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Statistical analyses on winter energy consumption characteristics of residential buildings in some cities of China

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ABSTRACT

The purposes of this paper are to analyze winter energy use of residential buildings in different cities of China, and to figure out the influence factors of winter residential energy use. The investigated residences were located in seven typical cities of five architectural thermotechnical design zones. Questionnaire surveys revealed building characteristics, household characteristics, the utilization of domestic appliances, and thermal environment in winter. Winter energy consumption in different cities bears obvious regional characteristics. In south China, Hong Kong has the largest mean household energy use amount, and Changsha and Chongqing follow Hong Kong; Kunming in the warm zone has the small energy use. In north cities, if district space heating is excluded from total energy use, Urumqi and Xi'an have the energy use at the smallest level, but space heating use is very huge. The energy use amounts of space heating of Tangshan, Urumqi and Xi'an are several times as large as the amounts of all the end uses in the southern cities. The analysis on influence factors of winter energy use are made for Chongqing and Hong Kong, respectively, by Quantification Theory I, and the results show there exist obvious differences in influence factors between the two cities.

1. Introduction

With the rapid development of the economics in China, building energy conservation has become a significant issue affecting the development strategy of the whole country. It is reported that the ratio of building energy use to total energy use increased from 10% in 1970s to 26.5% in recent years, and this ratio is projected to continuously rise to 35% in the coming years [1]. Meanwhile, the new construction completed every year amounts to 1.6–2 billion, of which 97% is the high energy intensity buildings [2,3]. Further analyzing the characteristics of urban residential energy use in China, it is found that: (1) there is a huge waste in district space heating in north China, as it runs 24 h per day continuously, and the residents cannot control the district heating based on the actual load due to the lack of thermostats and the defects of supply heating system forms; (2) with the improvement of living standard in recent years, there is a strong trend of the increase of energy use of space heating and cooling in south China. Taking the hot summer and cold winter zone as an example, the current household electricity load of space heating and cooling in this zone is 1–4 kW, and the annual household electricity use is 500–4000 kWh. According to this level, the total space heating and cooling loads can amount to 0.2 billion kW in this zone, and the annual electricity use amount can reach 224 billion kWh, which is equal to the installed capacity of 11 three gorge power plants and the annual generated electricity amount of 3 three gorge power plants [4]. In this situation, it becomes very significant for building energy conservation work in China to master the residential energy use in summer and winter and to further figure out the influence mechanism of winter and summer energy use, so as to put forward the corresponding energy saving measures. As a series of research, the summer residential energy use in some typical cities in the five architectural thermotechnical design zones is investigated and analyzed in reference [5] by the authors, and this paper, as one serial research followed by reference [5], focuses on the winter residential energy use characteristics in six typical cities of the five zones and their influence factors.

Some researchers also made the investigations to understand the actuality of residential energy consumption in China [6–10]. This research differs from their previous researches in the following ways: (1) most of the current researchers focus on only electricity use when they analyze winter energy use of the cities in south China, while gas use is neglected, but this research covers both electricity and gas use, so that the integrated structure of energy use can be reflected [7,8]; (2) few researches study the residential energy

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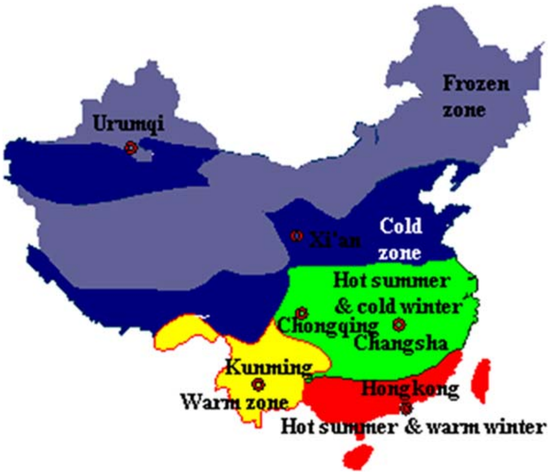

Fig. 1. The location of six cities.

use in winter, and the methods of investigations and analysis are different from each other [9,10], so the energy use in different cities is difficult to be compared. In this research, a uniform investigation method is used in six cities of five architectural thermotechnical design zones so that the specific characteristics of winter energy use in different zones can be revealed; (3) there is little measured data on district space heating in northern residential buildings in the exiting researches. While in this research, the household district space heating is measured and analyzed; (4) The influence mechanism on residential energy use composes a complicated system, where housing unit characteristics, household information, the usage of building technical systems all contribute to energy use. Most of the current analyses just focus on one aspect or several influence elements, while this research tries to reveal the influence factors in different aspects and their inherent principles affecting energy use.

2. Investigation method and data process

2.1. Investigation method

Fig. 1 shows the locations of six investigated cities in five architectural thermotechnical design zones in China. Table 1 lists the investigation time and family sample capacity in each city. A scientific sampling method of three-phase sampling method was adopted so as to obtain representative samples in each city. In the first phase, all the cities in China were classified into the five architectural thermotechnical design zones based on the classification sampling, namely the frozen zone, the cold zone, the warm zone, the hot summer and cold winter zone, and the hot summer and warm winter zone, and typical cities were selected in each zone by the way of representative sampling. In the second phase, in order to ensure the representativeness and universality of the selected samples, several typical residential districts were future selected in each administerial division of the investigated cities, and each residential district was required to represent the common situation of energy use in this administerial division. In the third phase, families were finally chosen from these residential districts by random sampling. In this way, typical family samples were selected, to reflect the characteristics of both space heating ways and residential energy use in each zone.

Questionnaire surveys covered housing unit characteristics, household characteristics, the possession and utilization of domestic energy use appliances, and the thermal environment. Electricity and gas use data of the previous month before the winter investigation in these cities were also recorded based on the energy use meters or bills. Indoor temperature of each investigated family was also recorded in the morning, noon and evening during the investigated periods.

District space heating occupies a large percentage in total energy use in north China, and it can never be neglected when analyzing the winter energy use. As there are usually no meters to measure space heating in most of the residential buildings in north China, and there are also no heat meters in the above investigated families in Urumqi and Xi'an, it is very difficult to get the actual use data of space heating. Hence, a new constructed building with household metering was selected in Tangshan city, a typical city in the cold zone, and the energy use of household district heating was measured, in order to understand district space heating use in north China.

2.2. The way to process missing data

The way to process missing data is the same as that used in reference [5]. When processing the missing data in questionnaires, the families are taken as the samples, and all the items in the questionnaires are taken as the variables. There are usually two kinds of missing data, no answers for all the variables in the questionnaires, and no answers for some items in the questionnaires. When processing the energy use data, the families are taken as samples, and the monthly energy use amount is the variable. Sample delete and interpolation are the two ways to deal with missing data: (1) sample delete: if the families refuse to fill in the questionnaires, these samples should be deleted from the whole sample collection. In addition, if the families just fill in a very small part of the questionnaires so that the questionnaires are useless for the analyses, this kind of samples should also be deleted. In this research, a limited value of 40% is assumed, and the family with the missing items in the questionnaires more than 40% is also deleted; (2) interpolation: interpolation is a way of using another value to replace the missing values. As for one variable, if less than 5% of total samples miss the value of this variable, the overall average value of this variable can be used to replace the missing values. If the sample ratio of missing values is more than 5% of total samples, the way of "hot deck" is recommended, in which similar samples are classified into a group and the mean value of this group is used to substitute the missing data in this group [5]. The way of interpolation is used to deal with the missing data of the variables of both monthly energy use amount and items in questionnaires. The final valid sample capacities are shown in Table 1.

Table 1
General information of the investigations in winter.

Architecture thermotechnical zone	Cities	Survey time	Investigated families	Valid samples
Frozen zone	Urumqi	2003/12/31–2004/1/7	100	98
Cold zone	Xi'an	2002/1/12–2002/1/18	100	94
Hot summer and cold	Chongqing	2003/1/7–2003/1/17	97	94
winter zone	Changsha	2003/1/8–2003/1/12	100	94
Warm zone	Kuming	2004/1/9–2004/1/16	101	100
Hot summer and warm winter zone	Hongkong	2002/1/5–2002/1/9	137	103