From prescriptive to outcome-based – the evolution of building energy codes and standards in China

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Abstract

China consumes approximately 20 % of primary energy in its building sector. It is estimated that energy use in buildings will continue to increase in the future due to the fast urbanization process. Codes and standards are widely believed as one of the most effective ways to improve efficiency and reduce energy use and CO_2 emission in building sector. China started to develop its own prescriptive building energy codes and standards in the late 1980s. Using the 1980s buildings characteristics as the baseline, the national prescriptive building codes in China have achieved 50 % and 65 % energy efficiency improvement. However, buildings meet the prescriptive codes requirements may not yield actual operation energy performance. Many buildings have demonstrated good energy performance in design stage, but not performed well in their operation stage. In order to fill in the performance gap between prescriptive standard and actual performance, China has developed an outcome-based building energy standard trying to regulate actual building energy use in buildings.

This paper reviews international best practice on outcome-based building codes. Based on previous study of prescriptive building codes in China, this paper presents the gaps between China's prescriptive code performance and the proposed outcome-based code requirements. To fill the gaps, the paper discusses certain operation measures that influence building energy use in the operation stage, and possible solutions to help buildings complied with prescriptive code performance to meet the proposed outcome based code requirement as well. Finally, this paper discusses about current barriers and feasible policies to solve the issues of compliance and enforcement of the proposed outcome based code.

Introduction

Buildings use a significant amount of energy in China and it is expected that energy use will continue to increase in Chinese building sector because of fast urbanization and increasing levels of people's living quality (Zhou et.al 2015). To control the fast increase of energy consumption in the building sector, the Chinese government has established comprehensive policies in its 11th, and 12th Five Year Plan (FYP)[1]. Building energy codes and standards have been found to be one of the most effective policies to reduce energy in buildings (Levine et. al 2010, R). China started to develop its own building energy efficiency standards in the 1990s. China issued its own standards for commercial (public) building (GB50189) in 1993, with an initial emphasis to reduce energy consumption in hotels. The update in 2005 mandated that buildings were required to be designed and built with 50 % energy reduction compared to a 1980s baseline where buildings were built without energy standard requirements. The update version of the commercial building standard in 2015 mandates that buildings will be 65 % efficient than the 1980s' baseline[2], but actually achieve approximate 62 % energy savings (Feng et. al 2014, MOHURD 2015).

1. 11th FYP, 2006~2010; 12th FYP: 2011~2015.

2. The baseline is developed using buildings' characteristics in the 1980s. In the 1980s, there was no energy standard. Buildings in China exhibited high energy use, especially in heating.

However, new issues are observed that buildings, designed efficiently, sometimes exhibited high operational energy use intensity compared to their original design performance. This is mainly caused by the unregulated operating conditions and occupant behaviours which the prescriptive standards do no mandate. Given that the prescriptive standards alone are not enough to regulate actual energy use, this brings new challenges for Chinese government to control building energy consumption. During the 12th FYP, the Chinese Ministry of Housing and Urban Rural Development (MOHURD) has initiated a new commercial building energy consumption standard (also called as "energy quota standard" or "outcome based standard") to regulate actual energy use in buildings. The standard was finalized in 2016 and became effective in October 2016 (MOHURD 2016). The energy quota standard no longer prescribes individual building technologies and components performance, but provides a set of energy use intensity levels (EUIs) for different building types in different climate zones. This gives birth to a new stage of Chinese building energy standard history which have been predominantly prescriptive-based in the past 20 years, turning into an outcome targets based standard.

The purpose of this paper is to

- Review international best practice of developing outcome based energy codes and standards, and provide recommendations for the new Chinese outcome-based energy standard.
- Evaluate the technical performance of the Chinese outcome-based standard target settings by comparing with the prescriptive energy standard.

The evaluation is also to quantify the impact of unregulated operating measures and behaviours in order to achieve the outcome based targets. This will help building operators better comply with new outcome based standard.

In the background section, this paper firstly reviews the characteristics of prescriptive energy standards and its drawbacks. Then it introduces the definition of outcome based standards and their development in selected countries and regions around the world, especially focusing on the Chinese outcome-based energy standard requirements. In the modelling and results section, this paper compares energy performance targets between the prescriptive commercial building standard and the outcome-based energy standard. It uses simulation models to quantify energy performance of the Chinese prescriptive standard, and use the simulated targets to compare with the outcome based standards target settings. The study also provides a list of operation measures for office buildings and study their impact to achieve outcome based standard requirements. Finally, in the conclusion section, recommendations are provided on the technical aspects and policy aspects of the Chinese outcome base energy standard.

Outcome based code

Building energy codes have been developed by many countries and regions in the world. Many countries have established their regulation using prescriptive measures to mandate building components and technologies performance (Rosenberg et. al. 2015). Prescriptive codes and standards mandate building envelopes, heating ventilation and air-conditioning (HVAC), lighting, plug load and other systems technical performance to reach minimum level of performance often based on buildings located climate zones. In some countries, the prescriptive energy standards also allow one building system's performance, if fails to achieve certain mandatory requirements, to trade-off with another system's performance. Such regulation is very useful to manage the approval of new constructions and associate measures performance with building permits. Moreover, to evaluate whole building level performance, a performance base compliance path is also established in some countries' buildings codes. Such path pays more attention to a whole building level performance rather than individual measures. And it allows buildings modelled energy performance to compare with a hypothetical baseline buildings performance, and quantify energy savings and code compliance. The whole building performance compliance path is well adopted by many countries' code development, and is especially widely used in evaluating energy savings potential of green buildings.

However, the prescriptive and performance based standards also exhibit issues in following circumstance:

- Prescriptive and performance-based standards are often applied to permit new construction, but not often used in existing building.
- Prescriptive and performance based standards tend to focus more on energy conservation measures and model energy performance, than on the actual energy use.
- There are "unregulated measures"[3] which are difficult to regulate through the prescriptive and performance based standards.

In order to address the issues raised by using prescriptive standards, some countries and regions have developed outcome based energy codes and standards. Outcome based codes and standards regulate one building's performance in its operation stage. It often requires buildings to continuously operate for at least one year after its occupation, and use the measured performance data obtained in that period to compare with targets set by the outcome based standard in order to achieve compliance.

The city of Seattle is one of the leading cities around the world developing the outcome based energy code (Pinch 2015, Seattle 2015). Starting in 2008, the city of Seattle has begun the outcome based energy code focused on compliance through verified energy performance. The code development is also associated with selected pilot buildings and collect their actual operation energy performance. A building, in order to comply with the outcome based code, needs to be continuously operated for at least 12 months and to have 75 % or more its space occupied during that operation period. Outcome based targets setting is borrowed from the city level benchmarking and disclosure data. However, since very few buildings included in the city's benchmarking database are built using the city's post 2009 code, the actual EUI settings are selected with much lower EUI compared to the cities' benchmarking results. Sub-metering system is desired to acquire detailed building energy use infor-

3. Unregulated measures mean conditions that are not mandated or controlled in the prescriptive standard. Such measures are often related to building operations, comfort, and occupant behaviours. Later part of this has some detailed analysis of unregulated measures impact on building performance.

Table 1. The outcome based targets of energy code for the city of Seattle.

Building Type	EUI target – kWh/m² (or kBtu/ft²)
B- occupancy office	126 (or 40)
B-occupancy medical office	157.5 (or 50)
R-2 occupancy multifamily	110 (or 35)
S-1 and S-2 occupancy warehouse	78.7 (or 25)
E-occupancy school	141.7 (or 45)
M-occupancy retail	189 (or 60)
I-2 occupancy hospital	472.5 (or 150)
Parking garages	31.5 (or 10) for enclosed garages; 18.9 (or 6) for open garages

mation. It also requires building to conduct energy modelling first to demonstration saving opportunities before collecting measured energy performance data. Sensitivity analysis is required to quantify the impacts of certain operation measures on building energy performance. To promote the adoption of the outcome based and demonstrate energy savings beyond code requirement, incentive programs are created.

Sweden is one of early adoption countries on outcome based code. Sweden developed its own out-come based code (BBR) since 2006 for residential and non-residential buildings for the country's different climate zones (Wahlström 2010, Boverket 2012, Boverket 2016). As heating consumes a majority of buildings' total energy use in Sweden, the outcome based code specifies building energy performance in terms of electrically heated buildings and non-electrically heated building. The code uses "specific energy use" definition, which is an EUI requirements including heating, ventilation and hot water energy use, but not including energy use from plug load, lighting and other operational use. The code requires buildings to verify its performance within 24 months its completion with continuous monitoring data for 12 months. The code differentiate target EUI settings into small houses, small houses with conditioned floor space less than 50 m^2, apartment buildings, apartment building blocks with conditioned space larger than 50 m^2, ordinary non-residential buildings and small non-residential buildings with conditioned floor space less than 50 m^2. Table 2 below provides non-residential building outcome based targets in Swedish outcome based code. Besides setting up outcome based targets, the Swedish code allows buildings to calculate their relative performance based on outdoor air different ventilation rates. Similar with Seattle's outcome based code, the Swedish code also use site energy for building energy use targets. The code provides a set of policies for buildings' compliance, in terms of commissioning, permitting, fines to fail to compliance and so on.

China started to develop its outcome based energy standard in 2013, and the standard is approved in by MOHURD in late 2016 and become effective. The standard, which is officially called as Civil Building Energy Consumption Standard, defines building energy performance targets based on existing buildings' energy performance data and subsequently local level energy benchmarking (also called "energy quota" in China). It setup EUI targets into two values for each building type, category and climate zone: 1) required value, and 2) recommended value. The required value is an annual measured EUI target mandatory to achieve for one building. The recommended value is an annual measured EUI target voluntary to achieve but the government promotes that direction or have buildings to demonstrate that level of performance. The required value is obtained based on a 50 % benchmarked performance of existing building stock (the target EUI is set to the value lower than 50 % of the surveyed building stock), and the recommended value is obtained based on a 75 % benchmarked performance (the target EUI is set to be lower than 75 % of surveyed buildings).

The Chinese standard develops very comprehensive requirements and distinctions. First of all, the Chinese standard separates heating use in the Northern China (which includes Cold and Severe Cold climate zones, based on Chinese climate zone shown in Figure 1) from non-heating energy use[4]. Since heating energy use in the Northern China takes approximately a quarter of the countries total energy comsumption, regulating Northern China heating is a very important topic. The EUI for northern China heating energy is mandated with the unit of kilogram of coal equivalent per square meter, or kgce/m2. However, for buildings in Transition (or called as Hot Summer Cold Winter), South (or Hot Summer Warm Winter) and Temperate climate zone, heating energy is incorporated into buildings total energy use and expressed in final energy style. The heating EUI targets in the northern part of China are separated into two categories, based on the fuel type of heating system: 1) heating using coal, and 2) heating using natural gas. Then, the EUI targets are further specified based on three different scales of heating system: 1) city level district heating, 2) community or small campus based heating, 3) individual building scale heating, and eventually given for 16 provinces of the Cold and Severe Cold climate zones. The standard also provides targets for building heating demand intensity in required values and recommended values for provinces in the Cold and Severe Cold climate zones. Based on heating EUI targets and heating demand targets, the standard further provides target for heating system pipeline loss and district heating pumps energy use. The advantage of this distinction is that it gives very detailed heating energy requirements based on climate and system types, and its regulate not only building itself, but also district heating system efficiency, which Seattle and Swedish codes do not regulate. However, this also impose complexity to imple-

4. The rationale for this distinction is that heating in the Cold and Severe Cold climate zones is primarily supplied by different types of district and campus scale system. And there is very few district heating system in Transition and Southern part of China.

ment the standard as the energy use boundary changes from buildings to district heating system.

For commercial buildings, the Chinese standard developed two categories of energy use targets. Category A defines buildings with operable windows, which can conduct natural ventilation when outdoor conditions are satisfied, and usually equipped with split HVAC system. Category B defines buildings without operable windows and are mainly served with mechanical ventilation and equipped with centralized HVAC system. Furthermore, the Chinese outcome based energy standard divides the EUI targets based on different building types (Table 3). The standard also specifies required values and recommended values in different climate zones. These targets exclude parking garages in commercial buildings. Parking garage EUI targets are provided separately for office buildings, hotels, and retail buildings regardless of their climate zones and categories. Data center, cooking and other special energy use is not counted into EUI targets. Local generated renewable energy is also not counted into these EUI targets.

Another feature of the Chinese outcome based energy standard is that it allows buildings to normalize their EUI performance, and use normalized EUI to compare with EUI targets. For office buildings, the EUI performance can be normalized based on occupancy intensity (standard value: 10 m^2/person), and operating hours (standard value: 2,500 hr); hotels, normalized based on guest room occupancy rate (standard value: 50 %), and guest room vs. total floor space ratio (standard value: 70 %); retail buildings, normalized based on operating hours (standard value: 5,500 hr for supermarkets, 4,570 hr for shopping centers/malls, and 5,000 hr for other shops and restaurants). A specific performance year's outdoor air temperature is used to normalize heating energy use for buildings in the Northern China.

For residential buildings, i.e. high-rise apartment buildings, the energy targets are given per household instead of per square meter. The targets exclude heating in the Northern China heating are provided in Table 4 for a standard energy use of a household with the 3 people. The Chinese standard allows households to normalize their energy performance if there are more than 3 occupants in one household.

Modelling

The outcome based building codes in the city of Seattle and Sweden define performance EUI target together with prescriptive measures requirements. However, the Chinese outcome based energy standard exists in parallel with traditional residential and commercial building prescriptive standards. As the Chinese outcome based energy standard will be applied to both new and existing buildings, it is necessary to discuss the relationship between the performance of Chinese prescriptive energy standard and the outcome based standard.

Table 2. Swedish outcome based code performance target for non-residential buildings.

Climate Zone	EUI target for non-electric heating – kWh/m^2	EUI target for non-electric heating – kWh/m^2
Climate zone 1	105	85
Climate zone 2	90	65
Climate zone 3	70	50
Climate zone 4	65	45

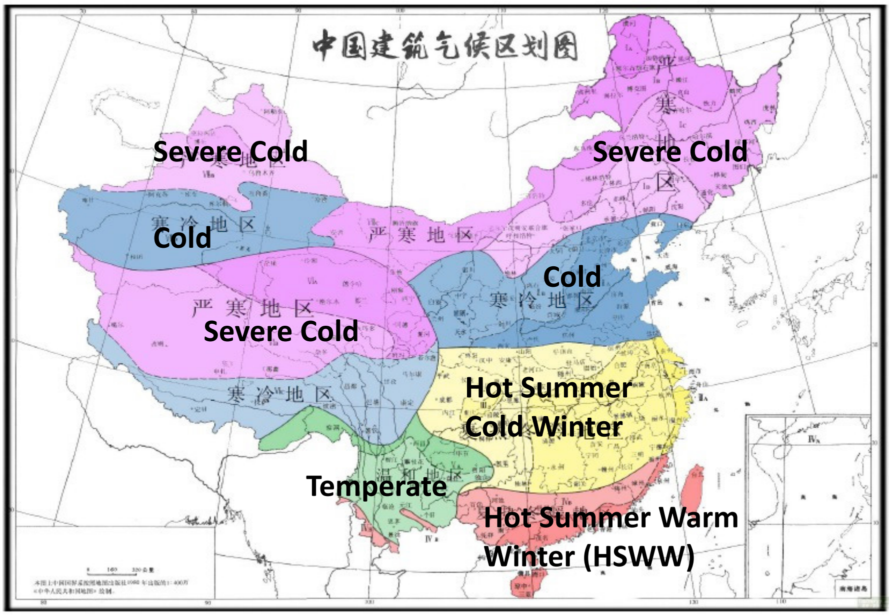

Figure 1. Chinese climate zone map.

Table 3. EUI targets of Chinese outcome based building standard for commercial buildings in Hot Summer Cold Winter climate zone.

Building	Category	Type and scale	EUI in Hot Summer Cold Winter Climate zone (Shanghai) – kWh/m²	
			Required value	Recommended Value
Office	Cat. A	Government office	70	50
		Commercial office	85	70
	Cat. B	Government office	90	65
		Commercial office	110	80
Hotel	Cat. A	3-star or lower	110	90
		4-star	135	115
		5-star	160	135
	Cat. B	3-star or lower	160	120
		4-star	200	150
		5-star	240	180
Retail	Cat. A	General store	130	110
		Shopping center	130	110
		General supermarket	150	120
		Restaurant	90	70
		General shop	90	70
	Cat. B	Large store	200	245
		Large shopping mall	260	300
		Large supermarket	225	290

Table 4. Chinese building outcome based standard energy targets for residential building.

Climate Zone	Required Electricity Use target – kWh/household	Required Natural Gas Use Target – m³/household
Severe Cold	2,200	150
Cold	2,700	140
Hot Summer Cold Winter	3,100	240
Hot Summer Warm Winter	2,800	160
Temperate	2,200	150

In order to understand the performance relationships between Chinese prescriptive energy standard and the outcome based energy standard, we modelled a few energy conservation measures, such as occupant based lighting control, natural ventilation, economizer control, supply air temperature reset, etc. These measures are not regulated in current Chinese commercial building prescriptive standard. The energy conservation measures are simulated individually first and then all the energy conservation measures are simulated all together to illustrate the total energy savings potential. Then the simulation results are compared with the baseline models to illustrate the energy savings potential.

ENERGY SIMULATION MODELS

The large and small office building models are developed as an example to quantify the performance of Chinese prescriptive commercial building standard and the building outcome based energy standard. Previous studies (Feng et. al 2014) have investigated the current Chinese commercial building energy efficiency prescriptive standard by developing large office reference buildings in China. We continue to use that model from previous studies, without repeating modelling details here, and adopt the energy performance results obtained through simulating the large office building model. We also developed a small office building model for this analysis. Different from the large office building model developed in previous study, the small office building is equipped with distributed HVAC system. The model follow the Chinese commercial building standards requirements on prescriptive measures.

Both the small and large commercial building models are simulated for three representative cities, Beijing (Cold), Shanghai (Hot Summer Cold Winter) and Guangzhou (Hot Summer Warm Winter) in EnergyPlus[5]. We use the current the

5. EnergyPlus is a U.S. Department of Energy developed whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting, and plug and process loads—and water use in buildings.

2015 Chinese commercial building energy standard's models for baseline performance analysis in this paper (MOHURD 2015). Energy conservation measures are modelled upon the 2015 baseline models. The next section introduces the details of selected energy conservation measures. The general information about the construction and energy systems are as follow. The small office building is a one-story building with total floor area of 8,176,56 m^2. The large office building is 18-story building with the total floor area as 26,142,48 m^2. Table 5[6] summarizes the key information of the simulated buildings. All these simulations use Chinese Standard Weather Data (CSWD) weather files for the three representative cities in this study.

ENERGY CONSERVATION MEASURES

Considering the availability and applicability, we selected six energy conservation measures for small building, which are heating and cooling setpoint adjusting, occupant based lighting and equipment operation, natural ventilation, as well as window shading control. Besides the measures applied in the small building, we also modelled more energy conservation measures for the large buildings, which are outdoor air economizer control and supply air temperature setpoint reset. The details about the implementation of each energy conservation measure are presented as follows.

Occupant based lighting and equipment control is simulated by energy saving discount upon the baseline models, which complies with the current building operation codes. The energy saving discount rate is 20 %, provided by a previous study (Sun et. al. 2016). As a result, the lighting and equipment turning on ratio is reduced by 20 % in the new simulation models.

Another energy saving achieved by temperature adjustment is modeled by increasing the cooling temperature setpoint to 28 °C during and by decreasing the heating temperature setpoint to 16 °C during the occupied hours from 8 am to 6 pm. The temperature setpoints at the unoccupied hours remain the same.

Natural ventilation is modeled by simply modifying the infiltration rate when the outside weather condition is appropriate for natural ventilation during the shoulder seasons. The infiltration rate is determined to achieve the same air exchange rate (ACH) as the natural ventilation provided in a previous study (Tong 2016).

Window shading is also an effective energy conservation measure when the outsider solar radiation is high. We implemented a roll shade for each window of the building in the model. It has transmittance as 0.075, solar reflectance as 0.7, conductivity as 0.1 (W/m-k), visible transmittance as 0.032, visible reflectance as 0.5. A shading controller determines the shading on/off control. In the cooling season, the window shading system will be turned on to reduce the heat gains, when the outside solar radiation is high.

All of these three large commercial buildings in this study use the variable air volume (VAV) systems. Therefore, besides the measures discussed above, we also investigate the energy saving potentials of outdoor air economizer. The outdoor air economizer uses fixed dry bulb temperature control type. The maximum and minimum limit dry bulb temperature is 23 °C and 13.5 °C.

6. AHU: Air Handling Unit; VAV, Variable Air Volume.

This study also investigates the energy saving potentials of the outdoor air temperature based supply air temperature setpoint reset for the large buildings. The temperature setpoint reset logic is when outdoor air temperature is lower than 0 °C, the supply air temperature setpoint is 16.7 °C, and when outdoor air temperature is higher than 32 °C, the supply air temperature setpoint is 12.8 °C.

Results

After including all the energy conservation measures, the energy savings potential is evaluated and compared in Figure 2 and Figure 3 for small and large buildings with all the energy conservation measures applied. We use final energy intensity method to show building energy performance results. The final energy intensity values are also equivalent to primary energy intensity values by using the Chinese coal equivalent conversion factors. We demonstrate the final energy results just for better comparison with the targets set up the Chinese outcome based standards in final energy format (in unit kWh/m^2). These two figures show that the energy conservation measures reduce the energy consumption significantly. Table 6 summarizes the energy savings potential breakdown and total energy savings values. The total energy density of small buildings in all these three cities are all around (or below) 55 kWh/m^2, and that for the large buildings are around (or below) 90 kWh/m^2 with heating energy consumption included.

The savings potential for each energy conservation measure is shown in Table 7. Plug load equipment and lighting control are the two measures with the highest energy saving potentials. The heating setpoint adjusting also achieves over 3 % energy savings in all of these three locations. Cooling setpoint adjusting achieves over 10 % and 14 % for large buildings in Shanghai and Guangzhou, where cooling load is higher. Natural ventilation is able to reduce energy consumption by over 10 % for large office buildings in all of these three locations, while the savings for small office buildings in Beijing and Guangzhou are very small.

We extract the total savings potential from the small office building (equivalent to Cat. A defined in the outcome based energy standard), and the large office building (equivalent to Cat. B defined in the outcome based energy standard) from Table 3 and compare them with the target settings of the outcome based energy standard. The comparison is shown in Table 8. From the results above, natural ventilation, lighting and plug load management are very effective in all buildings types to achieve outcome based energy use targets.

For small office buildings with split HVAC system and natural ventilation is allowable, the operating conditions sensitivity run's results obtained above show that the required targets set by the outcome based energy standard is achievable by comparing with "best practice" result with target values set by the outcome based energy standard. For Cat. A buildings, the recommended targets are slightly difficult to achieve especially for government office buildings, but still somehow achievable if more aggressive saving strategies is applied. For large office buildings with centralized HVAC system and natural ventilation is difficult, the result indicate that the required targets set by the outcome based energy standard is achievable as the "best practice" value of 81.82 kWh/m^2 is very close to the government office building target 90 kWh/

Table 5. Building construction and HVAC system of Baseline models.

	Beijing		Shanghai		Guangzhou	
	Small	Large	Small	Large	Small	Large
Cooling system	Package AC	AHU VAV + Chiller + Boiler	DX coil	AHU VAV + Chiller + Boiler	DX coil	AHU VAV + Chiller + Boiler
Heating system	Radiator + Boiler		Electric Coil		Electrical Coil	
Equipment density (W/m²)	15	15	15	15	15	15
Lighting density (W/m²)	9	11	9	11	9	11
Window U value (W/m²-K)	2.7	2.7	3	3	3.5	3.5
Window SHGC	0.59	0.59	0.42	0.42	0.336	0.336

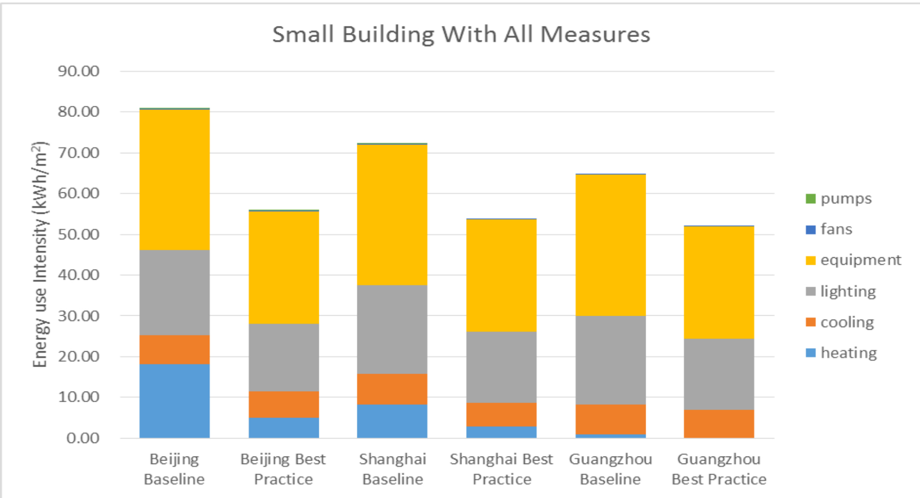

Figure 2. Small office building energy savings potential.

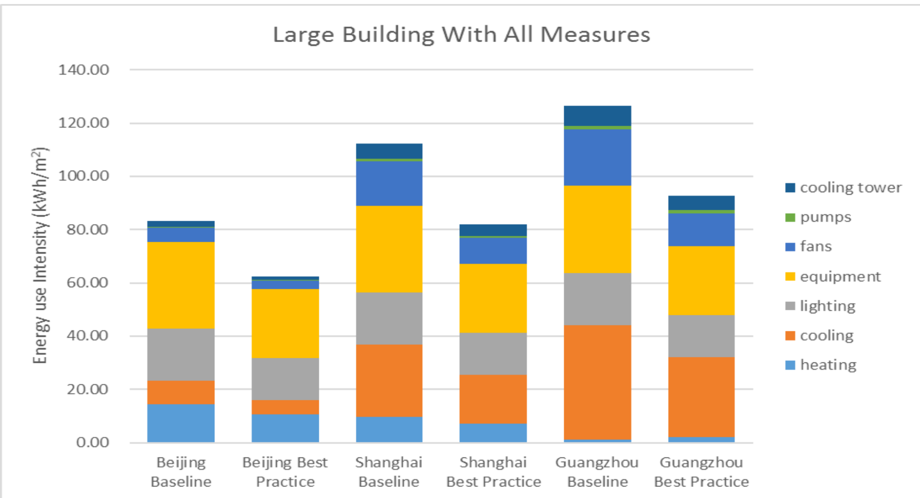

Figure 3. Large office building energy savings potential.

m^2. However, recommended values set by the outcome based energy standard for large size government office building is relative low, and it is difficult to achieve the target EUI by only adjusting energy conversation measures used in this study. This means that Chinese government office buildings with recommended EUI values may operate beyond the conditions set by the "best practice" in the study or may have employ some other energy conservation measures not investigated here. Given all the design prescriptive measures are fixed here, it is necessary for the Chinese outcome based energy standard to show what conditions buildings with centralized HVAC system are operated for government office building in order to achieve such low EUI targets, and the implication to those buildings comfort criteria and productivity levels when operating under such low EUI values.

Table 6. Energy consumption density breakdown (kWh/m²).

		Beijing		Shanghai		Guangzhou	
		Baseline	**Best practice**	**Baseline**	**Best practice**	**Baseline**	**Best practice**
Small Office Building	heating	18.05	5.09	8.28	2.78	0.94	0.15
	cooling	7.31	6.43	7.50	5.94	7.36	6.78
	lighting	20.71	16.57	21.74	17.39	21.74	17.39
	equipment	34.51	27.61	34.51	27.61	34.51	27.61
	fans	0.16	0.12	0.14	0.10	0.12	0.11
	pumps	0.01	0.00	0.01	0.00	0.00	0.00
	Total	80.76	55.81	72.19	53.82	64.68	52.05
	Saving		30.88 %		25.44 %		19.52 %
Large Office Building	heating	14.42	10.69	9.74	7.06	1.10	2.02
	cooling	8.68	5.31	27.05	18.36	43.10	30.06
	lighting	19.59	15.68	19.59	15.68	19.59	15.68
	equipment	32.66	26.13	32.66	26.13	32.66	26.13
	fans	5.42	3.14	16.70	9.75	21.13	12.27
	pumps	0.36	0.21	0.96	0.73	1.37	1.04
	cooling tower	1.99	1.11	5.52	4.11	7.40	5.47
	Total	83.11	62.27	112.22	81.82	126.36	92.66
	Saving		25.07 %		27.09 %		26.67 %

Table 7. Energy saving for each energy saving measure.

		Beijing		Shanghai		Guangzhou	
		Savings, kWh/m²	Savings ratio	Savings, kWh/m²	Savings ratio	Savings, kWh/m²	Savings ratio
Small Office Building	cooling setp	0.61	0.75 %	0.81	1.12 %	0.11	0.17 %
	heating setp	2.8	3.47 %	2.98	4.13 %	0.59	0.92 %
	lighting use	3.86	4.78 %	4.12	5.70 %	4.36	6.74 %
	equip use	6.27	7.76 %	6.35	8.80 %	6.9	10.67 %
	natural ventilation	1.01	1.25 %	7.68	10.64 %	1.18	1.82 %
	shading	0.2	0.25 %	0.11	0.15 %	0.16	0.24 %
Large Office Building	cooling setp	1.38	1.66 %	11.86	10.57 %	17.81	14.09 %
	heating setp	3.17	3.81 %	3.58	3.19 %	3.94	3.12 %
	lighting use	4.43	5.33 %	7.23	6.44 %	9.16	7.25 %
	equip use	7.17	8.63 %	10.85	9.67 %	13.01	10.29 %
	Natural Ventilation	10.71	11.62 %	14.19	12.10 %	14.87	10 %
	shading	0.77	0.93 %	3.27	2.91 %	4.63	3.66 %
	economizer	0.34	0.41 %	2.36	2.10 %	4.06	3.22 %
	SA reset	1.15	1.38 %	2.34	2.08 %	3.96	3.13 %

Discussions and conclusions

The simulation analysis results indicate that the Chinese prescriptive and outcome based energy standards demonstrate consistent performance targets, even though some cases performance gaps between the two standards is also observed. The office building simulation shows that despite it is difficult to explain the low EUI recommended targets set for Cat. B buildings, the performance gaps can be mitigated through optimize building operating conditions investigated in this study. Thus, even though the prescriptive energy standard and the outcome based energy standard are two separate and independent standards in China, they can both be potentially applied to the same buildings technically and get potentially consistent energy performance, with a few exceptions. We summarize the technical features of the outcome based codes in China, Sweden and City of Seattle in Table 9.

In general, the Chinese outcome based energy standard has most comprehensive definitions in terms of building type and end use targets, but very sophisticate to use. The definitions have different boundaries — buildings themselves and systems such as district heating system which is outside of buildings.

Table 8 Comparison the commercial builidng prescriptive energy efficiency standard performance and the outcome based energy standard for office buildings in Shanghai (kWh/m²).

	Baseline	Best practice	Outcome based required target		Outcome based Recommended target	
			Government office	Commercial office	Government office	Commercial office
Small office (Cat A)	72.19	53.82	70	85	50	70
Large office (Cat B)	112.22	81.82	90	110	65	80

Table 9. Technical summary of outcome based codes and standards in China, Sweden and City of Seattle.

	China	Sweden	City of Seattle
Physical boundary of energy balance	Varies. Has both building scale and e.g. heating in the Northern China outside of building scale (district heating). Primary energy for heating and site energy for non-northern China heating. Separate electricity and natural gas energy use in residential buildings	A building it self's site energy	A building it self's site energy
Targets EUI definition	EUI (kWh/m²) for commercial buildings, and per household energy density for residential buildings; also include matrix for district heating system.	EUI (kWh/m²) for all building types	EUI (kWh/m²) for all building types
Target categories	Two EUI values: required value and recommended value; Distinguish buildings with operable windows (Cat. A), and non-operable window (Cat. B)	Distinguish electric heating and non-electric heating	Single value
Building type	Commercial and Residential. Commercial includes office, retail, and hotel. And further division of each building type. Parking garage is separated.	Residential and All non-residential buildings	Commercial buildings: office, medical office, school, hospital, warehouse, retail, and parking garage
Data measurement period	One year data	One year data, 24 month after completion of construction	12 months continues monitoring within 3 years of building's occupation
End Use Coverage	All end use	Only heating, ventilation and hot water	All end use
Performance normalization or sensitivity analysis	Can be normalized by occupancy rate, operating hours, hotel guest room floor space ratio and residential number of persons per household	Can be normalized by outdoor air ventilation rate	Sensitivity analysis based on occupant density, lighting power, plug load, infiltration rates and temperature setpoints

In has mixed of target units and separated end use target (e.g. separate North China heating targets). Having many targets especially targets at different end use levels could require more efforts and trainings when conducting compliance analysis. This also impose challenges for building inspectors to evaluate the performance outside of building boundaries (e.g. district heating performance), and outside of their jurisdiction.

The other challenges of the outcome based code in China, instead of technical definitions on buildings energy performance, mainly exist in its implementation stage for compliance, enforcement, incentives and so on. Table 10 summarizes key policies for implementing the outcome based standard and code in China and the city of Seattle.

The first and foremost issue of the outcome based standard in China needs to solve is that its relationship between the current prescriptive energy standards, given that the Chinese outcome based standard is used in both new construction and existing buildings. The outcome based codes in Sweden and City of Seattle are developed with prescriptive measures and outcome based compliance path. Buildings need to achieve prescriptive measures first, than to achieve outcome based performance targets after 12 months of continuous energy performance monitoring. Since current Chinese prescriptive standard and outcome based standard are independent to each other, significant amount of work is required to harmonize the two standards and document the compliance procedures for new buildings to achieve both prescriptive standard in design stage and the outcome based standard in their operation stage (Rosenberg 2015). Another question for the Chinese outcome based standard is the compliance procedure when applying to existing buildings. Existing buildings, different from new construction, have been operated for a period of time and become difficult to regulate their energy use. Simply setting up targets without implementation procedure for compliance and supporting policies would be very challenging to achieve compliance in existing buildings.

As the Chinese outcome based energy standard is just released, incentive and disincentive policies are needed to promote the adoption of the standard. Comprehensive incentive programs for buildings perform exceeding outcome based standard's requirements are needed. It is also useful to learn Seattle's experience of setting up security fund from building owner, and deduced from fund if buildings not achieve their energy performance targets.

Chinese government has developed national level building energy data monitoring program supported with government funding for installing sub-metering system. This provide a fundamental data support for commercial buildings to achieve requirements set by the outcome based standard. However, the current outcome based standard does not clarify how data should be collected and reported, given complex data boundaries and end use level requirements aforementioned, and how buildings energy performance should be measured and verified. Once performance data are collected, how to better use the national level performance data is also very critical. A national level data disclosure and benchmarking program is necessary to establish to help China better define energy performance targets and rules for sensitivity analysis and performance normalization. This would in turn benefit China for its future outcome based standard update.

This paper is limited to use office building in three different climate zones to analyse building performance in order to achieve the outcome based standards' target settings. To achieve more detailed conclusions, more building types and climate zone analysis are needed. It would be necessary other countries and regions' outcome based energy standards development, in order to draw more comprehensive policy recommendations for the Chinese standard.

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Table 10. Policies for implementing outcome based codes and standards in China and City of Seattle.

	China	City of Seattle
New or Existing buildings	New and existing buildings	New buildings
Incentives	–	Utility incentives for savings beyond code requirements. Rebates are paid at two phases: 1) the completion of construction and 2) after 12 month continuous performance monitoring
Non-compliance penalty	–	Financial security. Fine based on % of EUI exceeding target
Measurement and verification	–	yes
Supporting mechanism	Commercial building sub-metering program with government subsidy.	Data disclosure and benchmarking; Energy Star Target Finder design tool and Portfolio Manager to set targets

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