Research on Applicability of Fuel Cells in North China's Residential Buildings: Based on Investigation of Living Habits and Energy Consumption of Urban Residents

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Abstract. The state's emphasis on energy conservation and emission reduction has been continuously strengthened, and the use of clean energy has received great attention. As the fourth generation of power technology, fuel cell technology has developed rapidly abroad. Household fuel cells have achieved market-oriented development in Japan. In order to understand the technical applicability of household fuel cells in China, a survey on household living habits and energy consumption in cities and towns was carried out. The application of fuel cells in China was preliminarily analyzed from three aspects: the situation of family members at home, the use of domestic appliances and bathing habits.

1. Introduction

With people's increasing attention to energy conservation and environmental protection, household energy consumption, as a part of China's energy consumption expenditure, has also attracted much attention. At present, relevant scholars try to use micro fuel cell based combined heat and power systems in residential buildings. Fuel cell, as a new energy application technology, can directly convert chemical energy in fuel (hydrogen, natural gas, gas) and oxidant (oxygen) into electric energy. Combined with cogeneration system, its energy conversion rate is as high as 85%. Mainstream fuel cells are mainly classified into the following five types according to electrolytes: proton exchange membrane fuel cell (PEMFC), phosphoric acid fuel cell (PAFC), alkaline fuel cell (AFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). PEMFC and SOFC are mainly used in household area. For household applications, fuel cells in Japan have developed most rapidly. Tokyo Natural Gas Company began selling fuel cells for ordinary consumers around the world in May 2008. By 2013, it had sold about 24,000 fuel cells and expected to sell 300,000 fuel cells by 2020[1].

At present, the micro-cogeneration equipment using fuel cell technology is still in the research and development stage. In order to understand its applicability in residential buildings, the first step is to investigate households' consumption habits of electricity and hot water in China.

2. Research on the energy consumption of residents in China at the present stage

Based on the statistical data of Shanghai in recent 10 years and the investigation results of actual energy consumption, Yang Xia analyzed the level, influencing factors and composition of residential building electricity consumption in Shanghai[2]. Based on a large-scale questionnaire survey, Feng Xiaohang et
al. studied the typical behavior patterns of using residential air conditioner in summer[3]. Through questionnaires, interviews and engineering tests, Wang Shanshan et al. found that compared with household water heaters, centralized domestic hot water has no significant advantages in price, comfort and convenience[4].

Family members’ living habits and energy consumption habits affect the suitability of fuel cells. A building with a lower heating than electricity demand would be better suited to a micro FC-CHP system because of its low heat-to-power ratio. In order to better understand the current resident's electricity heating law and determine the compatibility with fuel cell, a survey on the living habits of urban residents and household electricity heating demand was compiled in northern China. The questionnaire was conducted in two forms: online survey and field survey. It is distributed to Shaanxi Province, Liaoning Province, Henan Province and Beijing.

Table 1. Questionnaire survey content.

| Survey items                      | Main indicators                                                                 |
|-----------------------------------|---------------------------------------------------------------------------------|
| Basic Family Information          | Number, age, structure of resident population, etc.                             |
| Basic Building Information        | Housing type, building area, number of people at home, floor location, etc.     |
| Information on household energy   | The use of heating and cooling equipment, the quantity and use of high-power    |
| use and household habits          | household appliances, and the amount of electricity consumed, etc.              |

3. Research results
A total of 108 questionnaires were received. We considered the content of more than 85% of the questionnaires as valid, and finally harvested 100 copies as valid questionnaires. According to the questionnaire collected, the following questionnaires are organized as follows: According to the population classification, there are two members family and three members family with the largest proportion. They account for 30% and 29% of the total questionnaires respectively. It can be seen that the survey on the single-family households is limited. So we don't do a separate analysis, the focus is on the energy use of a family of two and a family of three. First, the questionnaire population is classified as follows, in order to compare the differences in living habits between different ages and different family structures. According to the classification, there are 13 samples in Y-2, 17 samples in O-2, 23 samples in Y-3, 6 samples in O-3, and the remaining 41 samples in Others.

![Fig. 1. Proportion of population](image)

Table 2. Questionnaire Classification and Definition.

| Name  | Significance                                    |
|-------|------------------------------------------------|
| Y-2   | Family of two, the age of two is 22-50 years old|
| O-2   | Family of two, both are over 50 years old       |
| O-3   | Family of three, couples over the age of 50      |
| Y-3   | Family of three, couples between the age of 22-50|
| Others| Living alone, family of four, family of five, family of six |
3.1. Analysis of the number of people at home during the day
Since the time spent indoors will affect the output of household energy consumption, and this has a positive impact on the use of fuel cells. Among young families, two family members have jobs accounts for the largest proportion. According to the population classification, a family of four has the most employment, and two people work most commonly. Retired people are common in families with more than four people. On the other hand, the ratio of two young adults to work is very high, and the ratio of nobody in the family may be the largest.

(a) Classification by population

(b) Classification by family structure

The analysis of the number of people at home during the day is as follows. Case 1 represents at least one person at home. Case 2 could basically represent those who went out for more than 4 hours between 6:00 a.m. and 18:00 p.m. and the time of going out is not fixed. Case 3 mainly represents a group of people who go out during the day but go home for lunch. Case 4 represents no one at home. As can be seen from the following figure, the proportion of Case 1 increases with the increase of family population, and not among young partners. Case 2 is about 28% of the total, mainly middle-aged and elderly groups, young families are less. Case 3 accounts for only 13% of the total population, which is less common in middle-aged and elderly families. Case 4 accounts for 21% of the total number, mainly in young partner families, the least in middle-aged and elderly families.

In general, it can be seen that the more people in the family have more chances of Case 1. This is mainly related to the existence of the middle-aged and elderly groups. On the other hand, not all the middle-aged and elderly people are basically at home. The old people who are used to going out regularly every day are the mainstream in this group. Youth partners are basically absent during the day. Considering the working characteristics of fuel cells and maintaining long-term operation, it is more suitable for the elderly and families with larger population.
3.2. Use of household appliances

3.2.1. The use of television

In the course of investigation, it was found that traditional high-power domestic appliances were very common. See the figure below for details. In view of the phenomenon of non-use, in interviews, respondents said that they often use computers, mobile phones and other devices for entertainment, instead of the previous dependence on television. You can see that young people use TV at least. Generally speaking, the situation of watching TV and using only one TV still dominates.

![Classification by population](image)

**Fig. 3. Statistics of daytime staffs at home**

3.2.2. The use of Air conditioner

The air conditioner usage of the subjects is as follows: 99 people participated in the survey, 85 people used air conditioner. Among the 85 samples, 56.47% had one air conditioner, 27.06% had two air conditioners and 16.47% had three air conditioners. Generally speaking, the use of air conditioning system has become the preferred cooling mode for most northern residents in summer. Nearly half of the households have more than one air conditioner.

![Classification by family structure](image)

**Fig. 4. Number of commonly used televisions**
3.2.3. Use of heating equipment

Table 3. Summary of heating modes.

| Heating mode | Using auxiliary heat source | No Auxiliary Heating Equipment | Wall-mounted Gas Boiler |
|--------------|-----------------------------|-------------------------------|------------------------|
| Central heating (82) | Air conditioner 14 | Electric blanket 5 | Electric radiator 4 | Gas Boiler 58 |
| Decentralized heating (14) | Air conditioner 8 | Electric blanket 3 | Wall-mounted Gas Boiler 6 |

Notes: A total of 100 valid questionnaires, 4 offered no explanation. A total of 24 households with auxiliary heat sources are used in central heating users, and there are cases where multiple heating equipment are selected at the same time.

In this survey, the central heating accounted for 85.42% of the total. This is related to the heating policy in northern China. Among them, 70.73% of the residents have no auxiliary heat source, and the rest choose air-conditioning auxiliary heating. Auxiliary heat sources are mainly used for a period of one to two weeks before and after the heating period, and will hardly be used all the time. For decentralized heating users, air-conditioning, electric radiator and gas wall-mounted stove are the three forms of heating, and air-conditioning is the main choice for heating.

In the process of investigation, it is found that the use of traditional electrical appliances is very common among residents. It is noteworthy that residents' electricity consumption habits are developing towards diversification. In this survey, many new common electrical appliances appeared. The pursuit of quality of life by residents has gradually increased the demand for electricity.

3.3. Analysis of domestic hot water

The energy consumption of domestic hot water is mainly caused by bathing behavior. In this questionnaire, the frequency of bathing is investigated in winter and summer. In general, the summer bathing frequency is significantly higher than the winter. The frequency of bathing 3 to 4 times a week is not much different between the two seasons. In summer, the frequency of bathing in a family of three is significantly lower than that of a family of two, and there is no significant difference in winter. The frequency of bathing in elderly families is lower than that in young families.

In Japan, domestic fuel cell systems often combined with the thermal tank, which provide domestic hot water and heating hot water for daily use. Based on the above research results, it can be seen that the water demand of residents of different age groups is different, and the water use habits are obviously affected by the seasons. Therefore, the capacity setting of the matching water tank for fuel cell equipment needs to be discussed in detail.
4. Summary

Through the analysis of 100 questionnaires, this paper focuses on the household living habits and energy consumption. From the analysis of the situation of family members at home, the elderly group and the families with more permanent population are more suitable for the operation of fuel cell equipment. The traditional high-power electrical appliances have been popularized, and the common household electrical appliances are diversified. Residents' demand for electricity is increasing year by year. Residents have different needs for domestic hot water and change with the seasons. Fuel cell adaptability needs further discussion and analysis. Because the current advanced household fuel cell equipment is designed based on the living habits of Japanese residents, the comparison of living habits between Chinese and Japanese residents can be added in the follow-up study. Understanding the principle and significance of fuel cell parameter design can help to complete the adaptability analysis of this technology.

References

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