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Energy and environment in Chinese rural buildings: Situations, challenges, and intervention strategies

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ABSTRACT

A large-scale national survey of energy consumption and indoor environmental quality of rural housing was conducted in China. Its purpose was to obtain fundamental data and to analyze key problems related to the homes of approximately 600 million rural people. The survey results indicate that the total annual household energy consumption in rural China reached 317 million tons of standard coal equivalent (tce) (9.3×10^9 GJ), in the forms of 192 million tons of raw coal (4.0×10^9 GJ), 5.9 million tons of liquefied petroleum gas (LPG) (0.3×10^9 MJ), 132 billion kWh of electricity (1.4×10^9 GJ), and 219 million tons of raw biomass (3.6×10^9 GJ). There is an upward trend in the use of coal for space heating and cooking, which is a significant source of air pollution. The pilot study of a program to provide passive energy savings in northern rural China was also conducted. Based on the results of actual demonstration projects, feasible intervention strategies for sustainable development in rural China are proposed, with the goal of achieving "zero coal villages". Projections show that achieving "zero coal villages" nationwide could provide huge and permanent benefits both to China and to the rest of the world. The results obtained from this study could also provide guidance for development of rural housing in other countries, particularly in the developing world.

1. Introduction

Currently, China has more than 600 million people, occupying 24 billion m^2 of building space, in vast rural areas [1]. Based on the latest projections of the World Bank, the total population of China will be approximately 1.5 billion in 2030 [2]. Even if China can maintain a stable urbanization rate and eventually achieve a two-thirds urbanization ratio, there will still be more than 500 million people living in rural areas within the next two decades. According to the Ministry of Housing and Urban-Rural Development of China (MOHURD), the average rural housing area should achieve 45 m^2 per capita by 2030. The total rural building area will be around 22 billion m^2. That means China has to face a long-term challenge regarding energy consumption by the large population in rural buildings.

Thus, promoting and accelerating the sustainable development of rural housing has strategic meaning for improving the living conditions of rural people, for reducing energy consumption, for improving environmental quality, and for promoting economic development. However, in view of the current national situation, special attention must be paid to this issue. In particular, the following questions are yet to be answered:

(1) What is the current energy consumption and indoor environmental quality in Chinese rural buildings?

Compared to the studies and effort related to urban buildings, the conditions and issues of rural buildings have not been given enough attention, or have even been ignored, for many years. As a result, comprehensive, detailed data on rural-building energy consumption is largely lacking. The Chinese national statistics bureaus estimate that roughly 70 million tons of raw coal was consumed by the rural residential sector each year [3,4]. However, this was mainly obtained by a "top down" method and no specific breakdowns of different usages (e.g., heating or cooking) were given. Such data are insufficient to provide a clear picture of current situations in the Chinese rural-building sector, and also leave open the question of the accuracy and reliability of the data.

There have been several local or regional studies focusing on the characteristics of energy consumption in Chinese rural housing. An

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energy consumption survey was conducted in six counties located in Hunan, Jiangxi, Liaoning, Sichuan, Jiangsu, and Shandong Provinces in 1987–1991 [5]. These were very early studies and did not reflect recent situations in most of rural China. Later, the characteristics of energy consumption in a few other counties were investigated and analyzed [6–11]. Although these surveys proposed some problems related to rural energy and environment, the results referred to the problems in some regions at different time periods. Thus, despite their potential usefulness for this work, comprehensive cross-provincial results covering the whole of rural China cannot currently be obtained.

(2) What are the main problems with rural buildings, and the causes of these problems?

Some basic problems of Chinese rural buildings can be summarized from the above regional surveys. These include excessive energy consumption (especially of solid fuels) in some regions, and the general trend in the changing financial structure of energy supply from non-commercial to commercial. However, due to the lack of national-scale comprehensive information (e.g., building types and envelope conditions, energy consumption for different end uses, indoor thermal comfort and air quality, and human habits and behaviors), the main problems and possible causes of these problems need to be better understood.

(3) How might we achieve sustainable development in rural buildings?

To solve the problem of excessive energy consumption by Chinese rural buildings and to achieve sustainable development are the ultimate goals. This would require proposing systemic and effective intervention strategies, implementing these strategies in rural communities with actual projects, and measuring the actual effectiveness scientifically.

The main purpose of this paper is to present some recent efforts to promote sustainable development of Chinese rural buildings in the future, with focus on the following three actions:

- Analyzing the status and features of energy and environment, as related to Chinese rural buildings, by means of a large-scale survey.
- Addressing the main problems and challenges of rural-building energy consumption and indoor environment.
- Proposing feasible intervention strategies to advance sustainable development of rural buildings, based on real projects.

Because the energy and environmental problems of China have become global issues, the results of this study should gain international interest. These results could also provide examples to guide rural development in other countries in the world.

2. Survey methodologies to be used in the study

To obtain basic information on rural-building energy consumption and indoor environmental quality, and to lay the foundation for further analysis, we conducted an investigation using a large-scale national survey in 2006 and 2007 [12]. The key information and methodologies of the survey are given below.

2.1. Survey areas

China has five climate zones, namely extremely cold (Z1), cold (Z2), hot summer and cold winter (Z3), hot summer and warm winter (Z4), and temperate (Z5), according to outdoor weather conditions. Z1 and Z2 are mainly in the north, Z4 and Z5 mainly in the south, and Z3 along the Yangtze River region. Z1–Z3 all require heating in winter, whereas Z4 and Z5 typically do not. Thus, from an energy consumption point of view, cold climates should be the main concern due to much higher energy use for heating. To balance the need for reliable results with logistical costs, the survey covered all 15 provinces considered Z1 and Z2, and nine provinces considered Z3. As the southernmost provinces were not directly covered in our survey, the average energy index was extrapolated based on the conditions in the nearest counties surveyed, that have similar weather condition and living habits.

We adopted a random sampling method to choose approximately ten counties in each province, about five villages in each county, and about ten households in each village. In total, the survey covered 150 rural counties, about 800 villages and 5000 households. Fig. 1 shows the geographic distribution of the surveyed counties.

2.2. Data collection methods

To obtain reliable household-energy-consumption data during the survey, on-site visits were made by trained personnel to collect the data house by house. The investigators conducted a face-to-face questionnaire interview, and carefully recorded the data. About 700 undergraduate and graduate students from various departments of Tsinghua University were recruited, professionally trained, and assigned to the field investigations. Basic data collected from on-site visits included building construction information; building envelope materials and types; cooking, heating, cooling and lighting facilities, and fuel types used (e.g., coal, firewood, straw, electricity, LPG); amount of annual energy consumption for heating, cooking and air conditioning; indoor air quality and thermal comfort conditions; the situation regarding renewable energy resources and utilization; and the economic and educational level of the families. It took 40–60 min to finish one survey questionnaire.

To ensure the surveyed information was valid, the survey team also talked to the village leaders to determine the overall status of the village, and whenever possible, to double or triple check the validity of the collected data.

2.3. Data analysis methods

A “bottom up” method was adopted to calculate the national total energy consumption, based on the survey data from each province. The total energy consumption of each province was calculated based on the household energy sources and usage. We also calculated the energy consumption breakdown by use (e.g., heating, cooking, cooling, and lighting). Coal, firewood, straw, liquefied petroleum gas (LPG), and electricity were the main energy sources used in rural households, according to the survey results.

Because coal, LPG, and electricity are from commercial energy sources that have to be paid, farmers were quite clear on the exact amounts of energy consumed, based on their payment records. As for non-commercial energy, the total amounts of firewood and straw consumed were estimated by the type, volume, and density of each type of firewood and straw. All sources of energy consumption were converted into standard ton of coal equivalent (tce, 1 tce = 29.3 GJ) by their heat values, except electricity, which was converted into coal consumed in the power plant according to the ratio between coal consumption and electricity generated.

Then the total national energy consumption, in tons of coal equivalent, was calculated using the following equation:

$$E_{total} = \sum_{i=1}^{n} E_{p,i} \quad (1)$$