# From Prescriptive to Outcome-Based

## The Evolution of Building Energy Codes and Standards in China

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# 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 its primary energy in its building sector. It is estimated that energy use in Chinese buildings will continue to increase in the future due to the fast urbanization process. Codes and standards are widely believed to be one of the most effective ways to improve efficiency and reduce energy use and $CO_2$ emissions in the 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% improvement in energy efficiency compared with the 1980s baseline. However, buildings that meet prescriptive code requirements may not yield actual operation energy performance. Many buildings demonstrate good energy performance during design but then do not perform well during operation. In order to fill in the performance gap between prescriptive standards and actual performance, China has developed an outcome-based building energy standard aimed at regulating actual building energy use in buildings.

This paper reviews international best practices on outcome-based building codes and standards. Based on previous studies of prescriptive building energy standards in China, this paper presents the gaps between China's prescriptive standard performance and the proposed outcome-based standard 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 comply with prescriptive code performance to meet the proposed outcome-based standard requirements as well. Finally, this paper discusses current barriers and feasible policies to solve the issues of compliance and enforcement of the proposed outcome-based codes and standards.

## Keyword

Buildings, Energy Efficiency Policy, Codes and Standards, Outcome Based Code

## Introduction

Buildings use a significant amount of energy in China. Energy use is expected to continue to increase in the Chinese building sector because of increased urbanization and increased quality of living (Zhou, et al. 2015). To control the rapid 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

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

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 on reducing energy consumption in hotels. The update in 2005 mandated that buildings be designed and built with 50% energy reduction compared to a 1980s baseline (where buildings were built without energy standard requirements). The updated version of the commercial building energy efficiency standard in 2015 mandates that buildings reach 65% greater efficiency than the 1980s' baseline[2], and achieve approximate 62% energy savings (Feng, et al. 2014, MOHURD 2015).

However, it became clear that building efficiency at design and actual efficiency during operation often greatly differed. This is mainly caused by unregulated operating conditions and occupant behavior, elements that the prescriptive standards do not mandate. Given that prescriptive standards alone are not enough to regulate actual energy use, new challenges face the Chinese government in controlling 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—standards that have been predominantly prescriptive-based during the past 20 years will now become outcome-based standards.

The purpose of this paper is to

- *Review international best practices for 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 them to prescriptive energy standards.*

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

In the background section, this paper first 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, focusing on the Chinese outcome-based energy standard requirements. In the modelling and results section, this paper compares energy performance targets of the prescriptive commercial building standard with the outcome-based energy standard. It uses simulation models to quantify energy performance of the Chinese prescriptive standard, and then uses the simulated targets to compare results with the outcome-based standards target settings. The study also provides a list of operation measures for office buildings and studies their impact in achieving outcome-based standard requirements. Finally, in the conclusion section, recommendations are provided on the technical aspects and policy aspects of the Chinese outcome-based energy standard.

## Outcome-based code

Many countries and regions around the world have developed building energy codes and standards. Many countries have established their regulations using prescriptive measures to mandate building components and technology performance (Rosenberg, et al. 2015). Prescriptive codes and standards mandate building envelopes; heating, ventilation, and air-conditioning (HVAC); lighting; plug loads; and other system technical performance to reach minimum levels of performance, often based on the building's climate zone. 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 regulations are very useful in managing the approval of new construction 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 and standards. 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 widely used in evaluating the energy savings potential of green buildings.

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

[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.

- Prescriptive and performance-based standards are often applied to permit new construction but not often used in existing buildings.
- 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 a building's performance in its operation stage. It often requires buildings to continuously operate for at least one year after its occupation. The measured performance data obtained in that period is compared with targets set by the outcome-based standard in order to achieve compliance.

The City of Seattle is one of the leading cities in the world in the development of outcome-based energy code (Pinch 2015, Seattle 2015). Starting in 2008, the City of Seattle began implementing outcome-based energy code focused on compliance through verified energy performance. Seattle is also working with pilot buildings, collecting 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 of its space occupied during that operation period. Outcome-based target setting is modelled on 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 systems are desirable to acquire detailed building energy use information. It is important to conduct energy modelling first to demonstrate savings opportunities before collecting measured energy performance data. Sensitivity analysis is required to quantify the impacts of certain operation measures on building energy performance. Incentive programs are effective to promote the adoption of the outcome-based codes and demonstrate energy savings beyond code requirement.

**Table 1, The outcome-based targets of energy code for the City of Seattle**

| Building Type | EUI target - $kWh/m^2$ (or $kBtu/ft^2$) |
|---|---|
| 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 |

Sweden is one of the early adopters of outcome-based code. Sweden adopted its own outcome-based code (BBR) in 2006 for residential and non-residential buildings in all of 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 buildings. The code uses a "specific energy use" definition, which is an EUI requirement including heating, ventilation, and hot water energy use, but not including energy use from plug loads, lighting, and other operations. The code requires buildings to verify its performance within 24 months of its completion with continuous monitoring data for 12 months. The code differentiates target EUI settings in small houses, small houses with conditioned floor space less than $50m^2$, apartment buildings, apartment building blocks with conditioned space larger than $50m^2$, ordinary non-residential buildings, and small non-residential buildings with conditioned floor space less than $50m^2$. 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 to 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 building compliance, including commissioning, permitting, fines to fail to compliance, and so on.

**Table 2, Swedish outcome-based code performance targets for non-residential buildings.**

[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 behaviors. Later part of this has some detailed analysis of unregulated measures impact on building performance.

| 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 |

China started to develop its outcome-based energy standard in 2013, and it became effective in late 2016. The standard, which is officially called the 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 set up 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 that is mandatory for a building to achieve. The recommended value is an annual measured EUI target that is voluntary, but the government promotes compliance and has demonstration buildings that achieve 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 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 Northern China uses approximately one quarter of the country's total energy comsumption, regulating Northern China heating is important. The EUI for northern China heating energy is mandated with the unit of kilogram of coal equivalent per square meter, or kgce/m$^2$. However, for buildings in transition climates (called hot summer cold winter), the southern climates (hot summer warm winter) and temperate climate zones, heating energy is incorporated into a building's total energy use and expressed in final energy style. The heating EUI targets for the northern part of China are separated into two categories, based on the fuel type of the 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 the heating system: 1) city level district heating, 2) community or small campus-based heating, 3) individual building scale heating—and then eventually specified for the 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 targets 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 it regulates not only building itself but also district heating system efficiency, which Seattle and Swedish codes do not regulate. However, implementing the standard as the energy use boundary changes from buildings to district heating system does add complexity.

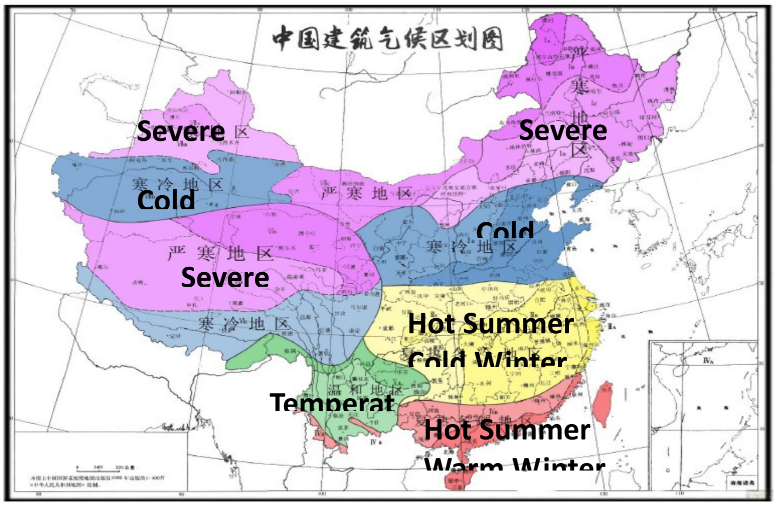


*Figure 1, Chinese climate zone map*

[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 systems. And there are very few district heating systems in transition climates and in the southern part of China.

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 are usually equipped with split HVAC system. Category B defines buildings without operable windows that are mainly served with mechanical ventilation and equipped with centralized HVAC systems. 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 centers, cooking, and other special energy use are not part of EUI targets. Local generated renewable energy is also not included in these EUI targets

**Table 3, EUI targets of Chinese outcome-based building standards 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/m$^2$ | |
|---|---|---|---|---|
| | | | 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 |

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 the EUI targets. For office buildings, the EUI performance can be normalized based on occupancy intensity (standard value: 10m$^2$/person) and operating hours (standard value: 2500hr); hotels are normalized based on guest room occupancy rate (standard value: 50%) and guest room vs. total floor space ratio (standard value: 70%); and retail buildings are normalized based on operating hours (standard value: 5500hr for supermarkets, 4570hr for shopping centers/malls, and 5000hr for other shops and restaurants). A specific performance year's outdoor air temperature is used to normalize heating energy use for buildings in 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, excluding heating in Northern China, are provided in Table 4 for a standard energy use of a household with three people. The Chinese standard allows households to normalize their energy performance if there are more than three occupants in one household.

**Table 4, Chinese building outcome-based standard energy targets for residential buildings**

| Climate Zone | Required Electricity Use target - kWh/household | Required Natural Gas Use Target - m3/household |
|---|---|---|
| Severe Cold | 2200 | 150 |
| Cold | 2700 | 140 |
| Hot Summer Cold Winter | 3100 | 240 |
| Hot Summer Warm Winter | 2800 | 160 |
| Temperate | 2200 | 150 |

## Modelling

The outcome-based building codes in the city of Seattle and in Sweden define performance EUI targets 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.

In order to understand the performance relationships between the Chinese prescriptive energy standard and the outcome-based energy standard, a few energy conservation measures were modelled in this study, including occupant-based lighting control, natural ventilation, economizer control, supply air temperature reset, etc. These measures are not regulated in current Chinese commercial building prescriptive standards. The energy conservation measures are simulated individually first, and then 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 standards and the building outcome-based energy standards. 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. This study uses that model from previous studies, and adopts the energy performance results obtained by simulating the large office building model. A small office-building model is also developed 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 follows 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]. The current 2015 Chinese commercial building energy standard's models for baseline performance analysis is used 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. General information about construction and the energy systems are as follows. The small office building is a one-story building with total floor area of 8176.56 $m^2$. The large office building is 18-story building with the total floor area of 26142.48 $m^2$. Table 5 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.

**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[6] + 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 |

## *Energy conservation measures*

Considering availability and applicability, six energy conservation measures were selected for small buildings: heating and cooling set point adjusting, occupant-based lighting and equipment operation, natural ventilation, and window shading control. Besides the measures applied in the small building, more energy conservation measures were modelled for the large buildings: 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 discounts in the baseline models, which comply 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.

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[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.

[6] AHU: Air Handling Unit; VAV, Variable Air Volume

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

Natural ventilation is modeled by simply modifying the infiltration rate when the outside weather condition are 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 outside solar radiation is high. A roll shade was implemented for each window of the building in the model. The shade transmittance was 0.075, solar reflectance 0.7, conductivity 0.1 (W/m-k), visible transmittance 0.032, visible reflectance 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 heat gain when the outside solar radiation is high.

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

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

## Results

After evaluating all of the energy conservation measures, the energy savings potential are evaluated and compared in Figure 2 and Figure 3 for small and large buildings with all the energy conservation measures applied. The final energy intensity method is used to show building energy performance results. The final energy intensity values can also be converted to equivalent primary energy intensity values, using the Chinese coal equivalent conversion factors. The final energy results are demonstrated 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 the three cities are all approximately (or below) 55 kWh/m$^2$; the large buildings are approximately (or below) 90 kWh/m$^2$ with heating energy consumption included.

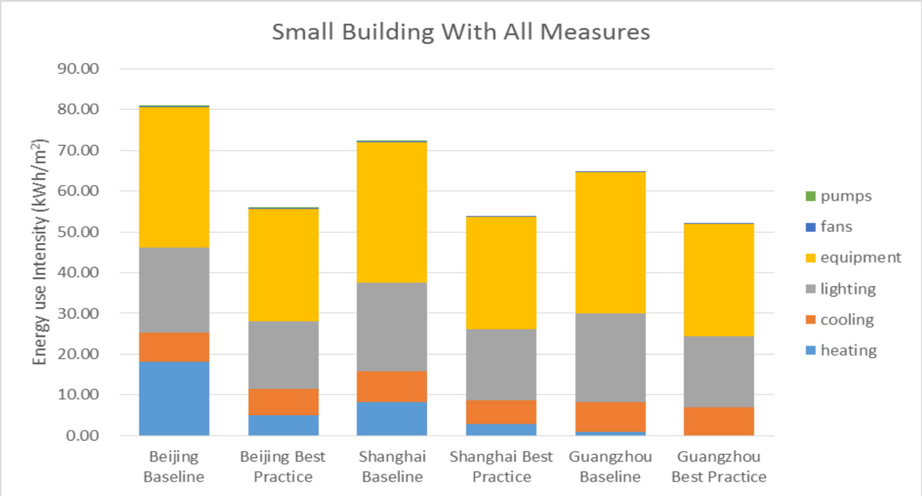


*Figure 2 Small office building energy savings potential*

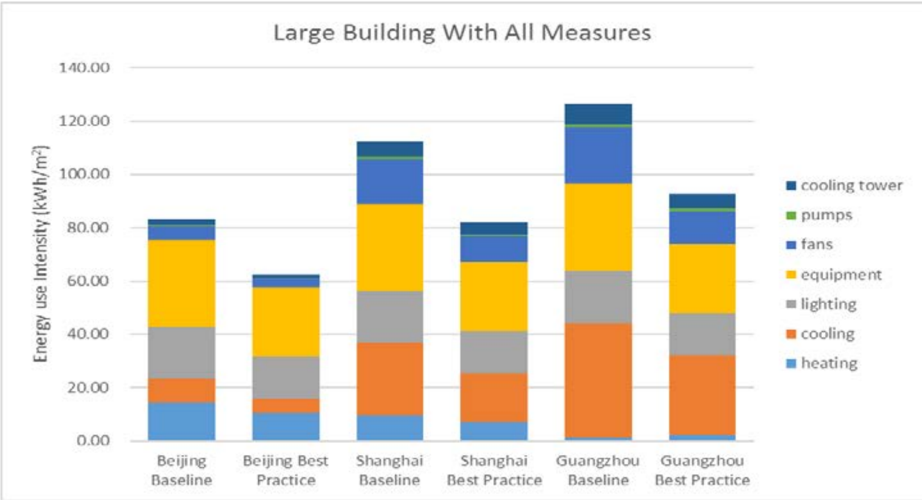


*Figure 3 Large office building energy savings potential*

**Table 6 Energy consumption density breakdown (kWh/m$^2$)**

| | | 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% |

The savings potential for each energy conservation measure is shown in Table 7. Plug load equipment and lighting controls are the two measures with the highest energy saving potential. Adjusting the heating setpoint also achieves more than 3% energy savings in all three locations. Adjusting cooling setpoint achieves more than 10% and 14% for large buildings in Shanghai and Guangzhou, respectively, where cooling load is higher. Natural ventilation reduces energy consumption by more than 10% for large office buildings in all three locations, while the savings for small office buildings in Beijing and Guangzhou are very small.

**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% |

The total savings potential is extracted 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) in Table 3 and then compared with the target settings of the outcome-based energy standard. The comparison is shown in Table 8. Results show that natural ventilation, lighting, and plug load management are very effective in all building types in achieving outcome-based energy use targets.

**Table 8 Comparison of the commercial building prescriptive energy efficiency standard performance and the outcome-based energy standard for office buildings in Shanghai (kWh/m$^2$)**

| | 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 |

For small office buildings with split HVAC systems and where 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 difficult to achieve, especially for government office buildings, but still achievable if more aggressive saving strategies are applied. Achieving the recommended targets in large office buildings with centralized HVAC systems and natural ventilation is difficult. Results here indicate that the required targets set by the outcome-based energy standard is achievable as the "best practice" value of 81.82 kWh/m$^2$, which is very close to the government office building target of 90 kWh/m$^2$. However, recommended values set by the outcome-based energy standard for large size government office buildings are relatively 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 to employ some other energy conservation measures not investigated here. Given all the design prescriptive measures that are fixed, the Chinese outcome-based energy standard should show what government office buildings that are conditioned with centralized HVAC systems should do to achieve the prescribed low EUI targets and achieve comfort criteria and productivity levels when operating under such low EUI values.

## Discussions and Conclusions

Simulation analysis results indicate that the Chinese prescriptive and outcome-based energy standards demonstrate consistent performance targets, even though, in some cases, performance gaps between the two standards are also observed. The office building simulation shows that, despite the difficulties of explaining the low EUI recommended targets set for Cat. B buildings, the performance gaps can be mitigated by optimizing 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 with potentially consistent energy performance, with a few exceptions. Technical features of the outcome-based codes in China, Sweden, and City of Seattle is summarized in Table 9 below.

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

| | China | Sweden | City of Seattle |
|---|---|---|---|
| Physical boundary of energy balance | Varies. Has both building-scale and outside of building scale i.e. heating in Northern China (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's own site energy | A building's own site energy |
| Targets EUI definition | EUI (kWh/m2) for commercial buildings, and per household energy density for residential buildings; also includes 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 separate. | Residential and all non-residential buildings. | Commercial buildings: office, medical office, school, hospital, warehouse, retail, and parking garage. |
| Data measurement period | One year of data. | One year data, 24 months after completion of construction. | 12 moths continuous 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 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 general, the Chinese outcome-based energy standard has the most comprehensive definitions in terms of building type and end use targets, but it is complicated to use. The definitions have different boundaries — buildings themselves and systems such as district heating system, which is outside of buildings. It has mixtures of target units and separated end use targets (e.g., separate North China heating targets). Having many targets—especially targets at different end use levels—could require more effort and training when conducting compliance analysis. This also creates challenges for building inspectors when evaluating performance outside of building boundaries (e.g., district heating performance) and outside of their jurisdiction.

The other challenges of using outcome-based code in China instead of technical definitions on buildings energy performance are compliance and enforcement during the implementation stage, as well as creating incentives. Table 10 below summarizes key policies for implementing the outcome-based standard and code in China and the City of Seattle.

**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 months of 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. |

The first and foremost issue that China needs to solve in order to implement outcome-based standard is the 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 the City of Seattle are developed with prescriptive measures and an outcome-based compliance path. Buildings need to achieve prescriptive measures first, then achieve outcome-based performance targets after 12 months of continuous energy performance monitoring. Since current Chinese prescriptive standards and outcome-based standards are independent of each other, a significant amount of work would be required to harmonize the two standards and document the compliance procedures for new buildings to achieve both prescriptive standards in design stage and then outcome-based standard in the operation stage (Rosenberg 2015). Another issue is the compliance procedure for existing buildings. Existing buildings, unlike newly constructed buildings, have been in operation for a period of time and it may be difficult to regulate their energy use. Simply setting up targets without implementation procedures for compliance and without supporting policies would create a challenging roadblock for existing buildings to comply.

As the Chinese outcome-based energy standard has just been released, incentive and disincentive policies are still needed to promote adoption of the standard. Comprehensive incentive programs are needed for buildings that exceeding outcome-based standards. It is also useful to understand Seattle's experience setting up security funds from building owners—funds that are used to pay fines if buildings do not achieve their energy performance targets.

The Chinese government has developed and funded a national building energy data monitoring program for installing sub-metering systems in cities. This provides 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, especially with the 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, a process for better using national performance data is also critical. A national data disclosure and benchmarking program needs to be established to help China better define energy performance targets and rules for sensitivity analysis and performance normalization. This would, in turn, benefit China when it next updates its outcome-based standards.

This scope of this paper is limited to office buildings in three different climate zones. The research analyses building performance to see if they achieve outcome-based standards' target settings. To achieve more detailed conclusions, more building types and climate zone analyses are needed. The scope would need to be expanded to include looking at outcome-based standards from other countries and regions in order to draw more comprehensive policy recommendations for the Chinese standard.

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