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A statistical analysis of a residential energy consumption survey study in Hangzhou, China

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ABSTRACT

Households are major contributors to the emission of greenhouse gases and, consequently, to global warming. The past decades have seen significant improvements in building energy efficiency through the introduction of new building regulations and the construction of low energy buildings. However, the expected energy reduction has not been observed, largely due to the complicated and hard-to-predict nature of occupant behavior. This paper explores the impact of occupants on residential energy consumption in China. Surveys related to behavior and energy use in the city of Hangzhou were collected in the winter ($n = 642$) and summer ($n = 838$). Findings show that occupant age is a more significant factor than income. Contrary to existing research, a negative correlation between occupant age and energy consumption was found in this study. Elderly residents exhibit a more frugal behavior pattern than the younger ones. In addition, this paper reveals that household socio-economic and behavior variables are able to explain 28.8% of the variation in heating and cooling energy consumption.

1. Introduction

It is well established that dwellings are key contributors to greenhouse gas emission. In 2005, their proportion of total global energy demand was 29%; it was even higher (36%) in non-OECD countries [1]. The energy use in the household sector includes space and water heating, cooling, lighting and the use of appliances [1]. Space heating is the biggest end-use, which makes up more than 50% of domestic energy consumption in OECD countries. Factors that determine space heating energy consumption include dwelling size, the number of occupants, the efficiency of heating equipment, and the demand for useful energy per unit of area heated (useful energy intensity) [1]. While the first two factors typically raise the energy demand for heating, the improvement in efficiency and useful energy intensity offsets the growing demand.

In order to reduce energy consumption in the residential sector, many countries, particularly OECD countries, have made significant effort to improve energy efficiency of residential buildings through the introduction of new building regulations. Beerepoot and Beerepoot [2] found that although energy performance regulations have been successful to a certain extent, the variation is still large for dwellings with the same characteristics. In fact, the energy saving achieved in practice often does not match predictions made by energy conservation studies. Jeeninga et al. [3] found that the actual energy consumption of households living in dwellings with the same theoretical energy performance can vary by up to a factor of two. It is widely recognized that residential energy consumption is not only influenced by building characteristics but also influenced by household characteristics, occupant behavior, and efficiency of the service system [4]. Due to its complex nature, occupant behavior provides a special challenge for researchers trying to understand the implication for energy.

Previous studies in the USA and the Netherlands have determined that building characteristics explain from only 40 to 54% of variation in energy use [5,6]. The relative impact of occupant characteristics and behavior, however, seems to differ in various studies. Guerra Santín [5] stated that occupant characteristics and behavior affect only 4.2% of variation in heating energy use in the Netherlands, while Sonderegger [6] found 33% of variation in heating energy use can be explained by occupant patterns in the US. Nevertheless, researchers have agreed that as the thermal properties of buildings improve, the role of building characteristics will decrease, thus making occupant behavior more important [4,7,8].

The occupant characteristics that potentially relate to heating energy use include occupant age, income, household size and education levels. Among these socio-economic demographic characteristics, links between household income and energy

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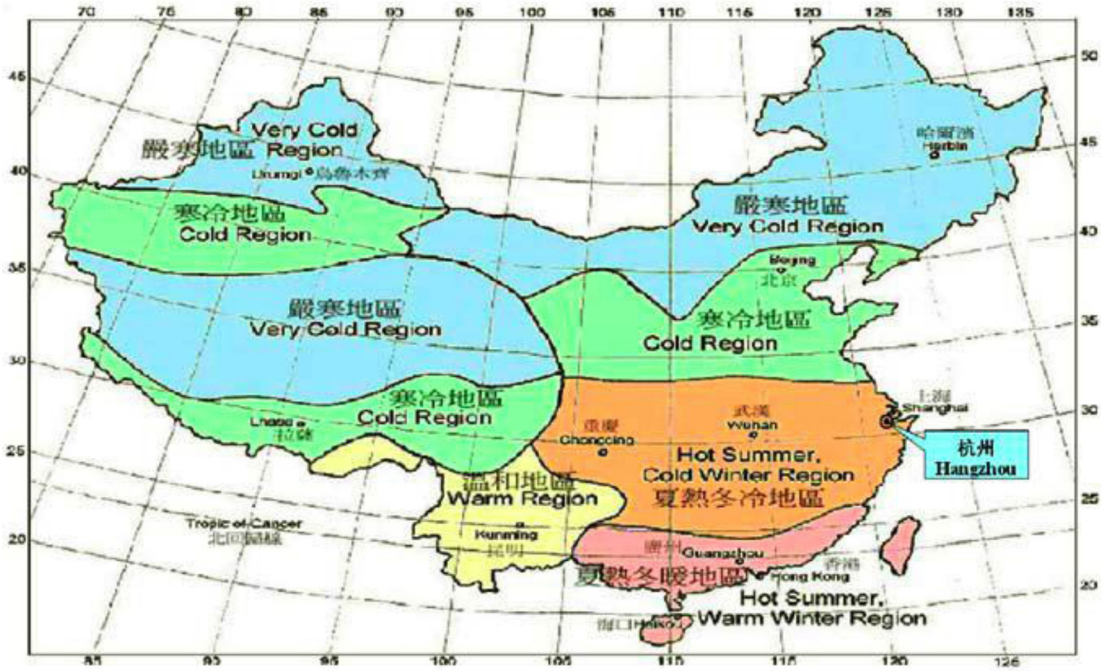

Fig. 1. Design climate zones of China and the location of Hangzhou.

consumption were found in numerous studies [9–13], Santamouris et al. [10] found that household income was an important determinant of the size, age, type, envelope quality of dwelling and type of equipment, which indirectly influences energy consumption.

In addition, age was found to be closely linked to thermal comfort related behavior, and hence influences heating energy consumption. Existing research indicates a positive relationship between occupant age and heating energy consumption in most studies. Generally, older households tend to consume more energy for space heating than younger households, as older occupants prefer a warmer indoor environment and use heating for longer hours [14,15].

In China, residential energy consumption accounts for 13% of total final energy consumption [16]. It is the second biggest energy-consuming sector next to industry [17]. The existing studies in residential sector in China largely focused on measures to improve building energy efficiency by fabric insulation [18–21], More recent studies also start to investigate the impact of occupants on energy consumption. Ouyang and Hokao tried to evaluate the energy saving potential by improving occupants' behavior in domestic life through energy-saving education [22]. Chen et al. analysed energy consumption characteristics and tried to find out influence factors of residential energy consumption in seven cities in China [23,24]. However, it is still unknown how much variation in residential energy consumption could occupant behavior and household characteristics explain.

The unique history of China, especially the rapid economic development in the last decades, and the population growth, might relate to distinctive occupant behavior patterns. For instance, existing research suggests that both dwelling type and building age have a key effect on energy consumption due to the associated envelope exposure and insulation levels [5]. However, in China, more than 80% of urban families reside in apartment buildings and more than 85% of residential buildings were built after 1990 [17,25]. These factors are likely to reduce the effect of building characteristics on energy consumption in China. Other factors such as occupant characteristics and behavior could thus have a more noticeable impact on energy consumption.

Therefore, this study aims to investigate the impact of household characteristics and occupant behavior on domestic heating and cooling consumption, through answering these questions:

1. Could occupant behavior and household characteristics explain some variation in residential energy consumption, in particular, heating and cooling energy consumption in could? If so, how much could they explain?
2. Is there any special characteristic about occupant behavior in the researched area in China?
3. Is age an important factor in thermal comfort perception and does this influence heating and cooling energy consumption?

2. Methodology

2.1. Survey/data collection

Since there is not a set of national data with individual household information and energy consumption for China, the authors had to conduct an independent survey to collect relevant data. The survey was conducted in Hangzhou, capital city of Zhejiang province on the east coast of China, about 200 km southeast of Shanghai. Hangzhou is a typical city in the "hot summer and cold winter" climate zone (Fig. 1). The monthly average temperature of the city in winter is around 4 °C with a minimum temperature of −5 °C. The monthly average temperature of in summer is around 29 °C with a maximum temperature reaching 38 °C. Most people use air conditioners for both cooling in the summer and occasionally for heating in the winter.

The surveys comprised two parts. The first part was carried out at the end of winter in March 2010 to collect information on household characteristics, energy consumption and occupant behavior in the winter. The second survey was carried out at the end of summer in August 2010 to investigate summer occupant behavior. The surveys consisted of a transverse research design with the aim of investigating how occupant behavior and household characteristics are related to the household energy consumption.