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China's building stock estimation and energy intensity analysis

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ABSTRACT

Reliable and objective data regarding building stock is essential for predicting and analyzing energy demand and carbon emission. However, China's building stock data is lacking. This study proposes a set of China building floor space estimation method (CBFSM) based on the improved building stock turnover model. Then it measures China's building stocks by vintage and type from 2000 to 2015, as well as building energy intensity (national level and provincial level) and energy-efficient buildings. Results showed that total building stocks increased significantly, rising from 35.2 billion m^2 in 2000 to 63.6 billion m^2 in 2015, with the average growth rate 4.0%. The deviations were well below 10% by comparing with *China Population Census*, which validated the reliability of CBFSM and the results. As for energy intensity, urban dwellings and rural dwellings showed relatively stable and increasing trend respectively. The commercial building energy intensity saw a downward trend during "12th Five Year Plan" period. This indicated the effectiveness of building energy efficiency work for commercial buildings since 2005.38.6 billion m^2 residential dwellings and 5.7 billion m^2 commercial buildings still need to be retrofitted in future. CBFSM can overcome shortages in previous studies. It can also provide Chinese government with technical support and data evidence to promote the building energy efficiency work.

1. Introduction

China has become the world largest CO_2 emitter with its increasing energy consumption since 2006 with 29.1 billion tons CO_2 emissions (IPCC, 2014). China faces the serious challenges on energy conversation and emission reduction, due to China's primary energy consumption grew at an average annual rate of 5.6%, 2.9 times that of the world over the same period from 1978 to 2015(IEA, 2013). The building sector is one of the three largest energy-consuming sectors, in addition to industry and transportation sectors, and is also an important source of GHG emissions (Zhang and Wang, 2017). The building sector consumes approximately 40% of total energy use in most developed countries (IEA, 2013). From 2000 to 2014, China's building energy consumption (BEC) increased 1.7 times, rising from about 301 to 814 million tons standard coal equivalent (tce) (Huo et al., 2018a,b,c), and is expected to increase further to 35% of the national total energy consumption by 2020 (Zhou and Lin, 2008). If accounting for the energy consumption of building materials manufacturing and excavation, the percentage will increase to 46.7% (Cai, 2014). Therefore, the energy saving and emission reduction in the building sector faces huge challenges and pressure.

In this context, China has performed much building energy efficiency (BEE) work, since the 1980s, such as the implementation of BEE codes for new buildings, existing building retrofits, and the application of renewable energy to buildings. However, over the past 30 years, the BEE work has been used to control the energy performance of the building components (e.g., enclosure structures, equipment systems, etc.) and it is the performance-based BEE work. Little attention has been paid to the building energy intensity and actual energy consumption. The actual energy saving outcome of the BEE work can therefore not be accurately calculated. Currently, China's 13th Five-Year Plan (FYP) (2016–2020) first proposed the cap control target of energy consumption. After that, the Ministry of Housing and Urban-Rural Development (MOHURD)'s 13th FYP for building energy efficiency and green building development proposed a mitigation action plan of

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improving urban residential energy performance 20% by the year of 2020 based on the 2015 level. Obviously, accurate and objective BEC data is the premise to carry out cap control, set BEC baseline, calculate actual energy savings and predict carbon peak value. However, there exists a significant shortage of energy consumption data in China's BEE field. The root cause is that China's energy consumption in the building sector are not counted as a separate type of energy consumption, but being mixed in other sectors in China's statistical system. More importantly, the lack of a unified calculation method and inconsistent data source for BEC are critical obstacles to obtain authoritative and high recognized BEC data (Cai, 2011; Cai et al., 2009). Such shortcomings resulted in the “heterogeneous” of current BEC in China.

In addition to the historical BEC data, the historical building floor space (BFS) is also an important factor for people to understand the actual energy consumption in the building sector (Huo et al., 2018a; Huo et al., 2018b). The building stock plays a significant role in actual energy savings calculation, energy consumption prediction, and carbon emission projection (Liu et al., 2017). Recent years, with the rapid urbanization, growth of household income and growth of the service sector (IEA, 2007), great quantities of buildings are being constructed and the total BFS in China increased from 10.2 billion m^2 in 1980 increased to 52.7 billion m^2 in 2008. Nearly half of the world's new building construction now is in China, which is about two billion m^2 of new buildings per year (NBS, 2014). It is projected that 800 million m^2 of new urban residential floor space will be built in China annually through to 2030 (IEA, 2007). The construction and operation of such great amount of buildings causes plenty of resources and energy consumption and eventually they are demolished with massive building wastes generation. Apart from that, the building stocks by vintages (i.e., the floor space of the existing buildings those were constructed during different periods, e.g., 1950–1959) are essential for the government to understand the situation of floor area of energy efficient buildings and set energy efficient retrofit plan. Unfortunately, there is not a set of general and authoritative time-series data on China's building stocks, demolished buildings and newly built buildings to date, which hinders China's BEE work. Therefore, quantifying the China's BFS and obtaining good quality and defensible data has become the key issues needs to address urgently.

In this context, research on macro BFS has drawn scholars' attention gradually. Current scholars adopted the BFS as the driving force to predict future energy consumption and material demand of China's buildings (Dong et al., 2017; Hu et al., 2010a; Zhou and Lin, 2008). They mainly obtained the base year BFS directly from *China Statistical Yearbook*, and then predicted the future BFS according to some assumptions and the national development plan (Hong et al., 2016; McNeil et al., 2016; Yang et al., 2017; Zhou et al., 2013). Obtaining BFS data directly from the *China Statistical Yearbook* is highly problematic, because there exist deficiencies in China's statistical system, such as the change of the statistical range and change of the statistical caliber over time, together with the incompleteness of time series data and other factors.

To address these gaps, we have developed a *Statistical Yearbook-energy balance sheet* based splitting method to estimate China's BEC and obtained the objective historical BEC data (Huo et al., 2018c). Based on our previous work, this study aims to conduct the four following tasks. Firstly, we extensively analyze the existing deficiencies of various statistical indictors pertaining to the floor space in *China Statistical Yearbook* by systematically combing the statistical reporting system related to the floor space in China over time. Secondly, we establish China building floor space estimation model (CBFSM) based on the improved building stock turnover model. Thirdly, we estimate the historical data of the building stocks and demolished buildings by type and vintages from 2000 to 2015 adopting CBFSM. Fourth, we validate the result of this study by comparing with the data from *China Population Census* and other studies. Finally, we calculate the building energy intensity by type and estimate the size of the energy efficient buildings. The proposed method (CBFSM) not only eliminates the deficiencies of inconsistent statistical caliber in the statistical yearbook, but also derives the authoritative and high-quality BFS data, and this can provide accurate and valuable data support for the government to determine material and energy demand, set reasonable energy efficiency policy and promote building energy saving work.

The rest of this paper is presented as follows: Section 2 is the literature review on BFS related research and review on existing deficiencies regarding BFS in *China Statistical Yearbook*. Section 3 provides the methodology. Section 4 shows the calculation results and validation, and Section 5 presents the analysis and discussion. The last section offers the conclusions and future directions for study.

2. Literature review

2.1. Review on building floor space related research

Building stocks are the main driving force for energy consumption and material demand in the building sector. The building stock has long lifespan characteristics, and many scholars calculated the volume of the building stock when they forecasted the energy and resource demands. For example, Ref (Müller, 2006). developed an archetypal dynamic material flow analysis (MFA) model and used this model to calculate and predict the housing stock of Netherlands from 1900 to 2100, and then projected the resource demands and waste emissions. Bergsdal et al. and Gallardo et al. then adopted this model to estimate the residential building stock of Norway (Bergsdal et al., 2007) and Chile's building stock calculation (Gallardo et al., 2014) respectively. Pauliuk et al. developed a comprehensive model by integrating the life cycle assessment techniques to this dynamic MFA model to measure the building stock (Pauliuk et al., 2013). On this basis, Sandberg et al. then utilized an extended segmented model to estimate the demolished and renovated residential building stock of Norway (Sandberg et al., 2014). Apart from that, Moura et al. adopted a dynamic stock-driven model to simulate and forecast the evolution of building stocks of the United States for 120 years (Moura et al., 2015).

As for China's building stock, Hu et al. adopted dynamic MFA model to calculate and predict the urban and rural housing stock of China, but did not identify the commercial BFS (Dong et al., 2017; Hu et al., 2010a, 2010b; 2010c, 2010d). Yang et al. studied the statistic method for China building energy consumption, and they directly used BFS data from the *China Statistical Yearbook* to calculate the energy intensity (Yang et al., 2017). Zhou et al. developed a bottom-up Long-range Energy Alternatives Planning (LEAP) model to project future energy consumption of end-use sectors in China, including the building sector (Zhou and Lin, 2008). Fridley et al. adopted the same method as Zhou et al. and calculated the BFS in China from 2005 to 2020 (Fridley, 2008; Hong, 2009). This processing method is unreliable, because the floor space of the industrial sector is included when subtracting residential floor area from the total building floor space. Ecom et al. studied China's long term building energy demand with macroeconomic model (Ecom et al., 2012). Hong et al. conducted a study on China building floor area (Hong et al., 2016). However, the lack of publicly available detailed data relating to inputs and assumptions, as well as the complex of the underlying algorithms, renders the derived results problematic. Additionally, many other scholars studied China building energy consumption-related floor