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Measures to enforce mandatory civil building energy efficiency codes in China

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ABSTRACT

Mandatory civil building energy efficiency codes strictly govern the energy consumption of new buildings in China. As the promotion of building energy efficiency in China has increased in recent years, compliance with mandatory civil building energy efficiency codes has also improved, increasing from less than 10% in 2000 to nearly 100% in 2012, a remarkable achievement. However, because the promotion of energy efficiency strategies in China has followed a unique pattern, some researchers doubt these statistics. In response to these doubts, this paper summarises and analyses the framework of measures implemented by the Chinese government to enforce mandatory building energy efficiency codes. First, the development and implementation of China's mandatory civil building energy efficiency code system is summarised. Second, the building supervision and inspection systems used to assess energy efficiency are introduced and analysed in detail in order to provide a framework for the development of energy policies in other countries. Third, the assessment and reporting processes used to determine compliance rates are reviewed. Finally, the improvement of compliance rates and its impact on building energy savings in China are discussed. Along with the increase in compliance rates in the construction stage from 71% in 2007 to 100% in 2012, the energy savings of new buildings per increased floor area per year increased from 20.4 kWh/m^2 to 28.4 kWh/m^2. The supervision and inspection systems reported in this paper are the keys to enforcing building energy efficiency codes.

1. Introduction

The urbanisation and the improvement in people's living standards in China has led to a rapid increase in energy consumption nationally (Bao et al., 2012). From 2004 to 2013, the average annual national energy consumption growth rate was 7.5% (National Bureau of Statistics of China, 2014). Total energy consumption in China was 1175 megatons of oil equivalent (Mtoe) in 2003, second only to the USA globally (Crompton and Wu, 2005). In 2010, China surpassed the USA and became the largest primary energy consumer in the world (British Petroleum, 2011; Liu et al., 2014).

The building sector, which consists of civil buildings, together with the industry and transportation sectors, is a major consumer of energy in China (Ding et al., 2011; Jiang, 2011). As shown in Fig. 1, the levels of building energy consumption per capita and per square metre in China were both lower than in developed countries in 2008. However, because of the large quantity of buildings in the country, the total energy consumption of buildings in China should be paid great attention to. The total energy consumption of buildings in China was nearly 413 Mtoe in 2008, which was larger than the sum of all of Japan, the UK and Germany's building energy consumption combined. Building energy consumption in developed countries accounts for 20–40% of total energy consumption and exceeds the energy consumption of all other sectors in both the EU and the US (Pérez-Lombard et al., 2008; Russell-Smith et al., 2015; Mattinen et al., 2014). The building sector is a major contributor to environmental degradation (Peuportier et al., 2013). The reduction of energy consumption in this sector can contribute to pollution control (Reijnders and van Roekel, 1999). In 2011, building energy consumption was 570 Mtoe, accounting for 23.4% of the total energy consumption in China (Building Energy Research Centre of Tsinghua University, 2013). With the constant growth of urban populations and people's living standards in China, this figure continues to increase (Jiang et al., 2013). Based on the

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Glossary

Civil building	Buildings in China can be divided into industrial and civil buildings. Civil buildings consist of residential buildings and non-residential buildings.
Construction administration	A construction administration is a governmental department and is responsible for developing, supervising and managing building energy efficiency policies and projects within relevant administrative regions. For instance, the national construction administration in China is the MOHURD, which is a department of the central government.
Construction drawing examining organisation	A construction drawing examining organisation is certified by the appropriate construction administration to examine construction drawings prior to implementation.
Construction quality testing organisation	A testing organisation is a company certified by the MOHURD. It is a third party organisation that offers quality testing services for construction projects.
Compliance rate	The compliance rate is calculated as the ratio of inspected urban buildings in compliance with mandatory civil building energy efficiency codes to total inspected urban buildings.
Public building	Non-residential buildings are called public buildings in China, otherwise known as commercial buildings in the USA.
Quality supervision administration	A quality supervision administration is a department within a construction administration. Quality supervision administrations are responsible for supervising the construction process and ensuring the appropriate behaviour of the organisations responsible for building construction quality.
Supervision organisation	A supervision organisation is a third party company certified by the MOHURD and hired by a developer to inspect the quality and process of construction as well as provide oversight of the builder.
Testing and labelling of BEE	This term refers to the test and calculation of building energy consumption and efficiency. Energy consumption and efficiency levels are tested and publicised on labels.
Province (autonomous region, municipality, special administrative region)	Provinces (autonomous regions, municipalities, special administrative regions) represent the first administrative division of government below the national government in China. A province (autonomous region, municipality, special administrative region) consists of a certain number of prefectures. There are twenty-three provinces, five autonomous regions, four municipalities and two special administrative regions in China.
Prefecture	Prefectures represent the second administrative division of government in China. A prefecture consists of a certain number of cities. There are three hundred and thirty-three prefectures in China.
Prefecture-level city	Prefecture-level cities are the capitals of prefectures.
County-level city	Except the prefecture-level city, the other cities in a prefecture are county-level cities.

increasing rate of energy consumption in China, it is likely that, if no effective policies or building energy efficiency (BEE) measures are implemented in time, building energy consumption in China will account for at least 40% of total energy consumption in the future (Pérez-Lombard et al., 2008). Thus, improving BEE is important for preserving the environment while maintaining economic and social development in China.

There were 47 Gm^2 (1 $Gm^2 = 1 \times 10^9$ m^2) of civil building floor area in China at the end of 2011, a figure that has increased rapidly in the ensuing years (Ding et al., 2011). Statistics (National Bureau of Statistics of China, 2014) show that the annual increase in floor area rose from 1.82 Gm^2 in 2001 to 3.50 Gm^2 in 2013, and the average annual increase in floor area during this timeframe was 2.58 Gm^2. The annual increase in urban floor area rose from 0.85 Gm^2 in 2001 to 2.57 Gm^2 in 2013, and the average annual increase in floor area during this time was 1.51 Gm^2. As shown in Fig. 2, the increases in floor area in 2001 are used as reference values to illustrate the development of annual increases in floor area. The annual growth rates for increases in total and urban floor area, as compared to the prior year, are also presented in Fig. 2. Total floor area can be divided into two parts: urban floor area and rural floor area. Urban buildings are governed by mandatory BEE regulations. Rural buildings are constructed by rural households for whom BEE technologies are optional. The compliance rates discussed in this paper refer to compliance with BEE codes in urban areas.

To reduce building energy consumption in China, a series of measures has been implemented to promote BEE. The main measures are listed as follows:

(1) Improvement of energy codes for new buildings (Li and Shui, 2015). This measure is designed to improve BEE through code enforcement. Compliance rates are used as indicators of this measure's successfulness. This is a fundamental measure proven to be effective in developed countries such as the US and the EU. The US government has contributed to the development of model codes and has required that states consider adopting them since 1977. Most states in the US have adopted codes based on model codes (Doris et al., 2009). In the EU, the implementation of the *Energy Performance of Buildings Directive* (2002/91/EC) has resulted in a phased change in the energy requirements found in building regulations (Economidou, 2012; Atanasiu et al., 2014).

(2) Energy labelling and evaluation of buildings (Li and Shui, 2015; Zheng et al., 2012). This measure requires that the energy consumption of buildings be posted on the building and publicised. In the US, national labelling standards come

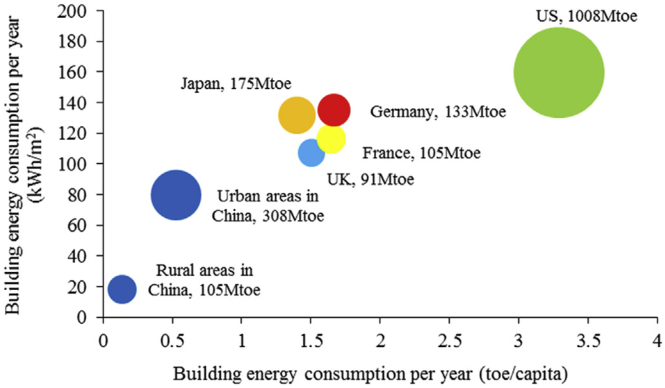

Fig. 1. Comparison of building energy consumption in China and developed countries in 2008 (Sources: Building Energy Research Centre of Tsinghua University, 2012; Energy Data and Modelling Centre, 2012; Department of Energy, 2011; European Commission, 2008).

Notes: (1) Numbers listed after country names refer to total energy consumption in the building sector. (2) According to Building Energy Research Centre of Tsinghua University (2012), the consumption of coal equivalent (ce) for electricity generation in China in 2008 was used for the unit conversion in the calculation of energy use intensity in the aforementioned countries. 1 kWh = 3.26×10^{-4} tce = 2.28×10^{-4} toe.

in two forms: comparative (Energy Guide) and endorsements (ENERGY STAR) (Doris et al., 2009). In the EU, a similar measure called the "building energy certification" has been implemented (Pérez-Lombard et al., 2009).

(3) Heat metering and energy efficiency retrofits for existing residential buildings in northern heating regions (Ding et al., 2011). This measure is designed to improve building energy performance and the indoor environment in heating regions. The US federal government has also provided significant financial assistance to support existing building retrofits (Ma et al., 2012). Building retrofits are also an effective means by which to meet the climate and energy targets set for 2020 and 2050 in the EU (Buildings Performance Institute Europe, 2015).

(4) Increasing the use of renewable energy sources in the building sector (Kong et al., 2012). This measure is designed to increase the use of renewable energy sources (such as solar energy and geothermal energy) in buildings. The Member States of the EU are required to increase the shares of energy from all renewable sources in the building sector, according to the EU Directive 2009/28/EC (European Commission, 2009).

(5) Energy efficiency supervision over government office buildings and large public buildings (Kong et al., 2012). This measure focuses on identifying energy consumption in government office buildings and large public buildings. This measure is similar to a national survey carried out in the US called the "Commercial Buildings Energy Consumption Survey" (Energy Information Administration, 2012).

Of the aforementioned measures, the enforcement of energy codes for new buildings plays a leading role in BEE. If new buildings do not meet BEE codes, 1.51 Gm^2 of high energy-consuming buildings would be constructed annually, albatrosses for a developing country.

The enforcement of BEE codes in China has been significant over the past decade. However, because little research has focused on the measures' abilities to promote the energy efficiency of new buildings, some researchers have expressed doubt about the improvement in BEE code compliance rates. To address these doubts, this paper first summarises the development of the BEE code system in China. Next, the paper analyses the key measures implemented by the Chinese government, including (1) the improvement to the BEE legal system, (2) the establishment of a whole-process BEE supervision system, (3) the supervision of construction quality, (4) the adoption of compliance rates with mandatory civil building energy efficiency codes (MCBEEC) as an assessment index for local governments, and (5) the inspection of BEE annually in detail. The entire assessment and reporting process related to compliance rates is then reviewed. Finally, the impact of the improvement in MCBEEC compliance rates on energy savings in China is discussed in this paper.

2. The Chinese BEE code framework

The Chinese government began to establish the BEE code system 30 years ago, and now it is nearly complete. The development process of the BEE code system can be roughly classified into 3 stages, with each stage representing mandatory codes designed to reduce building energy consumption by 30%, 50% and 65%

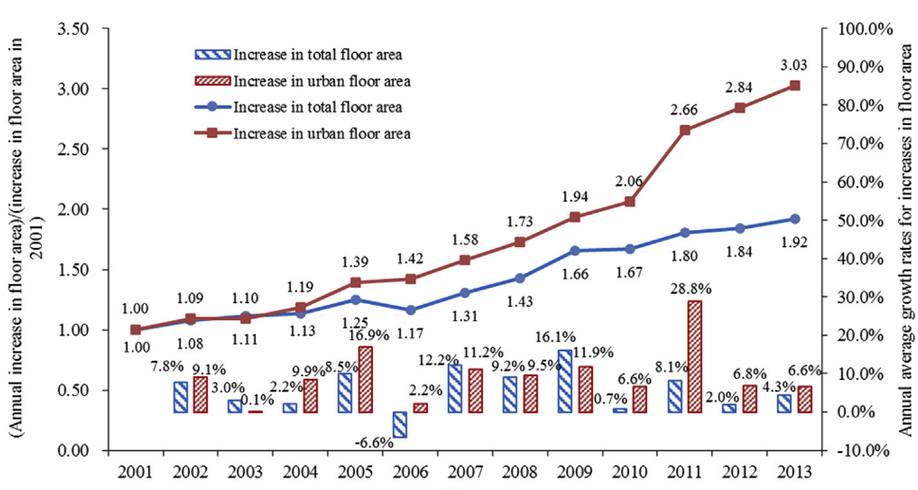

Fig. 2. Annual increases in floor area in China (Source: National Bureau of Statistics of China, 2014).

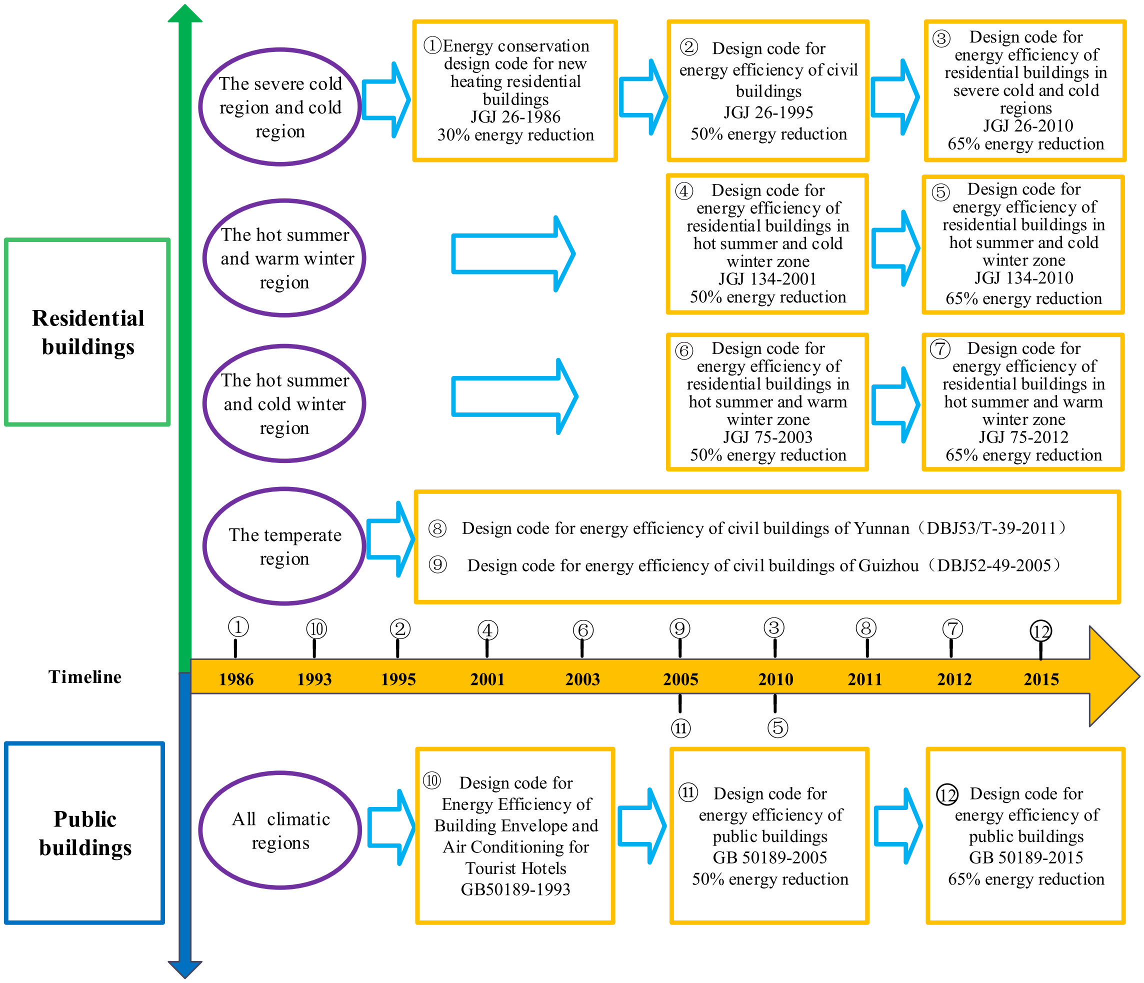

Fig. 3. The Chinese BEE code framework.

compared to buildings built in 1980–1981. As shown in Fig. 3, the code system can be divided into 2 categories: residential and public buildings. It can also be divided into 5 categories according to climatic regions: severely cold, cold, hot summer and warm winter, hot summer and cold winter, and temperate. It should be noted that the energy consumption of baseline buildings built in 1980–1981 is not a measured value but a calculated value. Baseline buildings refer to buildings designed according to the codes in force in 1980–1981. The energy consumption of baseline buildings was calculated by assuming the same indoor thermal environment (such as temperature, ventilation rate, lighting intensity and so on) as that within objective buildings (Lang, 2002). The identification of building energy consumption reduction rates varies with building category and climatic region. For example, for residential buildings in severe cold and cold regions, 50% energy consumption reduction refers to a reduction in the building's heating energy consumption by 50% compared with buildings built in 1980–1981. A comparison of energy consumption reduction for different building categories and climatic regions is shown in Table 1.

Table 1
Comparison of energy consumption reduction for different building categories and climatic regions (Source: Lin and Lang, 2007).

Building categories	Climatic region	Composing of energy consumption reduction
Residential buildings	Severe cold region and Cold region	Heating energy consumption
	The other regions	Heating and air-conditioning energy consumption
Public buildings	All regions	Energy consumption of heating, air-conditioning and lighting

The Chinese residential building code system was established from north to south by the Ministry of Construction (MOC, transformed into the Ministry of Housing and Urban–Rural Development, or MOHURD, in 2008). Because heating energy consumption in the northern region of China was 91 Mtoe annually at the end of the 1980s and accounted for approximately 11.5% of total energy consumption in China, heating was the main driver of energy consumption reduction initiatives in civil buildings (Lang, 2002). For that reason, BEE codes for the northern heating region of China were the first to be researched and developed. The BEE design codes for the severe cold and cold regions, the hot summer and cold winter region, and the hot summer and warm winter region were first implemented in 1986, 2001 and 2003, respectively. The temperate region mainly consists of Yunnan and Guizhou provinces. The average temperature in this region is higher than 9 °C in the winter and between 18 °C and 25 °C in the summer (Zhou et al., 2004). Because of the temperate climate, there is no need for heating or air-conditioning systems in residential buildings, and building energy consumption is relatively low. For this reason, there is no national BEE code for the temperate region. When the local codes for residential building energy efficiency were released by Guizhou province and Yunnan province in 2005 and 2011, respectively, all of the climatic regions in China had residential BEE codes that could be used for reference.

For public buildings, the MOC released the *Design Code for Energy Efficiency of Building Envelope and Air Conditioning for Tourist Hotels* (GB50189-1993) in 1993, which was the first specialised BEE code for public buildings in China. This code was only suitable for hotels. It did not include other public buildings, such as government office buildings, hospitals, shopping malls, etc. The *Design Code for Energy Efficiency of Public Buildings* (GB50189-2005) was released in 2005, which not only included other categories of public buildings but also raised the level of energy consumption reduction from 30% to 50%. GB50189-2015 was released in 2015 and raised the level of energy consumption reduction from 50% to 65%.

3. The BEE supervision system

To enforce MCBEEC, a series of measures have been released and implemented in China.

3.1. Improvement in the BEE legal system

Since the *Energy Conservation Interim Ordinance* (State Council, 1986) was released in 1986, the legal framework in support of BEE has continued to develop, as shown in Fig. 4.

3.1.1. Basic laws

(1) The *Energy Conservation Interim Ordinance* was released by the State Council in 1986 and provided overall direction for BEE efforts in China. This ordinance was the only specialised BEE law at first, and it was annulled after the *Energy Conservation Law* was enacted in 1997 (State Council, 1997). The articles related to energy efficiency of new buildings in this ordinance primarily addressed the application of advanced technologies and equipment in new buildings, the revision of design codes, demonstration of energy efficiency in a building project feasibility study, and the prohibition of unqualified building projects.

(2) The *Energy Conservation Law* was released in 1997 and revised in 2007 (State Council, 2007a). This law emphasises the importance of energy conservation and indicates that energy conservation is a long-term strategic principle for economic and social development in China. The articles related to energy efficiency in new buildings primarily address the duties of the design, planning, construction and supervision organisations, the prohibition of unqualified projects, the application of advanced technologies and equipment in new buildings, and requirements for the provision of BEE labelling and information to customers.

3.1.2. Specialised ordinances

(1) The *Quality Management Ordinance for Construction* was released in 2000 (State Council, 2000). This ordinance applies to all construction. Compliance with BEE codes is included in the supervision targets, according to the *Quality Management Ordinance for Construction*, because there are many mandatory articles among the various BEE codes. This ordinance prescribes the implementation of a construction quality supervision system in China, which requires the State Council to be in charge of supervising nationwide construction and local governments to be in charge of supervising construction under their jurisdiction. The articles related to the energy efficiency of new buildings in this ordinance primarily address the duties of the national and local governments in relation to strengthening the BEE supervision and inspection, as well as project inspection and supervision requirements.

(2) The *Management of Energy Conservation Regulation for Civil Buildings* was released in 2000 (MOC, 2000a). This regulation was implemented temporarily prior to the release of the specialised BEE ordinance.

The *Energy Conservation Ordinance for Civil Buildings* was released in 2008 (State Council, 2008). This ordinance is the first administrative ordinance specialised for BEE and is an indispensable aspect of the BEE legal system. BEE is classified and defined in detail, and an overall supervision system is established specifically to promote BEE. Compliance with mandatory articles is included in the inspection system outlined in this ordinance.

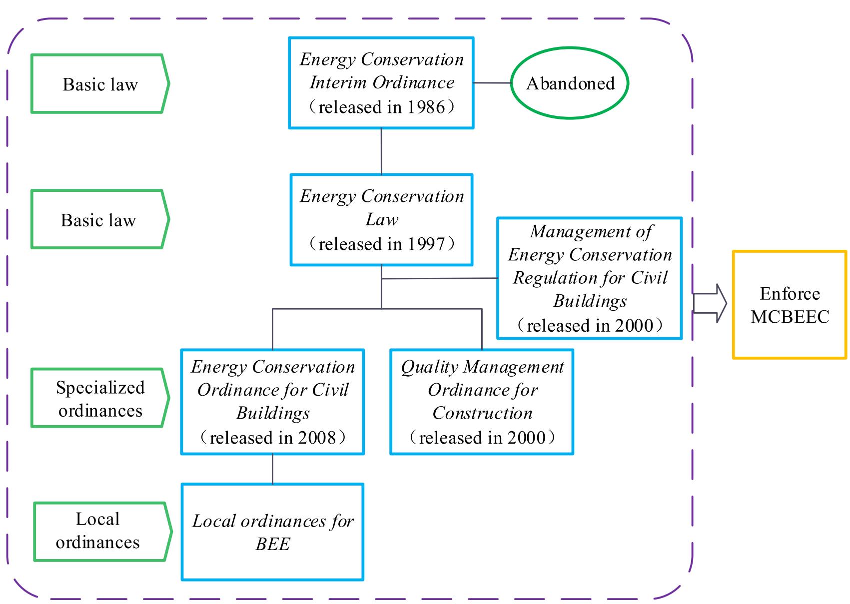

Fig. 4. The BEE legal system.

3.1.3. *Local ordinances*

The release of the *Energy Conservation Ordinance for Civil Buildings* improved the legal framework for BEE in China. By the end of 2011, 14 provincial governments had released specialised local BEE ordinances and 24 provincial governments had released governmental prescripts for BEE. With these local developments, the legal framework to support BEE efforts has been finalised in China, with the *Energy Conservation Law* as fundamental national law, the *Energy Conservation Ordinance for Civil Buildings* and *Quality Management Ordinance for Construction* as substantive guides, and local regulations as complementary standards. This legal system can effectively lead to the construction of new buildings in accordance with the BEE codes. Therefore, it effectively ensures that MCBEEC compliance rates will increase.

3.2. *Establishment of a whole-process BEE supervision system*

All processes related to planning, design, construction and acceptance of buildings are important to increasing compliance rates. Inability to meet the standards during any of these processes will directly affect the MCBEEC compliance rates. To increase the supervision of compliance with the MCBEEC, the MOHURD has required local governments to implement a whole-process supervision system that oversees the energy efficiency of new buildings. The specific articles in the *Energy Conservation Ordinance for Civil Buildings* are outlined as follows:

(1) In the planning stage, the urban–rural planning administration should determine whether the project plan meets the MCBEEC by seeking advice from the construction administration. The planning administration must not grant planning permissions to unqualified projects.
(2) In the design stage, the design drawings must meet the MCBEEC. The organisations responsible for reviewing construction drawings should examine the construction drawings for consistency with the MCBEEC and must not grant construction permissions to unqualified projects.
(3) In the construction stage, developers cannot require designers and builders to violate the MCBEEC. Related organisations and workers must strictly execute the MCBEEC.
(4) In the acceptance stage, developers should regard the compliance with MCBEEC as an important target. Certified acceptance reports must not be granted to unqualified projects. The owners of new government office buildings and large-scale buildings should organise the testing and labelling of said buildings with relevant BEE standards and publicise the results in accordance with relevant requirements.
(5) In the sale stage, estate development companies should publicise BEE information about the building, including energy consumption indices, energy-efficient technologies and insulation warranties, for consumers.
(6) In the after-sale service stage, builders should be responsible for the quality of the building insulation. If the building insulation is broken during the warranty period, the builder should be responsible for repairing it. If not repaired in a timely fashion, the builder should be responsible for compensating the injured party for related losses (i.e., damage caused by the absence of building insulation).

The establishment of the whole-process BEE supervision system enforces supervision of MCBEEC compliance for a building's lifetime. All of the organisations should be responsible for compliance with MCBEEC in different stages.

Stage 6 is important to ensure a high compliance rate, but it is not included in the annual national inspections of BEE (analysed in the Section 4). National BEE inspections focus on new buildings under construction or completed in the same year, and stage 6 usually does not cover them.

3.3. *Inclusion of MCBEEC compliance in the construction quality supervision system*

To ensure that completed buildings meet BEE codes, certain articles in the codes are mandatory and must be complied with during construction. Mandatory articles are extremely important in the codes and are included in the national inspections, although they are a small portion of the entire code system. The construction quality supervision system was gradually established beginning in the mid-1980s to intensify supervision over construction quality. This system includes 2 parts: supervision over construction quality and supervision over the organisations responsible for supervising building development in different stages (MOC, 2000b; MOC, 2003). Building projects are an important component in the construction process and are included in the supervision system. The construction quality supervision system is outlined in Fig. 5.

As the supervision system was established, third party quality supervision administrations were also established. These administrations included independent juridical individuals entrusted by

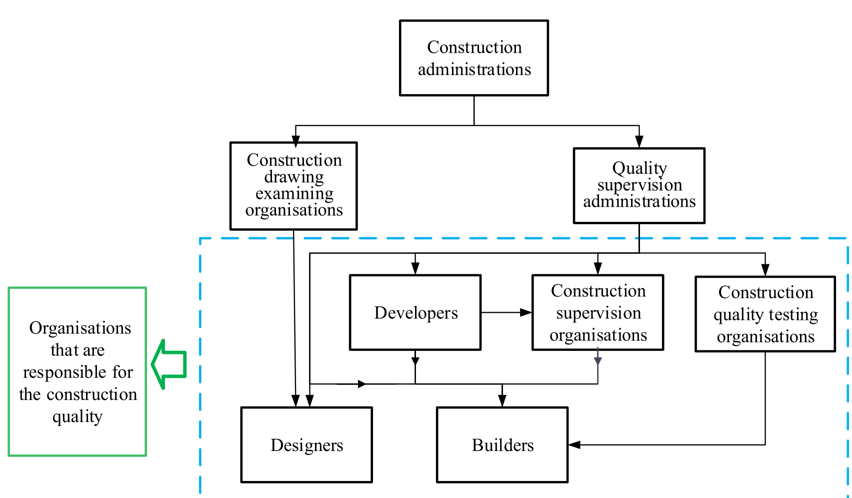

Fig. 5. Construction quality supervision system (Sources: MOC, 2000b, 2003).

local governments with the responsibility of supervising construction quality. More than 95% of cities have established a quality supervision administration (Xie et al., 2007). The actual supervision system in China is divided into three grades: the first grade consists of construction administrations and quality supervision administrations; the second grade consists of developers and construction supervision organisations; and the third grade consists of survey and designers and builders.

The quality supervision administrations entrusted by the local governments supervise construction quality by performing the following functions:

(1) Inspecting construction for MCBEEC compliance.
(2) Inspecting construction quality for major structural security and primary functions.
(3) Inspecting the operations of organisations responsible for construction quality.
(4) Inspecting the quality of building materials and components.
(5) Determining acceptance.
(6) Organising or taking part in investigations and handling accidents.
(7) Performing regular statistical analyses of construction quality.
(8) Citing out-of-compliance projects according to related laws.

The quality supervision administrations analysed here are different from construction supervision organisations. Construction supervision organisations are given the responsibility of supervising builders and construction quality by developers. The goals of construction supervision organisations include quality inspections and investment assessments. These organisations are also in charge of controlling the project timeframe and reconciling the relationships between different organisations.

Except for daily supervision organised by quality supervision administrations, annual inspections are organised by national and provincial administrations in the form of patrols, secret investigations and differentiating inspections. For example, 16,265 inspections were conducted in Beijing in 2011 to ensure construction quality; of those, 1761 punitive notifications were issued (MOHURD, 2011a). Inspection results are addressed in the following ways:

(1) Issuing punitive notifications to unqualified projects.
(2) Punishing the companies and persons responsible for the unqualified projects by limiting their qualifications for future construction and bidding.
(3) Forbidding the companies and persons responsible for seriously illegal projects from participating in construction forever.

The entire system of supervision over the energy efficiency of new buildings is a prerequisite to the implementation of a system of supervision over construction quality in general. Conversely, the system of supervision over construction quality is an important guarantee for BEE supervision. Both systems are implemented to enforce MCBEEC.

3.4. Adoption of MCBEEC compliance rates as an assessment index for local governments

Local governments execute the majority of BEE efforts. The failure of local governments to implement the policies or supervise building projects as required directly affects MCBEEC compliance rates. Thus, compliance with MCBEEC has been adopted as an assessment index for local governments to encourage them to attach more importance to the energy efficiency of new buildings.

The State Council of China released the *Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 11th Five-Year Plan* in 2007 (State Council, 2007b). In the assessment of local governments, this work plan required local governments to adopt the task of energy conservation and emissions reduction in a comprehensive assessment system related to social and economic development. It was regarded as a significant index for leaders in local governments.

In addition to the assessment system, the national State Council put forward an incentive in the *Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 12th Five-Year Plan* released in 2011 (State Council, 2011), which required relevant departments in the national government to encourage and reward regions and persons that made outstanding contributions to energy conservation and emissions reduction.

The assessment system utilised by the local governments in Jiangsu province to promote BEE is analysed as an example. The system is outlined as follows:

(1) Assessment target: all city-level governments.
(2) Assessment method: quantitative.
(3) Assessment indices: the achievement of energy efficiency targets, and the use of energy-efficient methods. The total score for this assessment is 100 points.
   (a) The achievement of energy efficiency targets is a quantitative index. City-level governments are assessed according to their progress toward energy efficiency compared to overall targets and annual targets outlined in the 12th five-year plan, as checked and ratified by provincial statistical bureaus. This index accounts for 40% (40 points) of the total score.
   (b) The improvement of energy efficiency is a qualitative index and accounts for 60% of the total score. BEE objectives are regarded as one component of the major energy efficiency efforts section of this assessment, and account for 7 of the total 12 points available in the section. Compliance rates account for 1.5 of the points in the BEE objectives section.
(4) Assessment grades: exceeds requirements (scores over 95), meets requirements (scores between 80 and 95), nearly meets requirements (scores between 60 and 80) and does not meet requirements (scores under 60).
(5) Rewards and punishments: The achievement of energy efficiency targets is regarded as an important part of the general assessment of city-level governments' performance and the personal assessment of leaders in charge of BEE. The achievement of these goals directly affects opportunities for commendation.

As an important part of energy conservation and emissions reduction in China, the importance of BEE is enhanced and will directly affect the final score of local governments in the assessment system. Using the MCBEEC compliance rate as a BEE assessment index in the development of the assessment system for local governments is an important way to enforce MCBEEC.

4. The BEE inspection system

The BEE inspection system is an effective measure used to check and ensure the implementation of the BEE supervision system. Four conventional measures in the supervision system used to enforce MCBEEC cover all new buildings. The supervision system plays a crucial role during the construction of new buildings. However, certain subjective or human-related factors, such as cheating action or negligence, may result in some unqualified buildings passing the supervision system and being accepted. Therefore, the BEE inspection system are necessary to check and enforce MCBEEC by sampling buildings after the construction process.

Annual inspections are conducted at two levels: the national level and the provincial level.

(1) National inspections of BEE: the MOC conducted the first national inspection of energy conservation and emissions reductions in the building sector in 2005. The primary inspection modes were formed in 2006. A national inspection is conducted annually, and the eighth national inspection was conducted at the end of 2012.
(2) Provincial inspections of BEE: all of the provinces (municipalities, autonomous regions) in China except Tibet have established periodic or non-periodic BEE inspections.

A comprehensive flow diagram of the BEE inspection system is shown in Fig. 6.

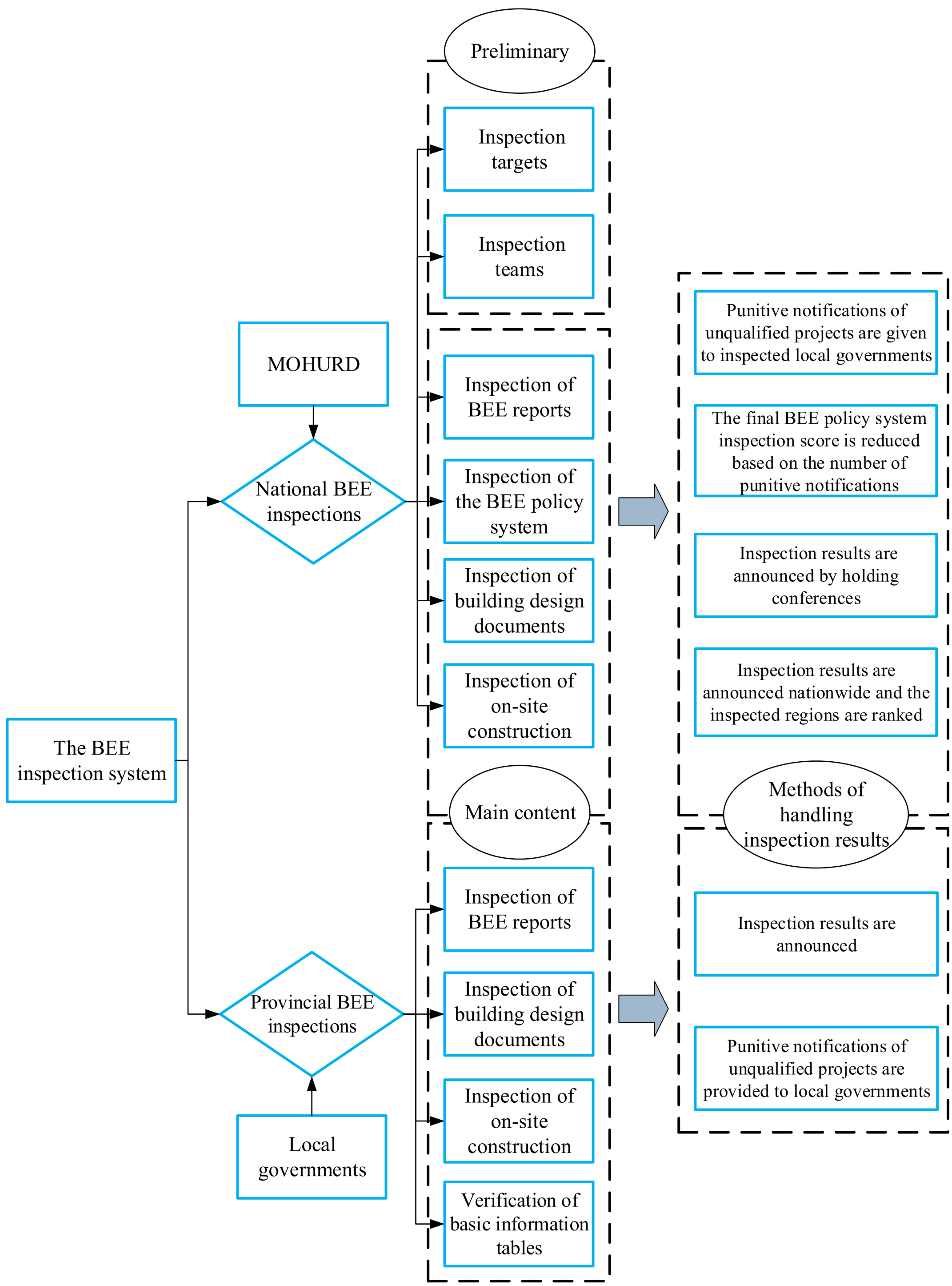

Fig. 6. Comprehensive flow diagram of the Chinese BEE inspection system.

4.1. National BEE inspections

The energy efficiency of new buildings is one of the most important components of BEE in China, so MCBEEC compliance rates are key indices used to assess the BEE achievements of local governments.

4.1.1. Preliminary

1. Inspection targets

In principle, the inspected regions comprise 26 provinces (autonomous regions), excluding Tibet, 4 municipalities (Beijing, Shanghai, Tianjin and Chongqing) and 5 cities specifically designated in state planning (Dalian, Qingdao, Ningbo, Xiamen and Shenzhen). Every provincial capital city is inspected. In addition, one prefecture-level city is randomly selected in each province (municipality, autonomous region) for inspection. The estimated total number of inspected cities was 61 from 2006 to 2008. Because BEE efforts in the provincial capitals and prefecture-level cities was far more effective than those in the county-level cities, one more county-level city (district) in each province (municipality, autonomous region) was randomly selected to be inspected in 2009. Thus, the estimated number of inspected regions included 61 prefecture-level cities and 35 county-level cities (districts). In reality, the actual number of inspected areas differs annually because of natural factors such as earthquakes, which limit the inspectors' abilities to reach certain locations. The numbers of inspected cities from 2006 to 2012 are shown in Fig. 7.

2. Inspection teams

Inspection teams are usually organised two weeks before the start of a national inspection. The members of each inspection team are selected from all over the country. No inspector is allowed to inspect the place he comes from. There are generally 10 inspection teams in total every year.

Members of the inspection teams include a team leader, a secretary-general, liaisons and inspection experts (shown in Table 2).

The duration of the inspection process is approximately 60 days. Preparations take approximately 15 days; inspections last approximately 15 days; and document organisation after the inspections usually requires approximately 30 days.

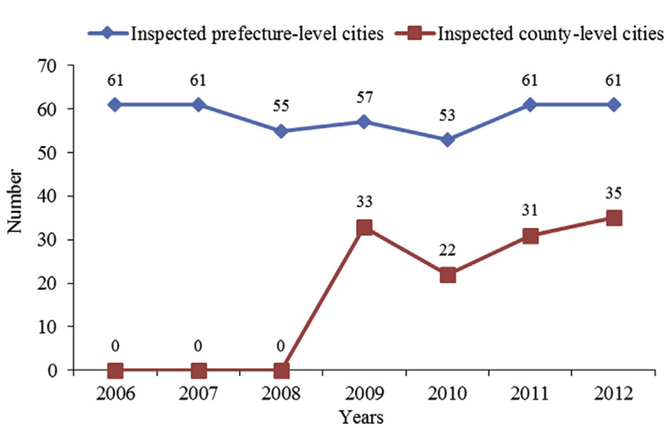

Fig. 7. Number of inspected cities (Sources: MOHURD, 2008b, 2010a, 2011b, 2012a, 2013).

Table 2
Members of an inspection team and their duties.

	Amount	Duties
Team leader	1	The team leader is responsible for overseeing all of the inspection work
Secretary-general	1	The secretary-general is responsible for writing the drafts of the inspection reports
Liaisons	3	The liaisons are responsible for making an inspection schedule and communicating with inspected organisations
Inspection experts	8	The inspection experts are responsible for inspecting the policy, building design documents and on-site construction
Total	13	–

4.1.2. Inspection content

Implementing BEE inspections is a comprehensive way to assess BEE in the provinces (municipalities, autonomous regions). These inspections include four components: inspection of BEE reports; inspection of the BEE policy system; inspection of building design documents; and inspection of on-site construction. These four components have been the focus of each national inspection since 2005 and are regarded as the keys to effectively promoting MCBEEC compliance.

1. Inspection of BEE reports

Inspection teams assess the overall BEE efforts of construction administrations according to reports prepared by local construction administrations. All of the following inspection components are related to these reports, which include the MCBEEC compliance rates at the design and construction stages.

2. Inspection of the BEE policy system

Inspection teams score the BEE efforts of administrations based on a BEE scoring system by checking issued policies and relevant documents. This score is an overall assessment of the BEE efforts made by local governments. New building energy efficiency progress is one component of this assessment. Because the severe cold and cold regions in China require building heating measures, heat metering and energy efficiency retrofits for existing residential buildings are just executed in these two regions. These efforts account for a certain portion of the scores in these two regions (heating regions). Therefore, scores for new buildings located in the severe cold and cold regions are different from those in other climatic regions.

In the scoring system, score weights represent the importance of certain components in the national inspections. In other words, if an effort is given more weight in the scoring system, local governments should pay more attention to it in practice. The weight given to the energy efficiency of new buildings in the BEE scoring system is shown in Fig. 8.

As shown in Fig. 8, the highest weight given to new building energy efficiency in the severe cold and cold regions was 34.2% in 2007 and 2008; the highest weight given in the other climatic regions was 40.6% in 2007 and 2008, illustrating that new buildings were the primary focus of inspections in these years.

On average, the score for new building energy efficiency accounted for 36.7% of the total inspection score in 2006. This value increased to 37.4% in 2007 and 2008, its highest point. The minimum weight given to this sector was 27.6%, which first appeared in 2009 and has remained constant since.

To increase compliance rates, the weight of new building energy efficiency remained high from 2006 to 2008. With increasing

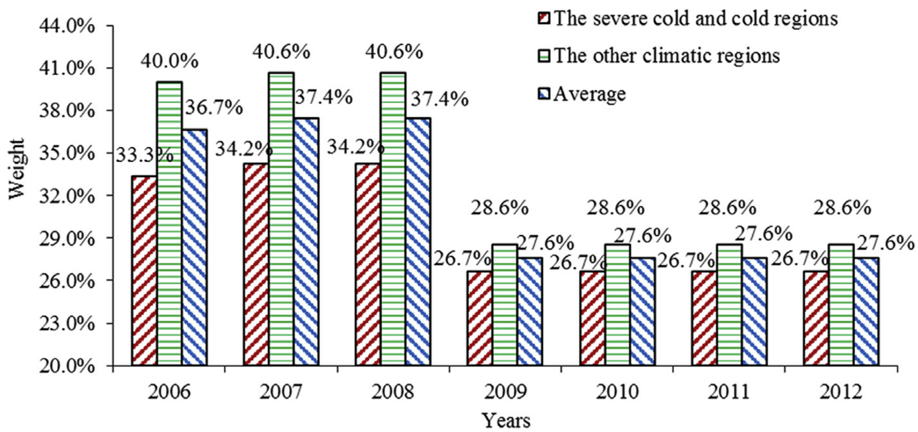

Fig. 8. Weight given to the energy efficiency of new buildings in the BEE scoring system (Sources: MOC, 2006b, 2007; MOHURD, 2008c, 2009, 2010b, 2011c, 2012b).
Notes: The BEE scoring system was divided into three levels from 2006 to 2008: the provincial (autonomous regional) level, the municipal level and the prefecture level. Among these three levels, the scores for new buildings were slightly different from each other. In 2009, the three levels were integrated. This paper uses the provincial (autonomous regional) level of the BEE scoring system from 2006 to 2008 to make comparisons.

compliance, this weight was readjusted. In 2009, compliance rates were nearly 99% in the design stage and 90% in the construction stage, meeting the 90% compliance objective for the construction stage set by the State Council of China. The inspection scoring system remained identical in the following 4 years analysed.

The score for new buildings includes seven criteria: market access system related to new buildings, BEE public notification system, the release of local codes and rules for compliance with the national codes, etc. (shown in Fig. 9).

The seven criteria in the scores for new buildings are explained as follows:

(1) Market access related to new buildings (L1, Fig. 9). This criterion addresses four requirements: (a) BEE is taken into account in the supervision of the construction plan; (b) mandatory items in the BEE codes are included in the supervision of building design drawings; (c) mandatory items in the BEE codes are strictly supervised in the construction stage; and (d) mandatory items in the BEE codes are reviewed and confirmed at the acceptance stage.
(2) Public notification system (L2, Fig. 9). This criterion addresses two requirements: (a) publicising a building's energy efficiency information, such as energy consumption indices, energy-efficient technologies and insulation warranties, to consumers at sale; and (b) releasing a guide associated with the building's specific energy information.

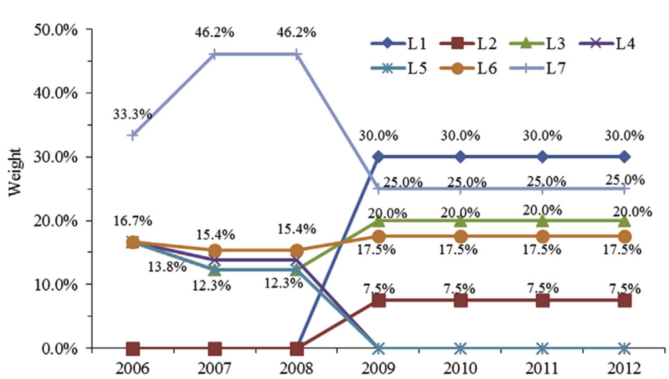

Fig. 9. Weights of seven criteria among the scores for new buildings (Sources: MOC, 2006b, 2007; MOHURD, 2008c, 2009, 2010b, 2011c, 2012b).

(3) The release of local codes and rules in compliance with national codes (L3, Fig. 9). This criterion requires local governments to release local codes and rules to meet BEE requirements specific to their region.
(4) The release of collections of standard design drawings and technical regulations related to BEE codes (L4, Fig. 9). This criterion requires local governments to release collections of standard design drawings to guide BEE design. In addition, technical regulations associated with BEE codes are required.
(5) Establishment of a special BEE administration (L5, Fig. 9). This criterion requires local governments to establish special BEE administrations which are in charge of BEE efforts overall.
(6) Periodic BEE inspections (L6, Fig. 9). This criterion requires local governments to implement annual provincial BEE inspections.
(7) MCBEEC compliance rates (L7, Fig. 9). This criterion is scored according to the MCBEEC compliance rates in the area. Based on the compliance rates, an inspected province is scored according to a comparison with average level from the previous year.

3. Inspection of building design documents. Because the design of construction drawings is the first key step in MCBEEC compliance, the failure of construction drawings to meet relevant BEE codes directly affects compliance rates. The inspection of a building's design documents has become an essential part of the annual BEE inspections. The selection of inspected building projects can be divided into 2 stages.

(1) In stage one, which lasted from 2006 to 2008, inspected building projects were randomly selected from within provincial capitals and prefecture-level cities. County-level cities were not included in the inspected cities.
(2) In stage two, which began in 2009, inspected building projects were also selected from within county-level cities. One public building project and 2 residential building projects were selected in each county-level city.

The total number of buildings selected for design document examination in each national inspection is shown in Fig. 10.

As shown in Fig. 10, the type and number of inspected buildings drastically fluctuated during the initial inspections because the

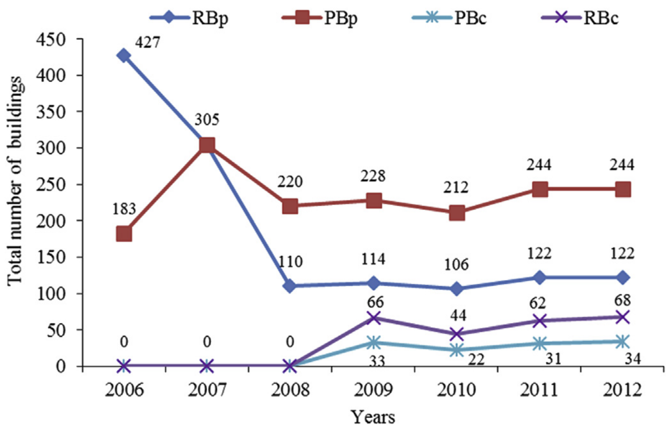

Fig. 10. Total number of buildings selected for design document examination in each national inspection (Sources: MOHURD, 2008b, 2010a, 2011b, 2012a, 2013).
Notes: RBp represents the residential buildings selected in all provincial capitals and prefecture-level cities; PBp represents the public buildings selected in all provincial capitals and prefecture-level cities; PBc represents the public buildings selected in all county-level cities; RBc represents the residential buildings selected in all county-level cities.

inspection system was not completely established at that time. In 2009, the scope of inspections was extended, and county-level cities were included in the inspections.

4. Inspection of on-site construction

The on-site construction of building projects is the final step in BEE technology implementation. Shoddy work and inferior materials may severely influence the implementation of BEE technologies, so the supervision of on-site construction is essential to the attainment of BEE targets. Inspections of on-site construction of new buildings in the provincial capitals and prefecture-level cities began in 2008 to improve the supervision process. Four public and two residential building projects were randomly selected for inspection from each city. County-level cities were included in the list of inspected cities in 2009, and one public and two residential building projects were selected for inspection from each city. The total number of buildings selected for on-site examination of construction in each national inspection is shown in Fig. 11.

As shown in Fig. 11, the number of buildings inspected on-site has been nearly constant since 2008. Based on the inspection of

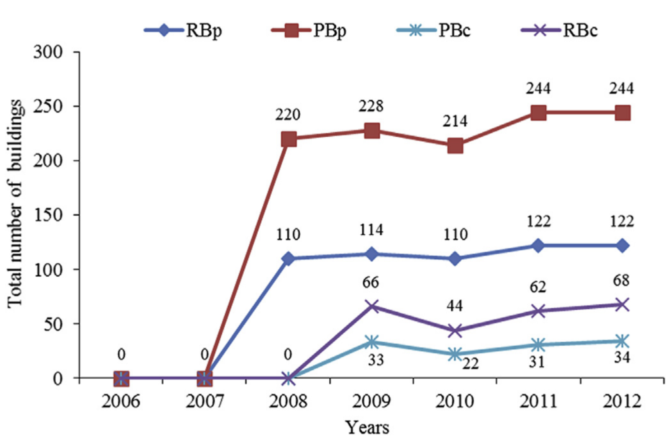

Fig. 11. Total number of buildings selected for on-site examination of construction in each national inspection (Sources: MOHURD, 2008b, 2010a, 2011b, 2012a, 2013).
Notes: The legends in Fig. 11 are the same as in Fig. 10.

building design documents, the ratio between inspected public and residential buildings was nearly 2:1 for both inspections of building design documents and on-site construction in provincial capitals and prefecture-level cities. This ratio indicates that BEE in public buildings has become more intensively supervised than that in residential buildings in China. This is because the average energy consumption per area in public buildings is much larger than that in residential buildings in China (Zhao et al., 2009). According to statistics calculated by Dai and Wu (2007), the annual electricity consumption of large-scale public buildings is 70–300 kWh/(m^2) per year, which is 10–20 times more than that of residential buildings. Furthermore, public buildings will consume an increasing amount of energy in the future, which cannot be offset by energy efficiency improvements (Zhou and Lin, 2008). The ratio between inspected building design documents and on-site construction for public and residential buildings in county-level cities is only 1:2. This ratio will likely keep increasing in the future.

4.1.3. Methods of handling inspection results

There are four methods of handling inspection results

(1) Punitive notifications of unqualified projects are given to inspected local governments. When the inspection work is complete, each inspection team issues punitive notifications about unqualified projects to the respective local governments. These notifications unambiguously list all project information and illegal behaviours identified during the construction process. Each local government is required to address these problems and report changes to the MOHURD within 15 weekdays. Projects are regarded as qualified when all issues are rectified.
(2) The final BEE policy system inspection score is reduced based on the number of punitive notifications. It is stipulated in the scoring system that certain points will be deducted for each punitive notification. An inspection team will deduct points according to the number of punitive notifications related to unqualified projects. If a province is not given punitive notifications, this criterion's score will be 0 (otherwise negative scores will be marked). The final BEE policy system inspection score is an overall assessment of the areas BEE efforts. In addition, this score is the basis for inspected provinces' (municipalities, autonomous regions) energy efficiency rankings. By ranking the provinces nationally, the government can effectively encourage local administrations to attach more importance to the punitive notifications of unqualified projects.
(3) Inspection results are announced by holding conferences. A conference is held by each inspection team at the end of the BEE inspection in each province (municipality, autonomous region). The leaders in charge of the BEE efforts in each province (municipality, autonomous region) are required to attend this conference and respond to the inspection results.
(4) Inspection results are announced nationwide and the inspected regions are ranked. The MOHURD releases an official announcement after analysing the nationwide inspection results and ranks the inspected provinces (municipalities, autonomous regions) using a score that consists of the policy system inspection, the design document inspection and the on-site construction inspection. Inspected provinces (municipalities, autonomous regions) with high scores are commended in the official announcement in order of their ranking.

4.2. Provincial BEE inspections

In addition to the national BEE inspections, provincial inspections are also important for ensuring compliance with MCBEEC in China (State Council, 2007b, 2011).

There are two modes of provincial inspections:

(1) The provincial construction administrations conduct BEE inspections that include almost all of the BEE work in China, such as new building energy efficiency, heat metering and energy efficiency retrofitting for existing residential buildings in northern heating regions; applying renewable energy systems in buildings; and constructing a system of supervision over the energy efficiency of government office buildings and large public buildings. The energy efficiency of new buildings is also a key part of the provincial inspection, which follows the same pattern as the national inspection.
(2) The provincial BEE inspections can be combined with the construction quality inspections. Building construction has been included in the system for supervising construction quality, in which MCBEEC compliance plays an important part (MOC, 2006a; MOHURD, 2008a). Because the planning, design, construction and acceptance of new buildings are all supervised during the inspections of construction quality, the compliance with MCBEEC is effectively ensured.

There are 4 procedures governing the provincial inspections of BEE, which are analogous to the national inspections.

(1) The inspected local administrations are required to submit reports to the inspection team.
(2) Building design documents are inspected.
(3) On-site construction are inspected.
(4) Basic information tables are verified by the inspection team.

There are 2 methods of presenting the results of provincial inspections, which are also analogous to the national inspections.

(1) Inspection results are announced.
(2) Punitive notifications of unqualified projects are provided to local governments.

The national inspections focus on the overall assessment of BEE work in the provinces (municipalities, autonomous regions) and aim to supervise the general condition of the provinces but not the details of every city. Because the provincial inspections include almost all cities, they are effective supplements to the national inspections. According to 2012 data, the number of provincial inspections was approximately 60 and the number of punitive notifications of illegal projects in provincial inspections was approximately 500, which illustrates the ability of the provincial inspections to ensuring compliance with the MCBEEC.

5. The assessment and reporting of compliance rates

The process for assessing and reporting compliance rates in China is shown in Fig. 12.

As shown in Fig. 12, a provincial BEE inspection usually precedes the national inspection. Provincial MCBEEC compliance rates, which are calculated during provincial inspections, are submitted to the relevant national inspection team. That inspection team then confirms the MCBEEC compliance rates by inspecting design documents and on-site construction. MOHURD gathers data from each

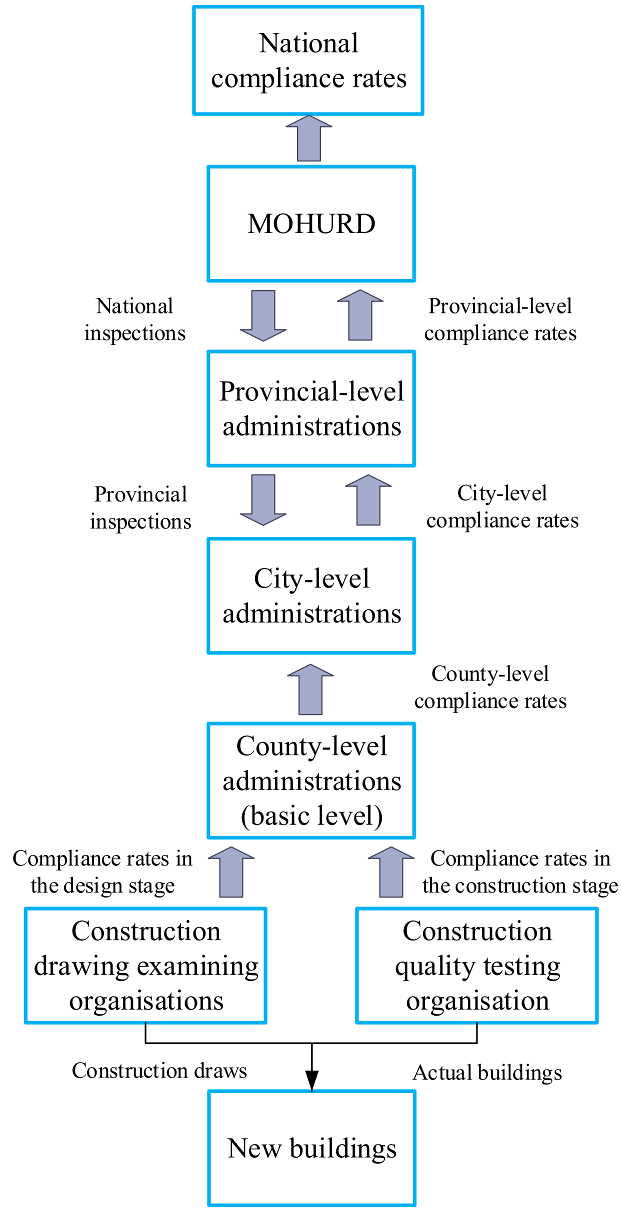

Fig. 12. The process for assessing and reporting compliance rates.

province after the national inspection and calculates the national compliance rate.

The national MCBEEC compliance rate is calculated using formula (1) as follows:

$$P = \frac{\sum_{i=1}^{j} (S_i \times P_i)}{\sum_{i=1}^{j} S_i} \quad (1)$$

where P represents the national compliance rate; i represents an inspected province (municipality, autonomous region); S_i represents the number of new urban buildings completed over the year in province i; P_i represents the provincial compliance rate for province i; and j represents the total number of inspected provinces.

Similar to the provincial compliance rates, city-level compliance rates are checked and calculated by city-level administrations.

At the building level, the compliance rate in the design stage is obtained by the construction drawing examining organisation according to the results of the construction drawing inspection. The compliance rate in the construction stage is obtained by the construction quality testing organisation according to the inspection results of the actual buildings. Compliance rates are collected by county-level administrations at both the design and construction stages. Although the projects inspected in the national and provincial inspections account for a small proportion of all projects, the compliance rates obtained from these level-by-level processes actually covers all new buildings in China.

6. Results and discussion

Compliance rates were very low at the beginning of the implementation of MCBEEC. According to the national statistics in 2000, new buildings in compliance with the BEE codes accounted for only 5.7% of all completed new buildings in China. With the implementation of BEE supervision and inspection systems, these rates increased extremely rapidly over the next ten years, from 5.7% in 2000 to 100% in the design stage and 95.5% in the construction stage in 2011 (MOHURD, 2008b, 2010a, 2011b). In 2012, the compliance rates were nearly 100% (MOHURD, 2013) in both the design and construction stages (Fig. 13). It is worth noting that announced compliance rates reflect only the compliance with mandatory items in the BEE codes in urban areas. Compliance with non-mandatory items and compliance rates in rural areas are not reflected in these figures (Li and Shui, 2015).

Inspection results in 2012 indicate that the MCBEEC compliance rates both close to 100% (MOHURD, 2013). Based on the data released by the MOHURD, the relationship between the energy savings of new buildings per increased floor area per year and compliance rate in the construction stage is shown in Fig. 14.

In residential buildings, energy savings come from heating and air-conditioning energy consumption. While in public buildings, besides the energy savings of heating and air-conditioning, lighting energy saving is also included. Other energy consumption, such as energy consumption for cooking, heating water and so on, is not included in the calculation of energy savings. Buildings built in 1980–1981 are the baseline buildings used to calculate the energy savings. The energy consumption of baseline buildings was calculated by steady-state method based on the heat-transfer coefficients and heat-loss percentages for each part of the envelope in 1980–1981 (Lang, 2004). At the same time, the indoor thermal environment of baseline buildings is assumed the same as that within objective buildings (Lang, 2002). Energy savings of a new building are calculated by multiplying the energy consumption of a

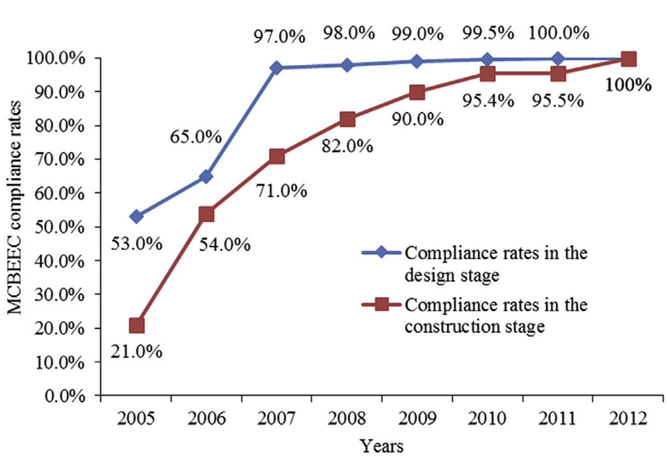

Fig. 13. MCBEEC compliance rates in China from 2005 to 2012 (Sources: MOHURD, 2008b, 2010a, 2011b, 2012a, 2013).

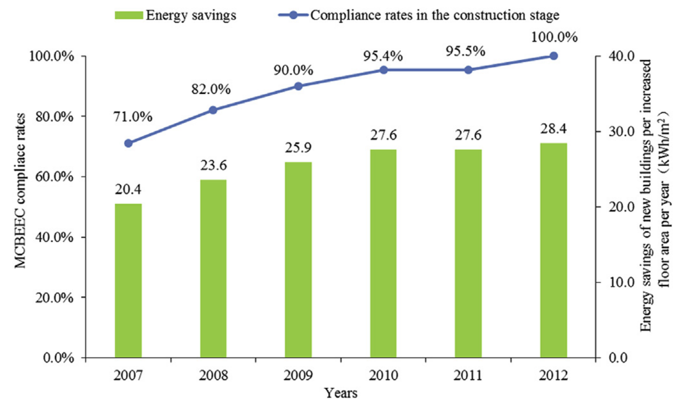

Fig. 14. The energy savings of new buildings per increased floor area per year (Sources: MOHURD, 2008b, 2010a, 2011b, 2012a, 2013).

corresponding baseline building by the energy consumption decreased ratio of this new building (30%, 50%, 65%) (Yang et al., 2011). The calculation of energy savings of new buildings can be expressed by formula (2)–(4).

$$ES_{sr} = E_{br}(k_1, \cdots, k_n) \times R_r \tag{2}$$

$$ES_{sp} = E_{bp}(k'_1, \cdots, k'_n) \times R_p \tag{3}$$

$$ES = \sum_{i=1}^{n} \left(\frac{ES_{sr \cdot i}}{A_{sr \cdot i}} \times A_{r \cdot i} + \frac{ES_{sp \cdot i}}{A_{sp \cdot i}} \times A_{p \cdot i} \right) \tag{4}$$

where ES_{sr} and ES_{sp} separately represent the energy savings of sampled residential buildings; E_{br} and E_{bp} separately represent the energy consumption of baseline buildings corresponding to the sampled residential and public buildings; $k_1,\ldots, k_n$ and $k'_1,\ldots, k'_n$ separately represent the coefficients (such as heat-transfer coefficients) used to calculate the energy consumption of baseline buildings, which can be achieved in energy efficiency codes; R_r and R_p separately represent energy consumption decreased ratios of new residential and public buildings (30%, 50%, 65%); ES represents the total energy savings of new buildings in China; i represents province i; $A_{sr \cdot i}$ and $A_{sp \cdot i}$ separately represent the floor area of sampled residential and public buildings in province i; $A_{r \cdot i}$ and $A_{p \cdot i}$ separately represent the total floor area of residential and public buildings in province i, which can be achieved from the statistical department.

The energy savings of new buildings per increased floor area are the ratios of energy savings to the total amount of new urban building floor area constructed in the same year.

As shown in Fig. 14, the energy savings of new buildings per increased floor area per year increased along with compliance rates in the construction stage. This is because the percentage of energy-efficient buildings in total new buildings increased. Energy-efficient buildings refer to buildings that completely meet relevant MCBEEC requirements in China. Along with the increase in compliance rates at the construction stage from 71% in 2007 to 100% in 2012, the energy savings of new buildings per increased floor area per year rose from 20.4 kWh/m^2 to 28.4 kWh/m^2. From 2006 to 2010, 4.86 Gm^2 of energy-efficient buildings were constructed, which implies a saving of approximately 32.2 Mtoe (MOHURD, 2011b; Li and Shui, 2015).

7. Conclusions

Improving compliance with building energy codes is a basic and effective way to improve BEE. The main purpose of this paper is to identify how the Chinese government enforces MCBEEC. The measures implemented by the Chinese government to enforce MCBEEC are worth referencing to support energy policies in other countries. The BEE supervision and inspection systems are analysed in detail and have been proven to be keys to the enforcement of MCBEEC.

The summary of the Chinese BEE code framework provided in this paper illustrates that the BEE code system reached full implementation when Yunnan and Guizhou provinces enacted their provincial BEE codes for residential buildings. All categories of civil buildings (residential and public buildings) are contained in the current code system.

As the promotion of building energy efficiency in China has increased in recent years, compliance with MCBEEC has also improved, rising from lower than 10% in 2000 to nearly 100% in 2012, a remarkable achievement. Among the BEE measures available, the establishment of a BEE supervision system is a key to enforcing the MCBEEC. The BEE supervision system consists of four components: (1) the improvement in the BEE legal system; (2) the establishment of a whole-process BEE supervision system; (3) the inclusion of MCBEEC compliance in the construction quality supervision system; and (4) the adoption of MCBEEC compliance rates as an assessment index for local governments. Based on the summarised frameworks and content of this paper, these four measures have been separately proven to comprise a successful BEE supervision system: (1) improving the legal system; (2) supervising the entire construction process; (3) drawing support from the effective construction quality supervision system; and (4) inspiring initiative of local governments.

The BEE inspection system is another key to enforcing MCBEEC in China. The details of both the national and provincial inspections are summarised and analysed in this paper and consist of the following components: (1) preliminary; (2) inspection content; and (3) methods of handling inspection results. Based on the analysis above, the inspection system has been proven to be effective and essential to the enforcement of MCBEEC.

The process for assessing and reporting compliance rates was also analysed in this paper. Compliance rates are collected by county-level administrations in both the design and construction stages. This level-by-level assessment results in compliance figures that actually cover all new buildings in China.

Finally, the relationship between the energy savings of new buildings per increased floor area per year and compliance rates in the construction stage is analysed. Based on the data released by the MOHURD, the energy savings of new buildings per increased floor area per year increased from 20.4 kWh/m^2 to 28.4 kWh/m^2 along with compliance rates in the construction stage, which increased from 71% to 100%.

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