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Analysis on urban residential energy consumption of Hot Summer & Cold Winter Zone in China

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ABSTRACT

The purposes of this study were to investigate and analyze the actual conditions of the residential energy consumption, and hence to ascertain what would be the important factors that influence the annual energy consumption in four Chinese cities. The questionnaire surveys revealed building characteristics, housing appliances, household characteristics, indoor environment and aspects of life style, during winter and summer seasons. The energy consumption analyses showed that the average annual energy consumption of households in Chongqing reached 41.1 GJ which was the largest among all households in the investigated cities. The influence factor analyses showed that the important influence factors were city location, floor area, CDD and water heater type. The standards "*Thermal design code for civil building*", GB 50176-93 helps to save energy. The households equipped with solar water heater (SWH) consumed less energy, however, its possession rate was low because of the poor quality in the Chinese market. Thus, corresponding policy steering mechanisms of SWH are needed for energy saving. The annual energy consumption for water heater in Shanghai, Chongqing and Changsha was 6.7, 8.3 and 5.7 GJ, accounted for 23%, 20% and 18% respectively. The more energy would be saved if more households use solar water heater.

1. Introduction

The rapid increase of residential energy consumption has become a key factor affecting natural environment and economic development in China. The residential sector in China consumed 308.1 million tons of standard coal in 2007 which ranked second among all sectors of China (National Bureau of Statistics, 2009). Urban households accounted for 63% of the total residential energy consumption in 2007 (Zhao, Li, & Ma, 2011). In order to achieve a good balance among energy consumption, natural environment and economic development, it is vital to know the actual situation of energy consumption and its influence factors such as indoor environment, usage of household appliances and characters families, this information enable us to estimate the future trend of residential energy consumption and indoor environment requirement, as well as the possibilities and the strategies for energy saving in China (Jones, 2002; Mohammad & Al-Homoud, 2001; Yoshino et al., 2006). Chen, Yoshino, and Li (2010) made analyses on summer energy consumption of residential buildings and their influence factors in seven cities. They got the characteristics of energy consumption in summer, and revealed the important factors influencing energy consumption in summer.

In existing researches on residential energy consumption and indoor environment in China, Zhou, Nishida, and Gao (2008) estimated that the residential energy consumption in the year 2020 would be doubled than that in 2000, from 6.6 EJ in 2000 to 15.9 EJ in 2020. Bojic and Yik (2005) made a simulation for the dependence of space cooling loads of residential flats on the constructions of external walls and partitions, and the location of thermal insulation layers in the walls and partitions, and evaluated the effect of insulating envelope and partitions on cooling energy for high-rise residential buildings in Hong Kong. Li and Jiang (2006) analyzed the characteristic of energy consumption of air-conditioner during summer in residential buildings in Beijing. They concluded that the average energy consumption of air-conditioning was reduced by 1.4 kWh/m^2 when the temperature of air-conditioned room was raised by 1 °C. Yoshino et al. (2002) investigated the energy consumption of residential buildings and indoor thermal environment in three Chinese cities. It was found that the air-conditioning units were popularly used for space heating by 45% of households in Shanghai. On the other hand, the heating system was not operated all day long in some cases although central space heating was popular in Harbin. Meier, Lin, Liu, and Li (2004) investigated standby power usage of household appliances in 28 Chinese families in Guangzhou, and obtained the average standby energy use

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Table 1
Houses of the survey.

City	Survey period	Distributed questionnaires	Feedbacks (summer/winter)	Meter reading
Maanshan	2007/10–2008/9	60	57/56	56
Shanghai	2007/10–2008/9	165	136/132	123
Chongqing	2007/10–2008/9	128	65/63	56
Changsha	2007/10–2008/9	80	29/27	26

per year in the urban homes. Lam (1996) made a survey on energy consumption in five different types of residential buildings in Hong Kong, and estimated the end use values of electricity. It was found that air-conditioners, refrigerator and lighting were the three main consumers. Geoffrey and Kelvin (2003) studied the domestic energy usage patterns in Hong Kong, and found the consumption distribution by energy type, end-use appliance consumption distribution, daily energy loading patterns and significant factors influencing electricity energy consumption level. In other two studies done by Yoshino and Lou (2002) and Zhang and Yoshino (2010), the indoor and outdoor temperature and humidity during summer and winter seasons in some Chinese cities were analyzed.

However, detailed analysis of the data collected to influence factors of energy use, characters of buildings, families and housing appliances is lacking in Hot Summer & Cold Winter Zone. Thus, the characteristics of energy consumption cannot be comprehensively revealed. For the above mentioned reason, an investigation was conducted in order to obtain useful results for preparing programs to minimize energy in China. This study aims to understand residential energy use characteristics in a year and their influence factors of Hot Summer & Cold Winter Zone in China.

2. Outline of the survey

2.1. Location of investigated cities

The survey was conducted in the urban areas of Maanshan, Shanghai, Chongqing and Changsha. Fig. 1 shows the location of these investigated cities. These cities are distributed in Hot Summer & Cold Winter Zone, and are all major cities in China (Department of Construction of the PRC, 1993).

2.2. Investigation method

This study was done by using questionnaire survey. The questionnaire was distributed as well as collected through the cooperative researchers in local universities. Total number of 433 families (in 433 buildings) living in urban areas of four cities were selected by the researchers. Table 1 lists the investigation date, and number of distributed questionnaire, feedback and meter readings. Each family was asked to answer a questionnaire for the summer and winter seasons, including basic information related to the characteristics of their building, heating & cooling periods, daily operation time, usage of heating & cooling appliances, number of occupants, annual income and thermal sensation as shown in Table 2. In addition, the monthly consumptions of electricity and gas of each family in a year were collected by the meter readings (students of local universities went to each family and collected data on the first day of the months).

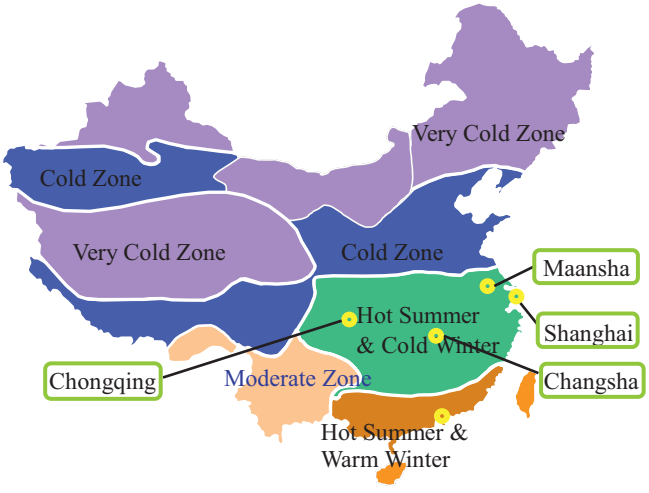

Fig. 1. Location of the investigated cities.

2.3. Processing for missing data

The families are taken as samples, and all the items in the questionnaire are taken as variables. The methods of the processing for the missing data refer to the method in research (Chen et al., 2010). Therefore, the numbers of feedbacks of questionnaire and meter readings shown in Table 1 are the valid sample quantities.

3. Results and discussion of questionnaires

3.1. Building characteristics

Most of the investigated buildings in Changsha and Chongqing were built after 2000. While in the other two cities, most of the investigated buildings were constructed between 1990 and 1999 which accounted for 70%. Most of the investigated buildings in these cities were made by brick concrete structure.

Regarding the floor area of residences, 67% of the dwelling units in Chongqing, and 52% of the dwelling units in Changsha were more than 120 m^2, as shown in Fig. 2. The average floor area in Chongqing was 130.6 m^2, which is the largest among the four investigated cities. And in Changsha, the average floor area was about 105 m^2. From the research conducted by Yoshino et al. (2006), it was found that the average floor area in Chongqing was 112.9 m^2 in 2003, and in Changsha was about 80 m^2 in 2004. It can be seen that the average floor area in Chongqing and Changsha Kunming has increased 17.7 m^2 and 25 m^2 in four years respectively.

Fig. 3 shows the material of window frames used in these four cities. More than 60% of the housing units used aluminum alloy

Table 2
Contents of questionnaire.

Building characteristic	Construction year, structure, floor areas, window, etc.
Housing appliance	Heating & cooling system, appliance of hot-water supply, usage time of appliances, etc.
Family characteristic	Number of occupants, annual income, age of occupants, etc.
Life style	Heating & cooling period, Heating & cooling time, number of staying persons, etc.
Satisfaction rating	Satisfaction of environment and indoor environment
Energy consumption	Electricity and gas consumption, satisfaction of energy costs