings’ outdoor formaldehyde concentrations exceed the standards, while about 35% of the indoor concentrations exceed. The formaldehyde concentrations in living rooms are relative lower. All of the indoor carbon dioxide concentrations we investigated do not exceed the standard. The ammonia concentrations are too high in residents’ toilets without exhaust fan, for it is difficult for the emissions of dirty gas.

Subjective evaluation is considered to be a significant method to study the indoor environment quality. From the questionnaire survey, we found that the total occupant satisfaction is more than 80%, so the indoor air quality of residential buildings in Chongqing reaches the acceptable state. The indoor air quality has particular relationship with the windows’ opening or closing. The indoor acoustic environment exerts the greatest influence on the overall indoor environment quality. Its unsatisfied rate ranks the top. Due to the weak degree and low frequency of Sick Building Syndrome, the urban residential buildings in Chongqing could be regarded as healthy buildings.

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