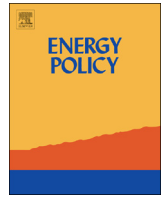




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Energy efficiency outlook in China's urban buildings sector through 2030



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HIGHLIGHTS

- We use a bottom-up modeling approach to quantify emission reduction from efficiency programs.
- Heating and cooling are the main focus of this study.
- We find that building codes lead to 17% reduction compare to the baseline.
- Other programs analyzed concern district heat, building labeling and retrofits of buildings.

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ABSTRACT

This study uses bottom-up modeling framework in order to quantify potential energy savings and emission reduction impacts from the implementation of energy efficiency programs in the building sector in China. Policies considered include (1) accelerated building codes in residential and commercial buildings, (2) increased penetration of district heat metering and controls, (3) district heating efficiency improvement, (4) building energy efficiency labeling programs and (5) retrofits of existing commercial buildings.

Among these programs, we found that the implementation of building codes provide by far the largest savings opportunity, leading to an overall 17% reduction in overall space heating and cooling demand relative to the baseline. Second are energy efficiency labels with 6%, followed by reductions of losses associated with district heating representing 4% reduction and finally, retrofits representing only about a 1% savings.

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1. Introduction

As part of its 11th Five-Year Plan (FYP) from 2006 to 2010, the Chinese government set for the first time a binding target for energy efficiency by requiring a 20% reduction in energy intensity per unit of gross domestic product (GDP) from 2005 to 2010 and began initiating sector-specific policies and measures to support further reductions in energy and carbon dioxide (CO₂) intensity through 2020. China has set continuing binding targets of 16% and 17% reductions in energy and carbon intensity per unit of GDP respectively, for its 12th Five-Year Plan (FYP) period from 2011 to 2015. More recently, on June 2015, China restated in its “intended nationally determined contribution” (INDC) its previously

announced goal to peak its emissions around 2030 and lower the carbon intensity of GDP by 60–65% below 2005 levels by 2030.

In light of these recent binding targets, evaluating and quantifying the impact of different policies in different sectors become increasingly important, both to guiding the development of near-term policies and prioritizing between them. While targets constitute an essential framework for action, energy savings originates from the implementation of policies and programs at the sectoral level. The goal of this paper is to quantify the significant contribution that can deliver specific energy efficiency programs in the building sector and quantify these impacts measured against energy savings target allocation. Description of ‘best practice’ energy efficiency building programs and policies implementation is available in Levine et al. (2012). Li and Shui (2015) provide a recent analysis of programs and policies implemented in the building sector in China. Policies considered include (1) enforcement of existing building codes and (2) increased penetration of district

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heat metering and controls, (3) increased penetration of high efficiency district heating generation and distribution, (4) promotion of building labeling programs and (5) existing building retrofits.

The past decade has seen the development of various scenarios describing long-term patterns of China's future energy consumption and GHG emissions. Some of the most notable of these include the International Energy Agency (IEA)'s World Energy Outlook 2013, (IEA, 2013), China's Energy Research Institute (ERI) (CEACER, 2009) and McKinsey & Company (McKinsey & Company, 2009). In general, the models used in these assessments provide interesting discussions and insights on understanding China's medium and long term energy and carbon emission trajectory from the macro-level. These modeling studies take a top-down or hybrid approach with primarily economic-based drivers. More recently, Yu et al. (2014) developed a detailed building energy model to insert in an integrated assessment framework. While this allowed a more robust analysis of trends in that sector, the building end-use technologies representation is too limited to quantify the impacts of building energy efficiency programs. Similarly, the recent IEA's publication on Building Energy Use in China done jointly with Tsinghua University (IEA, 2015) provides great insights on data for key cities and gives a useful description of emerging technologies but does not assess specific policies and programs impacts.

By contrast, the approach taken by Lawrence Berkeley National Laboratory (LBNL)'s China 2050 Model (Zhou et al., 2011a) is to forecast sector energy consumption as driven by the diffusion of various types of equipment; the performance, saturation, and utilization of which has a profound effect on energy demand. Using this bottom-up model, LBNL has undertaken various studies to perform retrospective and prospective sectoral and cross-cutting policy impact evaluation and to develop medium- and long-term outlooks for low-emissions pathways (Zhou, 2011a, 2007, 2012). Recently, Xiao et al. (2014), developed a bottom-up model to assess the carbon abatement potential and marginal abatement cost (MAC) of 34 selected energy-saving technologies/measures for China's building sector.

Zhou et al. (2012) performed a retrospective analysis of impacts based on actions taken during the 11th Five Year Plan and presented a bottom-up methodology of energy end-use demand to quantify the achievements of building energy efficiency policies during the 11th FYP. The study concluded that with this portfolio of policies, the Chinese government was on track to save 90 Metric Tons Carbon Equivalent (Mtce) by the end of 2010, or 90% of its goal. The majority of those savings (62 Mtce) were achieved by the successful tightening of enforcement of existing building codes.

The current study applies and expands this bottom-up methodology to the question of future savings potential in the building sectors if current policies are continued and strengthened. Using LBNL's China 2050 Model business as usual (BAU) scenario, this study estimates the energy savings potential for 5 programs in the residential and commercial building sectors and provides a detailed analysis of the end-use technologies savings assessments used as assumptions in the model.

This paper is divided into five sections. Following this introduction, Section 2 presents the policies to be evaluated and summarizes the impacts of these policies during the 11th FYP. Section 3 describes the methodology for forecasting energy end use demand and Section 4 describes the assumptions and parameters used to construct each policy scenario. Results and conclusions are shown in Section 5.

2. Buildings efficiency policies in China

The purpose of the current study is to look forward to ways of achieving as yet uncaptured savings from energy efficiency

policies in the building sector. Taking a long-term view, we model the potential savings from an aggressive set of policies targeting conventional, well-known energy efficiency technologies, in order to show feasible energy and emissions reductions versus Business as Usual (BAU) by 2030. The approach is to look at those measures that are judged feasible to implement in China in the near to medium term, with technologies that are already available on the market and that are cost-effective. For this reason, the results may be considered to be conservative.

The current analysis focuses on policies that target space heating and cooling energy. Lighting and appliances policies are not covered here. The impact analysis covers the five following policies:

- Accelerated Building Codes (Residential and Commercial) – Building codes affect new building heating and air conditioning loads by increasing the requirement of insulation of the building shell and heating, ventilation and air conditioning (HVAC) system efficiency. The policy considered is an acceleration of the update of building codes in China, towards alignment with levels defined by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), and subsequent updating of those codes through 2030.
- District Heat Metering and Controls (Residential) – Historically, district heat feeding residential buildings in China was not metered or controllable by residences, leading to significant heat waste. Controls and metering are standard on new buildings. The policy considered fills gaps in controls and metering through retrofits of existing buildings to allow for reduction of heating use by residents. This policy does not affect commercial buildings, which are generally fitted with heating controls and metering by default.
- District Heating Efficiency Improvement (Residential and Commercial) – This policy is defined by increased penetration of high efficiency district heating generation and distribution. Improvements considered are (1) increased plant efficiency (2) reduction of thermal losses in pipelines and (3) increased pumping station efficiency.
- Energy Efficiency Labels (Residential and Commercial) – This policy assumes increased construction of 5-star buildings as defined by the Ministry of Housing, Urban-Rural Development's (MoHURD) Building Energy Efficiency (BEE) labeling program. The BEE label evaluates buildings on a scale of one (least efficient) to five stars (most efficient) in terms of energy efficiency, with a focus on HVAC system efficiency, compulsory standard compliance, and optional building efficiency measures.
- Retrofits (Commercial) – This policy assumes an increased number of commercial building retrofits. Retrofit measures include improved building envelope (insulation, windows, shading and air-tightness), controls, and heating systems (boilers) in commercial buildings. Commercial buildings usually have larger internal heat load intensity (from lighting, equipment, occupants) compared with residential buildings and therefore the heating retrofit may not be that effective compared with a residential building.

3. Building energy end use modeling

This study uses the baseline scenario called *Continued Improvement Scenario* (CIS) of the China Energy Model described in Zhou et al. (2011a).

LBNL's approach to modeling energy demand growth and reduction potentials uses a bottom-up approach which characterizes energy usage at the 'technology' level (McNeil et al., 2008, 2013; Zhou et al., 2011a). The model includes the following

Table 1
Macroeconomic driver assumptions for all scenarios.

	2005	2030
Population	1.31 Billion	1.46 Billion
Urbanization Rate	43%	70%
GDP Growth		
2010–2020	7.7% per year	
2020–2030	5.9% per year	

macroeconomic drivers that affect the evolution of energy demand in China's buildings sector:

- Continuous trend toward urbanization.
- Continuous, but slowing growth in commercial building construction.
- Growing uptake and use of energy-consuming appliances by households with increasing income.
- Gradually increasing improvement in equipment efficiency and building shell insulation.

Rapid GDP growth is expected to continue for the next decade, but will gradually slow by 2020 as the Chinese economy matures and shifts towards a service-based orientation. Different rates of GDP growth were assumed for the periods between 2010–2020 and 2020–2030 as shown in Table 1.

Besides economic growth, another key driver is the urbanization rate and growth of the urban population. China as a developing country has and will continue to undergo changes in its physical built environment as a result of rapid urbanization. Over 290 million new urban residents have been added from 1990 to 2007, and 380 million new urban residents are expected from 2007 to 2030. The addition of new mega-cities and second-tier cities will drive commercial and residential demand for energy services and infrastructure development. To account for the potential effects of urbanization on buildings energy demand, the model uses widely accepted population growth projections from the United Nations and ERI's urbanization assumptions as macro-drivers in all scenarios.

End-use based modeling methodology serves as the basis for the quantitative evaluation of the potential energy and carbon impacts of China's building policies. By adopting an end-use approach to energy and emissions modeling and multiple scenarios to characterize the different paces of policy implementation, this study is able to separate out and isolate the effects of a specific policy or bundle of policies on potential energy savings and energy-related CO₂ emission reductions.

The largest energy end use in buildings is HVAC. We consider policy impacts on heating and air conditioning, including district heating, from improvements in equipment and the building envelope. Policies that affect smaller appliances within buildings or are targeted towards improving equipment efficiency only are not included, but covered elsewhere in studies of 'appliance' policies (see for example Zhou et al. (2011b)).

4. Policy impact modeling

As a first step, we extracted estimates of floor space by building type (residential or commercial), heating type (district heat or stand-alone), equipment type and fuel, and climate zone from LBNL's China 2050 model. In addition, we modeled building construction and retirements in order to distinguish between building stock impacted by construction policies and those affected by

retrofits. We then created policy scenarios by specifying the amount of floor space affected and the percentage reduction in heating and cooling energy in each year for each policy considered. Estimates of energy savings for building codes and retrofits relied on detailed models of heating and cooling load for prototype buildings using the US Department of Energy (DOE)'s EnergyPlus¹ building simulation software. Savings for energy efficiency labels followed the definitions of current programs in China.

Two important overarching assumptions were made in modeling building policies:

- Buildings policies are assumed to impact urban buildings only.
- Building policies affect either existing buildings (i.e. retrofits) or new construction only (codes and labels).

While the authors do not suggest that only urban buildings are important users of energy and uniquely appropriate for energy efficiency policy in China, historically, efficiency of rural buildings has been much less studied. As a result, data in the rural subsector is much more sparse, and the feasibility of policy implementation there is much less certain, and they are omitted on these grounds. Generally, for each building affected, each policy type improves the efficiency of either heating or cooling by the unit improvement $\phi^i(y)$, where i denotes either heating or cooling. Unit improvement is a percentage that can vary over year y , as in the case of building codes, which are updated periodically. The percentage of buildings affected, or penetration rate is denoted $\psi(y)$.

In the case that a given policy affects both existing and new buildings, energy savings is given by:

$$E_{policy}^i(y) = E_{BAU}^i(y) \times \phi^i(y) \times \psi(y)$$

where E_{BAU}^i is energy consumption for cooling or heating in the BAU scenario taken from LBNL China model (Zhou et al., 2011a) and E_{Policy}^i is the resulting energy consumption after policy implementation.

For policies that affect only new buildings, unit improvement and penetration rates apply to new construction only. The effect of these policies on the total building stock is therefore given by:

$$E_{Policy}^i(y) = E_{BAU}^i \times \sum_{y'=2015}^y \phi^i(y') \times \psi(y') \times construction(y') / stock(y')$$

4.1. Accelerated building codes (residential and commercial)

We modeled building code impacts using the simulation tool EnergyPlus. We assume that the existing building stock in northern China was in average built according to the building energy code of 1980.² In order to model energy consumption of such a building, we use a prototype eight-story high-rise residential building i with window to wall ratio (WWR) of 0.15. In the Hot Summer Cold Winter (HSCW) climate region for example,³ the exterior wall is modeled as lacking an insulation layer and having a U-value of 2 W/(m² K). The, roof U-value of 1.5 W/(m² K) and exterior window U-value of 6.4 W/(m² K). The building's air-tightness is modeled at 2 air changes per hour (ACH).

¹ EnergyPlus version 8.1, described at <http://apps1.eere.energy.gov/buildings/energyplus/>.

² JGJ 26 for cold and severe cold climate zone, and JGJ 134.

³ Residential buildings in other climate zones are modeled accordingly, in compliance with the Chinese residential building code: JGJ 26, JGJ 134, and JGJ 75. This description here only states the measures applied to residential buildings in HSCW climate region, but the building is modeled in all major Chinese climate regions.

Table 2
Residential Code Parameter Assumptions – HSCW Climate Region.

Year	Envelope				
	Roof U [W/ m ² K]	Wall U [W/ m ² K]	Window		Infiltration [ACH]
			U [W/ m ² K]	Solar Heat Gain Coefficient (SHGC)	
After 1980	1.50	2.00	6.40	0.95	2.0
2004	0.70	1.00	3.00	0.5	1.0
2010	0.65	0.9	2.8	0.4	0.6
2020	0.45	0.6	2.5	0.36	0.4
2030	0.35	0.4	2	0.33	0.2

New buildings (at year 2010) are modeled to have the similar characteristics as the current Chinese residential building code JGJ 26 and JGJ 134, prescribed as having exterior wall, roof, and window U-values of 0.7 W/(m² K), 0.6 W/(m² K) and 3.2 W/(m² K) respectively. The building infiltration rate is 1 ACH.

We assume that future residential buildings will have more aggressive energy efficiency codes under the policy scenario. In 2030, the residential building code in China is assumed to reach the same level as ASHRAE standard (90.1 for high rise residential buildings) projected in that year. Residential building performance in intervening years assumes progressively more stringent measures based on the existing standard. The result of the simulation shows a 45% heating energy reduction and 18% cooling energy reduction with respect to current building codes. These parameters are summarized in Table 2.

We modeled commercial building energy efficiency by analyzing reference office buildings with parameters determined by the Chinese commercial building code. The current Chinese commercial building code GB50189-2005 is used to model new construction. GB50189 also provides the characteristics of existing buildings built around 1980. Table 3 gives the building system characteristics in Shanghai (HSCW climate region) under different years. China currently has a less stringent commercial building code compared with ASHRAE standards. As in the case of residential buildings, we assume that Chinese commercial building codes catch up with ASHRAE standards by 2030 in the policy scenario and model improvement in intervening years similarly. The result of the simulation shows a 50% heating energy reduction and 40% cooling energy reduction with respect to current building codes.

For both residential and building codes, only the policy's impacts on heating and cooling loads are modeled and code requirements and potential savings related to lighting and equipment efficiency are not evaluated.

Table 3
Commercial building parameters – HSCW climate region.

Year	Envelope					HVAC		
	Roof U [W/ m ² K]	Wall U [W/ m ² K]	Window		Infiltration [ACH]	Chiller coefficient of performance (COP)	Boiler efficiency	System types
			U [W/ m ² K]	SHGC				
After 1980	1.50	2.00	6.40	0.95	2.0	4.00	0.58	Fan-coil unit (FCU)
2004	0.70	1.00	3.00	0.5	1.0	4.80	0.78	FCU
2010	0.55	0.8	2.8	0.4	0.6	5.3	0.83	FCU, Economizers
2020	0.45	0.6	2.5	0.36	0.4	5.7	0.87	Radiant panel, Economizers
2030	0.35	0.4	2	0.33	0.2	6.2	0.91	Radiant panel, Economizers, Natural Ventilation

4.2. District heating metering and controls (residential)

In northern China, district heating is the main source of heating during the winter. The typical district heating system in the building stock has few room thermostats. The heating fee is charged based on room floorspace rather than how much heat is used in one building. Due to this lack of control capability, building residents can not adjust their room set point or turn the heating off when they are not at home. One common phenomenon in northern China is that, because of the absence of room thermostat, rooms become over-heated and occupants open windows to cool down their rooms.

In the Severe Cold (SC) climate region, the heating season extends from October 15 to April 15; in the Cold (C) climate region, the heating season is from November 15 to March 15. The modeling of heating control assumes for existing building without terminal control system, that building room temperature is controlled at constant 25 °C in the winter; while for new buildings with thermostat controls, the room temperature is controlled at 18 °C and heating is off when occupants are absent weekdays from 8:00 am to 6:00 pm. According to simulations, thermostat controls applied in this way could lower heating energy demand by approximately 40%.

4.3. District heating efficiency improvement (residential and commercial)

In addition to reduction from consumption changes at the building level, the efficiency of district heating is considered. District heating can be improved at the central level through reduced transmission losses during pipelining, and reduction of losses at pumping stations.

District heating to Chinese residential and commercial districts is transported either directly through a single pipeline system (single-tier systems) or through a combination of primary and secondary systems with an intermediate pumping station (two-tier systems). Newly installed primary systems can be very efficient, with about 1–3% losses, while worn and old circuit losses can be as high as 30% (Zhong et al., 2011; Qi et al., 2008). The current Chinese standard requires that primary heating circuits be at least 90% efficient (CABR, 2001). We assume that (1) the average efficiency for primary systems is 80% and can be improved to 91% and (2) the average efficiency for two-tier systems is 60% and can be improved to 81%. Two-tier-systems are becoming less common in China as worn-out systems are replaced with 1-tier systems. We estimate the share of 2-tier systems at 20% in 2010, decreasing to 10% in 2020 (Zhong et al., 2011; Qi et al., 2008).

In addition to heat losses through the pipeline, district heating systems also waste energy through inefficiencies in pumping systems at the pumping station due to sub-optimal load matching.

Table 4
Residential building retrofit parameter summary.

	Envelope				
	Roof U [W/m ² K]	Wall U [W/m ² K]	Window		Infiltration [ACH]
			U [W/m ² K]	SHGC	
Before retrofit	1.50	2.00	6.40	0.95	2.0
After retrofit	0.70	1.00	3.00	0.5	1.0

We assume that the average electricity intensity is 1.75 kWh per m² of floor space for a single-tier pump system and 2 kWh/m² for a two-tier system (BERC, 2011). The electricity intensity can be reduced by 0.5 kWh/m² through system optimization (BERC, 2011), or roughly 5% of the average heating load.

4.4. Energy efficiency labels (residential and commercial)

China began promoting the voluntary use of whole building energy labels in the last few years and currently have a Green Building Evaluation and Labeling program and a Building Energy Efficiency Evaluation and Labeling Program, both of which are managed by the Ministry of Housing and Urban-Rural Development (MOHURD). The Building Energy Efficiency (BEE) labeling program evaluates buildings on a scale of one (least efficient) to five stars (most efficient) in terms of energy efficiency, with a focus on HVAC system efficiency, compulsory standard compliance, and optional building efficiency features. The Green Building labeling program covers a broader scope beyond energy that includes resource efficiency, indoor and outdoor environment criteria, land use and water efficiency (MOHURD, 2008). Because this report focuses on energy and energy-related CO₂ emissions, only the BEE labeling program is taken into consideration in our modeling and policy evaluation efforts.

Although the BEE labeling program is relatively new, there have been concerted efforts to increase the penetration of efficient buildings through incentives and demonstration energy efficient and emission reduction provinces and cities as part of the 12th FYP (MOF, 2011a,b). In addition, ongoing research and policy discussions related to the BEE labeling program have focused on expanding building coverage, the use of economic incentives to raise labeling interest and awareness and further promotion of the program at provincial and city levels (CABR, 2001).

Short-term acceleration of the construction of so-called “green” buildings and even “net-zero energy” (NZE) buildings could provide additional short-term opportunities. In the 12th FYP, China has the following targets for green buildings:

- At least 80% government-invested public buildings and 70% of low-income housing buildings in provincial cities need to be green buildings by 2015.
- 20% of new construction in key cities needs to be green buildings by 2015.

Table 5
Commercial building retrofit parameter summary.

	Envelope				HVAC		
	Roof U [W/m ² K]	Wall U [W/m ² K]	Window		Infiltration [ACH]	Chiller COP	Boiler efficiency
			U [W/m ² K]	SHGC			
Before retrofit	1.50	2.00	6.40	0.95	2.0	4.00	0.60
After retrofit	0.70	1.00	3.00	0.5	1.0	4.80	0.80

The BEE label evaluates buildings based on three key components: the energy consumption of heating, air conditioning, and lighting systems per m² in accordance with national building energy standards; compliance with minimum performance requirements for building enclosure and HVAC; and implementation of optional energy efficiency or renewable energy systems (Mo et al., 2010). To achieve the most efficient five-star rating, a building must achieve 85% HVAC and lighting energy savings relative to inefficient 1980s buildings, meet all minimum performance requirements and have incorporated a significant share of qualifying optional efficient and renewable systems (Cao, 2011). Because the current building standards require 50% energy savings relative to the same baseline of inefficient buildings, a five-star rated building essentially saves 70% more energy relative to a comparable existing building in compliance with building standards.

In this study, the most efficient five-star BEE rated buildings are thus modeled as achieving 70% energy savings in space heating for residential buildings, in HVAC for Southern residential buildings and in HVAC for all commercial buildings. Potential energy savings in lighting and equipment for the most efficient five-star BEE rated buildings are not modeled in this study. In light of the recently launched incentive policies for efficient buildings and ongoing policy discussions on expanding the BEE program, five-star rated efficient buildings are assumed to reach 10% share of new residential and commercial buildings by 2015, rising to 25% share by 2030.

4.5. Building energy retrofits (HSCW climate region) – (residential and commercial)

Residential building energy efficiency retrofits is mainly focused on northern China (Cold and Severe Cold climate region) and the HSCW climate region. The retrofit of residential buildings aims to improve building shell performance so it complies with the climate region's energy efficiency code. The before-retrofit building conditions are assumed at year 1980 as specified in Table 4 (for HSCW climate region), and the after-retrofit conditions are assumed to comply with what are specified in the current residential building code. The result of the simulation is a 25% heating and 10% cooling energy consumption reduction compared to 1980 building specifications.

For commercial buildings, the HSCW climate region is taken as representative of the national average. Buildings in this climate region are assumed to have no insulation layer in the envelope before retrofit. Thus, the exterior wall, roof, and window U-values are 2.0 W/(m² K), 1.5 W/(m² K) and 6.4 W/(m² K) respectively. Building infiltration rates are 2 ACH. After retrofit, the building's exterior wall, roof, and window U-values are improved to 1.0 W/(m² K), 0.7 W/(m² K) and 3.0 W/(m² K), and the infiltration rate is reduced to 1 ACH. In the absence of district heating systems, boilers and electric chillers are the main heating and cooling equipment. Boiler efficiency is assumed to be 60% before retrofit and 80% after retrofit. Chiller COP value is assumed to improve from 4.0 to 4.8 after retrofit. Shanghai's climate conditions are used to

Table 6
Summary of building policy modeling parameters.

Policy	Sector	Variable	Scope	Modeling Parameter	2015	2020	2025	2030
Accelerated Building Codes	Res.	$\phi(y)^{\text{heating}}$	New Buildings	45% heating energy and 18% cooling energy reduction compared to current buildings code by 2030. Based on simulation.	15%	28%	37%	45%
		$\phi(y)^{\text{cooling}}$			6%	11%	15%	18%
	Com.	$\psi(y)$	New Buildings	All new buildings affected.	100%	100%	100%	100%
		$\phi(y)^{\text{heating}}$			32%	42%	46%	50%
District Heating Metering and Controls	Res.	$\phi(y)^{\text{cooling}}$	Existing Buildings	50% heating energy and 40% cooling energy reduction compared to current buildings code by 2030. Based on simulation.	22%	32%	32%	40%
		$\psi(y)$			100%	100%	100%	100%
	Res.	$\psi(y)^{\text{heating}}$	Existing Buildings	Setpoint reduced from 22–25 °C to 18 °C. Heating off when unoccupied. Based on simulation.	40%	40%	40%	40%
		$\psi(y)$			0%	16%	32%	50%
District Heating Efficiency Improvement	Res.	$\psi(y)^{\text{heating}}$	All Buildings	Single-tier improvement 80–91% efficiency. Two-tier improvement 60–81% efficiency. 5% pump system efficiency improvement. Retrofit of 80 million m ² per year starting 2015.	21%	21%	21%	21%
		$\psi(y)$			1%	6%	11%	16%
Energy Efficiency Labels	Res.	$\phi(y)^{\text{heating}}$	New Buildings	Definitions of 5 Star include 70% heating and 80% cooling improvement relative to 1980 buildings.	70%	70%	70%	70%
		$\phi(y)^{\text{cooling}}$			80%	80%	80%	80%
	Com.	$\psi(y)$	New Buildings	10% of new buildings in 2015 increasing to 25% in 2030.	10%	15%	20%	25%
		$\phi(y)^{\text{heating}}$			70%	70%	70%	70%
Retrofits	Res.	$\phi(y)^{\text{cooling}}$	Existing Buildings	Definitions of 5 Star include 70% heating and 80% cooling improvement relative to 1980 buildings.	80%	80%	80%	80%
		$\psi(y)$			10%	15%	20%	25%
	Res.	$\phi(y)^{\text{heating}}$	Existing Buildings	25% heating energy and 10% cooling energy reduction compared to 1980 codes. Based on simulation.	25%	25%	25%	25%
		$\phi(y)^{\text{cooling}}$			10%	10%	10%	10%
Retrofits	Com.	$\psi(y)$	All Buildings	Goal of 400 million m ² per year (FYP 13 goal).	1%	4%	6%	6%
		$\phi(y)^{\text{heating}}$			20%	20%	20%	20%
Retrofits	Com.	$\phi(y)^{\text{cooling}}$	All Buildings	20% heating energy and 10% cooling energy reduction compared to 1980 codes. Based on simulation.	10%	10%	10%	10%
		$\psi(y)$			0.4%	2%	4%	5%
		$\psi(y)$			Retrofit of all pre-2000 buildings by 2030.			

evaluate building retrofits in the HSCW climate region. The result of the simulation is a 20% heating and 10% cooling energy consumption reduction compared to 1980 building specifications. These parameters are summarized in Table 5.

The parameters used to define the policy case, including heating and cooling savings and penetration rates of affected buildings are summarized in Table 6.

4.6. Policies interactions

Since the effects of each policy on building energy demand are significant, it is important to carefully track the interactions and overlap between policies. In general, the impacts of each policy are lower when implemented in combination to another policy, since they act on an improved baseline. In order to quantify these interactions, we consider four policy combinations:

- *Each Policy Individually* – This combination does not take interactions between policies into account.
- *All Policies Together* – This combination takes into account all interactions between policies.
- *New Buildings Only* – Policies that affect new construction only – Building Codes and Energy Efficiency Labels.
- *Existing Buildings Only* – Policies that affect existing buildings – District Heating Reform and Commercial Building Retrofits.

Accounting for the interaction between policies is straightforward. For example, if the efficiency improvement to heating from accelerated building codes is

$$\phi(y)^{\text{heating}}_{\text{Codes}}$$

And the efficiency improvement to heating from District Heating Metering and Controls is

$$\phi(y)^{\text{heating}}_{\text{Metering}}$$

then the savings from both policies applied is given by

$$E_{\text{Policy}}^i(y) = E_{\text{BAU}}^i(y) \times \psi(y) \times (1 - \phi(y)^{\text{heating}}_{\text{Codes}}) \times (1 - \phi(y)^{\text{heating}}_{\text{Metering}})$$

In the Section 5, we show results according to the different policy considerations.

5. Conclusions, policy implications and recommendations

The above sections describe the determination of elements that are then brought together in order to calculate potential energy savings from each measure. The analysis begins with a reference case of energy demand in residential in commercial buildings according to a previous study by the authors (Zhou et al., 2012). Calculation of energy savings potential then proceeds via a spreadsheet analysis that combines the parameters in Table 6 with reference energy intensities and projections of stock and construction and the equations provided in Section 4. Energy savings calculations in each year of the forecast are made separately for each policy, for new and existing buildings, and by sector.

Results of these calculations are given in terms of primary energy are in Table 7. The potential CO₂ emissions impact of building policies were then evaluated by multiplying the final residential and commercial energy demand and savings by annual CO₂ emissions factors for electricity, gas, coal and district heat. These results are also summarized in Table 7.

Some high-level results emerge from the detailed modeling of individual policies:

- Building codes are the most impactful policy considered for both building types, accounting for over half of all savings (Fig. 1).
- The next more impactful policies are heating reform from metering and controls in residential buildings and labeling in commercial buildings. Each of these policies could save around 100 Mtce cumulatively over the period 2015–2030 (Table 7) and 12.3 and 12.6 Mtce annual savings in 2030 respectively (Fig. 1).
- Savings from all policies for residential buildings are similar to commercial buildings.

Table 7
Potential Energy Impacts of Building Policies – Primary Energy and Emissions.

Policy	Primary Energy (mtce)			CO ₂ Emissions (mt CO ₂)		
	2010	2030	Cumulative	2010	2030	Cumulative
Residential						
BAU Scenario						
Heating	120.0	185.1		566.5	552.9	
Cooling	26.3	35.6		56.2	59.3	
All HVAC	146.3	220.7		622.6	612.2	
Savings/Mitigation						
Building Codes	29.5	263.7		85.0	843.4	
Heating Reform – Controls	12.3	103.8		43.2	398.0	
Heating Reform – Plant & Transmission Efficiency	2.1	19.0		7.2	73.3	
Energy Efficiency Labels	10.9	93.4		29.7	280.0	
Retrofits	3.2	34.2		9.2	110.6	
Total	58.0	513.9		174.3	1705.4	
Individual						
All Policies	52.5	478.0		152.6	1531.1	
Existing Buildings	16.7	150.1		51.3	498.3	
New Buildings	38.8	346.1		110.6	1095.9	
Commercial						
BAU Scenario						
Heating	75.3	103.0		245.7	288.6	
Cooling	35.1	62.0		161.2	231.3	
All HVAC	110.4	165.0		406.9	519.9	
Savings/Mitigation						
Building Codes	35.3	306.1		108.9	945.6	
Heating Reform – Plant & Transmission Efficiency	1.0	7.8		2.5	19.8	
Energy Efficiency Labels	12.6	100.5		24.7	195.4	
Retrofits	1.3	10.9		3.9	33.0	
Total	50.3	425.4		140.0	1193.8	
Individual						
All Policies	46.9	405.3		143.6	1242.3	
Existing Buildings	2.3	18.6		3.9	33.0	
New Buildings	45.3	390.7		140.8	1216.1	
Total						
BAU Scenario						
Heating	195.2	288.0		812.1	841.4	
Cooling	61.5	97.6		217.4	290.6	
All HVAC	256.7	385.6		1029.5	1132.1	
Savings/Mitigation						
Building Codes	64.8	569.8		193.9	1789.0	
Heating Reform – Controls	12.3	103.8		43.2	398.0	
Heating Reform – Plant & Transmission Efficiency	3.0	26.7		9.7	93.2	
Energy Efficiency Labels	23.6	193.9		54.4	475.4	
Retrofits	4.5	45.1		13.1	143.7	
Total	108.2	939.3		314.3	2899.2	
Individual						
All Policies	99.4	883.3		296.2	2773.3	
Existing Buildings	19.0	168.7		55.3	531.3	
New Buildings	84.1	736.8		251.4	2311.9	

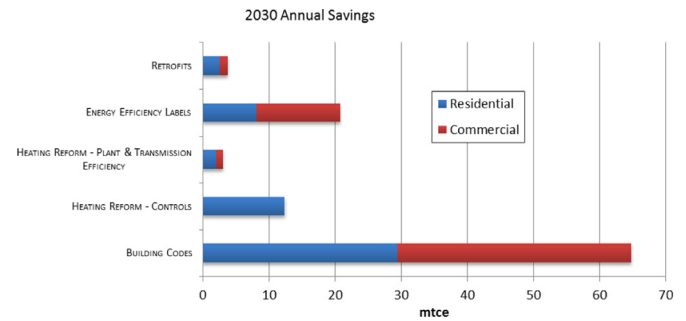


Fig. 1. 2030 Annual Energy Savings in Mtce.

- Most of the savings (83%) can be achieved by policies that affect new buildings.

5.1. Barriers and recommendations

A recent study by the authors considered recommendations for development and enforcement of building energy efficiency policies in China (Feng et al., 2015). Details are not repeated here, but some important recommendations are drawn from that study.

5.1.1. Building codes

In terms of primary energy, by far the largest savings is from the implementation of building codes. This is mainly because building codes impact all new buildings. Although the high construction rates China has seen in recent years is expected to peak and slow (already happened), due to continued urbanization, 32% of the residential building stock and 59% of the commercial building stock in 2030 will have been built in 2015 or later. Building codes have the potential to become gradually more stringent, leading to 45% reductions in space heating loads for buildings built in 2030. These two factors together lead to an overall 17% reduction in overall space heating and cooling demand relative to the baseline. The large savings yielded by building codes is driven by the assumption that these codes can be continually tightened in a process that reaches alignment with and keeps up with international best practices. This will require significant technical capacity in order to develop code specification, and adapt best practices to Chinese construction patterns and available technologies (Levine et al., 2012).

As (Zhou et al., 2012) demonstrated, enforcement of existing codes accounted for about the same amount of savings toward 11th FYP goals as did the establishment of those codes. In an environment of ever more stringent codes, enforcement will remain a top priority in order to lose much of the savings to “leakage” effects. A key element of improved building codes enforcement will be standardization of building simulations and methods to evaluate measure impacts. While compliance rates have shown a dramatic improvement in recent years due to tightening enforcement processes in China’s largest cities. However, compliance is generally much lower in smaller cities and rural areas. Therefore, we recommend that more attention be paid to extending compliance gains achieved in the largest cities to these sectors as well. Bridging this gap is largely an issue of building technical capacity to enable mayors of smaller cities and their enforcement staff to adequately enforce codes.

5.1.2. Energy labels

Second in overall potential are energy efficiency labels. Energy efficiency labels could save about 6% in heating and cooling relative to the baseline, or about a third of building codes. As with other nascent programs, China’s building energy efficiency

- Overlap between policies is moderate. Savings from all combined policies together is 6% less than the sum of individual policies.

labeling program suffers from relatively high transaction costs, due to a shortage of technical experts qualified to use the modeling software needed to evaluate building efficiency performance. In addition, incentives for builders are low. In order to overcome these barriers, we recommend a broad set of incentives, financial and otherwise from both government and private sector. In addition, governments have a role to play in leading by example, by requiring that public buildings exceed mandatory energy efficiency codes. These actions may serve to catalyze the market for labeled buildings and thereby also drive an increase in qualified experts to certify them.

5.1.3. District heating

Reductions of losses associated with district heating represent a similar potential to labels, with about a 4% reduction. A large majority of this savings arises from retrofitting heating controls in residential buildings to give the occupants the ability to regulate the thermostat. Despite the significant energy savings potential afforded by retrofitting heating controls in residential buildings, these measures have proven difficult to achieve, as acknowledged by a recent survey of district heating systems in China (Xu et al., 2014). Challenges include economic, organizational, behavioral, managerial and financial barriers. The authors recommend that fiscal incentives and penalties are an important factor to make large-scale retrofits more viable. In addition, they argue that a more fair competitive market for energy services through increased access and regulation as well as carbon trading schemes would incentivize energy efficiency investment by enterprises selling heating services.

5.1.4. Retrofits

Finally, retrofits represent only about a 1% savings because although the savings for each individual building can be quite large, high costs lead to an assumption that only a small fraction of the building stock are feasible to retrofit.

Our previous paper detailing the stated goals and progress in buildings efficiency during the 11th FYP (Zhou et al., 2012) concluded that Chinese policymakers and implementing agencies were on track to meet those goals by 2010. The energy impact of the stated goals was estimated at roughly 90 Mtce cumulative between 2005 and 2010. The majority of those savings (62 Mtce) were achieved by the successful tightening of enforcement of existing building codes. In the 2015–2030 period, we estimate a cumulative savings of 980 Mtce to be possible, or over 10 times as much in a period only three times as long. As in the previous case, the majority of the savings are from building codes. While this is an admittedly ambitious target, it does not require not-yet-commercialized technologies and relies on a policy tool that is already well-known and has had great impact in China. The study detailed here takes a medium to long-term perspective, focusing on potential savings starting in 2015 and extending through 2030. To some degree this perspective logically leads to an emphasis in efficiency programs that affect new buildings, since so much of the building stock in 2030 will have been built during the 2015–2030 period.

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