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Estimating Lifetimes and Stock Turnover Dynamics of Urban Residential Buildings in China

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Rising energy consumption and carbon emissions from buildings present a critical challenge to the Chinese government's pledge to peak its overall emissions by 2030. Strategically, China's building sector needs to undergo a transition towards low-carbon development whereby the increase of building energy consumption and emissions begins to decelerate. This challenge urgently calls for a sector-specific policy and regulatory framework to catalyse the envisaged sector-wide transformation.

To inform policies, it is essential to have a holistic and in-depth understanding of the current status of the existing building stock, which will serve as the baseline for assessing possible future energy and carbon trajectories. This is challenging in the Chinese context not only because of the magnitude of the building stock but also because of the lack of authoritative data. Official statistics on urban residential building stock only exist up to 2006. Therefore, forecasting possible trajectories of building stock expansion and the associated energy and emissions for the future will, first and foremost, require estimating how the building stock has evolved from 2006 to now. Essentially, what drives the evolution and expansion of the building stock is the dynamic interplay between new construction, meeting incremental demand growth as a result of economic growth and rising living standards, existing buildings remaining in use but undergoing an ageing process, and old buildings, which are either physically demolished or become functionally disused.

A critical factor in the dynamic relationship between old and new buildings is building lifetime. Shorter building lifetimes result in higher stock turn-over rate and greater complexity and uncertainty associated with stock characteristics, therefore having significant implications for stock-wide energy use and emissions over the medium to long term. Although this is believed to be the situation in China, aside from anecdotal claims that urban residential buildings in China are generally short-lived, there are no official statistics, and empirical data is extremely limited. Therefore, estimating building stock turnover dynamics and forecasting future trajectories requires building lifetime to be investigated more closely.

Previous studies estimating recent and future Chinese building stock and energy use make various assumptions about building lifetime and stock turnover in an effort to overcome the lack of available data. However, as evidenced by the wide variation in their results, there appear to be three main methodological concerns: (i) arbitrary choice of the mean and standard deviation of the assumed normal distribution of building lifetimes; (ii) ambiguity associated with existing building stock size and age profile in the start year for the modelling; and (iii) use of per capita floor area data leading to inflated estimates. Moreover, the dynamic profile of age-specific sub-stocks and the implications for whole life energy and carbon have not been greatly explored, which suggests a research gap in estimating building lifetime and stock turnover dynamics.

We develop a residential stock turnover model using a system dynamics approach. The model treats building stock evolution as a continuous process of introducing new cohorts which age over time, capturing the dynamic interplay between new construction, operation and demolition. Building lifecycle is regarded as a survival process subject to various factors. Demolition of buildings is modelled as a stochastic process based on a hazard function derived from a Weibull distribution. Using historical data starting with 1978, the first year official building stock statistics are available, the Weibull distribution's shape and scale parameters were calibrated. The specified Weibull distribution has a mean value of 34.1 years, representing the average building lifetime. Our result substantiates the general observation that urban residential buildings in China have an average lifetime much shorter than the design lifetime of 50 years. Based on the dynamically changing age profile, the total stock size of urban residential buildings was estimated to have increased from 17.8 billion m^2 in 2010 to 23.7 billion m^2 in 2017.

The value of estimating the building lifetime distribution and obtaining an explicit set of age-specific sub-stocks goes beyond understanding the dynamics of the residential building stock itself and offers three sets of insights. Firstly, the estimated lifetime distribution makes it possible to explicitly estimate new construction and demolition on an annual basis, which can be directly used to quantify the total initial and demolition embodied energy and carbon for every year. The impact of changing the lifetime distribution on embodied energy and carbon can be examined. Secondly, model granularity at the level of age-specific building sub-stocks provides a detailed representation of the building stocks' heterogeneity with respect to operational energy performance. As new buildings will be built to higher standards, separately tracking the aging process of different cohorts of buildings enables policy-makers to influence the dynamics of the stock composition of buildings with different operational performance and evaluate the trajectories of stock-wide average operational energy intensity. Thirdly, and perhaps most importantly, the ability to model the temporal dynamics of the building stock facilitates the integration of embodied and operational impacts. A dynamic model allows us to explore their relative importance in the context of further developments in green building materials, strengthening design codes for new buildings and scaling up energy-related retrofits of existing buildings.

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