Heating energy use in China: the current situation, challenges, and possibilities

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Abstract. Heating energy consumption in China is continually increasing because of the rapid urbanization and accompanied rising living standards. A panoptic description of China's current heating status is still in need of developing effective heating policies. In this paper, heating policy in China was introduced and a brief summary of the status of heating in different parts of China was described, the key features were characterized. Then, current and foreseen challenges for China's heating energy use were analyzed. Finally, related policy suggestions were proposed and the future possibilities of heating energy-conservation in China were discussed.

1. Introduction

Driven by rapid economic growth and fast-paced urbanization, heating energy consumption in China has become a significant part of the total energy consumption. Though China's heating energy use is significantly lower than that of developed countries[1], it is growing fast and accounted for 24.14% of the total building energy consumption in 2015, with the specific amount reached 208.53 Mtce, almost double the consumption of 2001. In the northern part of China, district heating has supplied more than 80% of the total urban building areas and covered almost all cities by 2015, with the building area served by district heating increased from 5 billion m^2 in 2001 to 13.2 billion m^2 in 2015[2]. In southern China, distributed heating increased rapidly, the total residential heating energy consumption in hot summer and cold winter zone reached 17.53 Mtce in 2015, representing an average annual increase of 18.4% in 15 years[3]. As a consequence of urbanization and improvement in people's living standards, heating will continue to be a key energy end-user in China.

In response to this growing trend, the Chinese government has implemented a series of policies, aiming at limiting the increase in heating energy use through technical advances, while the impacts of economic factors like urbanization and accompanying improvement of living standard, as well as shift of consumption patterns on China's heating sector, is still not clear.

Intensive studies have focused on the district heating energy use in northern cities of China[4,5,6]. Some studies have also discussed whether district heating should be provided in the hot summer cold winter zone[7,8,9]. These studies have provided plenty of useful information on heating energy use in northern China, but most existing studies failed to quantify the heating in southern China because of the lack of constant nationwide data.

Therefore, an overview of China's heating energy use is still in need for developing effective heating policies. Nevertheless, the impact of economic factors like urbanization on heating energy use should be taken into account when talking about the future heating energy use. A comprehensive

understanding of the present heating policy and the heating situation in different regions in China thus should, therefore, be enunciated, along with a detailed simulation of heating energy consumption under possible urbanization rates. In line with this, the challenges of urbanization and a possible pathway of heat development could be discussed, which is the aim of this paper.
Section 2 provided a brief summary of the status and key characteristics of district heating in northern China and individual heating in southern China. Section 3 discussed the challenges of heating caused by urbanization, different scenarios were set to discover the influence of urbanization on heating demand and predict the heating energy consumption trend. In Section 4, possibilities of energy conservation were proposed, potential ways to cut back the rising heating energy consumption were identified, policy recommendations were also given in this section. Finally, conclusions were drawn in Section 5 of the paper.

2. Status quo for space heating in China

2.1. Heating policies in China

China is a large country with a complex climate. China's national standard Thermal Design Code for Civil Building (GB50176-93) defines five climate zones as severe cold (SC), cold (C), hot summer and cold winter (HSCW), hot summer and warm winter (HSWW), and temperate (T) zones [10]. The zoning criteria are mainly based on the average temperatures in the coldest and hottest months of the year.
The varying climate among different regions in China leads to unique characteristics in regional energy consumption patterns. In addition, the current heating policy has given rise to the significant differences. In the 1950s, the central government set district heating zones in China according to the "Qin Mountains-Huai River" boundary, named the North-South heating line. According to this policy, district heating is only available at the northern part of the North-South heating line, which covers most urban areas in severe cold and cold zones, including 15 provinces and occupying more than 70% of the total mainland area[2]. In contrast, the district heating is not available in the southern part of the North-South heating line. While some parts of the HSCW zone in this area has a significant requirement for heating since it is at least as cold in winter as in some district heating areas in the North, in some cases even colder as far as humidity is concerned[7]. As a result, individual heating facilities have been widely utilized in the HSCW zone.

2.2. Data on heating energy in China

So far, the lack of consistent heating data from official statistics makes it difficult to get a comprehensive view of China's heating situation and to understand the underlying changes that affect energy consumption in heating. In order to get more information on key characteristics of China's heating sector, some researchers have carried out detailed regional or city-level surveys[11,12,13,14]. In addition, some researchers and institutions conducted nationwide surveys, among which, the China Residential Energy Consumption Survey (abbr. CRECS) administrated by the Department of Energy Economics at Renmin University of China and the China Building Energy Model (abbr. CBEM) built by Building Energy Research Center of Tsinghua University (abbr. BERC) are most influential.
The CRECS started in 2012 and included a sector of space heating and cooling. While only the data for the year 2012 has been open to the public by now. The CBEM was based on a series of surveys which included key information on China's heating energy use. Since 2007, Annual Report on China Building Energy Efficiency based on the data of CBEM has been published by BERC. According to these reports, building energy use in China was divided into four subsectors, namely, Space Heating in Northern Urban China, Commercial and Public buildings (excl. SHNUC), Urban Residential buildings (excl. SHNUC) and Rural Residential buildings. Heating in the HSCW zone was included in the Urban Residential buildings subsector. This paper used the data from CBEM to draw a picture of the heating energy use situation in both north and south China.

2.3. Status quo for space heating in different regions in China

2.3.1. Heating energy use, energy intensity, and heating floor area.

Figure 1 shows the energy use and energy intensity for heating in the SC&C zone and the HSCW zone. The amount of heating energy use in both regions increased rapidly from 2001 to 2015. In the SC&C zone, heating energy use rose from 115 Mtce to 191 Mtce, with an annual increase of 3.69% and accounting for 22% of total China's building commercial energy use by 2015[3]. While the heating energy use in the HSCW zone grew around 10 times from about 1.64 Mtce in 2001 to 17.53 Mtce in 2015. The annual growth rate of heating energy use in the HSCW area was 18.4%, almost 5 times that of the SC&C zone. Figure 1 also indicates the huge gap between the SC&C zone and the HSCW zone in total heating energy use, which of the SC&C zone was 69 times larger than that of the HSCW zone in 2015. One of the reasons for the increasing trend of heating energy use is the growing heating floor area. China is experiencing rapid urbanization, to satisfy the housing demand of new urban residents, urban residential floor area is increasing rapidly. In the SC&C zone, floor area served by heating rose from 5 billion m^2 to 13.2 billion m^2, with an annual increase of 7.15%. While that of the HSCW zone increased from 3.8 billion m^2 to 9.5 billion m^2, with an annual growth rate of 6.71%. Heating floor area in the SC&C zone was 1.38 times of that in the HSCW zone in 2015, it is one of the reasons for the gap in heating energy consumption in these two regions.

As for the energy use intensity, trends were different in the SC&C zone and the HSCW zone. As shown in Figure 1, the average heating energy use per unit of the floor area of the SC&C zone declined by 36%, from 22.8 kgce/ m^2 in 2001 to 14.5 kgce/ m^2 in 2015, showing the great progress of energy conservation. In contrast, that of the HSCW zone rapidly increased from 0.43 kgce/ m^2 in 2001 to 1.84 kgce/ m^2 in 2015, with an average annual growth rate of 10.94%. Though it increased rapidly in the past 15 years, the energy intensity of heating in the HSCW zone is still relatively low compared with that of the SC&C zone (which is about one-eighth of that in the SC&C zone).

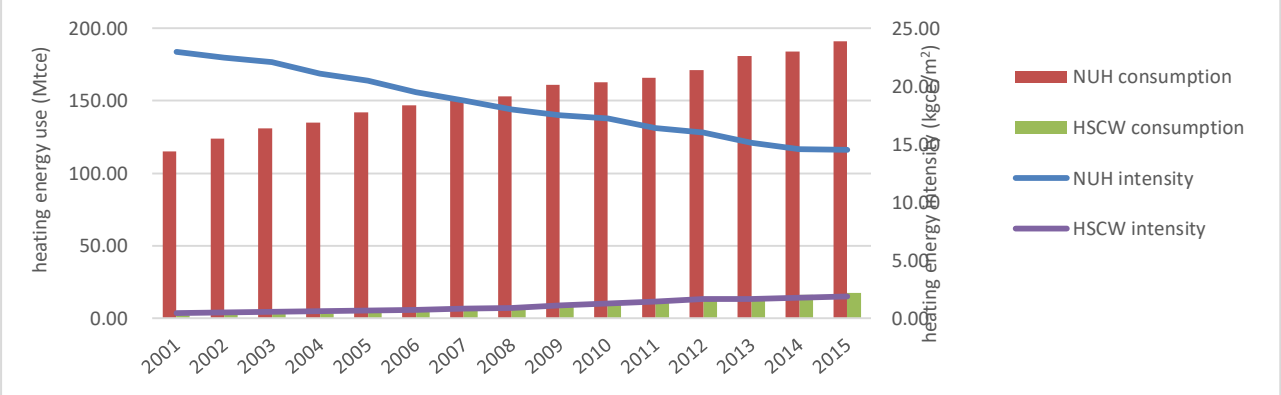

Figure 1. Heating energy use and energy intensity in the SC&C zone and the HSCW zone

2.3.2. Heating devices, usage mode, heating season and temperature.

Large differences in heating energy use and intensity of these two regions are not caused solely by climate conditions or heating floor area but are also significantly influenced by heating devices, usage mode and heating season.

(1) Heating devices. Heating devices vary significantly in the two regions. In the SC&C zone where district heating is widely used, the main heating devices are radiant floor heating and radiant heating systems. More than 60% of urban residential households in the SC&C zone utilized municipal centralized heating systems and another 14% used a gas boiler, while only 4% of households used other heating devices or did not have a heating device[14]. In contrast, most households in the HSCW zone used a decentralized heating device. The most popular heating devices in this region were air-source heat pumps and electrical heaters, used by 29% and 27% of households, respectively. In recent years, centralized heating systems expanded rapidly, from less than 3% in 2009 to about 10% in 2015. Only 29% of residents indicated that they use other heating devices or do not have a heating device.

Different heating devices have led to dissimilar intensities of heating energy consumption. For households using air-source heat pumps, the average consumption per unit of floor area was about 3.6

kWh/ m^2 (1.15 kgce/ m^2). For people using gas boilers, that was around 6 to 12 kgce/ m^2; for district heating, it was 15 to 20 kgce/ m^2. Different heating devices and heat sources are the main reasons for the huge gap between the energy consumption of the SC&C zone and the HSCW zone.

(2) Usage mode. In the SC&C zone, the district heating network keeps the heating system on without adjustment of the temperature for individual residences throughout the whole heating season. While in the HSCW zone, heating equipment is implemented separately by each household, consequently, people can adjust the indoor environment and use heating only when they feel cold in the room. The heating facilities in the HSCW zone are turned off during the most time during the heating season[13]. In a word, the district heating in the SC&C zone is operated full-time-full-space while the individual heating in the HSCW zone is operated part-time-part-space[15]. The relatively low heating energy use of the HSCW zone would increase if residents in this region use heating for a longer time and for more rooms.

(3) Heating season. According to China's heating policy, the heating period for district heating in the SC&C zone is determined by standard design, usually from mid-November to mid-March the following year in the cold zone and from late-October to mid-April the following year in the severe cold zone[16]. While in the HSCW zone, people can decide the length of the heating season, therefore, it varies among different households. According to BERC, the heating season in this region varies from less than one month to more than four months[7]. While in general, the heating season in the HSCW zone is shorter than that in the SC&C zone.

(4) Temperature. District heating helps to maintain 20 ℃ indoors in the SC&C zone during the heating season. While in the HSCW zone, the indoor temperatures vary among different households. For most of them, the temperatures of the heated room are around 11 to 18℃, however, in some cases, the rooms have temperatures of less than 5℃. By comparing the temperatures to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (abbr. ASHRAE) comfort zone limits, it is obvious that indoor thermal environments are relatively low in the HSCW zone[1,13,17,18]. If residents in this region want to get the same level of comfort as residents in the SC&C zone, they need to consume more energy. In other words, the gap in heating energy use between these two regions will be narrowed if we take comfort into account.

2.4. Key characteristics of heating in China

Based on the facts described above, several key characteristics of heating can be drawn.

Firstly, heating energy use in both the SC&C zone and the HSCW zone increased sharply from 2001 to 2015. Secondly, the trend in heating energy intensity is opposite in these two regions. The heating energy intensity in the HSCW zone has increased in the past years, while that of the SC&C zone has shown a great decrease, implying the possibility of energy conservation in the heating sector. Thirdly, the current heating energy use and energy intensity in the HSCW zone are relatively low compared with those of the SC&C zone, which is a result of the warmer climate, flexible heating devices, shorter heating season and lower indoor temperature. However, the indoor environments in the HSCW zone need to be improved, which indicates the huge growth potential of heating energy use in this region.

3. Challenges of China's space heating

A lot of researches have indicated that heating energy use is a function of climate, heating floor area, building performance, heating equipment, heating season and resident behaviors[1]. It seems most of these factors will increase heating energy use in China as the strong expectations for urbanization and improving living standard. Urbanization would result in great growth potential in heating floor area, besides, there is still sustained improvement potential in living standard caused by urbanization, which will lead to more energy use and higher energy intensity, especially in the HSCW zone. All of these expectations have put forward big challenges for heating energy conservation in China.

3.1. Challenge of increasing heating floor area caused by urbanization

China is experiencing rapid urbanization, as shown in Figure 2, from 2001 to 2015, the urbanization rate of China increased rapidly with an annual growth rate of 2.89%. To satisfy the housing demand of new urban residents, urban residential floor area has maintained a steady growth, showing an annual

increase of 6.96% during this period. Figure 2 visually demonstrate the relationship between heating floor area and urbanization rate, with a correlation coefficient of 0.99.

Considering the current urbanization level, China's urbanization process is unlikely to end soon, indicating more newly completed urban buildings and higher district heating demand in the future.

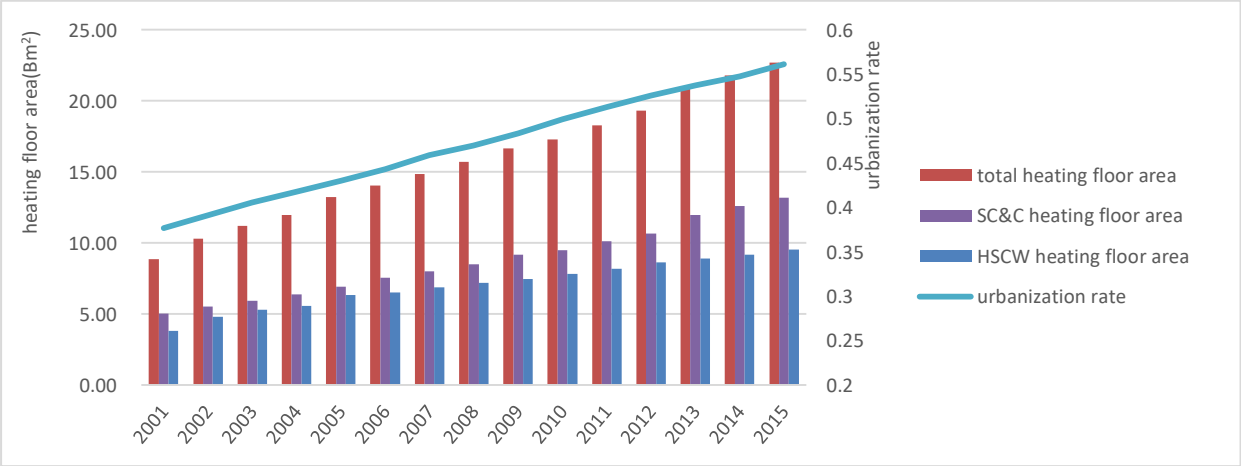

Figure 2. Urbanization rate and heating floor area (2001-2015)

3.2. Challenge of improving living standard caused by urbanization

Urbanization could also result in an increase in heating energy use by improving residents' income and living standard. The indoor comfort is far lower in the HSCW zone than that in the SC&C zone when heating season and temperature are taken into account. With the rapidly increasing urbanization rate and the accompanying growing household income and improvement of living standards, the residents in the HSCW zone will use heating equipment for a longer time to heat more rooms, they will also use larger capacity heating equipment to improve the indoor environment, which will result in more heating energy use in the HSCW zone[19].

3.3. Scenario analysis of heating energy demand in China

In 2016, the State Council of China released the National Population Development Strategy (2016-2030) [20], in which the rapid urbanization is expected to continue until 2030. As stated in this report, the total population of China will be 1.42 billion in 2020 and 1.45 billion in 2030, with the urbanization rate of 60% and 70%, respectively. That is, China's urban population will be 0.852 billion in 2020 and 1.015 billion in 2030.

In Scenario 1, the impact of urbanization on heating energy use was analyzed. We assumed the energy use intensity for space heating, the floor area per capita and the proportions of the urban population of different climate zones remain at the current level. Therefore, the urban population of the HSCW zone will be 274.67 million in 2020 and 327.22 million in 2030, that of the SC&C zone will be 354.75 million in 2020 and 422.62 million in 2030. Heating energy use of the SC&C zone would be 249.35 Mtce in 2020 and 389.78 Mtce in 2030. That of the HSCW zone would be 34.38 Mtce in 2020 and 117.73 Mtce in 2030. The results indicate that increasing heating floor area caused by urbanization could contribute to an increase in heating energy use by about 29.6% and 22.2% in 2020 and 2030 compared with the current level, respectively.

Based on this, Scenario 2 analyzed the impact of residents' usage pattern on heating energy use. Assuming residents in the HSCW zone change their usage mode from only using the heating devices when needed to use the devices for the entire heating season and improve the heating temperature to 16℃, then the energy consumption in the HSCW zone will be 58.46 Mtce in 2020 and 143.05 Mtce in 2030, indicating the usage mode contributes 46.32 Mtce in 2020 and 91.72 Mtce in 2030 to heating energy use.

Moreover, with the continuous urbanization and accompanying increase of household income and living standard, there is a hot debate on whether district heating should be extended to the HSCW zone.

In Scenario 3, we assume district heating is used in the HSCW zone and the energy use intensity of the district heating in the HSCW zone keeps the same path as that in the SC&C zone. Thus the heating energy use of the two regions in 2020 and 2030 would be 415.15 Mtce and 660.73 Mtce. The results indicate that the heating mode contributes 153.67 Mtce in 2020 and 219.61 Mtce in 2030 to heating energy consumption.

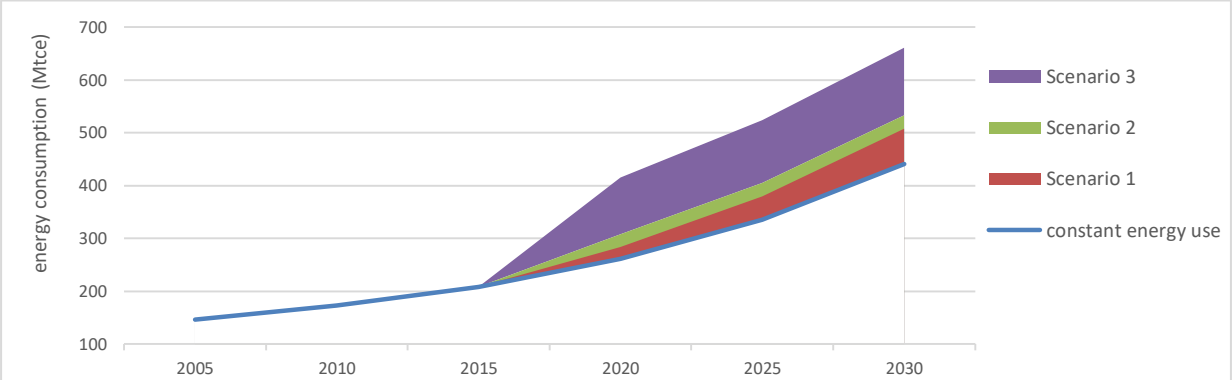

Figure 3. Scenario analysis of China's heating energy consumption

With the forecast of Scenario 3 which shown in Figure 3, the total energy use for heating in 2030 would be more than 2 times of that in 2015. As outlined in Revolution Strategy for Energy Production and Consumption (2016-2030) released by National Development and Reform Commission and National Energy Administration of China[21], China aims to limit the total amount of energy consumption to a target of 5 billion tce in 2020 and 6 billion tce in 2030. According to the NBS, the annual increase rate of residential heating energy use for 2014-2015 was 8.5%. If it keeps increasing at this rate, the residential heating energy use in 2030 will be more than 3 times that of the current level, namely, 708.85 million tce, which will amount to 11.8% of the total energy consumption of the country. The development target for China's energy system cannot accommodate this demand, therefore, the biggest challenge of China's heating sector is to find a suitable approach to limit the total energy use as well as provide an adequate living standard.

4. Possibilities of energy conservation in China's heating

As concluded above, the heating demand will increase as heating floor area increases and living standard improves. From 2001 to 2015, heating energy intensity increased rapidly in the HSCW zone, current heating energy policies have not paid enough attention to this region and the heating energy efficiency of this region is relatively poor[22]. In contrast, the energy use intensity of heating in the SC&C zone has shown a great decrease, indicating the great potential of energy conservation in the heating sector. The possibilities of energy conservation in the heating sector in China lie in these aspects.

(1) Improvement of building performance. In the SC&C zone, several design standards of energy efficiency were implemented to improve building envelope performance. For example, a standard established by MOHURD in 2010 set the target to reduce heat demand in new buildings by 65% compared to previous buildings (JGJ 26-2010)[23]. A standard of retrofitting existing residential buildings in the SC&C zone during 12th Five-year Plan period was also established by MOHURD. Besides, financial support has been provided by the Chinese government to improve the envelope insulation of existing buildings. These efforts greatly improved the insulation level of building envelopes and reduced heating energy intensity in the SC&C zone. While in the HSCW zone, the building performance is still very poor. Appropriate building design standards of energy efficiency need to be implemented in this region. Specific building performance efficiency policies applying to the HSCW zone should be improved to realize the potential for energy conservation in this area.

(2) Optimization of heating sources. Recently, in the SC&C zone, efficient heating sources such as large-scale combined heat and power (CHP) systems and industrial waste heat has expanded rapidly. High-efficiency CHP systems and boilers have replaced small coal boilers and household coal stoves at the regional level, while stoves, heat pump technology has developed rapidly and gas-source heating

systems are now used more widely. However, the efficiency of the heating devices in the HSCW zone is comparatively low. There are still no specific industry standards or regulations in regards to the energy efficiency of heating devices in the HSCW zone like electrical heaters[22]. Appropriate regulations and standards are needed to improve the efficiency of heating devices in this region.

(3) Adjustment in heating usage mode. The heating system in the SC&C zone is kept on for the entire heating season, without adjustment of the temperature for individual residence, resulting in serious overheating and network energy consumption, which consumes more than 30% of the total supplied space heating[1]. Therefore, flexible heating technology systems are inevitably called for. In the HSCW zone, residents' heating behaviors are much more diverse, thus the most important aspect to address in this region is the heating behaviors. In view of the top-level design, it is important to raise awareness of energy saving and encourage a "green" lifestyle. As for the detailed policies, some economic incentives like tiered energy pricing schemes should be promoted to encourage energy saving behaviors.

5. Conclusion

The main purpose of this research was to gain a panoptic description of heating energy use in China and to discuss the challenges caused by urbanization and possibilities of heating energy saving. An overview of China's heating sector was given and key characteristics of heating in different zones of China have been drawn in this study. Based on this, challenges of heating energy use caused by urbanization were analyzed, then the recommendations for future policy and technology development were given.

One of the limitations of this study concerns the quantitative analysis of the relationship between urbanization and energy usage mode as well as heating energy consumption. Another limitation of this study is the heating energy-saving technology was not discussed in detail. However, constant data for heat demand, heat resources, and heat grid are lacking to achieve these targets. Available data are strongly needed for further analysis. Further study would target these directions to study in a deep-going way if more heat metering devices were used and more specific data on heating were accessible to the public.

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