Building energy consumption quotas: a policy tool toward sufficiency?

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Abstract
As the level of building construction has grown in China over the past decade, with annual building construction levels surpassing two billion square meters of new construction each year, China has been investigating new regulatory mechanisms to reduce building energy use. One method being considered as part of the government policy to reduce the growth rate of building energy consumption (and resulting greenhouse gas emissions), is the development of "energy consumption quotas" for buildings, essentially setting an energy intensity limit for different building types within a given climate zone.

Experts and regulators in China have been investigating limits, or quotas, on the amount of energy that can be used by the building sector (as well as other industrial sectors). The process begins with looking at overall national building level consumption and intensity, then a target is set for total building energy use in a province or city, which can then be extended down to apply to individual buildings. The building energy quota concept, applied to individual buildings, has been advanced into a Chinese National Standard promulgated in 2016 (the National Standard for Civil Building Energy Consumption, GB/T 51161-2016). This paper focuses on how quota consumption limits have been applied, methods for developing appropriate quotas for different building types, potential implementation mechanisms for enforcing the quotas, and prospects for expanding implementation in China in the near future, and potential applicability beyond China.

Introduction
Over the past twenty years, China has grown from a rapidly emerging economy to by some measures, the largest economy in the world, and the world's biggest energy consumer and greenhouse gas (GHG) emitter. Despite this growth, with the largest national population in the world, Chinese per capita buildings sector energy consumption in 2012 was still less than half the level of EU countries, and one-quarter of the per capita consumption in the United States (IEA/IPEEC 2015).

GROWTH OF BUILDING ENERGY CONSUMPTION AND RESULTING EMISSIONS IN CHINA
With the growth of China's population and increase in living standards, the size of China's existing building stock has nearly doubled since 2001, from approximately 30 billion square meters (m^2) in 2001 to nearly 60 billion m^2 in 2016 (Tsinghua BERC 2018).

While the growth in building floor area has begun to slow down in the past two years, earlier this decade China was adding nearly 3 billion m^2 per year of new construction, responsible for about one half of total annual building construction volume, and annual growth more than half the total existing building stock of Germany as of 2012 (IEA/IPEEC 2015).

The total primary energy consumption from buildings in China in 2016 was approximately 26.3 EJ, as detailed in Table 1. The resulting GHG emissions from this energy consumption has risen to over 2.1 GT of CO_2 in 2016, significantly more than the total (all sectors) national GHG emissions from any European country; nearly three times the total CO_2 emissions of Germany, and over six times the CO_2 emissions of Italy (IEA 2018).

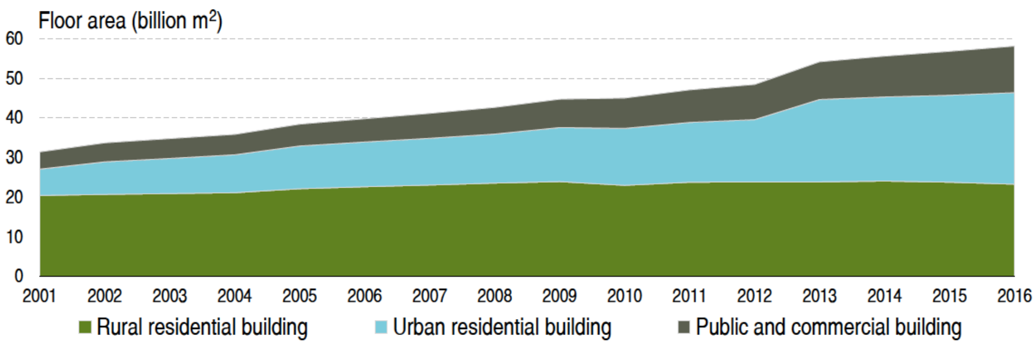
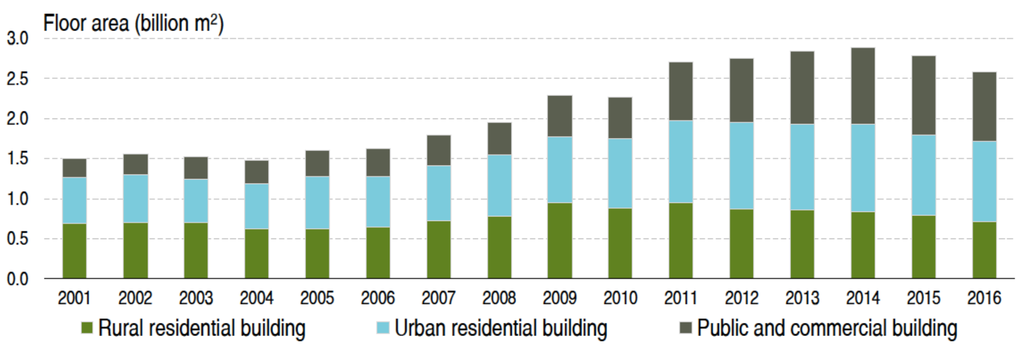


Figure 1. China's existing building stock (2001–2016).



Source: NBS (2017a)

Figure 2. New completed buildings in China (2001–2016).

Table 1. China's building primary energy consumption (2016).

Categories	Activity data	Electricity (TWh)	Commercial energy (Mtce)	Energy use intensity	CO_2 emissions (Gt of CO_2)
NUH	13.6 billion m^2	29.1	191	14.0 kgce/m^2	0.51
P&C buildings (excluding NUH)	11.7 billion m^2	689.6	275	23.5 kgce/m^2	0.54
UR buildings (excluding NUH)	0.28 billion hh, 23.1 billion m^2	457.9	209	738 kgce/hh, 9.0 kgce/m^2	0.35
RR buildings	0.15 billion hh, 23.3 billion m^2	223.7	221	1446 kgce/hh, 9.6 kgce/m^2	0.60
Total	1.38 billion people, 58.1 billion m^2	1400.3	896	649 kgce/cap	2.0

Notes: Only commercial energy consumption is included in this table. For RR buildings, the total energy use per household will be 2033 kgce/hh including the use of biomass.

Abbreviations: NUH – North Urban Heating
P&C – Public & Commercial
UR – Urban Residential
RR – Rural Residential
hh – households

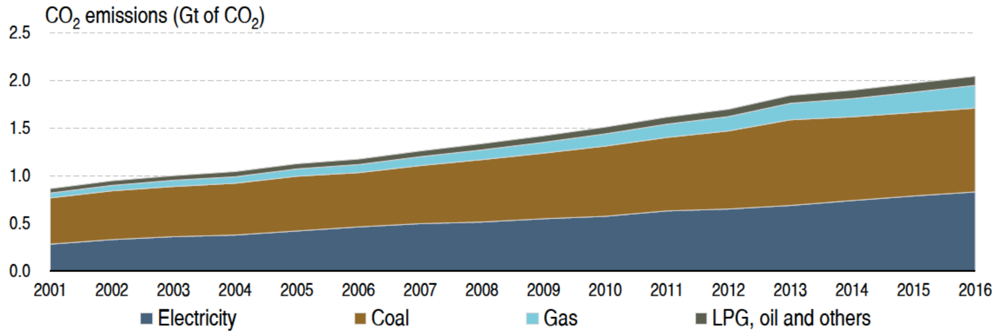


Figure 3. China's buildings sector CO_2 emissions (2001–2016).

HISTORY OF CHINA POLICIES FOR BUILDING ENERGY EFFICIENCY

Over the past decade, China has been widely recognized as a global leader in energy efficiency policy development and progress. In the International Energy Agency's (IEA's) Energy Efficiency 2017 trends report, it was reported that in 2016, China's "… energy intensity fell by 5.2 %, reflecting strong economic growth with minimal increase in energy demand. The size of the Chinese economy and its energy consumption means that it has a big impact on global energy intensity trends. Without China, the fall in global intensity in 2016 would have been only 1.1 %," when compared with the actual global energy intensity drop of 1.8 % (IEA 2017).

China's historical building energy efficiency policies have been well catalogued in several recent comprehensive reports, including "Building Energy Use in China: Transforming Construction and Influencing Consumption to 2050" (IEA/Tsinghua 2015), and the China Building Energy Use 2016, 2017 and 2018 annual reports (Tsinghua BERC 2016, 2017, and 2018).

CHINA FIVE YEAR PLAN POLICY DEVELOPMENT PROCESS

Key policy initiatives in China are articulated through the national Five Year Plan (FYP) planning process. National level targets and policies are established by the Central Government, and then these targets and policies are adopted for implementation by provincial and local government agencies. This planning process directly impacts all energy and environmental policies nationally and at all sub-national levels (Sandalow 2018).

The 11th FYP (2006–2010) and the 12th FYP (2011–15) established a variety of energy efficiency policies, including advanced energy codes and product efficiency standards, as well as energy intensity reduction targets. The 13th FYP (2016–20) established total energy consumption limits[1] and energy intensity targets for all energy consuming sectors in China, including buildings; a process informally known as the "quota standard."

The "Quota Standard" Concept

International energy studies and practices over the past 30 years have shown that building energy conservation has tremendous potential to save energy, among the most cost-effective GHG reduction areas, and is also the most effective measure to ease energy shortages. During the 11th Five Year Plan of China (from 2006 through 2010), great progress was made in building energy efficiency, though it mainly emphasized the design and construction stages. In practice, the continuous improvement of building energy efficiency does not necessarily reduce actual building energy consumption or save operating costs. Some buildings that use a lot of the newest energy-saving technologies still have extremely high energy consumption, sometimes far higher than other similar buildings. At the same time, the benchmark or baseline for building energy use, which is used to measure whether a building's actual energy consumption is reasonable or not, was not yet clear. A growing number of researchers are paying attention to how to control energy use at the operational stage, and understand the drivers behind any performance gap between predicted and actual building energy performance.[2]

In 2013, China promulgated "the 12th Five-Year plan for energy development" (SCC 2013) for the period 2013 to 2015, and put forward the development goal of "dual control of energy consumption intensity and total consumption." This critical concept of "dual control" means that there needs to be focus on consumption intensity, but also on total consumption, with the total consumption limit being a mechanism to drive energy sufficiency. This is particularly relevant in China, where both the economy, and the intensity of consumption of buildings that are starting from a much lower base of service and often comfort, are growing quite rapidly.

Total energy consumption control has also become an important indicator of local government performance appraisal. The establishment of the energy consumption quota system can effectively help achieve the goal of total energy consumption control.

Carefully developed energy quotas, or limits on the allowed total consumption, can be a very effective policy tool to effect "energy sufficiency" in an era of constrained energy resources (and the resulting environmental impacts).

1. As part of the 13th FYP, China has introduced total energy consumption quotas for major energy consuming enterprises and industries, as part of its plan to cap total national energy consumption at a maximum of 5 billion metric tons of standard coal equivalent by the year 2020 (Financial Times 2017).

2. See, for example, Zou et al 2018, and IPEEC 2018 (relevant discussion on pp 29–32).

QUOTA/ALLOCATION THEORY

At the end of the nineteenth century, quota management gradually became a class of business management science. At that time, American engineer Frederick Winslow Taylor put forward the scientific quota "Taylor theory," while China developed a grain quota and water quota. Taylor developed a process to determine the "work quotas," where through carefully planned research, workers could be assigned a "reasonable daily workload." A key principle was that work quotas should select the highest workload of workers, but not selected in the middle to upper workload sometimes, this "reasonable daily workload," should be "first-class workers to maintain, without prejudice to their health longer time speed "as the standard. This management process has been extended beyond labor quotas to energy consumption and other industrial metrics (Zhang 2015).

Because a total quantity is limited, the quota was proposed to control the quantity of the unit product; in a sense, it is a kind of redistribution of resources in society. In the same way, to control building energy consumption, the concept of a building energy consumption quota was put forward. The quota is the upper limit of energy consumption allowed to be used in the building during the binding period (usually a year), and the concept emphasizes the amount of control.

More details on how the upper limits of consumption are determined are described in Liu 2018 in the sections "Total energy consumption controlling strategies on the building energy quota" and "Research on the method to establish a public buildings quota"; as described in that paper, development of the individual building quotas can be developed through a process of "decomposition from top to bottom" whereby the index for energy conservation and emissions reductions for the whole country can be separated into a city level, and from there down to different types of buildings, and then individual building quota targets. This allocation from a "capped" total energy consumption is a form of driving sufficiency of energy use; if total consumption (or emissions) are capped, then there are defined limits to how much consumption is allowed for either the buildings sector in a city, or individual buildings (Liu 2018).

The quota is established to set an acceptable and basic level in the industry, to encourage owners to work together to transcend this level of value. In Europe and the United States, a relatively mature building energy-saving market already has been formed. A series of management measures have been carried out, including building energy consumption benchmarking, and setting the solutions to achieve the energy saving target. Japan has energy quotas and transaction models for commercial buildings (Reichl and Kollmann 2011). And Germany and Australia have also established similar building energy consumption level evaluation systems (Cao and Wei 2011).

Quotas on a variety of different materials or limits have been key metrics for different industries for many years, and in the early 2000s the Chinese national government began to set energy quotas for certain key manufacturing industries, such as energy per ton of cement produced, or per automobile or various types of steel produced. More recently, this concept has been expanded to China's rapidly growing buildings sector.

China's building energy quota standard: "The National Standard for Civil Building Energy Consumption"

Faced with an energy crisis, countries worldwide have enacted targets for energy conservation and emissions reductions. Controlling a building's total energy usage is one effective measure to address the tension around world energy supply. Thus, it is the starting point to develop the building energy consumption quota.

In China, in accordance with buildings' different functions and service objectives, buildings mainly are divided into two classes: civil and industrial. Civil buildings include residential buildings and public (internationally often referred to as commercial and institutional, or tertiary sector) buildings; among them, "ordinary" public buildings refer to a single building with an area of under 20,000 m^2 or a single building with an area of more than 20,000 m^2 that is not equipped with a central air conditioning system. With the rapid development of urban construction, building scales are constantly expanding, thus large new public buildings are being constructed at regular intervals. A "large" public building usually refers to a single building area of more than 20,000 m^2 that is equipped with a central air conditioning system. These include commercial, tourism, education and cultural, communication, and other public buildings.

During the 12th FYP period in China, office buildings (including commercial and government office buildings), retail stores, and hotels make up more than 70 percent of the existing public buildings, and comprise the large majority of public buildings energy consumption. The general method for the compilation of energy consumption quotas for public buildings is described in much more detail in Liu 2018.

A building energy consumption quota is a method used to establish total energy consumption limits. The different objectives that might be controlled can be divided into four levels: (1) a country's total energy consumption, (2) a city's total energy consumption, (3) a type of building's energy consumption, and (4) a single building's energy consumption. The specific quota can be determined by using one of two different kinds of "controlling" strategies: (1) decomposition from top to bottom, or (2) analysis from bottom to top (as shown in Figure 4).

- **Decomposition from top to bottom:** When considering the national energy consumption target, the index of energy conservation and emissions reductions for the whole country can be separated down to a city level, based on a variety of factors (e.g., economic activity, population, etc.). Then that can be divided into different types of buildings according to the city's economic base and building stock, and that information can be used to determine the energy consumption quota of single building. The country's overall target energy consumption is already clear, so this method is a fairly systematic theory and system.
- **Analysis from bottom to top**: Building energy consumption should not only be viewed according to a single building or type of building; analysts must also consider the city's total building sector energy consumption. These both complement and reinforce each other. In order to meet the reasonable energy service demand of a single building, the energy consumption quota can be calculated by using a scientific statistical calculation method. Using the floor ar-

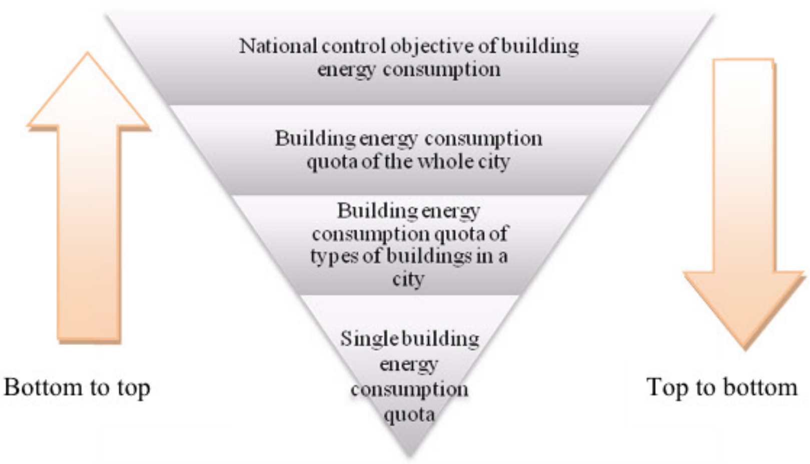


Figure 4. Detailed method for determining a building energy consumption quota.

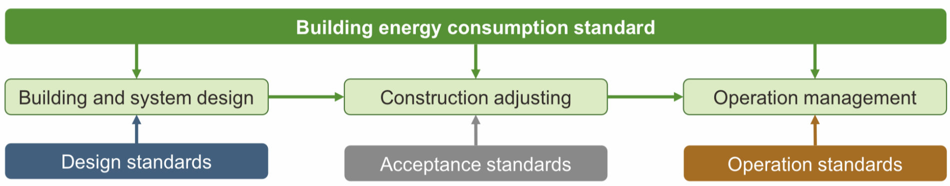


Figure 5. Relationship between energy consumption/quota standard and other guiding standards.

eas of the different building types, the total building quota can be calculated by a Weighted Sum Method. Finally, the national expected building energy consumption can be obtained through true-up of the different building types, through all of the cities and provinces.

In China, Beijing, Shanghai, Shenzhen, and some other cities pioneered the research and initial practice of energy consumption quotas for public buildings. In 2016, China formally promulgated and implemented the **National Standard for Civil Building Energy Consumption (GB/T 51161-2016)**. Energy consumption indices and their limits were developed for different types of buildings in different climate zones. Based on research results applicable to China's building energy consumption quota method, this paper discusses relevant work at the national and city levels. The implementation of the Standard, and further exploration and practice will lay the foundation for building total energy consumption control and can become the basis for building level energy efficiency (or emissions) trading systems.[3]

The National Standard for Civil Building Energy Consumption does not operate independently in China, it works in concert with a variety of other building energy related Standards, as shown in Figure 5. There are traditional building energy design standards in China (most notably China's Design Standard for Energy Efficiency in Public Buildings, GB 50189-2015) that aim to regulate energy efficiency during the design process, but as noted earlier, there is often a gap between expected energy performance and actual, measured performance. The Energy Consumption Standard is intended to regulate the actual energy consumption of buildings after they are put into use (Yan et al 2017).

WHAT IS COVERED BY THE STANDARD; HOW IT VARIES BY CLIMATE ZONE AND BUILDING TYPE

The National Consumption Standard prescribes energy intensity limits for a variety of different building types in different Chinese climate zones, as shown at a high-level summary in Figure 6.

For each building type, and major climate zone, the National Standard sets two different sets of energy intensity "limits": the "constraint value" (CV), which is the maximum energy intensity allowed for that building type in the given climate zone, and the "leading value" (LV), or definition of an advanced construction level for that same building. These two different limits are used in various policies in Chinese cities and provinces, as described later in this paper. A summary of the limits prescribed is shown in Table 2.

Challenge of the quota standard implementation

Most measured data in China shows that air conditioning or heating energy consumption in actual operation is lower than the calculated value under standard design conditions. This is mainly caused by the significant difference between actual op-

3. For a further explanation of how the Quota Standard is being used in the evolving carbon emissions trading systems in China, see the section on "The Construction of Carbon Emissions Trading System," part of Chapter 3 (on Building energy use in public and commercial buildings in China), that covers Policies for Public and Commercial Building Energy Management, included in China Building Energy Use 2018 (Tsinghua BERC 2018),

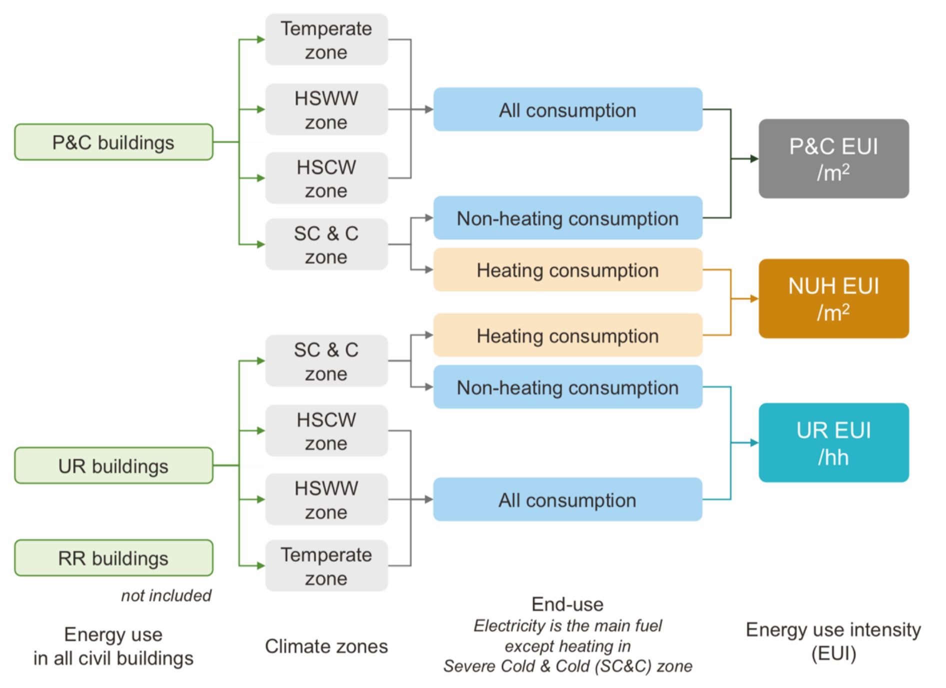


Figure 6. Different building sub-sectors covered by the National Standard.

Abbreviations:

P&C – Public & Commercial

UR – Urban Residential

RR – Rural Residential

HSWW – Hot Summer & Warm Winter

HSCW – Hot Summer & Cold Winter

SC&C – Severe Cold and Cold

EUI – Energy Use Intensity

NUH – North Urban Heating

Table 2. Energy Use Intensity limits for Public & Commercial Buildings.

Building type Unit: kWh/(m²·a)			**SC&C zone**		**HSCW zone**		**HSWW zone**		**Temperate zone**	
			CV	**LV**	**CV**	**LV**	**CV**	**LV**	**CV**	**LV**
Office	Class A	Governmental	55	45	70	55	65	50	50	40
		Non-governmental	65	55	85	70	80	65	65	50
	Class B	Governmental	70	50	90	65	80	60	60	45
		Non-governmental	80	60	110	80	100	75	70	55
Hotels	Class A	Five star	70	50	110	90	100	80	55	45
		Four star	85	65	135	115	120	100	65	55
		Three star or below	100	80	160	135	130	110	80	60
	Class B	Five star	100	70	160	120	150	110	60	50
		Four star	120	85	200	150	190	140	75	60
		Three star or below	150	110	240	180	220	160	95	75
Retail buildings	Class A	Department store	80	60	130	110	120	100	80	65
		Shopping mall	80	60	130	110	120	100	80	65
		Supermarket	110	90	150	120	135	105	85	70
		Restaurant	60	45	90	70	85	65	55	40
		General shop	55	40	90	70	85	65	55	40
	Class B	Department store	140	100	200	170	245	190	90	70
		Shopping mall	175	135	260	210	300	245	90	70
		Supermarket	170	120	225	180	290	240	100	80

Notes: Class A means the building using decentralized systems with openable window while Class B using centralized systems without openable window. Heating consumption is included in the energy consumption in HSCW, HSWW and temperate zone while excluded in SC&C zone.

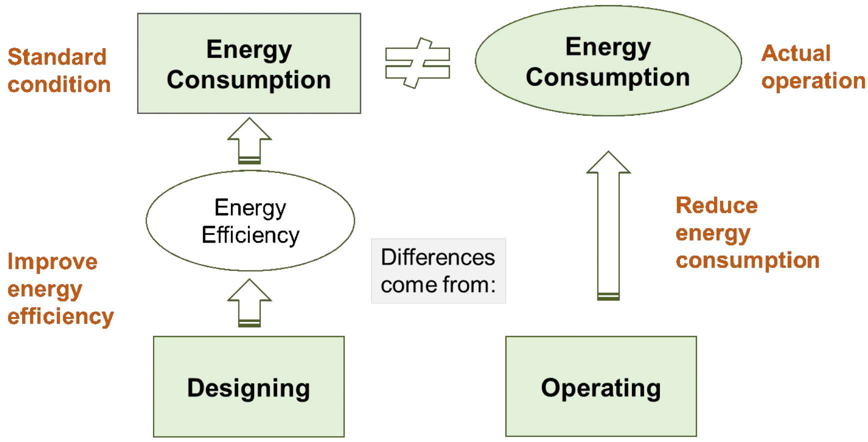


Figure 7. Energy consumption and energy efficiency in building design and operation.

eration and standard conditions,[4] as shown in Figure 7. In general, building energy design focuses on improving energy efficiency under standardized conditions, and when the building is in operation, the goal is to reduce actual, measured energy consumption. Due to the lack of basic energy consumption data and standards previously, building energy efficiency in design standards has assumed prominence beyond its original intent. In practice, it can be a challenge to harmonize the gap between design and operation in building energy consumption control.

With the accumulation and improvement of building energy consumption databases, energy consumption is beginning to be used to evaluate the performance of building design and operation. It is important to note that the quota standard focuses on achieving actual energy consumption control for civil buildings, which is result-oriented (or "outcome-based") and for the first time uses energy consumption as a regulatory measure for buildings in China. Combined with existing design standards, its implementation can accomplish the goal of process and result control, more directly impacting actual building energy consumption.

Implementation of the quota standard

INITIAL IMPLEMENTATION IN LEADING LARGE CITIES

Much of the policy evolution in China begins in leading research institutes in collaboration with experts in cities or provinces that are interested in advancing new policies or technical applications. This has been the situation with the Building Energy Quota Standard, as the technical development was coordinated nationally by Tsinghua University researchers along with the national Ministry of Housing and Urban-Rural Development (MOHURD), working alongside experts from provincial research institutes and other organizations.

The three cities highlighted below are generally early adopters of many policies in China, and in the case of the national quota standard, had developed or adapted the quota concept in advance of the national Standard being finalized.

SHENZHEN

Shenzhen is one of the first three cities which established the Public Building Energy Consumption Information Management Platform (The other two cities were Beijing and Tianjin). The Chinese Central Government, through MOHURD, made very large investments in building energy monitoring systems for large buildings as part of the 11th and 12th FYPs, which has allowed for tremendous amounts of measured performance data on how buildings consume energy.

The Shenzhen platform began to monitor energy data of public buildings from 2012. Then the data was analysed and published by the local Urban and Rural Construction Bureaus in an annual energy report. By the end of 2017, 563 public buildings have been incorporated into the platform.

Based on the National Standard for Civil Building Energy Consumption (GB/T 51161-2016), Shenzhen has also issued and implemented its local standard (SJG 34-2017), and put forward more stringent constraint values (CV) of public & commercial buildings. The different limits between SJG 34-2017 and GB/T 51161-2016 are shown in Table 3.

Furthermore, the CVs of local standard serves as the benchmark of the initial allocation amounts for buildings for the Shenzhen Emissions Trading System (ETS). Classified energy consumption and emission limits are used to determine allowance distribution to buildings. 197 large-scale public buildings have been included in emissions regulating. However, emissions allowances have not been traded in the building sector as yet.[5]

BEIJING

Since 2014, the Beijing Public Building Energy Consumption Information Management Platform has been established, and at the same time, the management system of energy consumption quota for public buildings has been formally implemented. By the end of 2017, 9,610 public buildings, representing 127 million square meters of building area, had been incorporated into

4. For more information about why the actual operational energy consumption is lower than predicted/calculated in the majority of Chinese buildings, see Chapter 4 (Occupancy behavior and building energy conservation) in Tsinghua BERC 2018.

5. Some aspects of City or Provincial Emissions Trading Pilots (including Shenzhen) have been delayed in their implementation since the Chinese National Government committed to implementing a national emissions trading scheme, which had a soft launch in 2017 and is still being expanded.

Table 3. Energy Use Intensity limits for Public & Commercial Buildings between Shenzhen local standard and national standard.

Building type Unit: kWh/(m².a)			SJG34-2017		GB/T 51161-2016 (HSWW zone)	
			CV (II)	LV	CV	LV
Office	Class A	Governmental	65	50	65	50
		Non-governmental	80	65	80	65
	Class B	Governmental	**75**	60	80	60
		Non-governmental	**95**	75	100	75
Hotels	Class A	Five star	100	80	100	80
		Four star	120	100	120	100
		Three star or below	130	110	130	110
	Class B	Five star	**140**	**105**	150	110
		Four star	**180**	**135**	190	140
		Three star or below	**210**	**150**	220	160
Retail buildings	Class A	Department store	120	100	120	100
		Shopping mall	120	100	120	100
		Supermarket	135	105	135	105
		Restaurant	85	65	85	65
		General shop	85	65	85	65
	Class B	Department store	**230**	190	245	190
		Shopping mall	300	245	300	245
		Supermarket	**280**	**230**	290	240

Note: II means the building of which energy efficiency is in line with the National Standard for Energy Efficiency Design of Public Buildings (GB 50189-2015).

the information management platform and the annual electricity quota index had been issued.

A regulation has been established on "Interim Measures for the Management of Electricity Quota in Public Buildings in Beijing," which stipulates that electricity users who exceed their annual quota of electricity consumption by 20 % for two consecutive years will be disclosed to the public. The enforcement departments of the local Urban and Rural Construction bureaus in Beijing districts then require those buildings to rectify the over consumption problem, with fines of between 30,000 and 100,000 RMB (approximately US$4,500 to 15,000) each year. In 2017, a total of 80 public buildings were reported and criticized. The Municipal Housing and Construction Commission has required those buildings to conduct energy audits to find the reasons for exceeding the quota, and to reduce their energy consumption.

The buildings with the top 5 % annual actual reduction in electricity consumption will be disclosed to the public and publicly recognized as "best buildings" by the government.

SHANGHAI

Like Shenzhen and Beijing, Shanghai has established a large-scale Building Energy Consumption Monitoring Platform that monitors the detailed energy performance of 1,288 non-residential buildings in Shanghai, covering more than 57 million m^2 of floor area (Natural Resources Defense Council 2017).

Shanghai has issued six energy use guidelines for government office buildings, hotels, commercial buildings, comprehensive office buildings, hospitals, large scale comprehensive cultural venues, and other building types, though at present these are all voluntary local standards for reference and guidance. Research on the policies for building benchmarking, energy management beyond quotas, and energy consumption information disclosure is still in the exploratory stage.

Discussion

China's experience with quota standards for a variety of industrial sectors has been quite successful, and while it is somewhat early in the implementation, it appears to be a strong complement to other building energy related standards in China as an important tool to cut building energy waste and resulting emissions.

The established building energy quotas, either using the constraint value or the leading value, can be the threshold on which a variety of policies are based. It can be used to help set allocations for an energy or emissions reduction trading system, where the quota could serve as the initial "allocation" of allowable energy consumption or emissions levels. The initial allocation could then be ratcheted down as shown in the left side of Figure 8, reducing by some percentage each year to meet an eventual very low energy building performance goal.

Alternatively, there could be voluntary or mandatory policies around exceeding the established benchmark, as shown on the right figure of Figure 8.

Conclusions

The China Quota Standard (the National Standard for Civil Building Energy Consumption), is a powerful tool that can complement other building energy standards and regulations to impact large scale energy performance improvement in buildings in China.

The building energy consumption quota standard on national level or regional level has more important guiding significance for existing buildings in the building operation stage. China already has systematic new building design standards, but lack of evaluation standards and tools for actual operation effect.

As China takes on a larger global leadership role in managing greenhouse gases and reducing energy consumption, the quota

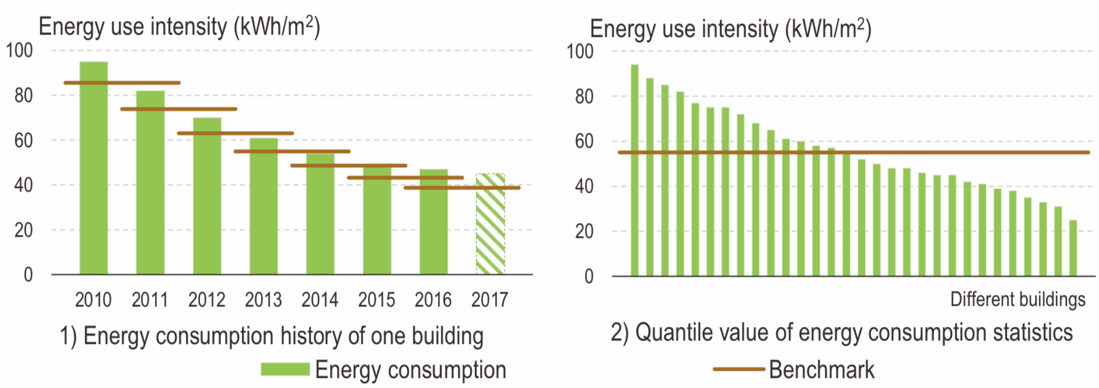


Figure 8. Alternative uses of quotas for individual buildings or groups of buildings.

standard is a model to limit both the intensity of energy use in individual buildings, but from a broader national or regional policy perspective, also take an established total building sector wide energy (or emissions) "cap" and distribute that sector wide cap down to different building sectors, and then have established "quotas" for individual buildings.

As noted, these quotas can then be enforced through different mandatory policies, or can become the basis for a trading system for reductions between different buildings or other voluntary or market-based initiatives. This system, more than traditional design level building regulations, offers the potential for setting a "sufficient," capped level of energy consumption in a city, and then spread that cap down to requirements that provide more of an "energy sufficiency" type of policy.

As China gains more experience using the established technical standard in implementation in regulations or other initiatives, there are likely to be many applications of similar standards in other countries that can learn from the China experience.

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