Increasing Residential Building Energy Efficiency in China

An Evaluation of Policy Instruments

Xiaoqi Xu

Laura Diaz Anadon

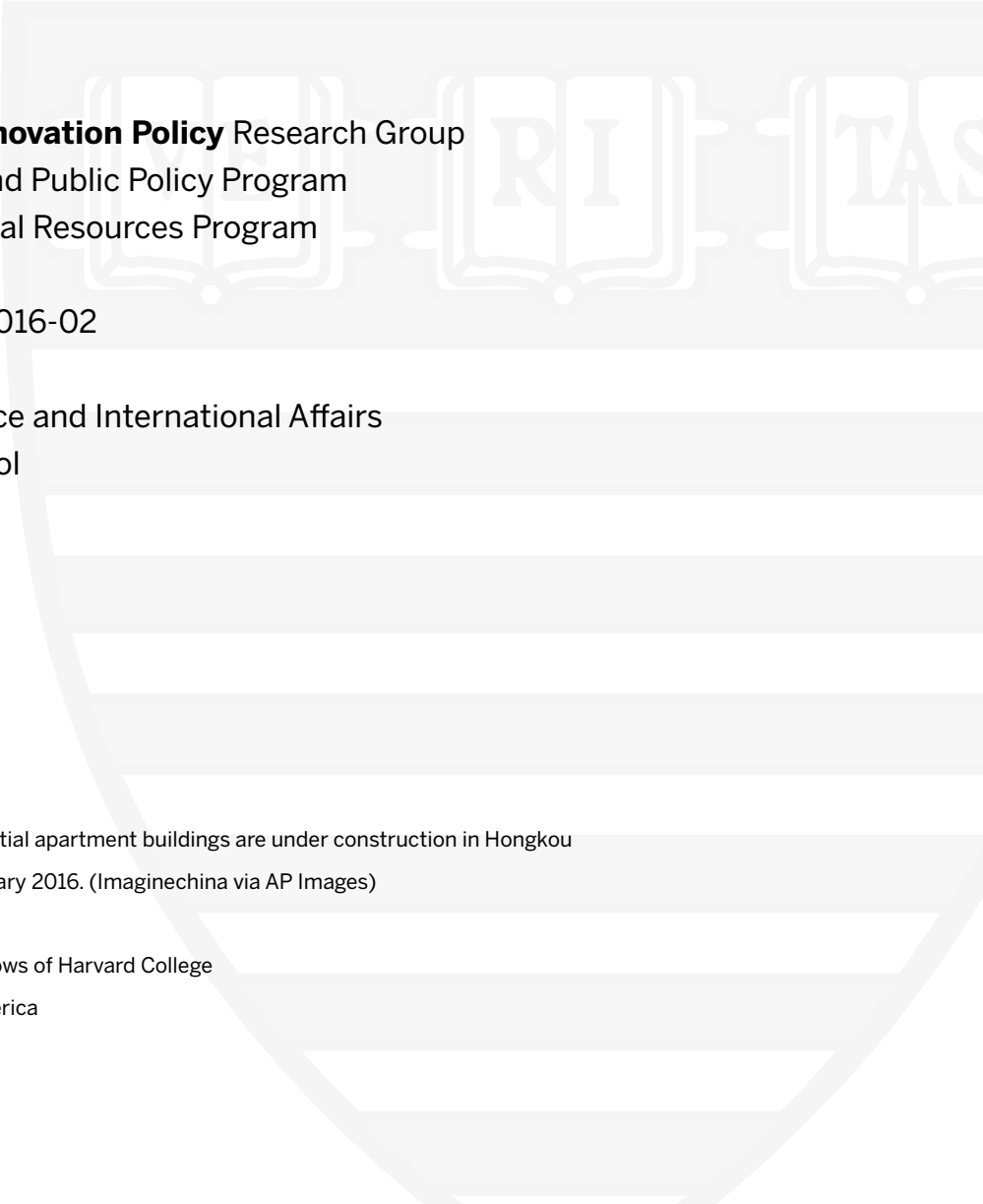Henry Lee

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New high-rise residential apartment buildings are under construction in Hongkou District, Shanghai, China, 29 February 2016. (Imaginechina via AP Images)

Abstract

Various policies targeting at building energy efficiency have been promulgated by the Chinese government in the past decade. However, few studies evaluate if China is on the right path to meet its energy goals through these policies by providing an assessment of their effect in reducing energy consumption in residential buildings or the feasibility of such policies to catalyze these reductions. This paper attempts to fill this gap by systematically quantifying (1) the energy savings catalyzed by existing policy instruments; (2) the additional energy savings that could be realized by strengthening these policies; and (3) the relative advantages of each policy. Results show that each instrument has different advantages, but collectively they are able to exert significant impact on China's future building energy outlook. A continuation of current policies is likely to reduce energy use in the urban residential sector by 9.7%-14.6% over the next ten years and an enhancement of them might reduce energy use by 15.8%-24.9%. The method applied in this paper for comparing building energy policies is adaptable for international use, and that the relative strengths of each policy instrument can serve as a rough approximation for countries with a similar building efficiency and institutional context.

Keywords: energy efficiency; quantitative evaluation; policy analysis; residential buildings

1. Introduction

Consuming approximately a fifth of final energy use, the building sector has recently been a focus of China's energy policy. In the eleventh five-year plan for national economic and social development program (2006-2010), the National People's Congress declared a target of reducing the energy intensity of its GDP by 20% and achieving 100 million tons of coal equivalent (tce) annual energy savings in buildings as compared to a business as usual estimate. In 2011, the Chinese Ministry of Housing and Urban-Rural Development announced that the country had surpassed this target by reaching savings of 110 Mtce [1]. But the specific contribution of each of the energy efficiency initiatives was not assessed in a comprehensive and systematic manner for the same time period, nor did the estimate take into account the impact of existing policies to improve building energy efficiency. During the current twelfth five-year plan (2010-2015), China further increased its energy savings goal to 114 Mtce above 2010 levels utilizing a portfolio of programs.

The urban residential building sector currently uses 32% of total energy consumption in the building sector, which makes up approximately 20% of total energy consumption in China. Consumption in this sector has increased rapidly due to the ongoing urbanization process that each year relocates 21 million people from rural areas to the cities, and it is expected to continue to grow in future years. To add to this expanding urban population, the more affluent Chinese population demands a more comfortable yet resource-intensive lifestyle [2]. Currently people in the top 10% income bracket consume energy at a level similar to that of Japan and approximately half of that of the U.S. on a per capita basis [3]. Rapid urbanization, and moderately greater energy intensity, will increase per capita energy consumption in China.

To curb the rate of increase, the Chinese government has accelerated the introduction and expansion of building energy policies in the eleventh and twelfth five year plans. Stiffer regulations, market-based incentives, fiscal instruments, and information measures were adopted to meet the new goals. Understanding the impact of various program initiatives in reducing energy use is important in order to insure that Chinese decision makers select the most appropriate and effective mix of policies. Yet studies have been lacking that compare this range of policies to gauge how they will help China reach its future energy target. While Chinese data on energy consumption has gaps and

is in the process of being refined, it is possible to make some rough estimates of whether past Chinese efficiency policies have been successful and whether this success is likely to continue in the future.

This paper analyzes major existing policies used by China to increase energy efficiency in urban residential buildings, and aims to fill the above knowledge gap by being the first to analyze and compare (1) the energy savings that have been realized by each existing policy; (2) the energy saving opportunities that may be realized in the future if each policy is strengthened; and (3) the relative performance of various policies, including measures of cost-effectiveness and co-benefits, as well as operational capacity and political support of implementation. The numerical results are intended to reflect the unique energy situation in China, therefore they are specific to the Chinese context only. But the relative strengths and weaknesses of each policy instrument along the various metrics used for evaluation can be taken as a rough indication of the tradeoffs associated with implementing various policies in other countries with similar building energy efficiency physical and institutional infrastructures. Furthermore, the established framework and methodology for comparing the possible impact of building energy policies can be adapted, by using different assumptions based on local experiences and factors, to be used internationally.

The rest of the paper is organized as follows. The context for energy efficiency in the building sector in China and a review of the scholarly literature in this area is introduced in Section 2. The policy analysis methods and the criteria used for comparison are described in Section 3. They are applied to policy instruments in Section 4. Section 5 presents the evaluation results in a standardized manner and illustrates the relative advantages of each policy option along with its energy savings potential. The trends that are shaping the impact of the various policies are also discussed in Section 5. Section 6 discusses future prospects and Section 7 concludes our paper and makes final recommendations.

2. Background

2.1 Status of buildings energy use in China

Efforts to reduce space conditioning are emphasized in the eleventh and twelfth five year plans, based on the household energy patterns depicted in Figure 1 for this period (year 2011) [3]. Space heating is the dominant energy use in northern China (the territory to the north of the geographical Qinling-Longhai Line), where the monthly average temperature is generally less than or equal to 5° C for more than 90 days in a year. Space heating intensity alone is 16.4kgce/m2 in the northern China, while the average total energy use intensity of the whole country is 17.5kgce/m2. On the other hand, space cooling is usually provided by air-conditioning units which have historically been included in China's appliance usage statistics. In recent years, demand for space heating for the southern part of China has increased due to higher request for living space comfort and is becoming a consideration for policy makers.

Figure 1. **China urban housing energy end-use breakdown**
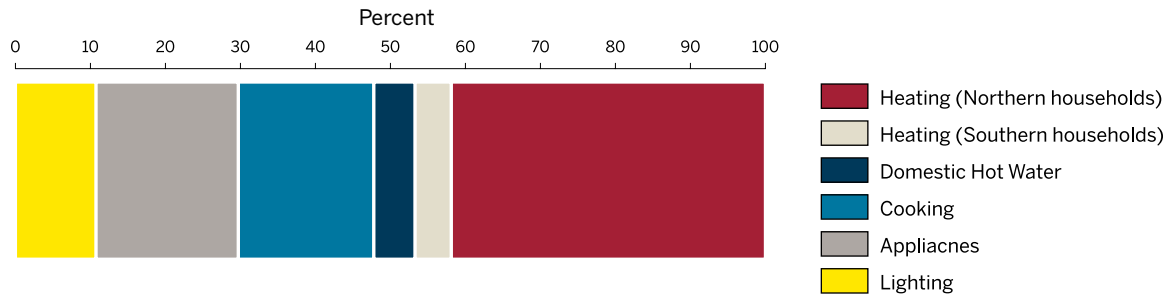
2.2 Barriers to building energy efficiency in residential buildings

Knowledge of the barriers that prevent increased energy-efficiency in residential buildings is important to design the most appropriate policies to improve energy-efficiency. Through an extensive literature review in the ScienceDirect scientific database searching for articles on energy efficiency barriers in the urban residential sector in China, we conclude that there are three main types of barriers. These are summarized in Table 1, and ranked in the sequence of decreasing citations to reflect the relative attention drawn to each. While there

are additional types of barriers that can prevent more efficient buildings, the list in Table 1 includes the only the most cited ones.

As the prioritized summary reflects, the major obstacles to achieve increased building energy efficiency in China are weak policy monitoring and enforcement, inefficient energy pricing, especially heat supply measurement and pricing, and the lack of information and experience among professionals. The sometimes misaligned relationship between central and local government that are in charge of building energy efficiency policy design and implementation in China underlies many of the barriers. The fact that the stringency level of building standards lags the international average and that the standards in the underdeveloped regions within China lags the national average requires concerted efforts from both the central and local governments. Literature suggests that the use of market mechanisms (such as financial channels leveraging the private sector) to encourage energy efficiency in the buildings sector is not widespread. Inefficiency rooted in conflicting interests and high initial investment costs need to be addressed in order to allow markets to work. Due to the lack of forceful code compliance and/or strong market demand for better performing buildings, developers and builders do not always have the right incentives to improve energy-efficiency. Overall, these barriers reduce the effectiveness of existing policies and slow the introduction of new initiatives aimed at strengthening the existing policies.

Table 1. **Summary of barriers to building energy efficiency in China**

Policy design and implementation	Market mechanisms	Stakeholder engagement
Weak monitoring and enforcement of government policies [4-8]	Inefficient energy pricing [4, 5, 9-14]	Lack of information and experience among professionals [4, 15-17]
Local government fails to create practical regulations to support energy efficiency improvements [8, 13, 14, 16]	Insufficient market financing channels [7, 12, 16, 18]	Lack of innovation [7, 11, 13]
Building codes stringency less than international average [7-9, 16]	Conflicting interests between stakeholders [4, 16, 17, 19]	R&D for improvements in envelope materials separated from energy efficiency goals [11, 13, 14]
Building energy efficiency promotion of underdeveloped regions lags that in more developed provinces [8, 9, 17]	Higher initial cost of energy efficient measures [4, 16, 20]	Unjustified perceived high risk of investment [17, 19]
Responsibilities among government agencies involved not specified [11, 21]	Small and scattered buildings require higher investment for certain saving [4, 10]	Immature building energy efficiency certification [12, 22]

3. **Methodology**

First, policies promulgated by the central government in the urban residential sector targeting at building energy efficiency are reviewed. They are classified into four categories, i.e., regulations, market-based incentives, fiscal instruments, and information measures. Second, we compute the efficiency, future impact, and cost-effectiveness through existing data or our own estimation for each policy instrument, and evaluate its co-benefits, operational capacity, and political feasibility for future. Then we compare the above policies across these six criteria to reveal their comparative strengths, and forecast energy outlook afforded by them and make final recommendations. This set of criteria are chosen here and commonly adopted in building energy policy analysis studies [23], because each of the criterion reflects an indispensable dimension and collectively, the criteria allow us to evaluate the performance of a policy along the most relevant dimensions.

The definitions of the set of criteria based on which the policies are compared are as follows:

- **Efficiency**: energy saving per unit area per year achieved by each policy instrument, measured in kgce/m2;

- **Future Impact**: potential energy saving expressed in percentage of energy use during 2015-2024 cumulatively if a policy is furthered;

- **Cost**: direct financial cost to the central government per unit energy saving, measured in ¥cent/kgce (this means that indirect effects through tax payments, for instance, are not within the scope of the study due to the added uncertainties surrounding them);

- **Co-benefit**: environmental and social benefit as positive externality beyond direct energy saving;

- **Operational capacity**: the likelihood that the intended saving will be realized, depending on available expertise, technology, and experience, among other operational issues;

- **Political support**: the extent of a policy's viability against stakeholders' influence on the policy making process due to the policy's cost and impact on them.

To determine future impacts during 2015-2024, we develop a second scenario in which we strengthen the seven policy instruments. Thus the paper assesses the energy saving opportunities in two different ways: (1) if the current policy instrument continues as is (using its latest specification), and (2) if the instrument is strengthened in the form of either enlarged scale or more stringent specifications (specific details on each policy are summarized in Table 2). The policy strengthening could be achieved through legal measures and/or more rewards from the government, and the references supporting the assumptions detailed in Table 2 are discussed in Section 4. We design the requirement in scenario 2 by using policies that are already under consideration by the government or based on our expectations of government intentions as a possible situation if the information does not exist. After updating the quantitative inputs in the model using the new specifications, we recalculate the energy savings by utilizing methods equivalent to those for scenario 1 as explained in the first paragraph in this section. We compare both to a business as usual case, in which none of these policies have been introduced since the eleventh five year plan -- that is we assume that the growth rate of energy use intensity stayed at pre-2006 levels [3]. The comparison of scenario 1 and 2 with the BAU will yield (1) the energy saving that is on the track to be achieved due to each of the current policies, and (2) the magnitude of additional saving opportunities if such policies are strengthened.

Table 2. **Policy analysis scenario overview**

Policy instruments	Scenario 1 (Current)	Scenario 2 (strengthened)
1. Building codes	Implementation of code at 50% saving level for new projects nationwide	Implementation of code at 75% saving level for new projects nationwide
2. Appliance standard and mandatory labelling	Latest update of standard to the current stringent levels	Update of standard to the world leading level
3. Green building labelling	Application in 15% of new projects	Application in 30% of new projects
4. Energy performance contracting	Growth at the rate expected by the government, i.e. double every five years	Expedited growth from expectation: market size double every three years
5. Retrofit reward	Renovation of existing buildings at the speed during the twelfth five year plan	Renovation speed doubles
6. Tax reduction	Integrated into code and retrofit reward	
7. Demand-side management	Lighting rebates supplied at the amount required in EEPPP; other DSM approaches save 0.3% electricity load	Lighting promotion size doubles, other DSM approaches save 0.6% electricity load
8. Awareness raising and information campaign	Education of 1% urban residents who save 10% of their initial use each year	Education scope triples

The overall policy evaluation process is conducted relying on engineering modeling, economic analysis, and other literature estimates. With the exception of appliance standards for which we adopt a bottom-up approach by collecting basic product registration records, we are able to obtain intermediate data from various sources to complete the quantification of specific policy instruments. The evaluated instruments are introduced in detail in the following section.

4. Building energy efficiency policies in China

This section synthesizes information regarding the history, future, scope, provision, related government actions, and resulting impact of each policy, which is the best practice to evaluate the appropriateness and effectiveness of various policies in all main policy analysis manuals (e.g., [24] and [25]). We conducted a thorough review of data from the scientific literature and government agencies to build our analysis with specific references provided in each following sub-section. Therefore, the data used for this analysis is the latest available from the various relevant sources of information. The results are summarized in Table 3. To avoid redundancy, each policy's co-benefits, operational capacity and political feasibility are presented in Table 3. For the special case of appliance standard and mandatory labelling for which a full bottom-up analysis is conducted, we explain our evaluation methods to thoroughly reveal the research depth.

4.1 Regulations

4.1.1 Building codes

In China, the Ministry of Construction, which was renamed Ministry of Housing and Urban-Rural Development (MOHURD) in 2008, has been supervising the formulation of building codes. Local authorities at provincial or municipal level implement these national building codes by adapting them to local conditions. Through an enforcement legal measure launched in 2006 by the central government and monitored at the local level, the compliance

rate of building codes during the construction process reached 95.4% nation-wide and remained in effect in subsequent code updates, which was a huge improvement from the previous situation where only 5.7% of building design implemented the code [8, 26]. In accordance with the objective of national codes, local governments are also encouraged to adopt local building codes that are more stringent than the national codes.

The first energy efficiency building code JGJ 26-1986 was released for the severe cold and cold climate zones in 1986. It stipulated a 30% space conditioning energy saving compared with the then building code, which is accepted as the pre-1986 benchmark against which all future codes' saving level are quoted. The code was updated in 1995 and 2010 twice with each update leading to an additional 30% saving. Since the effective enforcement initiative in 2006 which required all new buildings adopt the code with a 50% saving level, 6.9 billion square meters has been built under energy efficiency building codes nationwide among which 4.86B m^2 were built during the eleventh five year plan. For the future, the government is encouraging Beijing and other municipalities and developed cities to pilot the adoption of 75% saving level over the pre-1986 benchmarks [8], and is considering whether and when such level should be enforced nationwide. (This scenario is evaluated later).

4.1.2   Appliance standards and mandatory labelling

China requires appliances to meet a national standard and requires manufactures to put an energy use label on all appliances sold on the market. Launched by the National Development and Reform Commission (NDRC) and the General Administration of Quality Supervision, Inspection and Quarantine with the release of "Administration Regulation on Energy-Efficiency Labeling" in March 1, 2005, the mandatory appliance labelling system now covers 30 types of household appliances. It requires manufacturers to register each product at China National Institute of Standardization (CNIS) website before introducing it to the market and to attach a China Energy Label to each model revealing its energy efficiency grade as compared to the appliance standard. Appliance standards, on the other hand, set minimum allowable energy efficiency levels.

Refrigerators and air-conditioners were the first appliances to be regulated. They are two of the largest components of residential electricity consumption (consuming 17% and 24% of the electricity the residential sector in 2009).

Therefore we chose to use them in our assessment to infer the total impact of appliance labeling. The refrigerator standard has been updated twice in 2003 and 2008 from its 1999 version, with the latest GB12021.2-2008 implemented on May 1, 2009. Each update requires a more stringent "energy efficiency index" (EEI), the ratio between a product's tested energy consumption and the baseline consumption; based on this ratio an energy efficiency grade from 1 (most efficient) to 5 (least efficient allowed for sale) is assigned to the product. The air-conditioner standard was released in 1989 and updated in 2000, 2004, and 2010. Each update requires a more stringent "energy efficiency ratio", the ratio between output cooling power and input electric power, based on this ratio a grade from 1 to 5 (or 1 to 3 in the 2010 standard) is assigned. Because of the synergistic mechanism between the efficiency standard and mandatory labelling, we estimate their combined effect, specifically, the impact of the most recent standard update on the annual urban household energy use.

We conduct a counterfactual analysis for either type of product. Energy saving due to a standard update is calculated as the difference between the current energy use and the would-be energy use if the update had not happened. For either case, we compute (1) the energy efficiency under the latest standard as the average efficiency of products registered within one year after the new standard is implemented, and (2) the efficiency under the previous standard as the average within one year before the latest standard is implemented. The difference between the two is the efficiency increase due to the standard update. The efficiency data was obtained by taking a sample of 15% of all products registered at CNIS website (a population of approximately ten thousand refrigerators for the periods chosen). Figure 2 displays the distribution of such efficiency data by label grade, which reveals that the current air-conditioner standard seems to be more effective than the refrigerator standard because a large portion of the registered older air conditioner models are assigned an inefficient grade. Hence they face the possibility of not being able to meet the next standard when it is promulgated and not allowed to be sold. In contrast, a more stringent standard for refrigerators should induce higher savings because the current standard does not incentivize energy efficiency improvements, since a majority of the existing refrigerator models already meet the new efficiency target. For the enhanced scenario 2, we hypothetically assume the required refrigerator EEI is decreased by 1/3 to the EU Energy Label level and that other appliance standards are strengthened by the same percentage. These assumptions are only meant to represent a possible future situation that can help estimate what magnitudes of energy savings would be possible with

specific policies, without any assumptions about whether this is what will or should happen.

Figure 2. **Refrigerator (left) and air-conditioner (right) energy efficiency grade distribution**
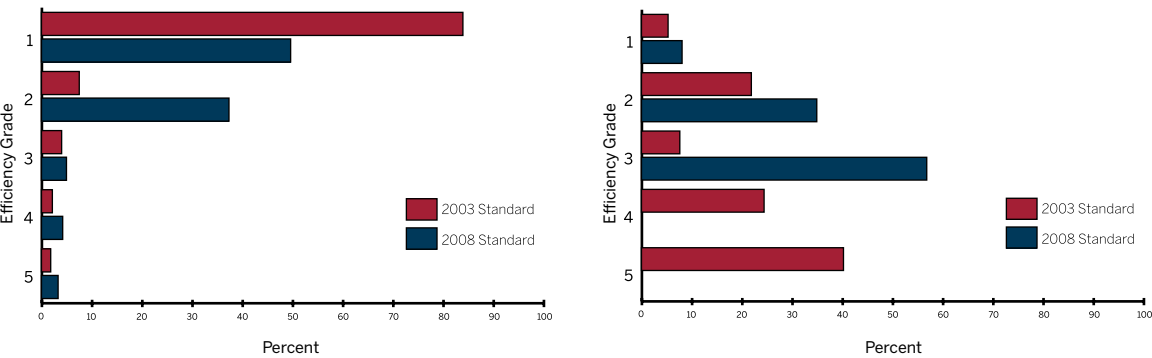
Based on the efficiency increase, the energy savings are calculated by factoring in Chinese demographical trends. We establish a model for the dynamic urban population growth, and multiply the population by the increasing appliance ownership percentage to compute the total units of refrigerators held by urban residents for each year. This combination of parameters is a reasonable estimate of future markets that has been adopted in similar studies [27]. The penetration of new models complying with 2009 standard is estimated by assuming that the existing stock is replaced at a constant rate throughout the average lifetime of a unit, i.e. 12 years, which is used to calculate the energy saving due to standard update. In aggregate, the accumulated energy saving is estimated to be 119.6TWh from 2015 to 2024. The counterfactual analysis is similarly conducted for air-conditioner except that the living area per person substitutes the appliance ownership in the calculation because air-conditioners are chosen on an area basis. On average for each product, CNIS receives a budget at ￥0.1M from the central government for standard development and implementation and a possible ￥0.9M from international cooperation program [27] , which is the latest data available that would allow us to calculate the cost of appliance standards. Final numerical results are given in Table 3 together with other policies.

4.2 **Market-based incentives**

4.2.1 Green building labelling

In 2006, the Ministry of Construction promulgated the "Evaluation Standard for Green Building", also known as the "three-star standard". The standard awards up to three stars to buildings based on their performance scores in six categories, namely, site choice, energy efficiency, water conservation, material utilization, indoor air quality, and operational management. The standard is voluntary for residential buildings, but mandatory for some government buildings. One hundred and twenty seven residential buildings have achieved green certificates from 2006 to 2011 [28]; on average these buildings saved 58% more energy than control buildings built upon 50% saving practices [8]. To accelerate compliance, the Chinese government provides rewards of ￥45/m2 for two-star buildings and ￥80/m2 for three-star ones to the builders, and aims to have 15% of the new buildings built according to green building standards [29].

4.2.2 Energy performance contracting

Under energy performance contracting, an energy service company (ESCO) provides energy consulting, financing, and retrofitting service to the client and, and receives a share of the future energy savings to pay back its initial investment and earn a profit. In 2010, the NDRC released a document entitled, "Opinions on Accelerating the Implementation of Energy Management Contracts for the Development of the Energy Services Industry". The NDRC announced a new program to provide grants of ￥240 from the central government and an additional ￥60~260 from the local government for each ton of coal equivalent saving produced by ESCOs. This initiative was geared both to save energy and to jump start the industry. International experience suggests an average 20-40% energy saving from ESCO projects compared to a business as usual scenario [23]. In 2009, ESCOs were able to save 13.5 Mtce with approximately 20% of this savings stemming from the residential and commercial buildings sector [30]. Observing its rapid emerging and growth in China, the government plans to double the market size and saving impact of ESCOs every five years [31].

4.3 **Fiscal instruments**

Fiscal instruments were adopted to stimulate greater building energy efficiency targets for existing building retrofit in northern China where district heating constitutes 63% of building energy consumption.

4.3.1 Retrofit reward

In 2007, the Ministry of Finance announced a reward for new measurement systems of heating supply and for adopting energy savings investments to retrofit building, such as installing thicker envelop insulation. The reward was determined to be ￥45~55/m2 varying with the climate zone and the amount of energy saved. During the same year, ￥0.9B was awarded, resulting in 182M m2 of retrofitted space and forming a 2Mtce energy saving capacity [8]. For the twelfth five year plan, the award is expected to stimulate an addition 80 million square meters of retrofitted building space annually.

4.3.2 Tax reduction

The Ministry of Finance and State Administration of Taxation declared a 50% added-value tax refund for the sale of energy efficient wall materials. Due to the tax reduction, 350B energy efficient bricks were sold during the eleventh five-year (2006-2010), which makes up 70% of the wall material in the market [8]. For the purpose of policy analysis, we integrate the impact of tax reduction on energy efficient materials into that of the building code and the retrofit reward program.

4.4 **Information measures**

4.4.1 Demand-side Management

Still in its early stage, demand-side management (DSM) in China mainly consists of energy efficient appliance rebates to stimulate energy conservation. Under the Energy Efficient Product Promotion Project (EEPPP), the

government subsidizes 50% of the price of efficient lighting for residential users. This subsidy, together with a companion subsidy from local governments, reduces the price of a compact fluorescent light bulb which was approximately ten times more expensive than a regular incandescent bulb with the same wattage more affordable to consumers. Since initiated in 2007, 655 million efficient lamps, including LED and CFL bulbs have been distributed, which resulted in 18.5TWh energy saving every year. The cost of these subsidies was ￥4.16 billion [32]. Starting in 2012, the NDRC requests the nationwide grid companies, i.e. State Grid Corporation of China and China Southern Power Grid Company and their affiliated provincial-level grid companies, to reduce both electricity sale and maximum electricity load by 0.3% each year [33]. Through electricity price differentiation and end use mode shift, among other DSM approaches, the grid firms reached the target and even exceeded it in some provinces in 2012 and 2013 [34, 35]. The development of smart grid for load monitoring and control and the establishment of an integrated DSM platform for the country are also under consideration for achieving further reduction. Overall, DSM could fall into different categories of policies, but is classified here for China as an information measure because of the collection and utilization of price and load information.

4.4.2 Awareness raising and information campaign

Public education and information campaigns can be utilized either as a stand-alone approach, or as a supplement to other policy instruments, such as in conjunction with appliance rebate promotion or other DSM methods. While the actual savings are measured sparingly since the impacts are indirect in most cases, these programs can be quite cost effective and efficient [36] because no physical changes are required on the buildings [23, 37]. As the only available records in China show, because of the critical role of end user behaviors plays in residential energy performance [38], behavioral changes could save 10% of electricity use [36] and 3-18% of a buildings heating load [39]. Despite their fairly unpredictable impact, the co-benefits of such information measures extend well beyond direct energy saving to reducing actual and potential externalities.

5. Results and discussion

Table 3 is a scorecard of the previously discussed policy instruments according to our six evaluation criteria. Because the data comes from different sources in different years with each specified in corresponding sub-sections in Section 4, we process them to derive standardized results according to the definition of each criteria outlined in Section 3.

To make the different criteria comparable, we normalize the score to a scale from 0 to 100 with the two ends being the worst-performing and best-performing policies in each criterion. For each of the three quantitative criteria, we calculate the score of each policy using the equations below:

1. efficiency score =
   $(efficiency_i — efficiency_{min}) / (efficiency_{max} — efficiency_{min}) \times 100$

2. future impact score =
   $(futImpact_i — futImpact_{min}) / (futImpact_{max} — futImpact_{min}) \times 100$

3. cost effectiveness score =
   $(cost_{max} — cost_i) / (cost_{max} — cost_{min}) \times 100$

where *i* stands for policy 1 to 7, and *min* and *max* represent the minimum and maximum values among the efficiency results of these policies. Higher efficiency, higher future impact (current scenario) and lower cost lead to higher scores. The normalized scores are shown in parentheses in the columns in Table 3. With respect to the qualitative criteria, i.e. co-benefits, operational capacity, and political support, we present factors in Table 3 that we consider impactful to the performance of each policy. We then exercise our own judgment based on the extent to which these factors have affected the outcome of policies in the past and synthesize them to a ranking of high, med/high, medium, med/low, and low, and assign a score of 100, 75, 50, 25, and 0 correspondingly. We choose these particular ratings to allow us to show the performance of all the policies for all indicators in the same figure, but we would like to emphasize that the linear relationship implied between the ratings (i.e., high, etc.) and the score (i.e., 100, etc.) for each policy in terms of operational feasibility is artificial—i.e., the difference between implementing a policy that is ranked high from a policy that is ranked med/high may be much smaller than the difference between implementing a policy with an operational capacity rated as med/low to a policy that is rated as low.

Table 3. **Analysis summary of building energy efficiency policies**

	Efficiency (kgce/m²)	Future impact	Cost-effect. (c/kgce)	Co-benefits	Operational capacity	Political support
Regulations						
building codes	5.4 (44)	5.6% (100)	0.012 (100)	medium: cost saving from heat supply O&M; pollution mitigation; generation capacity saving	high: compliance rate ~95%	medium: tension b/w construction firms, central gov, local gov
appliance standard & mandatory labelling	0.5 (0)	3.1% (53)	0.025 (100)	medium: pollution mitigation; generation capacity saving	high: compliance rate ~100%	medium: concentrated lobbying power of manufacturers
Market-based incentives						
green building labelling	11.8 (100)	1.2% (16)	7.7 (68)	high: higher standard of living and resident health; benefits on water and resource conservation; pollution mitigation; generation capacity saving	medium: have int'l lessons, but intended impact scale is challenging due to the shortage of professionals	med/high: reward helps, but doesn't cover entire cost increment at ¥400/m²; developers demand sale price premium
energy service company (ESCO) support	5.3 (42)	2.4% (38)	0.5 (98)	med/high: lower lifetime energy expense; pollution reduction; generation capacity saving	medium: promising market, but credential of professionals needs verification	high: strong market-driven momentum
Fiscal instruments						
retrofit reward	11.0 (93)	1.0% (11)	18.2 (25)	medium: cost saving from heat supply O&M; pollution mitigation; generation capacity saving	med/high: moderate uncertainty in realizing intended saving as the reward is partially result-dependent	med/high: reward facilitates retrofit, but doesn't cover entire cost at ¥300/m²; negotiation needed among gov, heating enterprises, and home owners
tax reduction	*integrated into code and retrofit reward*					
Information Measures						
demand-side management	1.1 (5)	0.9% (9)	24.2 (0)	med/high: lower peak load and higher electricity reliability; pollution reduction; generation capacity saving	medium: manufacturers defraud ¥90M rebates; recent load cut target met but other DSM expertise not proven	med/low: tension b/w utilities & residents for load management, e.g. reluctance of peak hour cutoff; rebates welcome
awareness raising, information campaign	1.75 (11)	0.4% (0)	0.5 (98)	high: future market transformation; conservation of related resources beyond energy saving	low: fairly unpredictable result, high operational uncertainty	high: noble mission, virtually no political opposition

Table 3 reports the results of the analysis for each policy instrument. It is worth noting that the impact of some policies depends on climate and occupancy (e.g., building codes and retrofit reward), while others are not sensitive to these factors. To ensure comparability between these policy instruments, all quantitative results are national average values weighted by the residential building area of different climate zones and occupancy levels. Taking appliance standards and mandatory labelling, for example, the latest update to the policy in 2014 will lead to energy saving of 0.5 kilogram coal equivalent per square meter in every year since the update for households adopting the appliances complying with the most recent standards. In aggregate, the energy savings from this new appliance standard will reduce energy use in the entire urban residential sector by 3.1% between 2015 and 2024 cumulatively if the appliance standard stays at the latest stringent level (see scenario 1). This appliance standard and mandatory labelling program will cost the central government ￥0.025 cent/ kilogram coal equivalent saving per year. Beyond these direct energy savings, the current appliance standard program will result in reductions in local air pollution and in generation capacity needs due to the reduced need for electricity. Per the pollution and generation coefficients in China, there will be a medium level of co-benefits over the time-horizon used for the evaluation. On the implementation feasibility side, the likelihood that the forecasted savings will be realized is estimated to be very high because in previous standard programs the compliance rate of such standard and labelling program has been near 100% due to the way the labelling is monitored and the high technology availability as required by the standard. However, the influence from consolidation of appliance manufacturers could interfere with the government's efforts to make the standards more stringent in the future, thus limiting this instrument's political viability to a medium level. Among all the policy instruments we evaluated the appliance standard policy performs best on cost-effectiveness and worst on efficiency; thus, its normalized scores on these two dimensions are 100 and 0, respectively. The future impact score of 53 indicates a medium level performance compared with the best and worst instruments in this criterion.

We translate the policy analysis results into a radar map as shown in Figure 3 to facilitate an easy visual comparison. Each criterion is represented by one dimension, and the distance of each policy along that dimension from the center point is proportional to its score in that criterion. The overall performance of each policy in all six criteria forms a polygon which is depicted in different styles and can thus be tracked for observation of relative strengths.

Clear trends regarding the relative strengths of each policy are evident in Figure 3. Below we briefly discuss the results by providing the explanations and causes that undergird such trends:

- Regulations such as building codes and appliance standards and mandatory labelling have superior advantages in terms of their operational capacity and cost-effectiveness, as verified by the experiences in many other countries [23]. Building codes exhibit the highest potential in terms of future savings in China. This assessment is supported by the fact that all new building projects are already compliant to building code specifications, and any changes in codes in the past have translated into rapid compliance. Due to the fact that appliances only make up 19% of each family's energy end use, the impact of increasing appliance standards is diluted substantially when evaluating the impact to total end use. Despite this, the appliance standards are predicted to exert a significant future impact through their application to multiple devices, as the government is planning to progressively promote the use of China Energy Labels for the entire household appliance stock.

- The market-driven incentives, namely, green building labels and energy performance contracting, rank high in political support and cost-effectiveness because of the expectations about market-powered momentum. This momentum translates in a decrease in government effort for the promotion of the policy, once the policy has reached critical levels of deployment. Green building labelling in particular is the best-performing policy on efficiency and co-benefits, because it is by design able to realize the biggest energy efficiency improvements through making building specific improvements beyond the level required by building codes, while providing substantial co-benefits, such as healthy indoor environment and conserved water usage. Nonetheless, its future impact on energy savings is small considering the limited scope of candidate residential building projects.

- Fiscal instruments, or retrofit rewards in the case of China, also have a high efficiency score because significant energy use intensity improvements are expected from renovating poorly insulated older buildings, based on previous successful experience in China. However, the substantial outlay of government funds results in a relatively low cost-effectiveness, which may also have an impact in its long term sustainability.

Furthermore, its future impact is constrained by the pace of renovation of the residential housing stock.

- Information measures such as demand-side management and awareness raising exhibit low efficiency and future impact scores when compared to other policies. In addition, given their limited application to date in China, it is very hard to predict the resulting behavioral change from widespread education and information campaigns and the result of the estimation is highly uncertain. In contrast, experience in other countries suggests that these policies are likely to be relatively cost-effective, with high political support and co-benefits. The reason for this is that there is a growing realization that they do not require capital expenditures to adapt the building stock and they can positively complement larger regulatory and financial initiatives and result in incremental benefits, in the form of greater energy savings and reduced emissions.

Figure 3. **Multi-dimensional comparison of policy instruments**
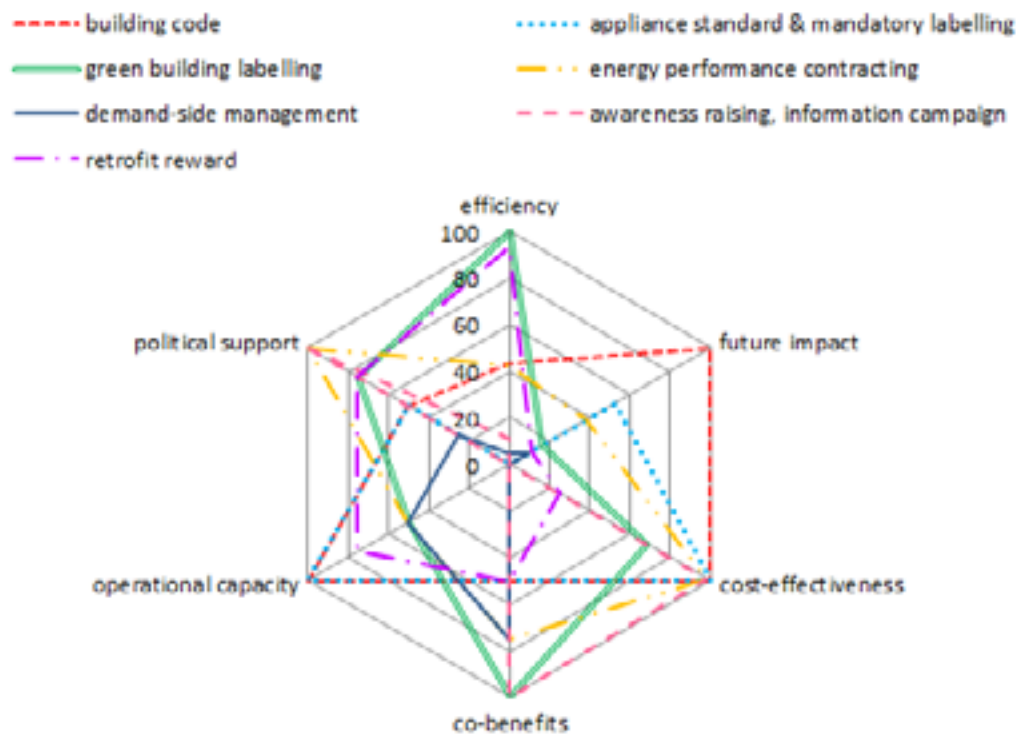
6. **Future prospects**

Figure 4 displays an energy outlook for the urban residential sector for the next ten years under two different policy scenarios, denoted s1 and s2, as defined in Section 3. Starting from the business as usual scenario (assuming no policy was introduced in the eleventh five-year plan as defined in Section 3), each wedge represents the energy savings opportunity over time from either a continuation of a current policy (s1) or an enhancement of it (s2); the percentage contribution of which is shown next to each. Under scenario 1, all measures taken together will reduce China's energy consumption in the building sector by 14.6% over the baseline during 2015-2024, the compound annual growth rate will be accordingly mitigated from 7.1% to 4.9%. These savings are illustrated by the difference between the top red business as usual curve and the middle yellow sc1 curve. This difference represents the total estimated impact until 2024 of policies targeting urban residential building energy efficiency since 2006. Collectively, we estimate pollution mitigation from such energy savings to be 1.86B tons of CO_2, 19.1M tons of SO_2, 16.4M tons of NO_x, and 7.8M tons of particulates, assuming existing emission factors in China associated with space heating and electricity.

Under scenario s2, each opportunity wedge represents the additional esti-mated savings due to the expansion of current policies as outlined in Table 2. Motivated by the determination of the Chinese government to further control the escalation of energy use, we ask the question what would be the impact, if the government decided to strengthen each of these policies. We estimate that such a scenario could lead to as much as a 24.9% decrease in energy consump-tion for the period from 2015 to 2024, or 71% higher than in scenario 1, and higher level of co-benefits in terms of reduction in pollution and power plant demand, etc. The 2014-2025 energy use growth rate is drastically reduced to 2.9% (bottom line in Figure 4) from the baseline 7.1% (top line in Figure 4). It is important to note that, to avoid double counting, we only compute the savings from green building certification that are not part of the changes in building codes. The implementation scopes of the other policies should not overlap with each other.

Figure 3. **Urban residential building energy use prospect (2015-2024)**
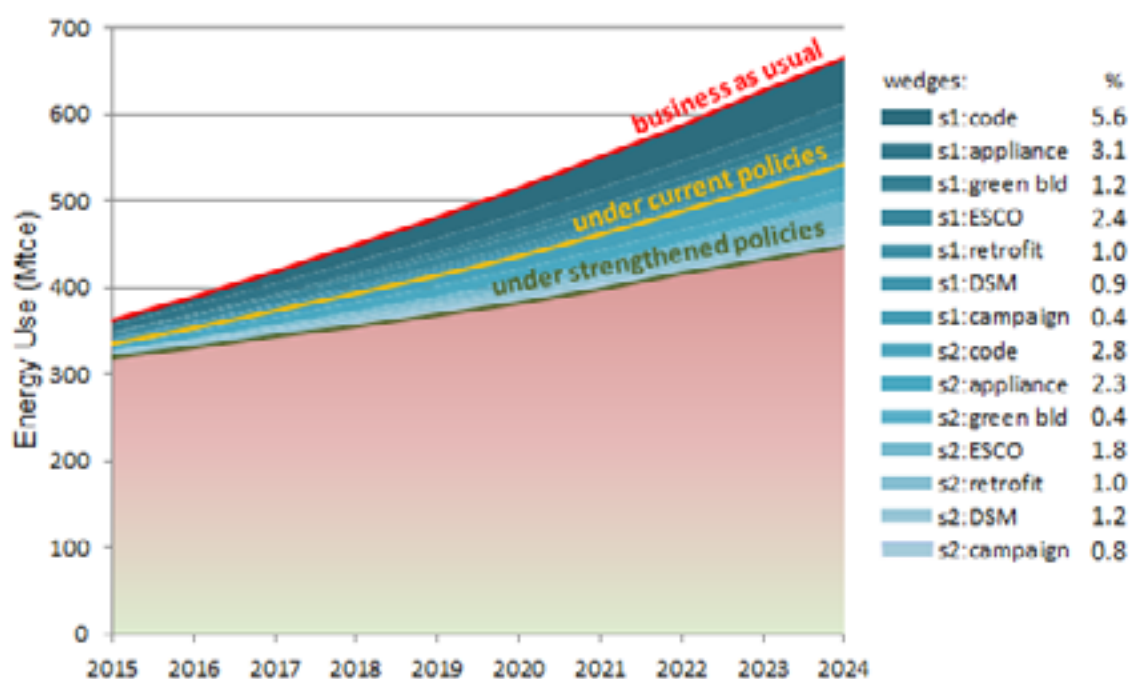
The energy outlook is forecasted by treating each policy independently. While the policies under evaluation are still in their early stages of implementation and it is, thus, possible that in the future there will be interactions and synergies between the policies that had not been previously identified or foreseen, we expect that this limitation will have limited impacts on the overall results and the comparison across policies. The energy-efficiency gap, also known as the rebound effect, which might also result in less than anticipated saving from intervention, is implicitly accounted for because the forecast is based on empirical data that already includes the rebound effect.

To obtain a more conservative estimate accounting for the operational capacity limitations identified in the analysis, we construct another scenario to account for the potential obstacles that may weaken each policy's impact by assuming no savings will be realized from policies with an operational capacity lower than med/high. In reality, it is unlikely that these policies will result in no positive impacts (for instance, there will be some savings from the construction of certified green buildings, even though there is uncertainty about their future level of deployment). Thus in a more conservative projection, the energy saving is estimated to be 9.7% in scenario 1 and 15.8% in scenario 2 from the business as usual case.

7. Conclusions and recommendations

In order to examine how the primary policies in urban residential buildings will help China to reach its future energy target, this paper conducts a systematic, quantitative evaluation of the realized and possible energy savings from these policies and provides an assessment of the feasibility of implementing these policies from an operational and political perspective.

A multi-dimensional comparison of all four types of policies according to a set of six criteria reveals the following relative strengths of each policy instrument: (1) regulations are superior in operational capacity, cost-effectiveness, and future impacts on energy savings; (2) market-driven incentives rank high in political support and cost-effectiveness, with leading efficiency and substantial co-benefits from green building labelling; (3) fiscal instruments, specifically retrofit rewards, are very effective in realizing short term efficiency gains, but may not be fiscally sustainable in the longer term; and (4) information measures such as demand-side management and awareness raising are limited in efficiency and future impact, but may perform better than other policies in terms of cost-effectiveness, co-benefits and political support.

The results of this study show that no single policy instrument exhibits superior performance relative to all six criteria; but collectively they can have a significant impact on China's future energy outlook. Specifically, a continuation of current combination of policies could save 9.7-14.6% energy consumption in the urban residential sector for the next ten years compared with a business as usual forecast based on the pre-2006 situation, and furthermore, a likely enhancement of the existing policies could reduce energy use by 15.8-24.9% energy use and be associated with larger co-benefits.

We freely admit that our results have significant limitations. First of all, up-to-date data on Chinese residential energy consumption is limited and not publicly accessible [8], thus the authors have often had to make assumptions based on the best available data, some of which is three to four years out of date. These assumptions will need further verification in future studies when and if more information is released. In particular, although our treatment of the qualitative indicators is common in multi-criteria decision analysis [24], a possible alternative that can be used in future research is to base these

scores on the results of carefully crafted and conducted expert elicitations to parameterize future uncertainty [40]. When more data becomes available, to incorporate the interaction between policies is also a future research area.

Generalization of the results to other countries should be undertaken considering the uniqueness of China, given that the assessment of the quantitative and qualitative indicators applies to each specific policy instrument in the Chinese context. Despite this, we make international comparisons wherever suits with relevant citations provided [23, 37], such as estimating efficiency of ESCO measures and information campaigns. Furthermore, our framework and methodology for comparing building energy policies is adaptable for practical use internationally, and that the relative tradeoffs for various policies (not the specific results) can serve as a rough approximation for countries with a similar building efficiency and institutional context. The implication of policy advantages and comparison framework create an area for future studies to investigate once the evaluation of Chinese policies has been performed with sufficient depth.

Overall, this paper allows policy makers to compare policy instruments against each other in a systematic, quantifiable manner, and consequently facilitate a transparent and more holistic choice of policies depending on the government's budget, expectancy of the impact, and operational and political considerations. The estimated future energy savings for both a continuation and an expansion of current set of policies will empower policy makers and other stakeholders to gauge the magnitude of energy conservation opportunities in China's urban residential sector. Overall the presented research is expected to inspire discussions and contribute to scholarship and practice of building's sustainability development in China and comparable countries.

Acknowledgements

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