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Opinion paper

Urban residential heating in hot summer and cold winter zones of China—Status, modeling, and scenarios to 2030

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HIGHLIGHTS

- Energy consumption for HSCW zones in China low but increasing rapidly.
- Large variations of heating intensity due to heating system and occupant behaviors.
- Scenario analysis of heating energy consumption in 2030.
- Centralized district heating system is not feasible for the HSCW zones.
- Heating efficiency and energy-saving behaviors should be promoted.

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ABSTRACT

Space heating energy consumption in urban residential areas of the hot summer and cold winter zones (HSCW) in China has increased dramatically during the last decade. Large-scale surveys and in-depth measurements of residential heating consumption is important to monitor trends. More importantly, a macro energy model that reflects the current status and that can be used to analyze future scenarios is needed. In this paper, a bottom-up model was established, and the results show the total energy consumption in the HSCW and the influences of building envelops, heating equipment efficiency, and especially occupant behavior on energy use. Related technical and policy suggestions were analyzed in different scenarios. Presently, energy consumption for heating in urban residential areas of the HSCW is relatively low, but is increasing rapidly, so the establishment of superior national building energy efficient designs requires attention. The findings suggest that the district heating network would not be feasible for the HSCW and decentralized heating should be the major heating method employed. Besides building efficiency, appliance efficiency should also be improved. Lastly, residents' behaviors in regards to the opening of windows can significantly influence energy use and should be carefully considered by policy makers and engineers.

1. Introduction

China is the second largest economy in the world after the United States and the country consumes the most energy in terms of the total primary energy supply (IEA, 2015a). Limiting such energy consumption is a critical issue in China. In response to a trend of rapidly increasing energy consumption, the Chinese government has implemented a series of policy actions. The aim of these actions is to control the growth of both energy consumption and CO_2 emissions with reference to the total amount of energy consumed including that of the building sector. In 2009, as part of a national policy initiative, the *Energy Conservation and Emission Reduction Plan* was announced. In addition, relevant to the 12*th Five-Year Energy Development Plan* of 2013, an ambitious target was set to cap the total consumption of energy (State Council, 2013). According to this plan, the target for 2020 is to cap the total energy consumption at 4.0 billion tce (tonne of coal equivalent). In 2014, this total energy consumption cap was raised to 4.8 billion tce by the *National Energy Development Strategy and Action Plan for* 2014–2020 (State Council, 2014a). In addition, measures have been put in place in China to reach the peak of CO_2 emissions by approximately 2030, and efforts are being made to reach this peak even sooner (NRDC, 2015). The national targets pertaining to the cap on primary energy consumption and the peak of CO_2 emissions have put much pressure on both the production and the consumer sectors.

The building sector, which is comprised of residential and

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Nomenclature

BE	behavior
CL	climate
EC	energy consumption
EP	energy performance
EQ	equipment
FA	floor area
hh	household
HSCW zone	hot summer cold winter zone
HSCW-UR	urban residential building in hot summer and cold winter zone
tce	tonne of coal equivalent
VRV	variable refrigerant volume system

services subsectors, is the largest energy-consuming sector in the world, and it accounts for 31% of the global final energy used and 8% of the global direct energy-related CO_2 emissions from final energy consumers (IEA, 2014). In view of China being a developing country, the proportion of energy consumed by the building sector in China is lower than that of fellow developing countries; however, it is increasing rapidly. In 2013, China's building sector accounted for 19.5% of the total energy consumption of the country, and the specific amount reached 0.75 billion tce, i.e., double the consumption of 2001 (BERC, 2015).

Climatic conditions vary significantly between the different regions in China, and this leads to unique characteristics in regional building energy consumption patterns. In addition, the current urbanization trend has given rise to significant differences between the urban and rural areas (Peng et al., 2015). According to the classification scheme used by the Building Energy Research Center of Tsinghua University (BERC) (BERC, 2015), Chinese building energy use is comprised of four main subsectors, namely, heating energy use (mainly district heating) in northern China, public and commercial building energy use, urban residential building energy use, and rural residential building energy use. Among the urban residential building energy use subsector, heating in the hot summer and cold winter zones (HSCW) of China is particularly significant with regard to building energy efficiency and efforts to control the total energy consumption of China. This is because (1) this region covers 16 provinces (almost half of all the provinces of China), and it is experiencing rapid economic growth and a high rate of urbanization. (2) The HSCW zone is the most densely populated of the five climate zones in China, and it contains 21% of the urban residential population and 40% of the urban residential building stock of China according to 2013 data (National Bureau of Statistics of China, 2013). (3) The demand for heating has grown rapidly in this region, and there has been a corresponding increase in indoor temperatures from 2001 to 2011 made possible by the high rates of economic development and the attendant increase in living standards (Yoshino et al., 2006; Zhang et al., 2010). The consumption of electricity for heating increased five fold during this period, from 7.7 billion kWh to 41.4 billion kWh (BERC, 2013), thus embodying the characteristics of a small base zone with a large incremental increase and rapid growth in demand. (4) Although building energy consumption in this region is growing fast, it is still small in comparison with China's total building energy consumption, and the energy intensity is still low compared with that of northern China. Notably, current building energy efficiency policies have not paid enough attention to this region and the building energy performance of the region is therefore mostly poor (Fu, 2002). (5) Economic growth and the resultant rise in family income have led to a large increase in the demand for convenient heating sources as a countermeasure to extremely cold weather. In the urban residential section, in particular, the use of diversified heating equipment and various heating behaviors have brought about large differences in the demands for heating and in the consumption of energy (Zhang et al., 2010, 2014). Taking into account the above-mentioned factors, more attention should be paid by researchers, policy makers, architects, designers, and engineers to energy consumption for heating in the HSCW urban residential areas (HSCW-UR).

Numerous surveys and measurements have been done in this region and useful information has been collected. Personnel at BERC have conducted surveys in Wuhan, Shanghai, and other cities in the HSCW, and data from these surveys indicate that diversified heating equipment is being used in this zone. The main types of heating equipment used include local electric heaters, split air conditioners, and, recently, domestic central air conditioners (VRV, Variable Refrigerant Volume systems), as well as gas boilers. Some high-income families in districts with new dwellings have started using central heating systems, which are associated with higher comfort levels but higher costs. In addition, the heating behavior of individuals differs, and the opening of windows, for cultural and traditional reasons, is common during winter (BERC, 2013; Guo et al., 2014a, 2014b). Various researchers have also conducted indoor environment surveys, and the findings show that indoor temperatures in the HSCW vary between 12 and 18 °C; not much difference was found between the indoor and outdoor temperatures because of the practice of opening windows (Yoshino et al., 2006). Another reason for the low indoor temperatures is that local electric heaters only raise the temperature of a small area where people stay. In general, the various types of heating equipment used and the disparate behaviors in this region have led to a large range of heating energy intensities. Chen et al. (2009, 2011) conducted on-site investigations and showed that the average amount of electricity used in Chongqing and Changsha was 2.8 kWh/m^2 and 3.4 kWh/m^2, respectively. However, the energy demand of district heating in the HSCW could be as high as 32 kWh/m^2 (Guo et al., 2014a, 2014b). Policy makers have started to pay attention to the HSCW, and policy recommendations have been put forth by local authorities calling for the adoption of large-scale district heating as a measure to promote the common welfare. Such proposals were supported by more than half of all respondents based on the results of an online survey (China Daily, 2013).

Researchers have provided useful information from real data that have generated much insight into the current situation in the HSCW. However, it is difficult to gain a comprehensive perspective from these different studies. In particular, a macroscopic view could not be gleaned from the current studies, as there was a lack of information on the total amounts and proportions of heating-related energy consumption. This lack of data can probably be attributed to the assessment system of China, which does not contain adequate building energy use information and consumption data. The lack of pertinent information impedes policy makers from fully understanding the status, the crucial problems, and the developing trends of heating in the HSCW. Therefore, it has been difficult for them to formulate effective policies to improve building energy performance and residential comfort levels.

To help alleviate the above-mentioned problems, a bottom-up model was established in this paper based on large-scale survey and monitoring data. The purpose of this model is to convey a perspective of how much energy is being consumed and how