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A long-term, integrated impact assessment of alternative building energy code scenarios in China

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HIGHLIGHTS

- We assessed long-term impacts of building codes and climate policy using GCAM.
- Building energy codes would reduce Chinese building energy use by 13–22%.
- The impacts of codes on building energy use vary by climate region and sub-sector.

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ABSTRACT

China is the second largest building energy user in the world, ranking first and third in residential and commercial energy consumption. Beginning in the early 1980s, the Chinese government has developed a variety of building energy codes to improve building energy efficiency and reduce total energy demand. This paper studies the impact of building energy codes on energy use and CO_2 emissions by using a detailed building energy model that represents four distinct climate zones each with three building types, nested in a long-term integrated assessment framework GCAM. An advanced building stock module, coupled with the building energy model, is developed to reflect the characteristics of future building stock and its interaction with the development of building energy codes in China. This paper also evaluates the impacts of building codes on building energy demand in the presence of economy-wide carbon policy. We find that building energy codes would reduce Chinese building energy use by 13–22% depending on building code scenarios, with a similar effect preserved even under the carbon policy. The impact of building energy codes shows regional and sectoral variation due to regionally differentiated responses of heating and cooling services to shell efficiency improvement.

1. Introduction

Building energy demand continues to increase globally, generating an unprecedented amount of CO_2 emissions from the sector. Building sector's contribution to energy demand has been steadily growing and, in 2009, it accounted for nearly 45% of the world's final energy (IEA, 2011). The trend is not likely to wane anytime soon as a less developed part of the world grows at a rapid pace demanding the standards of living that its predecessors have experienced.

China is already the world's second largest building energy user, ranked first and third in residential and commercial energy consumption, respectively (IEA, 2012). Building energy consumption in China is expected to grow at least for the next several decades, as the country undergoes rapid income and population growth, requiring continued expansion of building floorspace and installation of energy-consuming devices (Eom et al., 2012; Li and Yao, 2009). This poses substantial challenges for the Chinese government to maintain adequate supply of energy and for international society to address global climate change.

Development and implementation of building energy codes in China may be a sensible domestic strategy to fulfill building energy demand in an economically efficient way while at the same time reducing CO_2 emissions. Building energy codes intend to promote energy performance of buildings by setting legal requirements on building design and their compliance provisions during construction period. They usually include standards for thermal properties of building envelope and may also cover heating, ventilation, and air conditioning (HVAC), lighting, electrical power, renewable, and building maintenance (Evans et al., 2009; Liu et al., 2010). The Chinese government has implemented building energy codes since 1980s with the particular focus on the

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Table 1
Development of building energy codes in China.

Building type	Climate region			
	SC	C	HSCW	HSWW
Urban	Design standard for energy efficiency of residential buildings in severe cold and cole zones (JGJ 26); Years of Enactment: 1986, 1995, 2010		Design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ 134); Years of Enactment: 2001, 2010	Design standard for energy efficiency of residential buildings in hot summer and warm winter zone (JGJ 95); Years of Enactment: 2003, 2012
Commercial	Design Standard for Energy Efficiency of Public Buildings (GB 50189); Years of Enactment: 1993, 2005			
Rural	Design Standard for Energy Efficiency of Rural Residential Buildings (GB 50824); Year of Enactment: 2012			

improvement of envelope insulation (Huang and Deringer, 2007; Shui et al., 2009). All new urban residential and commercial buildings are currently required to comply with Chinese building energy codes in both design and construction stages.

This paper investigates the potential long-term impact of China's building energy codes on building energy use and CO_2 emissions based on a detailed building energy model nested within the Global Change Assessment Model (GCAM). In particular, the model represents the influence of building code implementation on the improvement of buildings shell efficiency and resulting energy demands, by extending and adapting the model presented by Yu et al. (2013), which disaggregates Chinese buildings into 12 different sectors—three building types in four climate zones. Specifically, the impact of building energy codes is captured through a building stock module that describes the expansion of building floorspace as a result of new construction and retirement at the regional level, as well as the interaction of the building stock with building energy codes in place, code compliance, and the degree of retrofits. The building stock module shares the same regional information for major drivers (e.g., income, population, and per capita building floorspace) with the building energy model that generates ultimate energy results. This modeling approach allows for assessing the effect of building energy codes on building energy demand and associated CO_2 emissions in a consistent manner, while at the same time capturing the effects of regional differences in socioeconomic development, code implementation, climate impact, and fuel choices.

In this study, we focused on the long-term impacts of various types of building energy codes that are being contemplated or could be implemented by the Chinese government. Four distinct but interrelated scenarios of Chinese building energy codes were taken into account to span possible futures of the building sector, to provide broader policy insights, and to guide the development of building codes at the regional and national level. By examining the influence of two major policy variables – the coverage by building type and the stringency of the energy codes – we suggest the pathways that next generation building codes in China are advised to take.

This study draws three important conclusions. First, the implementation of building energy codes may substantially reduce overall building energy consumption in China, and this finding remains unchanged with global climate change, modest assumptions of voluntary technological improvement, and economy-wide carbon policy. Second, the Chinese government can see significant impacts from expanding its efforts to improve building shell efficiency beyond new buildings in urban centers. In particular, promoting retrofits of poorly performing buildings and expanding building energy codes to rural areas may result in earlier and more drastic energy savings. Finally, the potential impact of building energy codes will differ by region and sector. The greatest energy savings will accrue in urban residential buildings, particularly those located in cold regions.

2. Background

2.1. Building energy codes in China

The Chinese government has a strong commitment to reducing building energy consumption as expressed by its relatively long history of building energy code implementation and continued expansion of the program. The Ministry of Housing and Urban-Rural Development issued its first building energy codes in 1986 for residential buildings in the severe cold and cold climate zones,[1] in an attempt to reduce building energy consumption by 30% compared to ordinary buildings built in early 1980s without energy-efficiency measures. Since then, the Chinese government has developed building energy codes for other climate zones and building types, and continued to ratchet up building energy efficiency standards.[2] As of April 2013, China has national energy codes for commercial buildings and rural residential buildings as well as energy codes for large residential buildings in different climate zones: severe cold (SC) and cold (C), hot summer cold winter (HSCW), and hot summer warm winter (HSWW) (Shui et al., 2009; Song et al., 2011). Requirements for thermal conductance are more stringent in SC and C regions than HSCW and HSWW regions (Table 1). These building energy codes set performance requirements mainly for the building envelope and some HVAC systems, and requirements for lighting, room air-conditioning, and commercial HVAC systems are in separate standards (Evans et al., 2009). It is expected that, in accordance with the improvements in building materials and changing building construction practices, the codes will become increasingly stringent.

The Chinese government has also developed retrofit programs for buildings, and the programs would continue to help improve buildings energy efficiency in China. Currently, there are technical guidelines to support building renovations, such as *Technical Specifications for Energy Conservation Renovation of Existing Heated Residential Buildings* and *Technical Code for Retrofitting Public Buildings for Energy Efficiency*. Government-funded building retrofit programs helped renovate the 180 million m^2 of residential buildings in the Northern Heating Zone over the past five years (Zhang, 2011). The *12th Five-Year Plan for National Economic and Social Development (2011–2015)* and the *Green Building Action Plan* stipulates the continuation of energy-efficiency retrofit programs in Northern China and its expansion to residential and public buildings in the HSCW and HSWW regions (MOHURD, 2011; State Council, 2013).

[1] The Ministry of Housing and Urban-Rural Development divides China into five climate zones based on heating and cooling degree days: severe cold, cold, hot summer cold winter, hot summer warm winter, and temperate zones.

[2] Current building energy codes collectively reflect the goal of reducing national building energy consumption by 50% by 2020 (and by 65% in major metropolitan areas) compared to the energy consumption of hypothetical buildings with the energy performance held fixed to the 1980s level (Mo et al., 2010; Shui et al., 2009).