Introduction

Energy consumption of China is increasing rapidly due to the recent economical growth and development. That is one of the major reasons behind the air pollution problems in large cities of China. In residential buildings of developed countries, energy consumption used for space heating and cooling plays an important role in the total residential energy consumption.

In order to estimate the future trend of the residential energy consumption in China, it is necessary to understand the situation of the usage of facilities and the indoors thermal conditions. Authors have previously reported the winter survey of indoor thermal environment of urban residential buildings in China [2]. In this paper, the purpose of this survey is to look into the actual conditions of urban residence of China, during the summer period.

The apartment houses under investigation were located in the urban areas of Shanghai, Hong Kong and Xi'an. The questionnaire survey together with the measurements of indoor temperature and humidity were done in the summer of 1998 for Shanghai and 2001 for Hong Kong and Xi'an. Figure 1 shows the location of the three cities under investigation. Figure 2 shows the climograph [3] of major cities in China and Japan. For the climate in August, Hong Kong and Shanghai are very hot and humid. These cities are almost similar to Naha, and Xi'an is similar to Tokyo.

Abstract

The purpose of this survey is to look into the actual conditions of the residential indoor environment in urban areas in China during the summer for discussing thermal comfort and the possibility of space cooling energy conservation.

The apartments under investigation were located in Shanghai, Hong Kong and Xi'an. The questionnaire survey and the measurement of indoor temperature and humidity were done in the summer of 1998 for Shanghai [1] and 2001 for Hong Kong and Xi'an. The questionnaire survey revealed the life style within residences of summer season, the types of air-conditioners used and so on. The measurement showed that indoor temperature and humidity in Hong Kong and Shanghai are very high. In comparison with these three cities, it was found that the indoor environment was not so severe in Xi'an.

Keywords: China; indoor thermal environment; residential building; questionnaire survey; field measurement
2. Outline of Survey

2.1 Questionnaire and Temperature Measurement

In this study, two sets of identical questionnaire and measuring device were distributed to the families of secondary school and university students (hereafter denoted by families). The contents of the questionnaire are classified into six key elements and tabulated in Table 1. A simple type of liquid crystal thermometer (Chromophore type and it is with 0.5°C tolerance) for measuring temperature data was used as the measuring device in this investigation and they were adhered to a 5mm thick polystyrene board. From the previous investigation [4], it was found that the difference between the reading value of the thermometer and the recording value with thermister sensor was less than 2°C. The families were given two of this liquid crystal thermometer and requested to fix it onto the wall at a height of 1.1m from the floor level in a bedroom and living room of their houses. The measurement was carried out in three different sections of five consecutive days from 6a.m.-8a.m. (morning), 11a.m.-1p.m. (mid-day) and 7p.m.-9p.m. (evening). The families were required to record the temperature reading from the liquid crystal thermometer within the interval of each of the section. The questionnaires were also completed by the families. The time period for the indoor temperature measurement of this study was separated into two summers. The first measurement was carried out in Shanghai and done in August 1998 whilst the second measurement was taken from Hong Kong and Xi’an in 2001.

2.2 Detailed Measurement of Indoor Environment

Three major cities; Hong Kong Special Administrative Region, Shanghai and Xi’an of China were designated for this investigation. In each of the city, several families within the distributed families were selected for further measurement. The families for taking up further measurement were given a set of three small data loggers with thermister sensor. These loggers were used to record the measurement of temperature and humidity for indoor and outdoor. Each thermister sensor for the indoor measurement was mounted on supports at a height of 1.1m from the floor level in living room and bedroom. The sensor for the outdoor measurement was fixed in an aluminum flexible duct for protecting solar and sky radiation. Thus, in these families, the indoor temperature was measured not only from the liquid crystal thermometers, but also was obtained by this small data logger. All these measurements were done in five consecutive days during the investigation period. The results of this questionnaire based on the further measurement were summarized in Table 2.

3. Results of Questionnaire Survey

3.1 Characteristics of Housings

Results are discussed mainly for Hong Kong and Xi’an. Figure 3 shows the floor areas of housing in Hong Kong and Xi’an from this study. The floor areas range from 20 m² to 80 m² in Hong Kong and from 60 m² to 100 m² in Xi’an, with average areas of 55.6 m²

### Table1. Contents of the Questionnaire Survey

| Building Characteristic       | Construction year, Structure, Height of building, Architectural area, Condition of veranda, Windows |
|------------------------------|---------------------------------------------------------------------------------------------------|
| Housing Equipment            | Cooling system, Equipment of supplying hot-water                                                |
| Residential Characteristic   | Number of residents, Income                                                                      |
| Life Style                   | Cooling period, Cooling time, Number of staying persons, Garment insulation value, Windows opening|
| Satisfaction rating          | Sense of thermal comfort, Satisfaction of the residence environment                               |
| Energy Consumption           | Consumption of city gas and electricity                                                          |
| Indoor Thermal Environment   | Temperature in the morning, midday and evening                                                   |

### Table2. Summary of the Results of Questionnaire Survey

| Subject city | Survey period | Distributing number | Number of respondents | Number of apartment houses under measurement | Outdoor conditions | Average of relative humidity |
|--------------|---------------|---------------------|-----------------------|---------------------------------------------|------------------|------------------------------|
|              |               |                     |                       |                                             | Outdoor temperature |                             |
|              |               |                     |                       |                                             | Average | Maximum | Minimum |                             |
| Shanghai     | 8/1998        | 100                 | 75                    | 5                                           | 30.6°C     | 36.9°C     | 27.0°C   | 73.4%                         |
| Hong Kong    | 8/2001        | 132                 | 120                   | 12                                          | 29.4°C     | 33.2°C     | 25.0°C   | 79.0%                         |
| Xi’an        | 8/2001        | 100                 | 100                   | 10                                          | 24.7°C     | 34.4°C     | 19.1°C   | 69.7%                         |
and 75.8 m², respectively. Figure 4 shows the height distribution of buildings, in terms of number of stories, in these two cities. Most buildings have the number of stories from 10 to 40 in Hong Kong but from 4 to 8 in Xi’an, with their averages are 23 and 8, respectively. The population density in Hong Kong is 6200 person/km² whilst it is 600 person/km² in Xi’an. Figure 5 shows the comparative situation of balconies in Hong Kong and Xi’an. It can be seen that 91% of balconies in Xi’an housing units are sealed whereas in Hong Kong about 67% of residences have no balcony.

3.2 Way of Life

Figure 6 reveals that 70-75% of residents in Hong Kong remain at home during the day from 8 a.m. to 5 p.m.. On the other hand, the records show very slight variations in Xi’an that approximately 60% of residents remain at home in the morning from 8 a.m. till noon and in the afternoon from 1 p.m. to 5 p.m.. During lunch hour from noon to 1 p.m., the value reaches 90%, and this is because many residents prefer to return home for lunch. The clothing of the occupants, male and female, worn is shown in Fig. 7, in terms of thermal resistance of clothing (clo). It can be seen that the clo values of the two cities are found in around 0.2-0.3. The average clo values for male and female are, in Hong Kong, 0.27 and 0.29, respectively. But in Xi’an, these values are 0.23 clo (male) and 0.28 clo (female). The average clo values of male in these two cities are both lower than the female. In comparison with Hong Kong and Xian, these average values for male and female are found lower in Xi’an.
3.3 Air-conditioning and Its Usage

A comparison of the possession ratio of air-conditioner is given in Fig. 8. About 80% of the families have equipped air conditioners in both living room and bedroom in Hong Kong, and most of them are window-unit type. On the other hand, only 55% of the families in Xi’an have installed air-conditioners in living room and bedroom, which are mostly the split type. The use of air-conditioning in Shanghai is different from the cities of Hong Kong and Xi’an. This can be observed, in Fig. 8, that about 60% of air conditioners are put in the bedroom and the split type is commonly used.

Among these three cities, the period of using air-conditioning in Hong Kong is the highest, whilst Shanghai is of a modest level and Xi’an is the shortest, as shown in Fig. 9. Based on the 50% line in Fig. 9, the periods of air-conditioning used in Hong Kong, Shanghai and Xi’an are 4, 3 and 2 months, respectively. From this survey, it is found that the adoption of air-conditioning in Shanghai and Xi’an commences in the same months, however, the ending time of using air-conditioning in Xi’an finishes a month earlier than in Shanghai. This is due to the difference of the geographic location between these two cities where Xi’an situates in the middle of the mainland and Shanghai stays at the eastern coast of China. Hot temperature generated and trapped during the summer season in Shanghai requires longer time to disperse, thus the period of using air-conditioning is longer than in Xi’an.

Figure 10 shows the rate of air-conditioning used in these three cities for a typical summer day. In comparison with Xi’an and Shanghai along, two peaks are seen in both of these two cities during the daytime from noon to 3 p.m. of 50-60% and in the evening from 5 p.m. to 11 p.m. of 70-80%. Although the indoor temperature during the daytime is higher than in the evening, the usage of air conditioning is low. This is due to the fact that lesser residents stay at home during such time of the day. On the other hand, in the situation of Hong Kong the usage peak of air-conditioning is found throughout the night until morning. However, the lowest usage rate is 16.8% at 11 a.m.. In comparison with Xi’an and Shanghai, the lowest usage rate obtained in Hong Kong at 11 a.m. is lower than those observed in Xi’an and Shanghai at the same time on the day.

3.4 Results of Indoor Temperature Measurement by Liquid Crystal Thermometer

The average values and standard deviations of the temperatures in the living room, bedroom and outdoor of residents in each city are shown in Figure 11.

a) Hong Kong: Since many families use air-conditioning from night to morning, the temperature of the bedroom is lower than the living room in the morning. The average temperatures of bedroom and living room are 27.2°C and 28.8°C, respectively. Moreover, the standard deviation of indoor temperature is higher than the outdoor because it is influenced by using air-conditioning.

b) Xi’an: The temperatures of the living room and the bedroom are almost the same at all time, and the average is about 27°C which is also higher than the outdoor. The standard deviations of outdoor temperature are larger than other cities because of the great difference between good weather and bad weather.

c) Shanghai: The temperature of the bedroom is about 1°C lower than the living room at all time because families spend a lot of time in the bedroom.
4. Results of Field Measurement

4.1 Indoor Temperature and Humidity

The differences of indoor temperature and humidity in Hong Kong, Xi’an and Shanghai based on this investigation are described as follows. Measurements were taken in 5 consecutive days in Hong Kong and in Xi’an from August 8 (0:00 hour) to August 12 (24:00 hour) and August 17 (0:00 hour) to August 21 (24:00 hour), respectively. For the case of Shanghai, the measurements were taken in 7 consecutive days from August 1 (0:00 hour) to August 7 (24:00 hour).

a) Hong Kong: A lot of residences have operated air-conditioning in bedrooms during sleeping hours. The result of the measurements at House-A is shown in Figure 12(1). House-A is reinforced concrete construction type built in 1997. Air-conditionings are set in living room and bedrooms. Air-conditioning is used in the bedroom during sleeping time and in the living room during daytime and in the evening. The differences of temperature, relative humidity and absolute humidity between living room and bedroom are 5-10°C, 20-30%RH and 10-23g/kg, respectively. The indoor temperature and humidity become the same with the outdoor. Therefore, it is thought that the windows are opened instead of using air-conditioning.

b) Xi’an: The occupants generally cool the houses by opening the windows, thus less families use air-conditioning during the measurement period. However, some families are found using air-conditioning on August 17 and 18, due to the hot weather of these two days. The result of the measurements at House-B is shown in Figure 12(2). House-B is mixed construction type with brick and reinforced concrete built in 1994. Air-conditionings are set in living room and bedroom. In both living room and bedroom, the temperatures are between 24.5-30°C, and changes are small in comparison with the outside temperature. From the night to noon, indoor temperatures are higher than the outdoor temperature. And from daytime to the evening, indoor temperatures are lower than the outdoor temperature. The variations of indoor relative humidity are within the range of 50-74%RH in both rooms. The indoor absolute humidity within the range of 11-18g/kg shows almost the same value as the outdoor. Therefore, it is believed that the residents leave the windows opened to allow the outside air entering into the rooms. It was reported, during the investigation period, that the outside temperature is lower than other usual years because the weather was not good on the dates of August 19 and 20.

c) Shanghai: The result of the measurements at House-C is shown in Figure 12(3). House-C is reinforced concrete construction type built in 1995. Air-conditioning is set in living room, which combines with bedroom. The indoor temperature, relative humidity and absolute humidity distribute in the ranges of 26-33°C, 48-86%RH and 10-23g/kg, respectively. Air-conditioning is used at noon and 6p.m.-12p.m.. During these two periods, the indoor temperature and humidity are lower than the outdoor, which the difference of temperature is about 2-8°C. For other time during the day, the indoor temperature and humidity become the same as the outdoor.

4.2 Relationship Between Outdoor and Indoor Temperature

Figure 13 shows the relationship between indoor and outdoor temperatures in the three cities during the measurement period. The sleeping hours, daytime and evening are specified as 0:00-4:00, 12:00-16:00 and 18:00-22:00, respectively.

a) Hong Kong: The distribution of indoor temperature is the most varied in comparison with Xi’an and Shanghai, because many families use air-conditioning during the measurement period. However, some families are found using air-conditioning on August 17 and 18, due to the hot weather of these two days. The result of the measurements at House-B is shown in Figure 12(2). House-B is mixed construction type with brick and reinforced concrete built in 1994. Air-conditionings are set in living room and bedroom. In both living room and bedroom, the temperatures are between 24.5-30°C, and changes are small in comparison with the outside temperature. From the night to noon, indoor temperatures are higher than the outdoor temperature. And from daytime to the evening, indoor temperatures are lower than the outdoor temperature. The variations of indoor relative humidity are within the range of 50-74%RH in both rooms. The indoor absolute humidity within the range of 11-18g/kg shows almost the same value as the outdoor. Therefore, it is believed that the residents leave the windows opened to allow the outside air entering into the rooms. It was reported, during the investigation period, that the outside temperature is lower than other usual years because the weather was not good on the dates of August 19 and 20.

c) Shanghai: The result of the measurements at House-C is shown in Figure 12(3). House-C is reinforced concrete construction type built in 1995. Air-conditioning is set in living room, which combines with bedroom. The indoor temperature, relative humidity and absolute humidity distribute in the ranges of 26-33°C, 48-86%RH and 10-23g/kg, respectively. Air-conditioning is used at noon and 6p.m.-12p.m.. During these two periods, the indoor temperature and humidity are lower than the outdoor, which the difference of temperature is about 2-8°C. For other time during the day, the indoor temperature and humidity become the same as the outdoor.

![Fig.11. Average Values and Standard Deviations in the Living Room, Bedroom and Outdoor](image)
during sleeping hours, the temperatures in the bedrooms are 3-8°C lower than the outdoor temperature.

**b) Xi'an**: There are few residents used air-conditioning, the indoor temperature is distributed with a comparatively narrow range of 23-30°C and this indoor temperature is lower than the outdoor temperature during the day. However, it becomes the same in the evening as outside temperature and is higher than the outdoor temperature during sleeping hour, except on the dates of August 19 and 20 of which the outdoor temperature is about 20°C.

**c) Shanghai**: The indoor temperature is distributed within the range of 26-33°C, even though several houses used air-conditioning in the daytime and evening. For the evening and sleeping hours, indoor and outdoor

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![Graphs showing temperature and humidity changes over time for different houses (A, B, C)].

*Fig.12. Results of the Change of Temperature and Humidity*
temperatures are almost the same, and indoor temperature is lower than outdoor temperature in daytime.

4.3 Evaluation of the Indoor Thermal Environment Based on Comfort Index

Figure 14 shows the Discomfort Index (DI) [3] in each city and Eq. 15 shows the comfort zone of ASHRAE [5] in summer and indoor thermal environment.

a) Hong Kong: There are a lot of houses with air-conditioning operated during the sleeping hours. The temperature and humidity during sleeping time in the bedroom are distributed inside or close to the range of the comfort zone of ASHRAE. However, it is found in a lot of the families that the DI exceeded the value of 80 during daytime and the evening. The temperature and humidity in the living room are as high as the outdoor. Although many families open windows and use fan, it is difficult to say that the indoor thermal environment is comfortable. Most of occupants evaluated that indoor thermal environment in summer was ‘neutral’ or ‘slightly hot’.

b) Xi’an: The average Discomfort Index (DI) is 74-76 at all time. Indoor temperature and humidity are in the ranges of 23-29°C and 50-70 %RH at daytime, night time and sleeping time. These are distributed near the comfort zone of ASHRAE. Indoor absolute humidity is the same as the outdoor because a lot of residences open windows and use fan. Many occupants evaluated that indoor thermal environment in summer was ‘slightly hot’ at daytime, and half of occupants responded ‘slightly cool’ at night.

c) Shanghai: There is no family use air-conditioning during the sleeping period and there are a lot of houses where the DI exceeds of 80. Indoor temperature and humidity are higher than the comfort zone of ASHRAE. Discomfort Index is 75-85 at both daytime and in the evening, and the indoor temperature and humidity are out of the comfort zone of ASHRAE. Therefore, it is difficult to say that the indoor thermal environment is comfortable.

5. Conclusions

Questionnaire survey for indoor living conditions and field measurement for two summers were carried out to the urban residence (family type) of three cities, Hong Kong Special Administrative Region, Shanghai and Xi’an in China. The results from this study are drawn as follows:

1) Air conditioner type used in Hong Kong is mostly the window-unit type, while the split-unit type is commonly found in Xi’an and Shanghai. About 80% of the households in Hong Kong and 55% in Xi’an have air conditioners in living room and bedroom, respectively, but in Shanghai 60% of the households have air-conditioners equipped in bedrooms.

2) The peak period in operating the air-conditioning is from mid-night until morning in Hong Kong, while it is in the daytime and evening in both Xi’an and Shanghai.

3) The indoor temperature and humidity are found high in Hong Kong except during the sleeping time, but no changes in Shanghai. There are 55-80% of the families that the Discomfort Index exceeds 80 in Hong Kong and Shanghai.

4) Among the three cities under the current investigation, it is found that the indoor thermal environment is relatively comfortable in Xi’an.

Fig. 13. The Relationship between Indoor and Outdoor Temperatures for Measurement Period
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