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A survey on energy consumption and energy usage behavior of households and residential building in urban China

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ABSTRACT

Building performance, equipment efficiency, and occupant behavior play important roles in China urban residential building energy conservation. An online survey was conducted in 2015 to study the urban residential energy and usage behavior. A total of 4964 Chinese urban households participated in the survey, answering questions about their family composition, buildings, energy use and conservation behaviors, and reactions to specific energy conservation policies. The results suggest that the general trend in Chinese urban households is larger unit sizes (on average, 109 m^2 per household) and smaller families. The average electricity consumption of urban residential buildings is 1690 kWh per year per household in 2015 and it continues to grow as home electronics become more widespread and the demand for higher quality of life increases. China urban residential buildings energy use has the following characteristics: steady growth in size and energy consumption of the buildings associated with rapid urbanization, decentralized and individual equipment with diversified energy usage behavior, and relatively low energy consumption level compared to other countries. In addition to the current energy efficiency programs, China should focus on energy consumption and intensities target of building sector, and the key for urban residential building energy efficiency is to retain traditional behaviors and lifestyles, as well as promoting outcome-based energy conservation policies and technology systems to improve indoor environment and comfort.

1. Introduction

Rapid development of Chinese economy and high concentration of urban populations results in an increases in terms of the number of urban residential buildings and corresponding energy consumption. The urbanization rate in China increased from 37.7% in 2001 to 55.0% in 2014, and the urban population grew from 155 million to 264 million households [1]. Rapid urbanization promotes the development of the construction industry and drives growth in energy demand, especially demand for electricity. The completed floor area has been increasing by more than 1.5 billion m^2 every year since 2001 [1]. Among these newly constructed buildings, 75% are residential to accommodate the growing urban population. According to BERC (Building Energy Research Center of Tsinghua University) [2], the total floor area of China's urban residential buildings has reached 21.3 billion m^2, with primary energy consumption of 0.32 billion tons of coal equivalent (TCE), which is 39% of the total building energy consumption and 8% of the total primary energy consumption. Urban residential electricity use has more than tripled between 2001 and 2014, from 123 billion kWh to 408 billion kWh [2].

In response to the growing trend in consumption of energy, the Chinese government implemented a series of policies aiming at controlling the increase in primary energy consumption and CO_2 emissions [3]. In 2013, ***The 12th Five-Year Energy Development Plan*** was released, with the ambitious goal to cap the total energy consumption in 2020 at 4.0 billion TCE [4]. In 2014, the cap was raised to 4.8 billion TCE by the ***National Energy Development Strategy and Action Plan for 2014–2020*** [5]. In addition, measures have been put in place to peak China's CO_2 emissions by approximately 2030, and efforts are being made to reach this peak value even sooner [6,7]. Considering the energy consumption predictions for the industrial, transportation, and building sectors, energy use for the building sector in 2020 should not exceed 1.1 billion TCE in order to meet the stated goals [8].

Building energy use is mainly driven by weather, house size, building envelope, building services systems, indoor environment,

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building operation and occupant behavior [9]. It is essential to make building energy related information available for suitable analysis and efficiently energy policies planning for the future target achieving. However, available information on China's residential building is clearly insufficient and not proportional to its importance. There is a lack of consistent and comprehensive building energy data from national level, which makes it difficult to understand the underlying changes and key factors that affect energy consumption in urban residential building sector. The National Bureau of Statistics of the People's Republic of China releases total amount of urban residential energy consumption in national energy balance sheet annually [1]. However, this statistical data only provides overall energy consumption of urban residents sector, the lack of specificity in the information generates barriers to policy makers in promoting urban residential building energy conservation and technology recommendations [10].

In order to get more information on key factors and promote suitable energy efficiency technologies and policies, researchers conducted detailed surveys of urban households at the regional or city-level explicitly focusing on indoor comfort and household energy consumption. For example, BERC [11] conducted a survey in seven cities from five climate zones, with a valid sample size of approximately 1000 from each city, providing information on urban residential energy use including electricity and natural gas consumption, family and building information, and type of energy systems. In addition to nationwide surveys, several researchers have carried out city-level surveys focusing on space heating and space cooling due to their large proportion on building energy use. Such as Ling [12] surveyed seven urban residential districts in Beijing to find key characteristics of urban household energy consumption and space heating energy use, and Li [13] surveyed space cooling consumption and factors that influence the consumption level in Beijing.

Occupant behavior was concluded as one of the predominant factors influencing urban residential building energy consumption based on these surveys and other detailed case studies. Occupancy behavior refers to activities such as switching on and off lights, turning on and off cooling and heating systems, and adjusting the thermostat [9]. A high rebound effect of at least 30% in the household energy efficiency of China is assumed according to other studies of other countries, which is mainly caused by demand growth and occupant behavior transition [14]. With rapid growth of urbanization and economy booming, the diversity of urban households has been so large that the energy consumption of most energy consuming families could be ten times higher than that of the lowest energy consuming families. For instance, measured electricity consumption of air conditioners per unit floor area in the same apartment building varied from almost zero to 14 kWh/m^2 (on average 2.3 kWh/m^2); such difference was caused by the operating modes of the split-type air conditioning (AC) system [15].

Previous studies showed that different occupant demand and behaviors require specific technical solutions, which may induce or alter the behavior patterns and that the occupant behavior influences the adaptability and implementation of technologies [16,17]. The lack of a clear knowledge on occupant behavior in urban residential building causes misunderstanding and impropriate decisions on both policy making and engineering design. Unsuitable technologies are improperly promoted without full understanding of occupant behavior. For example, centralized space heating was promoted impropriate in hot summer and cold winter zones of urban China without understanding of the major differences of space heating behavior in northern China and HSCW (hot summer and cold winter zone) zone[18].

In summary, the research gaps for previous research on China urban residential building energy use are:

(1) Lack of nationwide surveys to understand the full picture of urban households and residential buildings. Surveys from a few cities are not enough for policy makers to identify the potential energy savings of national wide and regional disparity.
(2) Energy consuming equipment and corresponding behavior were identified to be one of the most significant influencing factors on total building energy use. Understanding typical behavior among a group of people is critical for engineers to optimize building and building system design. However, occupant behavior has never been described and surveyed in previous research studies.
(3) Promotion of energy efficiency products and energy-saving behaviors are important energy saving actions and policies in China urban residential buildings. Effects of energy-saving policies and residents feedback also lacks of investigations in previous research studies, however, with urgency.

In order to address the above mentioned knowledge gaps on the urban residential building energy use in China, an online survey was undertaken in 31 regions of China (not including Hong Kong, Macao, or Taiwan) during the fall of 2015. The survey has the following three goals to achieve:

(1) Understand the characteristics and trends of urban residential building energy consumption.
(2) Explore a full picture of the urban residential building energy usage behaviors and understand the distribution of typical behaviors of urban households.
(3) Investigate the effect and reactions of current energy efficiency policies and behaviors driven policies in urban residential building sector.

The result of above study could provide policy makers comprehensive information on predominant influence factors of urban residential building energy use and urban households' energy usage behavior. In addition, it will improve related policies, such as raising awareness of energy efficiency labeling system and adjusting electricity pricing scheme. It would also help residential architects and HVAC (heating, ventilation and air-conditioning) system engineers to better understand the real demand from occupants and behavior distribution, leading to proper architectural designs, and better technology selections. Finally, recognition and distribution of occupant behavior are also critical for building simulation researchers to improve accuracy of building energy simulation results, and greatly expand the use of building simulation tools.

2. Methodology

2.1. Survey design

The amount and type of energy used in residential buildings are mainly related to weather, architectural design and envelope performance, energy device and energy usage behavior of occupants [19]. Apart from the current status quo of energy consumption, the satisfaction of urban households on residential indoor environment, their awareness and reaction on previous energy-saving policies are also an important reference to promote energy saving measures for police makers and engineers. In order to understand the energy consumption and energy usage behavior of households of urban residential building in a holistic way, the survey is designed with content and coverage area as shown in Fig. 1. The survey content includes occupant and building information, energy consuming device and occupant usage behavior, energy consumption level and satisfaction on indoor environment, resident's attitudes toward energy-saving policies. A summary of types of questions is