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

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Abstract

China is one of the largest developing countries and has a large, rapidly growing commercial building stock. Commercial-building energy demand is growing rapidly. China has made significant efforts to moderate growth in commercial-building energy consumption, including implementation of building energy-efficiency standards. However, it is challenging to regulate the energy performance of existing commercial buildings. Through the energy-efficiency policies promulgated during the 12th Five-Year-Plan, China aims to retrofit least 60 million square meters of commercial building space by the end of 2015. As part of this effort, the government selected four cities – Tianjin, Chongqing, Shenzhen, and Shanghai – to implement pilot commercial-building energy-efficiency retrofit programs.

This paper systematically compares retrofit program information collected through site surveys and other investigations in the four pilot cities, including information on program organization and progress, retrofit program structure and implementation procedures, the design of supporting policies, technical solutions, and costs and benefits. Based on the results of our study, we recommend next steps for improving the energy performance of existing commercial buildings in China.

Introduction

From 1980 to 2014, the urbanization rate grew roughly by 1.02 % annually, from 19.4 % to 54.8 %. As a result, a large number of commercial buildings have been constructed in cities across China, and commercial-building energy demand is growing 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 and BEERC 2014). The average energy intensity of China's commercial buildings is three to five times greater than that of residential buildings. Large-scale, high-end commercial buildings can be as much as 10 to 20 times more energy intensive than typical commercial buildings (MOHURD 2007). In 2012, China's commercial buildings consumed more than 182 million tonnes coal equivalent, accounting for 26.4 % of all building-sector energy use (BEERC 2014). A study done by the Energy Information Administration (EIA) projects 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 China must continue to improve commercial-building energy efficiency to help reduce growth in energy consumption.

During the past two decades, the Chinese government has implemented energy-efficiency policies for commercial buildings. In 1993, the Ministry of Housing and Urban-Rural Development (MOHURD) issued an energy-efficiency standard for hotels (GB50189). In 2005, this standard was revised to include other types of commercial buildings. The standard requires that all new buildings be 50 % more efficient than a baseline defined using 1980s building characteristics. A proposed revision to this standard that takes effect in 2015 sets the efficiency level at approximately 30 % more than that of the 2005 standard, i.e., equivalent to 65 % more efficient than the 1980s baseline.

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 RMB/m^2 for 4 million m^2 (80 million RMB/city)
Subsidy payment	✓	60 % prepaid, 40 % after inspection

Figure 1. China's climate zones and the location of the four cities in the commercial-building energy-efficiency pilot program.

Energy efficiency in existing commercial buildings is more challenging to regulate and improve than in new construction ones. Most commercial buildings that were built before China's 2005 efficiency standard are in need of retrofitting. The energy-efficiency policies promulgated during China's 12th Five-Year-Plan aim to retrofit 60 million m^2 of commercial buildings by the end of 2015, reducing 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 % (CMF & MOHURD 2012). To accelerate energy-efficiency improvements and maximize the energy-saving potential in existing commercial buildings, the Chinese government selected four cities that represent a range of climate zones and other local conditions – Tianjin, Shenzhen, Chongqing, and Shanghai – to carry out pilot commercial-building energy-efficiency retrofit programs. One goal of the program is to support, with subsidies, deep retrofits that will maximize energy savings. In total, the programs in these four cities must retrofit 4 million m^2 within two years, improving energy performance by 20 %, with a central-government financial subsidy of 20 renminbi (RMB)[1]/m^2 (MOHURD 2011). (See Table 1.)

1. In this paper, 1 U.S. dollar ≈ 6.20 RMB.

This pilot program aims to identify effective strategies, technical solutions, and cost benefits associated with retrofitting existing commercial buildings to improve energy efficiency. The goal is to transfer relevant experience from the program's four pilot cities to other cities in China. As of June 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. The research reported in this paper is based on data collected through surveys and other investigations to document the progress of the pilot programs. The remainder of this paper outlines background conditions and current progress in the four pilot cities; describes the organizational structures and implementation procedures of the retrofit programs in each city as well as supportive government policies; presents a detailed case study of the retrofit technical solutions as well as a cost-benefit analysis of the program in Chongqing; and describes our conclusions and recommendations.

Background and Progress in the Pilot Cities

Figure 1 shows the locations of the four cities carrying out pilot commercial-building energy-efficiency retrofit activities. Tianjin is a coastal city in the Chinese cold climate zone 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 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 construction (Peng et al. 2013).

The four cities are all economically developed with relatively mature market systems, including available human resources, financial instruments, and quality building technologies. Furthermore, in recent years, all of the four pilot cities have received central-government support to establish commercial-building energy-consumption monitoring platforms. These monitoring platforms can collect and analyze real-time energy use data on buildings' primary energy-consuming systems.

All major categories of 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. Each pilot city selected its demonstration projects

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

	Program details	Tianjin	Chongqing	Shenzhen	Shanghai
1	Pilot start date	8/2011	8/2011	8/2011	8/2012
2	Site investigation period	12/2013	1/2014	3/2014	4/2014
3	Location	north	southwest	south	east
4	Climate zone	cold	hot summer cold winter	hot summer warm winter	hot summer cold winter
5	Planned retrofit floor area (million m^2)	5.80	4.44	7.78	4.00
6	Current percent progress	64 %	78 %	60 %	58 %
7	Total demonstration projects	140		185	
8	Projects begun or completed		68	109	46
9	Social investment (million RMB)	242,87	>300,00		
10	Average energy savings	≥20 %	≥20 %	≈14 %	≥20 %

Table 3. Program organizational structure in the four pilot cities.

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

** EMC – energy management company.*

independently, as described in detail in the next section of this paper. Table 2 presents basic information on the cities and the progress of their commercial-building energy-efficiency activities.

Thus far, based on the current program status in the four pilot cities, Chongqing has been most successful in achieving the targeted results. Besides Chongqing's progress in carrying out the retrofit program has been the most rapid, the commercial building retrofit market has been incentivized and cultivated there too, and an additional 3 million m^2 of floor area is likely to be retrofitted in the near future. The final section of this paper prior to the conclusions presents a case study of the program in Chongqing. The other three cities have also achieved unique results, and their experiences should be comprehensively studied so that lessons can be learned for implementation in other cities in the future.

Organizational Structures and Implementation Procedures in the Pilot Cities

A unique characteristic of building energy efficiency in China is that the market has been heavily influenced by the government for more than 25 years through frequent policy and code updates and significant financial support including subsidies. One advantage of this government support is that policies can be implemented quickly and smoothly. The experience in the four cities where the commercial-building energy-efficiency program is being piloted demonstrates that central-government-supported policies can be customized to achieve local impacts. Although all four cities use the same central-government policy framework, each city has devised slightly different organizational structures and implementation procedures (Table 3, Figures 2–4).

PROGRAM ORGANIZATIONAL STRUCTURE

The pilot cities have each developed a management structure for retrofit projects as well as technical guidance and reporting protocols. They have also worked with other government agencies in carrying out the energy-efficiency retrofit program. Specific activities have included:

- Setting up and staffing retrofit project management offices.
- Developing institutional support, including local technical guidance and documentation on demonstration projects (e.g., assessment, process management, inspections, and subsidy payments).
- Working with other government departments to identify demonstration projects and integrate resources. 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 other government agencies that are in need of retrofit and can serve as demonstration projects. Some departments have internal retrofit or building-update

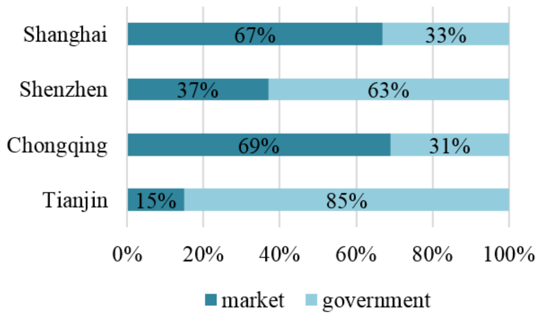

Figure 2. Demonstration project source.

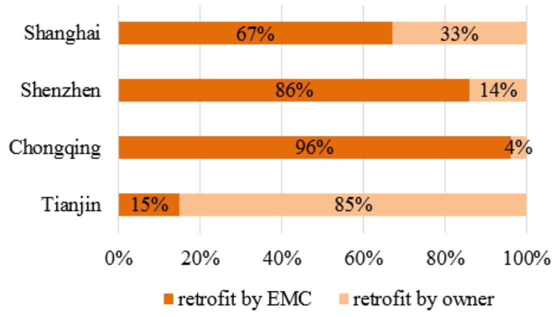

Figure 3. Retrofit entity distribution.

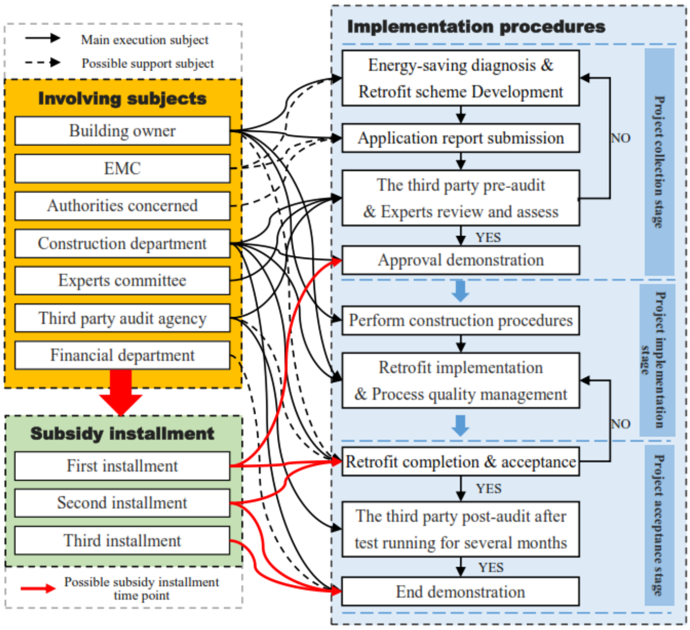

Figure 4. Retrofit demonstration project implementation procedures.

policies that can be integrated with the pilot program to amplify the total policy effect. These other departments include the Finance Committee, Development and Reform Commission, Government Offices Administration, Department of Education, 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, Figure 2, and Figure 3 compare the program organizational structures in the four pilot cities. Tianjin's program is primarily organized by the government. Most of Tianjin's demonstration projects have been come from government channels; some projects have been referred from other government departments, and others have been assigned top down from the city-level construction department to supporting construction administrative departments in local districts. Only 0.6 million m^2 out of a total of 5.8 million m^2 in Tianjin have been retrofitted by energy management companies (EMCs).

By contrast, in Chongqing and Shanghai, demonstration projects have been identified mainly through market channels, and EMCs have retrofitted 96 % and 67 % of floor space, respectively, in these two cities. Although EMCs in these two cities have used both the "shared energy savings"[2] and "energy saving guarantee"[3] approaches, the shared-energy-savings approach has been used in a majority of the projects.

Shenzhen has identified and implemented projects through a mix of government and EMC participation. Sixty-three percent of the demonstration projects in Shenzhen were identified by the government, and 86 % of the retrofits have been carried out by EMCs. This is because retrofits of governmental public buildings in Shenzhen are required to be carried out by EMCs. Additional analysis is presented in the section entitled "Supportive Local-Government Policies" later in this paper.

IMPLEMENTATION PROCEDURES

Figure 4 shows the general implementation procedures for retrofit demonstration projects in the pilot cities.

The first stage of implementation focuses mainly on identifying potential demonstration projects and selecting the projects to be implemented. The sources of these demonstration projects are as shown previously in Figure 3. A notable element of the first phase of program implementation in Shenzhen was the development of a demonstration project management information system that has enhanced project management.

The second stage of implementation entails carrying out the retrofits. In this phase, retrofit quality management is the primary challenge. Both building owners and the local construction department are responsible for retrofit quality management. EMCs that perform retrofits under the programs in Chongqing, Tianjin, and Shanghai must register with local government departments. Shenzhen has stipulated specific qualifications for construction enterprises that wish to participate in the program. This stricter requirement in Shenzhen has helped ensure retrofit quality.

The third stage of implementation focuses on inspection and approval of retrofit projects. Chongqing and Shenzhen have es-

2. "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.

3. "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.

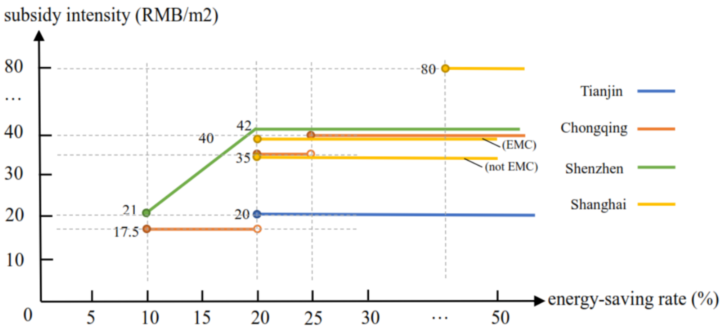

Figure 5. Relationship between subsidy and energy savings in the four pilot cities.

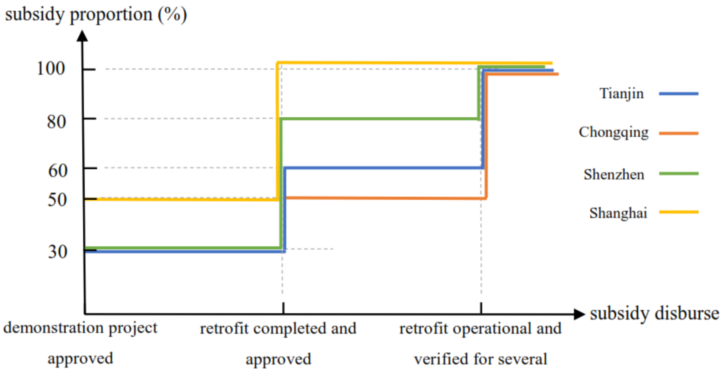

Figure 6. Subsidy installments in the four pilot cities.

tablished a post-retrofit energy audit policy for this phase. The audit periods are 3 months in Chongqing and 1 year in Shenzhen. The audit results are the basis for payment of post-retrofit subsidies. The audit requirement helps ensure that retrofits are completed as planned.

Chongqing and Shenzhen both use third-party auditors for measurement and verification (M&V) of energy savings in retrofitted buildings. Shenzhen uses the Shenzhen Institute of Building Research Co. Ltd as its third-party auditor, and Chongqing hired three-third party auditors to ensure market competition. Through random cross-verification among the auditors, the quality and accuracy of the M&V work in Chongqing can be compared and improved.

The financial department in each city pays the retrofit subsidy. To ensure retrofit quality and achievement of energy savings, the subsidy is designed to be paid in two or three installments. The installments are linked to acceptance of the project into the 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 next section of this paper.

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 RMB/m^2 retrofitted, the four cities each developed individual financial support policies (Table 4, Figure 5, Figure 6).

TIANJIN

In Tianjin, the local government matched the central government financing of 20 million RMB. The 20 million RMB in local funds are used for capacity building, including development of standards and institutions to support the retrofit program, and for administrative expenses. The direct subsidy for the demonstration projects comes from the central government fund of 20 RMB/m^2.

No particular incentive policies were formulated in Tianjin to encourage EMCs to carry out retrofit projects or to enhance the energy savings.[4] As a result, the market response in Tianjin has not been very strong. Only 15 % of projects have been identified through the market with retrofits implemented by EMCs. The majority of projects – up to 85 % – have come through the government administration, with retrofits carried out by building owners (Figure 3, Figure 4).

The subsidies in Tianjin are paid in three installments: 30 % when a project is approved as a demonstration, 30 % when the retrofit is finished, and 40 % when the energy savings are verified by a third-party auditor (Table 4, Figure 7).

CHONGQING

Chongqing's comprehensive policy links the subsidy rate directly to energy saved and promotes implementation by EMCs.

4. The National Development Reform Commission (NDRC) EMC policy remains valid, independent of the Ministry of Housing and Urban-Rural Development (MOHURD) retrofit policies. This paper evaluates only MOHURD-related policies.

Table 4. Subsidy policies in the four pilot cities.

	Tianjin	Chongqing	Shenzhen	Shanghai
Subsidy				
Total local finance matching (million RMB)	20	80	120	80
Central subsidy: local subsidy	1:0.25	1:1	1:1.5	1:1
Energy-saving threshold				
Demonstration threshold	20 %	20 %	10 %	20 %
Subsidy threshold	20 %	10 %	10 %	20 %
Total subsidy intensity (RMB/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 %	

I. The subsidy was designed to give larger incentives to demonstration projects that pursue greater energy savings, as described by equation 1:

$$\text{subsidy amount } (\text{RMB/m}^2) = \begin{cases} 0, \textit{ when energy saving rate} < 10\ \% \\ 17.5, \textit{ when } 10\ \% \le \textit{energy saving rate} < 20\ \% \\ 35, \textit{ when } 20\ \% \le \textit{energy saving rate} < 25\ \% \\ 40, \textit{ when energy saving rate} \ge 25\ \% \end{cases} \quad (1)$$

When we surveyed Chongqing's 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 use of EMCs for retrofit implementation, Chongqing allocated 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.

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

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 poses a greater challenge in Shenzhen than in the other pilot cities. Shenzhen's innovative approach to the program includes setting the energy-savings target at 10 %, which is only half of the target in other three pilot cities; however Shenzhen targeted 7.78 million m^2 of floor area for retrofit, much more than in in the other pilot cities and almost twice the city-level target set 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 (Chuncheng et al. 2014).

I. To promote greater energy savings, Shenzhen's subsidy was designed as described in equations 2–4:

$$\text{subsidy amount} = 42\ (\text{RMB/m}^2) \times \textit{retrofit floor area}\ (\text{m}^2) \times \alpha \quad (2)$$

Where: α is the conversion coefficient of retrofit floor area and can be calculated as described in equation 3:

$$\alpha = \begin{cases} \frac{\textit{energy saving rate}}{20\ \%}, \textit{ when } 10\ \% \le \textit{energy saving rate} < 20\ \% \\ 1, \textit{ when energy saving rate} \ge 20\ \% \end{cases} \quad (3)$$

Therefore:

$$\text{subsidy amount } (\text{RMB/m}^2) = \begin{cases} 0, \textit{ when energy saving rate} < 10\ \% \\ 21, \textit{ when energy saving rate} = 10\ \% \\ (21, 42), \textit{ when } 10\ \% < \textit{energy saving rate} < 20\ \% \\ 42, \textit{ when energy saving rate} \ge 20\ \% \end{cases} \quad (4)$$

This design encourages demonstration projects to pursue greater savings by offering larger subsidies for larger amounts of savings. To date, all of the retrofit projects completed in Shenzhen have achieved their target energy savings, with an average savings of 14 %. Most projects achieved energy savings rate in the range of 10 % to 20 %, with proportional subsidies.

II. With regard to EMC participation, 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).

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.

SHANGHAI

In recent years, Shanghai has implemented many effective measures in commercial buildings. One of the most noteworthy is the commercial-building real-time energy-use monitoring system. Metered data from this system are used in the commercial building retrofit program. Shanghai's subsidy scheme is as shown in equation 5 (Deming and Wang 2014).

$$\begin{aligned}&\text{subsidy amount}\\&\quad(\text{RMB/m}^2)\\&=\begin{cases}0, \textit{when energy saving rate} < 20\ \%\\35, \textit{when energy saving rate} \geq 20\ \%\ \textit{and not EMC}\\40, \textit{when energy saving rate} \geq 20\ \%\ \textit{and EMC}\\80, \textit{when retrofit meets standard}\ \text{GB-50189}\end{cases}\end{aligned} \quad (5)$$

I. To promote greater energy savings, Shanghai compares retrofit project energy performance to its local commercial building energy-efficiency standard for new construction. Shanghai's subsidy can be as much as 80 RMB/m^2 when the demonstration project meets or exceeds the standard. However, it is difficult to meet the standard because of the incremental costs of retrofits are high. No project thus far has met the standard. All of the retrofit projects have received the 35 RMB/m^2 or 40 RMB/m^2 subsidy.

II. Shanghai's approach to EMC participation is slightly different from the approaches in Chongqing and Shenzhen. For projects that achieve the same level of energy savings, those implemented by an EMC receive a subsidy of 40 RMB/m^2 and those not implemented by an EMC receive 35 RMB/m^2. As of the date of our site survey, 67 % of the demonstration projects completed in Shanghai had been implemented by EMCs.

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.

DISCUSSION

We find the following regarding the subsidy designs and retrofit accomplishments in the four pilot cities:

- *Subsidy level.* Tianjin's subsidy level is low compared with the levels in the other three cities (Table 4 and Figure 6), and the response from the market is also weak in Tianjin. In contrast, the other three pilot cities offered larger subsidies using local matching funds and received a strong market response. Although the central government offered the same subsidy level across the board, the impact in each city is different because of variations in local economic conditions. The subsidy amounts affect the program's appeal and the motivation of market actors to participate. We recommend that the government set subsidy levels taking into account local financial resources and the cost of retrofits that use local technical solutions. We find that linking the subsidy level to the energy saved, as has been done in Shenzhen, is effective; this can motivate demonstration projects to pursue greater energy savings.
- *Subsidy installments.* The subsidy installments were paid at three critical milestones in all four pilot cities (Figure 5 and Figure 7). Making the first payment when a project is approved can provide start-up capital for those carrying out retrofits and thereby motivate participation in the program. The second payment is most commonly made when a retrofit is completed and approved. The third payment, after a retrofit has been operating and energy savings are verified, is the most effective for guaranteeing retrofit quality and actual energy savings.
- *Subsidies to encourage EMC participation.* Chongqing and Shanghai have successfully incentivized the participation of EMCs through differing subsidy designs. In Chongqing, the subsidy is the same whether an EMC participates or not, but the benefit sharing between the owner and the EMC differ. In Shanghai, the subsidy amount differs by 5 RMB/m^2 depending on whether an EMC is involved. We can see that Chongqing's design saves the local government money. This approach is especially attractive for governments whose financial resources are limited.
- *Subsidy calculation.* In addition to the current method of calculating subsidies based on retrofitted floor area, subsidies could depend on total retrofit cost, or could be based on the energy saved.

Case Study: Chongqing Retrofit Technical Solutions and Cost-Benefit Analysis

Each of the four pilot cities in the commercial-building energy-efficiency retrofit program 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.

For this case study, we performed detailed quantitative analysis on 68 completed and approved demonstration projects in Chongqing. The subsections below summarize the technical solutions utilized in these projects and our cost-benefit analysis of the projects.

RETROFIT TECHNICAL SOLUTIONS

Figure 7 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 ret-

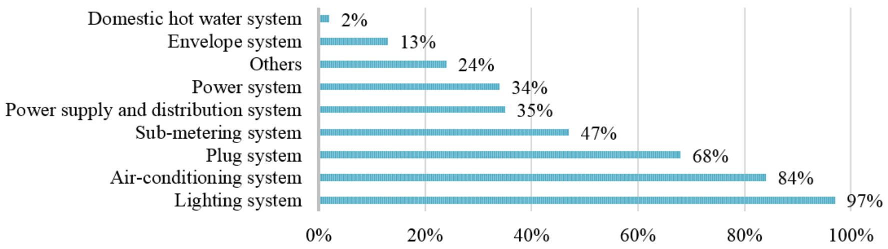

Figure 7. Building systems receiving energy-efficiency retrofits in Chongqing.

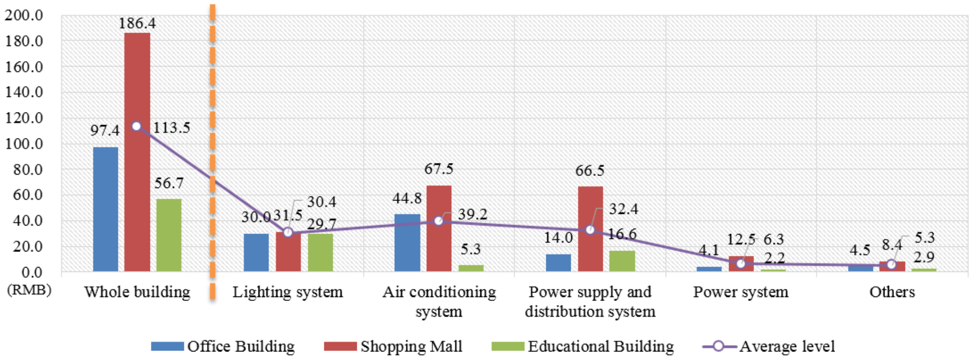

Figure 8. Retrofit cost for five building systems in three typical buildings in Chongqing.

rofit. The second most common retrofit, 84 %, was of air conditioning systems. The least-common retrofit was to domestic hot water and envelope systems (He et al. 2014) because of the technical and economic challenges associated with retrofitting these building systems.

COST-BENEFIT ANALYSIS

Our investigation of the retrofit projects in the four pilot cities shows that subsidies cover approximately 20 to 40 % of total retrofit cost. However, this proportion varies substantially among cities and projects. In Tianjin, for example, building envelope retrofit costs are approximately 100 to 150 RMB/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 RMB/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.

We use the 68 projects that we studied in depth as a database for quantitatively assessing the impact of government subsidies on the retrofit economy and on the static payback periods for the demonstration projects. Figure 8 and Figure 9 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 Figure 9 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 RMB/m^2) but provide significant post-retrofit savings (2.4 RMB/m^2).

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 RMB/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 (Figure 10). Retrofits of power systems in the three types of buildings have the shortest payback period, 1.5 to 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 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 government office buildings and public buildings like schools, hospitals, etc. are eligible to receive.

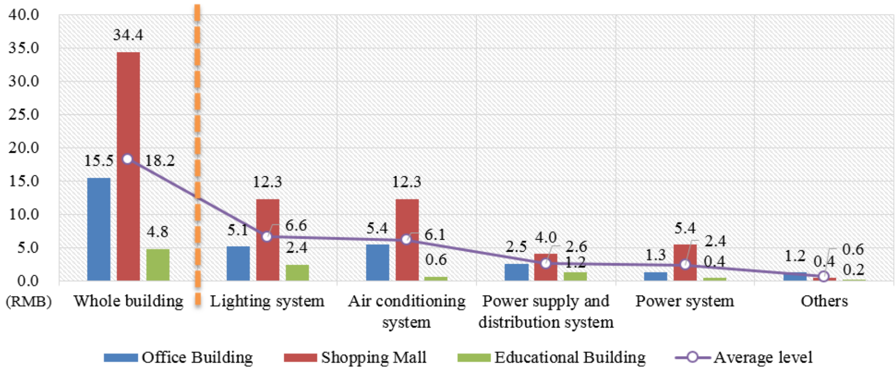

Figure 9. Annual savings from retrofits of five systems in three typical buildings in Chongqing.

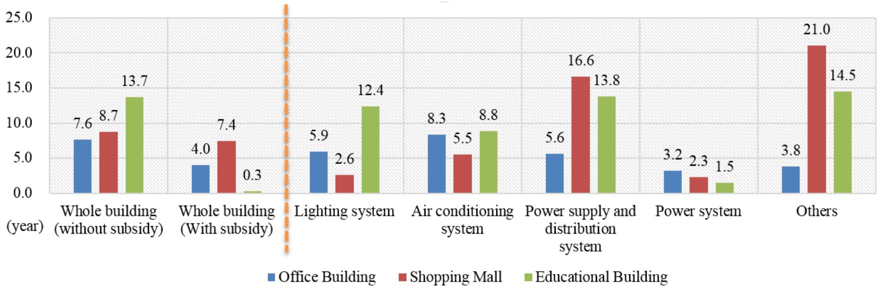

Figure 10. Static payback for retrofits in three types of commercial buildings in Chongqing.

Conclusions and Recommendations

Our research shows that central-government subsidies can drive local matching funding for energy-efficiency retrofits and thus stimulate market investments. For both the entire market and for individual demonstration projects, the degree of incentive to undertake retrofits is directly linked to the subsidy level. At the same time, because subsidies are unlikely to be sustainable for long periods, their primary effect is to stimulate the market. Therefore, key outcomes of the demonstration projects should be the identification of the retrofit technical solutions and business models that are best suited to the local stock of existing commercial buildings in each area. Implementation of the demonstration projects produces both technical and management experience that can support an ongoing, sustainable commercial-building retrofit market.

With regard to policy design, the government should craft policies taking into account not only the local economic conditions and each city's funding capacity but also the local cost of retrofit solutions. In addition, our study shows that different cities have different energy-efficiency baselines and thus different savings potentials. For example, Shenzhen's baseline is much more efficient than the baselines in the other three pilot cities; therefore, Shenzhen's energy-savings potential is relatively smaller. This phenomenon is even more common at the single-building level. Therefore, local governments should develop policies that address the range of efficiency baselines within their territories. Policy makers should consider the following recommendations:

I. Subsidy intensity should be linked to the cost of local technical solutions.

II. Linking the subsidy level to the energy savings achieved, as has been done in Chongqing, encourages building owners or EMCs to pursue greater energy savings than they might in the absence of such an incentive. Commercial building owners tend to seek the maximum efficiency from a one-time capital investment in retrofits.

III. Linking the subsidy level to EMC participation in implementing retrofits, as has been done in the pilot cities of Shanghai and Chongqing where subsidies create preferential economics for retrofits carried out by EMCs, can effectively promote EMC participation in the retrofit market.

IV. Paying subsidies in installments linked to clearly defined milestones can help ensure retrofit quality and achievement of target energy savings. The design used in the pilot cities of Shenzhen and Chongqing is particularly effective, paying the last subsidy installment after the retrofitted building has been in operation for a certain period and after energy savings have been measured and verified.

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