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Comparative study of commercial building energy-efficiency retrofit policies in four pilot cities in China

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HIGHLIGHTS

- Data and information were collected through site surveys to the four pilot cities.
- Policy design and effectiveness in four cities were comparatively analyzed.
- Well-designed policy increases market response, energy savings and EMC adoption.
- Lighting is the most common retrofit while envelope is the least common one.
- Subsidy incentive is greatest for educational buildings due to the utility tariff.

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ABSTRACT

The energy efficiency of existing commercial buildings is more challenging to regulate and improve than the energy efficiency of new constructions. In 2011 and 2012, the Chinese Government selected four cities- Shanghai, Tianjin, Shenzhen, and Chongqing- to implement pilot commercial building energy efficiency retrofit program. Based on site surveys and expert interviews in these pilot cities, this research conducted a comparative analysis on incentive policies of local city level. The analysis results show that policy designs of existing commercial buildings should be further improved. The aspects that influence the implementation effect in the future, such as subsidy level, installments, and business model promotion, should be specified in the policy clauses. Referring to the technical solution and cost-benefit in Chongqing, we found that lighting system is the most common retrofit objects while envelope system is the least common one. And the subsidy incentive is greatest for educational buildings, followed by office buildings. In the end, we further discussed the problems and obstacles in commercial building retrofit market, and provided a series of recommendations.

1. Introduction

1.1. Commercial building sector development overview

As a result of rapid, steady economic growth in the past two decades, China has become the largest energy consumer and carbon dioxide (CO_2) emitter in the world (BP Group, 2010). Rapid urbanization can also be seen in the same period. From 1980 to 2014, the population of permanent residents in Chinese cities and towns increased from 191 million to 749 million, and at the same time, the urbanization rate grew roughly by 1.02% annually, from 19.4% to 54.8% (Fig. 1) (CGPRC, 2014). As a result, a large number of commercial buildings[1] have been constructed in cities all over mainland China. The growing number of commercial buildings also indicates that commercial building energy demand is growing

Abbreviations: CBEER, Commercial Building Energy Efficiency Retrofit; CNY, Chinese Yuan; DRC, Development and Reform Commission; DOE, Department of Education; EUI, Energy Usage Intensity; EIA, Energy Information Administration; EMC, Energy Management Company; GOA, Government Offices Administration; MOC, Ministry of Construction; MOHURD, Ministry of Housing and Urban-Rural Development; M&V, Measurement and Verification

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[1] In this article, commercial buildings refer to both governmental buildings and buildings used in service sector, which are not used as residences, nor part of industrial facilities. By building functions, commercial buildings mainly include office, retail, hospital, school, hotel and other building types.

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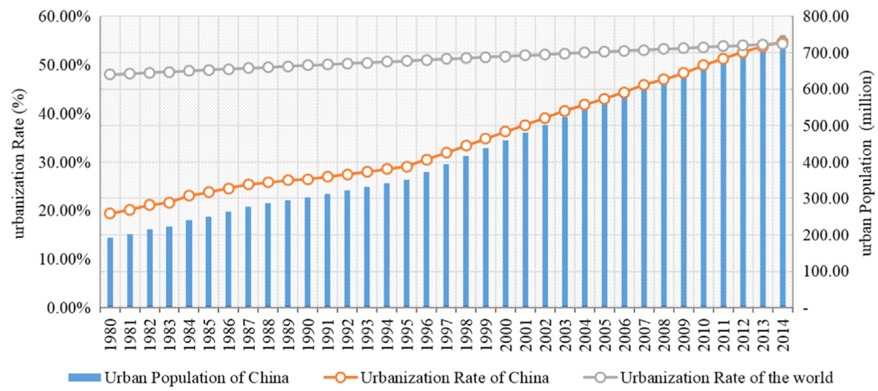

Fig. 1. Urbanization levels in China, 1980–2014 (Source: National Bureau of Statistics data and China's New Urbanization Plan (2014–2020)).

rapidly.

From 1996 to 2012, total commercial floor space in China increased from 2.8 billion square meters (m^2) to 8.3 billion m^2 (NBS, 2013; BECRC, 2014). The average EUI of China's commercial buildings is three to five times more than that of residential buildings. Large-scale, high-end commercial buildings can be as much as 10 to 20 times more EUI than typical commercial buildings (CGPRC, 2007; Liu, 2012; Xu et al., 2012). In 2012, China's commercial buildings consumed more than 182 million tonnes coal equivalent, accounting for 26.4% of overall energy consumption in the building-sector (BECRC, 2014). A study conducted by the EIA projects reveals that commercial building energy use will increase by 2.7% per year in developing countries between 2007 and 2035 (EIA, 2010). These values make clear that commercial building energy efficiency should be kept increasing to help reduce growth in energy consumption.

1.2. *Energy efficiency of new construction commercial buildings*

In an effort to achieve large scale energy savings, the governments typically rely on energy policy tools which can help conserve energy in thousands of commercial buildings such as building energy standards and codes (Azar and Menassa, 2014). In the past two decades, the Chinese Government had implemented energy-efficiency policies for new constructed commercial buildings. In 1993, the MOC[2] issued a building energy-efficiency standard for hotels (GB50189[3]). In this phase, the criteria of the standard were not rigid enough. Besides, the standard enforcement scope was not comprehensively included for all types of commercial buildings (MOC, 1993). In 2005, the GB 50189 was revised to include other types of commercial buildings. The standard required that all new buildings should be 50% more efficient than the baseline defined with 1980s building characteristics (Feng et al., 2014)[4]. The latest revision to this standard has been issued by the MOHURD on May 15th 2015 and taken effect in October 1st 2015, which sets the efficiency level at approximately 30% more than that of the 2005 standard (Hong et al., 2015a), i.e., equivalent to 65% more efficient than the 1980s baseline. Therefore, along with the constant update of the mandatory efficiency standard-GB50189, energy-efficiency in new constructed commercial building sector has been effectively controlled and improved step by step.

1.3. *Energy efficiency of existing commercial buildings*

Most commercial building energy efficiency policies target at new construction, whereas technical specification for energy efficiency improvement in existing commercial buildings are still underdeveloped due to inadequate financial and technical capacities (Li and Shui, 2015). In addition, energy efficiency in existing commercial buildings is more challenging to regulate and improve than the energy efficiency of new constructions. Most commercial buildings that were built before GB50189-2005 are in need of retrofitting. In addition, some large-scale and high-end ones that were built according to GB50189-2005 still have a high EUI. Their energy efficiencies need to be improved through retrofit as well.

A lot of energy statistics, energy audit and energy-saving diagnosis revealed that all kinds of commercial buildings have high energy consumption, low energy efficiency issues, in different levels. Jiang et al. (2010) estimated that the average energy saving potential in most large scale commercial buildings are generally over 30%. While Hong (2009) thought the potential is about 50% by combining energy conservation measures with improved operations. Although some researchers have noticed the big energy saving potential in China's existing commercial building sector, further in-depth research or energy efficiency retrofit practice is very limited. Only a few researchers analyzed commercial building retrofit of one single type or one single climate zone by using eQuest or DeST software (Xing et al., 2015; Peng et al., 2014). Some developed countries go faster than China, apart from a lot of retrofit practice, researchers even developed some energy efficiency performance database and energy retrofit analysis toolkits to supports commercial building retrofit (Hong et al., 2015b; Lee et al., 2015a; Lee et al., 2015b). However, the experiences from these researches that China can learn are limited. Because there are many differences exist in not only commercial building type, scale, energy consumption behaviour, etc., but also the CBEER market maturity, data foundation, national promote pattern, etc.. Therefore, a comprehensive study about China CBEER is very necessary and helpful.

This research studied a large number of existing commercial building retrofit projects within a four-pilot-city program in China. With a comparative study of the incentive policies in different cities, this research also aimed at comprehensively probing into some other important aspects associated with existing commercial building retrofit industry. Technical solution, cost-benefit, business model, and barrier and obstacle are focused on in this paper.

2. Methodology

Fig. 2 shows the process, method, and objective of this

[2] The MOHURD was founded in 2008. Its predecessor was the MOC.

[3] GB 50189 is a national standard named “design standard for energy efficiency of public buildings”. GB, in Chinese pinyin “Guo Biao” means national standard.

[4] The 1980s characteristics (baseline) assumes that buildings in China were constructed without rudimentary energy efficiency measures.

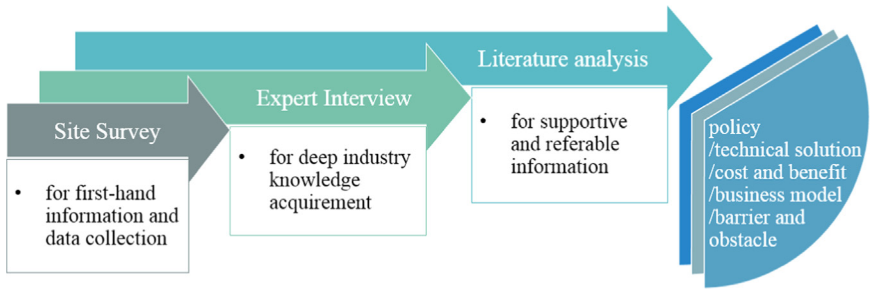

Fig. 2. Research process, method, and objective.

research. Throughout the research, we conducted site survey, expert interview, and literature analysis.

It is difficult but critical to obtain first-hand information and data. In order to gather detailed policy design information, implementation effect, and precise data of the pilot program progress, we first conducted site surveys in the four pilot cities -Tianjin, Chongqing, Shenzhen, and Shanghai–in December 2013, January 2014, March 2014, and April 2014, respectively. During the site survey in each city, we convened several symposiums involving local construction government, commercial building owners, EMCs, and a few financial institutes like banks.

To have a deeper understanding of CBEER in China, we also conducted expert interviews to acquire further knowledge of the industry. We selected many renowned experts who are familiar with CBEER based on their professionalism, experience, capability. On the whole, experts can be divided into two categories, one is experienced front-line staff from construction agency in both central government and local government; the other is from research institutes, colleges, associations, and enterprises. Considering that the experts with different background can provide suggestions from different views on each aspect of retrofits, we conducted interviews in an open-ended way. Interview framework included policy, market, technical solution, cost-benefit, business model, obstacle and suggestion.

Indispensably, literature analysis and document review were used for supportive and referable information inquiry throughout the research process.

3. Materials

3.1. Program background and progress in the pilot cities

The energy-efficiency policies promulgated during China's 12th Five-Year-Plan aimd to retrofit 60 million m^2 of commercial buildings by the end of 2015. The retrofit task will reduce energy intensity in ordinary commercial buildings (floor space less than 20,000 m^2) by 10% and in large-scale commercial buildings (floor space equal to or more than 20,000 m^2) by 15% (MOF and MOHURD, 2012). To accelerate energy-efficiency improvements and maximize the energy-saving potential in existing commercial buildings, the Chinese Government selected four cities which represent a range of climate zones and other local conditions-Tianjin, Shenzhen, Chongqing, and Shanghai–to carry out pilot commercial-building energy-efficiency retrofit program. The pilot program is to support deep retrofits that will maximize energy savings with subsidies. In total, the programs in the four cities must finish retrofit of 4 million m^2 buildings within two years, improving energy performance by 20%, with a central-government financial subsidy of 20 CNY[5]/m^2 (Table 1) (MOF and MOHURD, 2011).

Table 1
Four-city pilot commercial-building energy-efficiency retrofit program.

Policy details	
Requirements	
Floor area target	✓Minimum 4 million m^2 floor area
Time schedule target	✓Completed within 2 years
Energy saving target	✓Energy performance enhanced by 20%
Subsidy	
Subsidy amount	✓20 CNY/m^2 for 4 million m^2 (80 million CNY/city)
Subsidy payment	✓60% prepaid, 40% after inspection

3.1.1. Background of the four pilot cities

The four pilot cities are all economically developed with relatively mature market systems, including available human resources, financial instruments, and quality building technologies. In recent years, the four pilot cities received financial support from the Chinese Central Government to establish commercial building energy consumption monitoring platforms. Those monitoring platforms are able to collect and analyze real-time energy use data on buildings' primary energy-consuming systems. All major service sector commercial buildings are included in the pilot program: government office buildings, commercial office buildings, educational facilities (schools and colleges), hospitals, hotels, shopping malls, and mixed-use buildings.

Fig. 3 shows the locations of the four cities carrying out pilot CBEER activities. Tianjin is a coastal city in the cold climate zone in China where most commercial buildings were built after 1949. Chongqing is located in the hot summer, cold winter climate zone; most of the commercial buildings in Chongqing were also built after 1949. Shenzhen, situated in the hot summer, warm winter

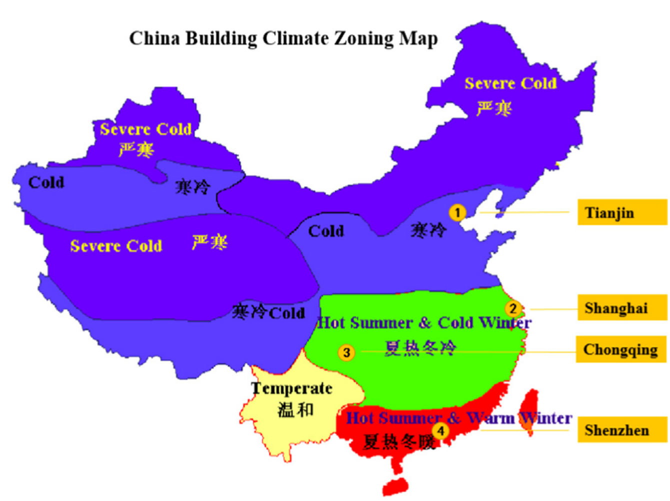

Fig. 3. China's building climate zones and the location of the four cities in the commercial-building energy-efficiency pilot program.

[5] In this paper, 1 U.S. dollar ≈ 6.20 CNY. Besides the 20 CNY/m^2 subsidy from

Table 2
Basic information on pilot cities and progress of energy-efficiency efforts.

	Program details	Tianjin	Chongqing	Shenzhen	Shanghai
1	Location	north	southwest	south	east
2	Climate zone	cold	hot summer cold winter	hot summer warm winter	hot summer cold winter
3	Planned retrofit floor area (million m^2)	5.80	4.44	7.78[*]	4.00
4	Current percent progress	64%	78%	60%	58%
5	Energy-saving threshold	20%	20%	10%[*]	20%
6	Average energy savings achieved	≥ 20%	≥ 20%	≈ 14%[*]	≥ 20%

[*] Shenzhen's average retrofit energy savings of 14% is less than 20%, in part because the buildings there are more recently constructed and already relatively energy efficient compared to the buildings in the other three cities. Shenzhen targeted lower energy savings (10%) compared to the targets in the other cities but over floor area of 7.78 million m^2, which is almost double the area required by the central government and targeted in the other cities. Saving at least 10% over pre-retrofit energy over this floor area in Shenzhen would reduce energy use by an amount equivalent to what would be saved if energy use was reduced by 20% over a floor area of 4.05 million m^2.

climate zone, is a newly developed city; all of its buildings were built after 1980. Shanghai, in the same climate zone as Chongqing, has a combination of buildings built before 1980 (dating back as far as the 1930s) and new constructions (Xu et al., 2013).

3.1.2. Progress in the pilot cities

In June of 2014, the programs in the four pilot cities were still in the implementation phase, but the fundamental elements of the programs, such as development of local supportive policies and identification of demonstration projects had been established, enabling us to assess progress and make recommendations for the future.

Each pilot city has selected its demonstration projects as described in detail in the next section of this paper. Table 2 presents the basic information of the pilot cities and the progress of their CBEER activities.

Thus far, based on the current program status in the four pilot cities, Chongqing is the most successful one in achieving the targeted results. Not only the retrofit program in Chongqing has been carried out with the most rapid speed, but also the commercial building retrofit market has been incentivized and cultivated successfully. An additional 3 million m^2 floor area commercial buildings are likely to be retrofitted in the near future in Chongqing after the pilot program. The other three cities have also achieved inspiring results, and their experiences should be comprehensively studied so that lessons can be learned for implementation in other cities in the future.

3.2. Organizational structures and implementation procedures in the pilot cities

Although all four cities use the same central-government policy framework, each city has devised slightly different organizational structures and implementation procedures (Table 3, Figs. 4–7).

3.2.1. Program organizational structure

The pilot cities have each developed a management structure

(*footnote continued*)
the central government, local government were asked to develop supportive policy for the pilot program too.

Table 3
Program organizational structure in the four pilot cities.

	Tianjin	Chongqing	Shenzhen	Shanghai
Dominant influence on progress-market vs. government	government	market	government	market
Dominant channel for collecting demonstration projects	government	market	market	market
Dominant retrofit entity	owner	EMC	EMC	EMC

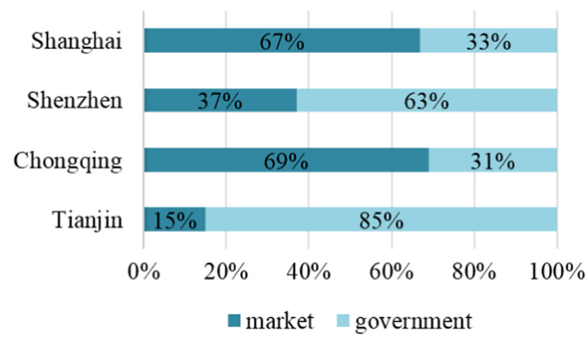

Fig. 4. Demonstration project source.

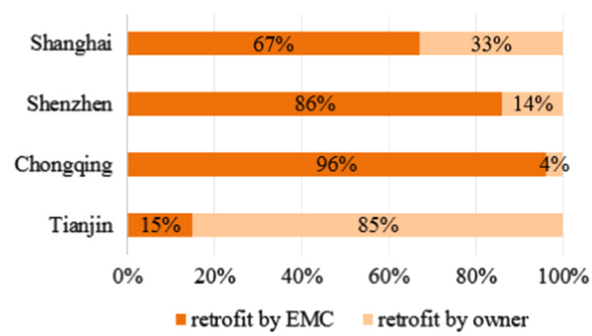

Fig. 5. Retrofit entity distribution.

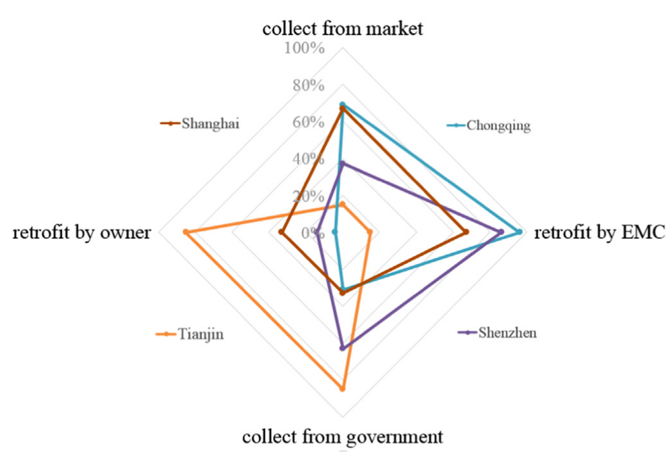

Fig. 6. Demonstration projects source and retrofit model distribution.

for retrofit projects as well as technical guidance and reporting protocols. They have also worked with other government agencies in carrying out the pilot program. Specific activities have included:

- Setting up and staffing retrofit project management offices in city level.
- Developing institutional support, including local technical

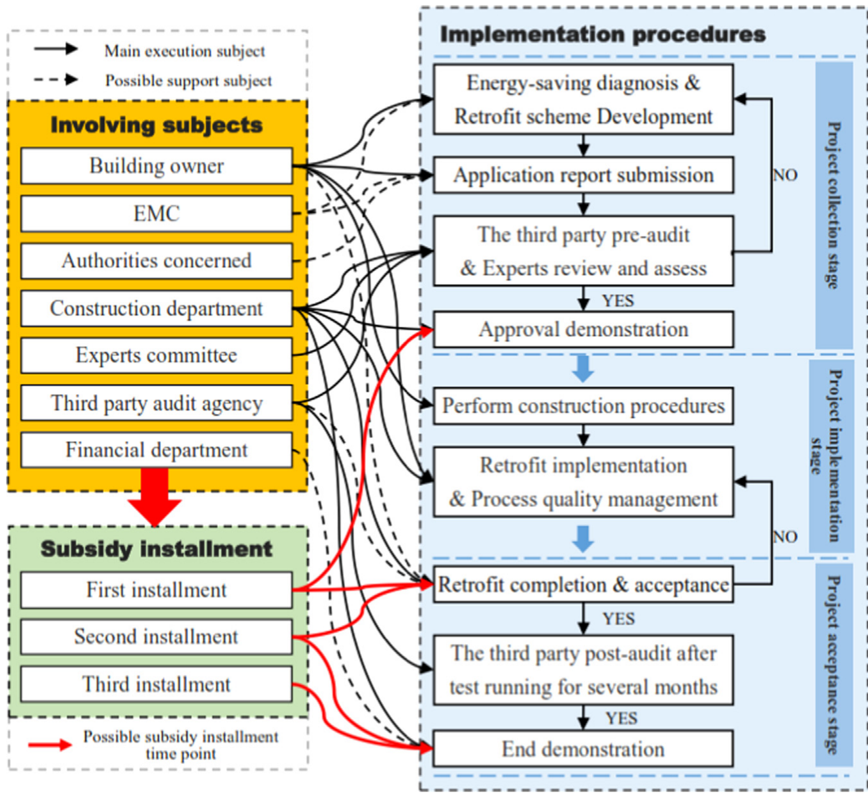

Fig. 7. Retrofit demonstration project implementation procedures.

guidance and documentation on demonstration projects (e.g., assessment, process management, inspections, and subsidy payments).

- Working with other government agencies to identify demonstration projects and integrate resources[6]. These agencies include the DRC, GOA, DOE, Finance Committee, Health Bureau, Commerce Commission, Tourism Bureau, and the State-owned Assets Supervision and Administration Commission. Industrial associations and other market players have also been mobilized to participate in the retrofit market.

Table 3 and Fig. 6 displayed the program organizational structures in the four pilot cities. Figs. 4 and 5 further showed the "demonstration project source" and the "retrofit entity distribution", separately. Tianjin's program is primarily dominated by the government. Most of Tianjin's demonstration projects come from government channels; some projects have been referred from other government agencies, and others have been assigned top down from the city-level construction department to supporting construction administrative departments in district-level. And only 0.6 million m^2 out of a total of 5.8 million m^2 in Tianjin have been retrofitted by EMCs.

By contrast, in Chongqing and Shanghai, demonstration projects have been identified mainly through market channels, and EMCs have retrofitted 96% and 67% of their total retrofit floor space, respectively, in the two cities.

Although EMCs in these two cities have used both the "shared energy savings"[7] and "energy saving guarantee"[8] approaches, the shared-energy-savings approach has been used in a majority of the projects. For the "shared energy savings" approach, building owners don't pay for the retrofit but share post-retrofit savings with EMC. They bear no risk but have immediately benefit. However, for the "energy saving guarantee" approach, building owners pay for the retrofit but have no immediate money income. They have no immediately benefit but bear input risk. Therefore, most of the building owners prefer to adopt "shared energy savings" approach.

Shenzhen has identified and implemented projects through a mix of government and EMC participation. 63% of the demonstration projects in Shenzhen were identified by the government, and 86% of the retrofits have been carried out by EMCs.

3.2.2. Implementation procedures

Fig. 7 shows the implementation procedures for retrofit demonstration projects in the pilot cities.

The first stage of implementation focuses mainly on identifying potential demonstration projects and screening the projects to be implemented. The sources of these demonstration projects are as shown previously in Fig. 4. In this phase, Shenzhen developed a demonstration project management information system and enhanced the efficiency and effectiveness of project management.

The second stage of implementation entails carrying out the retrofits. In this phase, retrofit quality management is the primary

[6] In China, government departments have a top-down administrative organization from central to local, and these various levels of government agencies occupy a large number of commercial buildings. Therefore, the pilot cities have identified numerous buildings of government agencies that are in need of retrofit and can serve as demonstration projects. Some agencies have internal building retrofit or update plans and policies that can be integrated with the pilot program to amplify the total policy effect.

[7] "Shared energy savings" is one EMC business model in which the EMC pays for the retrofit, and the post-retrofit savings are shared by the EMC and the building owner. The allocation of savings and time period during which the savings are shared are specified by contract.

[8] "Energy saving guarantee" is another EMC business model in which the building owner pays for the retrofit, and the EMC does the retrofit work and guarantees a specified level of post-retrofit energy savings. After the retrofit is finished and the final energy savings are verified, the EMC is paid by the building owner if the energy savings specified in the retrofit contract have been achieved.

challenge. Both building owners and the local construction agency are responsible for retrofit quality management. For quality assurance, EMCs that perform retrofits under the program in Chongqing, Tianjin, and Shanghai must register with local government agencies. Shenzhen has stricter requirement with stipulating specific qualifications for construction enterprises that wish to participate in the program.

The third stage of implementation focuses on inspection and approval of demonstration projects. Chongqing and Shenzhen have established a post-retrofit energy audit policy for this phase. The audit periods are 3 months in Chongqing and 1 year in Shenzhen. It helps to ensure that retrofits are completed as planned by connecting the last subsidy installment with the post-retrofit audit results.

Both of Chongqing and Shenzhen used third-party auditors for M&V of energy savings in retrofitted buildings. Shenzhen selected the Shenzhen Institute of Building Research Co. Ltd as its third-party auditor, and Chongqing hired three-third party auditors to ensure market competition. And through random cross-verification among the three auditors, the quality and accuracy of the M&V work in Chongqing can be compared and improved.

The financial agency in each city pays the retrofit subsidy. To ensure retrofit quality and achievement of energy savings, the subsidy was designed to be paid in two or three installments. The installments are linked to acceptance of the retrofit project into the pilot program, completion of the retrofit and successful inspection, and operation of the retrofitted building for a defined period with verification of energy savings. We will discuss this further in the following Section 3.3.

3.3. Supportive local-government policies

Supportive local policies are vital to the success of the pilot cities' demonstration projects. In response to the central government subsidy of 20 CNY/m^2 retrofitted, the four cities each developed individual incentive policies (Table 4, Figs. 8, 9).

Table 4
Subsidy policies in the four pilot cities

	Tianjin	Chongqing	Shenzhen	Shanghai
Subsidy				
Total local finance matching (million CNY)	20	80	120	80
Central subsidy : local subsidy	1:0.25	1:1	1:1.5	1:1
Energy-saving threshold				
Demonstration apply threshold	20%	20%	10%	20%
Actual subsidy threshold	20%	10%	10%	20%
Total subsidy intensity (CNY/m^2)				
Minimum amount	20	17.5	21	20
Maximum amount	20	40	42	80
Subsidy installments	3	2	3	2
First installment	30%	50%	30%	50%
Second installment	30%	50%	50%	50%
Third installment	40%		20%	

3.3.1. Tianjin

I. In Tianjin, the local government matched the central government financing of 20 million CNY in total, which were used for capacity building, including development of standards and institutions to support the pilot program, and for administrative expenses. The direct subsidy for the demonstration retrofit projects only comes from the central government fund of 20 CNY/m^2 (Fig. 8).

II. No particular incentive policies were formulated in Tianjin to encourage EMCs to carry out retrofit projects or to enhance the energy savings. As a result, the market response in Tianjin has not been very strong. Only 15% of projects had been identified through the market channel with retrofits implemented by EMCs. The majority of projects–up to 85%–had come through the government administration channel, with retrofits carried out by building owners (Figs. 4 and 5).

III. The subsidies in Tianjin are paid in three installments: 30% when a project is approved as a demonstration project, 30% when the retrofit is finished and 40% when the energy savings are verified by a third-party auditor (Table 4, Fig. 9).

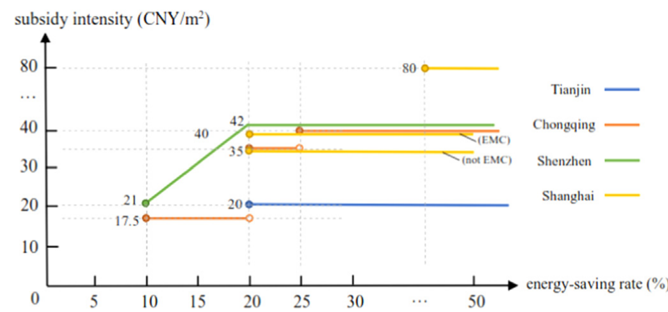

Fig. 8. Relationship between subsidy and energy savings in the four pilot cities.

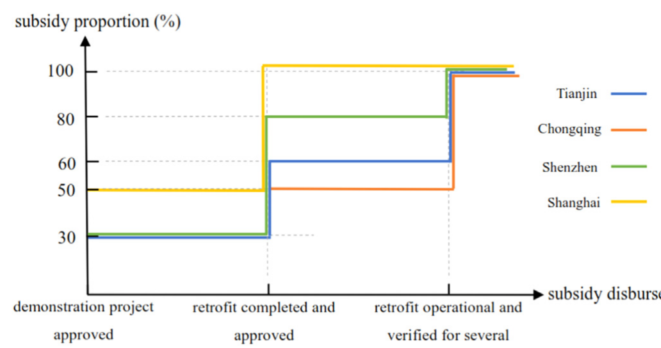

Fig. 9. Subsidy installments in the four pilot cities.

3.3.2. Chongqing

Chongqing's policy linked the subsidy intensity directly to energy saving rate, and designed to promote EMCs' participation.

I. The subsidy was designed to give larger incentives to demonstration projects that pursue greater energy savings, as described by Eqs. (1) and (2) (Fig. 8):

$$\underset{(\mathrm{CNY}/m^2)}{\text{subsidy amount}} = \begin{cases} 0, \text{ when energy saving rate} < 10\% \\ 17.5, \text{ when } 10\% \\ \leq \text{ when energy saving rate} < 20\% \\ 35, \text{ when } 20\% \\ \leq \text{ when energy saving rate} < 25\% \\ 40, \text{ when energy saving rate} \geq 25\% \end{cases} \tag{1}$$

Where:

$$\text{when energy saving rate} = \frac{\text{annual energy consumption before retrofit} - \text{annual energy consumption after retro}}{\text{annual energy consumption before retrofit}} \tag{2}$$

When we surveyed Chongqing's pilot program, 68 retrofit projects has been completed and passed government inspection. Of these, 67 had saved more than 20% over pre-retrofit energy use; the only project that fell below the 20% mark had saved 14%.

II. To encourage adoption of EMC models for retrofit implementation, Chongqing designed to allocate subsidies in a manner that benefits owners financially when EMCs carry out retrofits. That is, when an owner carries out a retrofit, the owner pays all of the retrofit cost and receives all of the government subsidy. However, when an EMC carries out a retrofit, the EMC pays all of the retrofit cost and receives 80% of the government subsidy with the remaining 20% given to the building owner. As a result of this subsidy design, as many as 96% of demonstration projects in Chongqing were carried out by EMCs (Fig. 5).

III. The Chongqing subsidy was designed to be paid in two installments of 50% each. The first 50%, 35 CNY/m^2, is paid after the completed retrofit floor area and energy savings are verified by a third-party auditor. The second 50% is paid after the retrofitted building has operated for at least 3 months (Table 4, Fig. 9).

The second installment is paid at a tiered rate. There are four tiers. Tier 1 applies when the retrofit energy saving rates are greater than 25% compared to pre-retrofit energy use; in this tier, the subsidy intensity is relatively high, 40 CNY/m^2. Tier 2 applies when the retrofit's energy saving rates are between 20% and 25%; this subsidy is 35CNY/m^2. The tier 3 subsidy applies when the retrofit's energy saving rates are less than 20% but more than 10%. In this tier, the subsidy is 17.5 CNY/m^2. Tier 4 applies when the retrofit's energy saving rates are less than 10%. In this tier, the second subsidy installment is zero, and the initial 50% subsidy will be revoked.

3.3.3. Shenzhen

Shenzhen is one of the newest cities in China, with most buildings constructed after 1980. In recent years, a package of building energy-efficiency measures has been implemented in Shenzhen, resulting in baseline commercial-building energy use that is much more efficient than in other Chinese cities. As a result, achieving the retrofit program's 20% energy-saving target posed a greater challenge in Shenzhen than in the other three pilot cities.

Shenzhen's innovative approach to the program includes setting the energy-savings threshold at 10%, which is only half of the threshold in the other three pilot cities; however Shenzhen targeted 7.78 million m^2 of floor area for retrofit, much more than in the other three pilot cities and almost twice the city-level target required by the Central Government. Meeting these targets will result in a total energy savings in Shenzhen that is the same as in the other pilot cities (Gong et al., 2014).

Shenzhen's supportive policy was designed as the following:

I. To promote greater energy savings, Shenzhen's subsidy was designed as described in Eqs. (3), (4) and (5):

$$\text{subsidy amount} = 42(\text{CNY}/m^2) * \text{retrofit floor area}(m^2) * \alpha \tag{3}$$

Where: α is the conversion coefficient of retrofit floor area and can be calculated as described in Eq. (4):

$$\alpha = \begin{cases} \dfrac{\text{when energy saving rate}}{20\%}, \text{ when } 10\% \\ \quad \le \text{when energy saving rate} < 20\% \\ 1, \text{ when energy saving rate} \ge 20\% \end{cases} \tag{4}$$

Therefore:

$$\underset{(\text{CNY}/m^2)}{\text{subsidy amount}} = \begin{cases} 0, \text{ when energy saving rate} < 10\% \\ 21, \text{ when energy saving rate} = 10\% \\ (21, 42), \text{ when } 10\% < \text{energy saving rate} \\ \qquad < 20\% \\ 42, \text{ when energy saving rate} \ge 20\% \end{cases} \tag{5}$$

This design encourages demonstration projects to pursue greater savings by offering larger subsidy intensity for higher energy saving rate. To date, all of the demonstrations projects completed in Shenzhen have achieved their target energy savings, with an average energy saving rate of 14%. Most projects achieved energy saving rate in the range of 10–20%, with proportional subsidies (Fig. 8).

II. With regard to EMC promotion, local government of Shenzhen required that all government office building demonstration projects be carried out by EMCs. As a result, of the retrofits completed in Shenzhen, 86% were implemented by EMCs (this includes both government and non-government buildings) (Fig. 5).

III. Subsidies in Shenzhen are paid in three installments. The first installment of 30% and the second of 50% are paid at similar milestones as for the first two subsidies in Tianjin. The final 20% installment is paid after a retrofit project operates for 1 year, and savings are verified by a third-party auditor. This installment plan makes Shenzhen the most rigorous of the pilot cities in terms of project quality management (Table 4, Fig. 9).

3.3.4. Shanghai

Metered data from the commercial-building real-time energy-use monitoring system have been used in Shanghai's pilot program.

Shanghai's supportive policy scheme is designed as the following (Eq. (6)):

I. To promote greater energy savings, Shanghai's subsidy is as shown in Eq. (5) (Fig. 8). Shanghai compares retrofit project energy performance to its local commercial building energy-efficiency standard for new construction (DGJ08-107-2012). Its subsidy can be as much as 80 CNY/m^2 when the demonstration project meets or exceeds the energy efficiency requirements of the standard. However, it is difficult to meet the standard requirements because of the high retrofit costs. No project thus far has met the standard. All of the retrofit projects have received the 35 CNY/m^2 or 40 CNY/m^2 subsidy up to now (Zhang and Wang, 2014).

$$\underset{(\text{CNY}/m^2)}{\text{subsidy amount}} = \begin{cases} 0, \text{ when energy saving rate} < 20\% \\ 35, \text{ when energy saving rate} \ge 20\% \\ \qquad \text{and not EMC} \\ 40, \text{ when energy saving rate} \ge 20\% \\ \qquad \text{and EMC} \\ 80, \text{when retrofit according DGJ08-107-2012} \end{cases} \tag{6}$$

II. Shanghai's approach to promote EMC is slightly different from the approaches adopted in Chongqing or Shenzhen. For projects that achieve the same level of energy savings, those implemented retrofit by an EMC will receive a subsidy of 40 CNY/m^2 and those not implemented retrofit by an EMC will receive 35 CNY/m^2 only. As of the date of our site survey, 67%

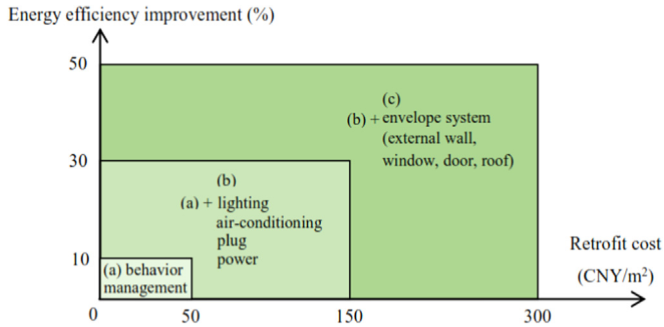

Fig. 10. Energy-saving potential distribution and retrofit cost.

of the demonstration projects completed in Shanghai had been implemented by EMCs (Fig. 5).

III. Shanghai's subsidy is paid in two equal amounts. The first 50% is paid after the retrofit application is approved, and the second 50% is paid after completion of the retrofit and M&V by a third party (Table 4, Fig. 9).

3.4. Technical solution and cost-benefits

Fig. 10 shows a general distribution of energy-saving potential and their retrofit cost from previous researches (Hou et al., 2014).

I. Tier one

Improve energy efficiency up to 5–10% through measures include energy management measures, operation optimization, and human behaviour improvement. Retrofit cost for this tier is low, basically below 50 CNY/m^2 in average with a static payback period of less than 3 years.

II. Tier two

Improve energy efficiency up to 20–30% through building energy consumption system retrofit in addition to the measures in tier one. The building energy consumption systems include lighting, air-conditioning, power, plug, and domestic hot water (Zhao et al., 2009). The retrofit costs for these measures are approximately 100–150 CNY/m^2 with a static payback period of 3–5 years.

III. Tier three

Improve energy efficiency up to 30–50% through measures of envelope system in addition to the measures in tier two. The envelope system basically includes external wall, window, door, and roof. The retrofit costs for these measures are approximately 300 CNY/m^2 with a static payback period of more than 5 years.

In the CBEER pilot program, each pilot city developed slightly different local technical solutions. For example, in Tianjin, retrofits targeted four primary building elements: envelope, heating system, central air-conditioning system, and renewable-energy system. Although technical solutions in the other three pilot cities addressed the building envelope and heating system to some degree, they focused primarily on lighting, power supply and distribution, and elevators.

In this study, we took Chongqing as an example for quantitative analysis its technical solution and cost-benefit. The dataset came from 68 demonstration projects which completed retrofit and approved energy savings (He et al., 2014).

3.4.1. Retrofit technical solutions

Fig. 11 shows the building systems that have been retrofitted in the projects studied in Chongqing. Lighting systems were retrofitted in 97% of cases, making this the most common retrofit. The second most common retrofit, 84%, was of air conditioning systems. The least-common retrofit was to domestic hot water and envelope systems because of the technical and economic

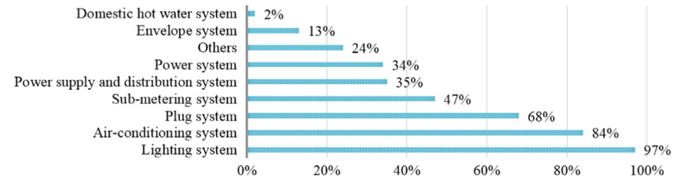

Fig. 11. Building systems receiving energy-efficiency retrofits in Chongqing.

challenges associated with retrofitting these building systems.

3.4.2. Cost-benefits

Our investigation of the retrofit projects in the four pilot cities shows that subsidies (from both central government and local government) cover approximately 20–40% of total retrofit cost in average. However, this proportion varies substantially among cities and projects. In Tianjin, for example, building envelope retrofit costs are approximately 100 to 150 CNY/m^2 with a static payback period of more than 10 years. Because of these economics, few demonstration projects included building envelope retrofits. In contrast, the retrofit cost for air conditioning systems is lower, 50 CNY/m^2, with a static payback period of 3 years. As a result, the penetration of air-conditioning retrofits is much greater than that of envelope system retrofits.

68 demonstration projects were used as a database to quantitatively assess the impact of government subsidies on the retrofit economy and static payback periods for the demonstration projects[9]. Figs. 12 and 13 show the average retrofit cost and the average annual savings for building systems in three typical buildings in Chongqing (He et al., 2013).

We can see from Fig. 12 that educational buildings have the lowest retrofit cost among the three building types, and shopping malls have the highest. The average retrofit cost for a shopping mall is more than three times that of the cost for a retrofit of an educational building. When comparing the retrofit costs for different building systems, we found that lighting systems in educational buildings have the highest retrofit costs (29.7 CNY/m^2) but provide significant post-retrofit savings (2.4 CNY/m^2) (Fig. 13). For shopping malls, retrofits of air-conditioning and of power supply and distribution systems have the two highest costs, and lighting systems provide the highest post-retrofit savings. In office buildings, the retrofit cost for air-conditioning systems is 44.8 CNY/m^2, higher than for other systems, and lighting system retrofits are the most economical.

These data also allow us to calculate the static payback period for retrofits of different building systems as well as the whole building (Fig. 14). Retrofits of power systems in the three types of buildings have the shortest payback period, 1.5–3.2 years, and power supply and distribution system retrofits in shopping malls and educational buildings have the longest static payback periods, 16.6 years and 13.8 years, respectively. In office buildings, air-conditioning system retrofits have the longest payback period, 8.3 years.

The whole-building static payback period is 7.6 years for office buildings, 8.7 years for shopping malls, and 13.7 years for educational buildings. However, when the subsidy is taken into account, the static payback periods are shortened to 4.0 years, 7.4 years, and 0.3 years, respectively. Thus, we can see that the subsidy effectively reduces the payback period for all three building types. The reduction is most significant for educational buildings, from 13.7 years to 0.3 years. This is strongly correlated with the preferential utility tariff (e.g., for electricity and natural gas) in educational

[9] Our calculation and analysis here is based on some initial cost-benefit data collection and analysis conducted by Chongqing's local MOHURD. They reserved the right of final explanation.

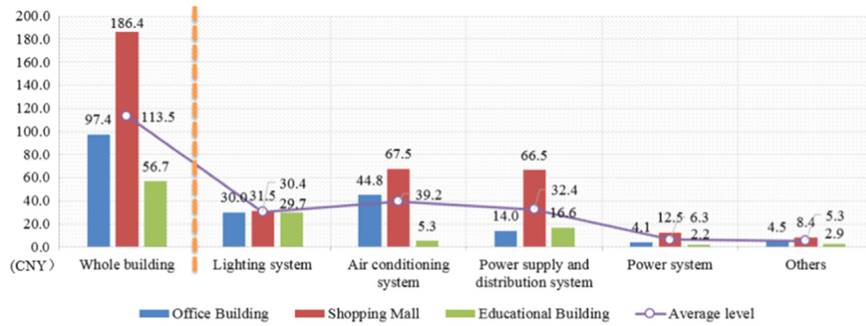

Fig. 12. Retrofit cost for five building systems in three typical buildings in Chongqing.

buildings. Therefore, the economic incentive is greatest for educational buildings, followed by office buildings. Shopping malls have the smallest incentive. Even so, commercial buildings like malls still have incentives to undertake retrofits because these buildings are not eligible for the same levels of government funding that the government office buildings and public buildings like schools, hospitals, etc. are eligible to receive.

4. Results and discussions

4.1. Subsidy level (subsidy intensity)

- Subsidy levels affect policy's attraction to motivate relevant market players to perform CBEER. Higher subsidy level leads to stronger market response.
- Linking the subsidy level proportionally to energy savings is effective to encourage CBEER projects to pursue greater energy savings within one-time retrofit.
- Same central-government-subsidy impacts differently in each pilot city because of variations in local economic conditions and retrofit costs.

4.2. Subsidy installments

- Subsidy paid in several installments is good to retrofit quality management.
- Critical milestones for subsidy installments include: when the retrofit start (can provide start-up capital for carrying out retrofit); when the retrofit is completed and approved (ensure the retrofit is implemented as plan); when the retrofit project has operated for defined period with verification of energy savings (guarantee the actual energy savings).
- Installments are not the more the better due to the increase of the policy implementation cost. It needs to be designed reasonably according to the actual circumstance.

4.3. Subsidy encourage EMC

- Connecting subsidy level or subsidy allocation with EMC application can vigorously promote market mechanisms.
- Administrative requirements can promote EMC application directly and quickly within government-owned office buildings.
- Difference between Chongqing and Shanghai in policy design for encouraging EMC leads to differences not only in incentive mechanism but also in government fiscal expenditure. In Chongqing's design, the subsidy rate is the same no matter EMC participating or not, but the benefit sharing between the owner and the EMC differ. However in Shanghai, the subsidy rate differs by 5 CNY/m^2 depending on whether an EMC is involved. Therefore, building owners got greater motivation in Chongqing than Shanghai; and Chongqing's design saves money for the local government.

4.4. Policy strategy adoption

- Combined central government policies with local government policies
- All of the four pilot cities combined the central government policy with their local government policies. In this way, the central government policy was customized to achieve local impacts and the local government policies became a good supplement and refinement.
- Integrated policies from different government agencies

The pilot cities effectively integrated policy resources from different government agencies. As different government agencies in China always have their own policies about some relevant topics,

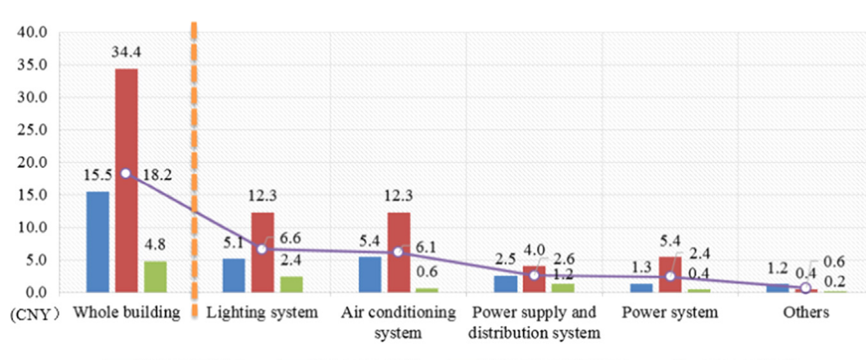

Fig. 13. Annual savings from retrofits of five systems in three typical buildings in Chongqing.

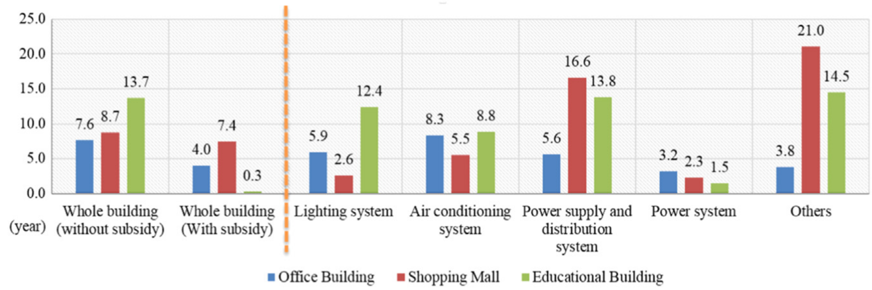

Fig. 14. Static payback period analysis for retrofits in three types of commercial buildings in Chongqing.

for the same time period. For existing commercial building retrofit, besides subsidy policy from MOHURD, other departments like DRC, GOA, and DOE have their own retrofit or building-update policies as well. These policies have been more or less considered by pilot cities to integrate resources, amplify incentives, and better achieve their common goals.

4.5. *Technical solution and cost-benefits*

- From the perspective of single technical measure
  Lighting system and air-conditioning system are the first and second common retrofit; envelope system is the least-common retrofit. Lighting system has the highest retrofit cost in educational buildings; air-conditioning system has the highest retrofit cost in both shopping malls and office buildings.
- From the perspective of building type
  Educational buildings have the lowest retrofit cost but the longest whole-building static payback period before subsidy due to the preferential utility tariff; shopping malls have the highest retrofit cost; office buildings have a medium retrofit cost between educational buildings and shopping malls.
- From the perspective of policy effectiveness

The incentive is greatest for educational buildings, followed by office buildings, and shopping malls the smallest. Even so, private-owned commercial buildings like shopping malls are very sensitive to financial incentives to decrease retrofit cost.

5. Problem and obstacle

5.1. *Difficult to organize and coordinate*

Firstly, different commercial building types have different energy consumption characteristics and energy efficiency retrofit demands. It is a complicated system which needs further study and explore. Secondly, CBEER involves multi-stakeholders, including property owners, operators, users, property management companies, EMCs, financial institutes, different government agencies, etc. Neither the energy conservation rights and obligations of all parties are clear, nor are the interests of these parties easy to coordinate and unify. Thirdly, retrofit implementation would cause interference to the normal use of buildings, more or less, especially for private-owned commercial buildings (such as shopping malls, hotels, etc.). This decreases owner's willingness to retrofit but increases the difficulty in coordination. Last but not least, relationship between different government regulations needs to be further straightened out. For example, besides the factor of high retrofit incremental cost, strict fire prevention policy for building envelope system gives constraints to implement building envelope system retrofit, results in a limitation to maximize the retrofit benefits.

5.2. *Imperfect market mechanism*

Market mechanisms application in CBEER market is insufficient and imperfect. Firstly, public-service buildings have most initiatives to use market business models because the lacking of both technical ability and financial strength. However, the willingness for EMCs to conduct retrofit for these buildings is relatively low because of the payback period without subsidy is too long. Secondly, although the willingness for EMCs to conduct retrofit for government-owned office buildings is very high due to the fiscal guaranteed payment ability, there are some institutional obstacles which include the inflexible accounting system and the energy-saving-sharing barriers, for these buildings to adopt EMC models. Thirdly, the other commercial building owners have very limited information or knowledge to select a capable EMC or develop a suitable business model when they want to perform the retrofit through EMCs. Fourthly, when using EMC model to perform the retrofit, the negotiation period is very long because the substantial divergence of opinions about capital efficiency, income share proportion, contract period, and the energy savings verification, between the owners and the EMCs. Fifthly, building owners and EMCs do not trust each other enough. Sixthly, EMCs are still hard to obtain loan from financial institutes like banks and the loan threshold is always too high for them. Furthermore, EMCs' capacity is not enough to perform comprehensive retrofit in a integrate way, but the substandard competition among EMCs is quite general and retrofit quality varies, etc.

5.3. *Hard to assess the energy savings*

It is challenging to quantify operation-related energy savings potential (Azar and Menassa, 2014). The retrofit energy savings are hard to assess and verify either. On the one hand, commercial building energy use is closely related to the factors of climate conditions, energy-use habits and human behaviour, operation and management, etc. These factors are critical but hard to control or measure to impartially calculate the energy savings get from the retrofit. This indirectly influences the application of the EMC models. On the other hand, since there are no uniform national energy-efficiency verification technical standards or guidelines for CBEER projects, energy savings assessments in different projects or different places conducted by different third party auditors are not comparable.

5.4. *Other barriers*

There are several other barriers for the Chinese CBEER. Firstly, government-owned buildings have no enough energy efficiency retrofit initiatives because their energy expenditure are totally paid with government fiscal and energy savings cannot be shared by staff. Secondly, building retrofit quality is hard to control because the CBEER quality management system has not been constructed yet. Thirdly, the lack of sufficiency, transparency and availability of relevant information and data influence CBEER market a lot.

6. Conclusions and policy implications

The pilot program has achieved its initial purposes in identifying the market characteristic, technical solution, and cost benefits of Chinese CBEER. All of the valuable experiences get from this program should be learned for better implementing CBEER in the future.

First of all, as policy maker, government should take available measures to maximize both the efficiency and effectiveness of policies with limited budget. Drivers for different commercial buildings to improve their energy efficiency are different. Policy makers should choose the most appropriate way and policy tools to achieve more energy savings, for instance, applying administrative policy to government-owned office buildings, fiscal subsidy to private-owned commercial buildings and a combination of these two to public buildings such as schools. Besides applying policy tools appropriately and flexibly, strategies including combining central government policies with local government policies, integrating policies from different government agencies should be comprehensively used in the future.

Next, with regard to the subsidy policy design, the government should craft policies taking into account not only the local economic conditions and local fiscal capacity but also local commercial building energy-efficiency baseline and energy saving potential, and linking subsidy level to the real energy savings. Furthermore, policy design should always take sustainable market cultivation into consideration. It's necessary and helpful to have government support at the beginning of CBEER, but market-oriented and market-based mechanisms are more sustainable in the long run. Therefore, policies should serve the purpose of sustainable market cultivation, including contributing to creation and maintenance of a healthy market environment, establishment of operation rules and performing of supervision responsibilities.

Thirdly, with regard to the technical solutions, measures like energy management, operation optimization, human behaviour improvement, lighting system retrofit, and air conditioning system retrofit could be done without subsidy. However, envelope system needs incentive policy to improve its retrofit economy. In addition, comprehensive retrofit solutions, which integrate multi energy use systems should be incentive to maximum retrofit savings and minimum retrofit cost. Integrate retrofit technical solutions for different commercial building types located in different climate zones should be preliminarily developed as soon as possible by government.

Fourthly, with regard to business models, CBEER market has a huge space and prospect for business model application and innovation. Besides private-owned commercial buildings, public-service buildings like schools will still need subsidies in the near future to shorten its payback period to attract EMCs, and government-owned buildings need to overcome the institutional obstacles by revising its energy expenditure accounting system and energy-saving-sharing limitation to make business models more applicable.

Fifthly, to better overcome the interrelated and interacted obstacles and barriers, different government agencies should work together and enhance coordination. Relevant laws, regulations, standards, and guidelines should be refined or developed. Social credit system should be built gradually.

Chinese CBEER market potential is huge. The coming 10–15 years is an important opportunity for Chinese commercial building sector to improve its entire energy efficiency. Chinese government should draw up a plan or a roadmap and implement step by step to realize energy conservation and emission reduction.

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References

Azar, E., Menassa, C.C., 2014. A comprehensive framework to quantify energy savings potential from improved operations of commercial building stocks. Energy Policy 67, 459–472.

BECRC (Building Energy Conservation Research Center, Tsinghua University), 2014. Annual Report on the Development of Building Energy Saving in China 2014. Building Energy Research Center, Beijing, China.

BP Group, 2010. BP statistical review of world energy.

CGPRC (Central Government of People's Republic of China), 2007. Regulations on Reinforcing Energy-efficiency for Public Institutions and Large-sized Commercial Buildings. 〈http://www.gov.cn/zwgk/2007-10/29/content_788896.htm〉 (accessed 26.09.15).

CGPRC (Central Government of People's Republic of China), 2014. China's New Urbanization Plan (2014–2020). 〈http://www.gov.cn/zhengce/2014-03/16/content_2640075.htm〉 (accessed 26.09.15).

EIA (Energy Information Administration), 2010. International Energy Outlook, World Energy Demand and Economic Outlook. Energy Information Administration. Department of Energy.

Feng, W., Huang, K., Levine, M., Zhou, N., Zhang, S., 2014. Evaluation of Energy Savings of the New Chinese Commercial Building Energy Standard, the American Council for An Energy-Efficient Economy (ACEEE) 2014 Summer Study on Energy Efficiency. The American Council for an Energy-Efficient Economy, Pacific Grove, CA.

Gong, C., Wang, Y., Tang, Z., Luo, C., Liu, Q., 2014. Progress of energy-efficiency works in pilot city Shenzhen. Constr. Sci. Technol. 10, 51–54.

He, D., Dong, M., Huang, Y., Ding, Y., 2013. Analysis on energy saving reconstruction efficiency of typical public buildings in Chongqing. Chongqing Architecture, vol. 6, pp. 45–48.

He, D., Huang, Y., Ding, Y., 2014. Systematically Analysis and Study on Technical Measures of Energy Savings for Typical Public Buildings in Chongqing Journal of Chongqing University of Science and Technology (Natural Sciences Edition), Vol. 16, pp. 112–116.

Hong, T., 2009. A close look at the China design standard for energy efficiency of public buildings. Energy Build 41, 426–435.

Hong, T., Li, C., Yan, D., 2015a. Updates to the China design standard for energy efficiency in public buildings. Energy Policy 87, 187–198.

Hong, T., Chen, Y., Lee, S.H., et al., 2015b. Commercial building energy saver: an energy retrofit analysis toolkit. Appl. Energy 159, 298–309.

Hou, J., Wu, Y., Liu, Y., 2014. Research on the Marketization ways of Existing Public Buildings' Energy Efficiency Retrofit. 6. Urban Development Studies, China, pp. 1–6.

Jiang, Y., Huang, Z., Wei, Q., 2010. Energy management in large public buildings and energy-saving diagnosis technique. Constr. Sci. Technol. 22, 20–23.

Lee, S.H., Hong, T., Piette, M.A., et al., 2015a. Energy retrofit analysis toolkits for commercial buildings: a review. Energy 89, 1087–1100.

Lee, S.H., Hong, T., Piette, M.A., et al., 2015b. Accelerating the energy retrofit of commercial buildings using a database of energy efficiency performance. Energy, Available online 22.08.15.

Li, J., Shui, B., 2015. A comprehensive analysis of building energy efficiency policies in China: status quo and development perspective. J. Clean. Prod. 90, 326–344.

Liu, H., 2012. Research on Incentive Policy for Energy Efficiency Reconstruction in Large Public Buildings. Chongqing University,, China.

MOC (Ministry of Construction, China), 1993. Energy Conservation Design Standard on Building Envelope and Air Conditioning for Tourist Hotels. China Architecture and Building Press, Beijing.

MOF (Ministry of Finance, China), MOHURD (Ministry of Housing and Urban-Rural Development), 2011. Guidance for Further Promoting Building Energy Efficiency in Public Buildings. 〈http://www.gov.cn/zwgk/2011-05/11/content_1861716.htm〉 (accessed 03.10.15).

MOF (Ministry of Finance, China), MOHURD (Ministry of Housing and Urban-Rural Development), 2012. The 12th Five-Year-Plan of China Building Energy Efficiency Plan.

NBS (National Bureau of Statistics, China), 2013. China Statistical Yearbook 2013.

China National Bureau of Statistics.
Peng, C., Wang, L., Zhang, X., 2014. DeST-based dynamic simulation and energy efficiency retrofit analysis of commercial buildings in the hot summer/cold winter zone of China: A case in Nanjing. Energy Build. 78, 123–131.
Xing, J., Ren, P., Ling, J., 2015. Analysis of energy efficiency retrofit scheme for hotel buildings using eQuest software: a case study from Tianjin, China. Energy Build. 87, 14–24.
Xu, P., Huang, J., Shen, P., et al., 2013. Commercial building energy use in six cities in Southern China. Energy Policy 53, 76–89.
Xu, Q., Zhuang, Z., Zhang, B., Jiang, Y., 2012. Shanghai Large-Sized Public Building Energy Use Quota Research. Constr. Sci. Technol. 10, 28–31.
Zhang, D., Wang, J., 2014. Effectively promote energy-saving retrofit works of existing public buildings in Shanghai. Constr. Sci. Technol. 10, 41–43.
Zhao, J., Zhu, N., Wu, Y., 2009. The analysis of energy consumption of a commercial building in Tianjin, China. Energy Policy 37, 2092–2097.