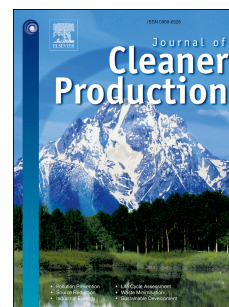


# Accepted Manuscript

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PII: S0959-6526(18)33794-6

DOI: <https://doi.org/10.1016/j.jclepro.2018.12.086>

Reference: JCLP 15144

To appear in: *Journal of Cleaner Production*

Received Date: 13 February 2018

Revised Date: 5 December 2018

Accepted Date: 8 December 2018

Please cite this article as: Liu Y, Liu T, Wang B, Xu M, Developing a methodology for the ex-post assessment of Building Energy Efficiency Special Planning in Beijing during the 12th Five-Year Plan” period, *Journal of Cleaner Production* (2019), doi: <https://doi.org/10.1016/j.jclepro.2018.12.086>.

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**Developing a Methodology for the Ex-Post Assessment of Building Energy  
Efficiency Special Planning in Beijing  
during the “12<sup>th</sup> Five-Year Plan” Period**

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**Abstract:** In order to carry out an ex-post assessment of the completed Building Energy Efficiency Special Planning, a comprehensive ex-post assessment methodology is established. The methodology sets out the ex-post assessment criteria from three dimensions and 27 indexes, and apply the Fuzzy Synthetic Evaluation Method to build the ex-post assessment model. Applying the methodology, this research assesses the effectiveness of the Building Energy Efficiency Special Planning in Beijing during the “12<sup>th</sup> Five-Year Plan” period. The results show that it is generally effective in terms of realizing the main planning targets, reaching the desired development level of Building Energy Efficiency and ensuring the facilitating mechanisms to be in place. To be specific, substantial increase of the proportion of energy efficient buildings and considerable effects of energy saving and carbon emission reduction have been achieved, whilst the electricity consumption per unit area in small and median-sized commercial buildings being increased. The research further identifies the main barriers to the implementation of building energy efficiency program includes high electricity consumption of large-scale commercial buildings, insufficient data information, slow uptake of modern information technology, lack of market participation and lack of wider social recognition. Based on the assessment result and subsequent analysis, commensurate policy recommendations were proposed. This research was the first attempt examining the implementation effects of BEE Special Planning in Beijing.

**Key Words:** Building energy efficiency; Special Planning; Implementation effects; Ex-post assessment; Fuzzy Synthetic Evaluation Method

## 1 Introduction

During the last decades, energy consumption of China has largely increased due to rapid economic growth and social development. Currently, China has become the world's largest energy consumer and carbon dioxide emitter (BP Global, 2010). The Building Energy Consumption (BEC) represents a major share of China's total energy consumption (Lin and Liu, 2015). According to the National Development and Reform Commission (NDRC, 2014), total amounts of BEC reached 1.27 billion tce (tons of standard coal) in 2014, which accounted for 29.8% of the total energy consumption. The Building Energy Conservation Research Center (BERC, 2016) predicted that the total amounts of BEC should be controlled within 1.1 billion tce (not including renewable energy sources), which accounts for 23% of China's total energy consumption amounts of 4.8 billion tce by the end of 2020. With regard to the ambitious goals to achieve energy savings in the building sector,, a Building Energy Efficiency (BEE) program was initiated. The BEE program mainly involves five aspects: (1) adoption of energy efficiency measures on newly constructed buildings, (2) promotion of Energy Efficiency Retrofitting (EER) of existing buildings, (3) utilization of renewable energy, (4) enhancement of energy efficiency of operation management of large-scale commercial buildings, and (5) adoption of energy efficiency measures on rural residential buildings.

The series of BEE Special Planning were useful policy documents to guide the implementation of BEE program (Evans et al., 2014; Hou et al., 2016). Dating back to 1996, the central government formulated the first BEE Special Planning, the *Building Energy Efficiency '9<sup>th</sup> Five-year' Planning (1996-2000) and Perspective Long-term Planning of 2010*. In February 2017, *Development Planning of Building Energy Efficiency and Green Building during the 13<sup>th</sup> Five-year Period (2016-2020)* was issued by the Ministry of Housing and Urban-Rural Development, which stands for the 5<sup>th</sup> BEE Special Planning in China. Meanwhile, local governments released their own BEE Special Planning to guide BEE development in practice. For

example, the Beijing Municipal Government issued the local BEE Special Planning - *Development Planning of Civil Building Energy Efficiency in Beijing during the 13<sup>th</sup> Five-year Period*. Despite the availability of a series of Special Planning policy documents, an ex-post assessment of the completed BEE Special Planning has not been carried out to date. A systematic methodology has not been established to execute the ex-post assessment. Here, the ex-post assessment refers to an evaluation that systematically and objectively analyzes and assesses the purpose, execution process, benefit, effect and influence of a policy document after the enforcement period ends. It remains unclear whether the Special Planning has provided a useful and operational guidance on the practical implementation of BEE.

The research, reported in this paper, aims to develop a robust and systematic methodology for the ex-post assessment of BEE Special Planning in the context of China and apply the methodology to perform an ex-post assessment of Building Energy Efficiency Special Planning in Beijing during the “12<sup>th</sup> Five-Year Plan” Period. This research was part of the research project commissioned by the Beijing Municipal Commission of Housing and Urban-Rural Development in 2015. A diagram of the research design is shown in Fig. 1. The methodology presented in this paper provides a practical template to evaluate the effectiveness of BEE Special Planning, and other BEE policies, which can be used elsewhere by incorporating different contextual elements. By applying the methodology to the evaluation of BEE Special Planning in Beijing during the “12<sup>th</sup> Five-Year Plan” Period, the challenges BEE work facing and shortcomings of policy instruments can be identified, which provide important reference for policy makers to adjust the policy directions and further facilitate informed and effective policy making.

This paper is divided into six sections. Following this introduction, Section 2 presents the literature review, which summarizes and evaluates the literature in relation to the assessment of BEE policies. Section 3 describes the methodology proposed to conduct an ex-post assessment of BEE Special Planning. Section 4 reports on how the proposed methodology being applied to the ex-post assessment of BEE Special Planning in Beijing during the “12<sup>th</sup> Five-Year Plan (FYP)”

period. Section 5 discusses the results of the assessment and identifies barriers hindering the implementation of BEE Special Planning. Section 6 concludes the research and proposes the policy recommendations.

## 2 Literature Review

### 2.1 Overall evaluation of BEE policies

Studies have been conducted to systematically review the BEE policies in China. For example, Zhou et al. (2010) reviewed the development of BEE policies in China, including building energy standards in different stages, building energy conservation regulation ordinance bill and building energy efficiency labeling. They proposed five important policy directions to strengthen the BEE program: (1) enhancing existing building standards; (2) implementing the standards effectively; (3) controlling the use of energy-inefficient building materials; (4) enforcing energy efficiency retrofit; and (5) stimulating the practice of BEE policies. Li and Shui (2015) performed a comprehensive analysis of BEE policies with regard to improvements in energy performance, living standards and climate change. Shen et al. (2016) investigated BEE policy instruments classified them into three types, including mandatory administrative instrument, the economic incentive instrument, and the voluntary scheme instrument. Guo et al. (2016) summarized and analyzed the framework of measures implemented by the Chinese government to enforce mandatory BEE codes, and they found that the energy savings of new buildings per increased floor area per year increased from 20.4 kWh/m<sup>2</sup> in 2007 to 28.4 kWh/m<sup>2</sup> in 2012. By conducting a comparative study of China and Japan, Huang et al.'s (2016) policy analysis suggested that Building Energy Saving Policies have promoted building energy saving. They also identified the obstacles to the effective policy implementation, such as high transaction costs and lack of applicable methodology.

A number of researchers further analyzed the implementation effects of various policies on BEE program from a project's perspective via case studies. Liu and Guo (2013) analyzed the energy conservation and emission reduction effect through an actual energy efficiency retrofit case in North China. Kong et al. (2012) analyzed six fiscal incentive policies and four specific

programs for BEE work during the “11<sup>th</sup> Five-Year Plan” period (2006-2010), identified the drawbacks of the present BEE mechanism and recommend four proposals to enhance the development of BEE. Xing et al. (2015) revealed that the actual energy consumption can reach 77.3% after an energy efficiency building retrofit based on a case study of a hotel building located in Tianjin, China. Liu et al. (2018) studied a residential EER building project and showed that the actual energy savings did not reach the theoretically calculated value. By conducting an economic cost-benefit analysis based on the calculation of costs and benefits over life cycle, the research found that in China, the retrofit of existing buildings generally lacks of attractiveness to investors from an economic perspective.

From a wider industry perspective, scholars have endeavored to assess the effectiveness of national and local BEE policies during the 11<sup>th</sup> FYP and 12<sup>th</sup> FYP period. For example, Price et al. (2011) conducted an assessment of selected policies and programs that China had instituted to accomplish the national goals, and they revealed that China had greatly enhanced its enforcement of new building energy standards, but energy-efficiency programs for buildings’ retrofits were not well achieved. They further suggested that it is important to maintain and strengthen the existing energy-saving policies and programs which have positive effects, whilst introducing new policies to remove the barriers to the successful implementation of BEE. Lin and Liu (2015) found that occupants’ lifestyles, residents’ living standards, and energy price have significant influences on BEC and the building sector is likely to contribute approximately 20% to China’s energy conservation through electricity pricing reform by the end of 2020.

## **2.2 Evaluation of energy saving effects of BEE policies**

Extant literature has presented research undertaken to examine the actual energy savings and carbon emission reductions, which evidently reflect the implementation effects of BEE policies. Ma et al. (2017) introduced the concept of comparable building energy consumption per unit area and utilized an IPAT-LMDI model approach to calculate China’s building energy savings at national level. The research found that the calculated building energy savings exceeded the

officially planned amount. Researchers have also adopted innovative methods to conduct an analysis of energy savings in different types of civil buildings, such as residential buildings (Yan et al., 2017) and commercial buildings (Ma et al., 2018), and the research findings showed that the implementation of BEE works in China significantly contribute to energy savings in both type of buildings. In addition to the energy savings effects, the measurement of carbon emission reduction has been researched. For example, Ma and Cai (2018) showed that in the commercial building sector, the carbon mitigation values in 2001 – 2005, 2006 – 2010, and 2011 – 2015 were 123.96, 252.83, and 249.07 Mt CO<sub>2</sub>, respectively, which demonstrate that China's BEE work has achieved considerable progress in reducing carbon emission.

Since energy consumption in the residential sector is a primary part of energy consumption at the country scale, it offers great opportunities for energy conservation. It is thus important to investigate the determinants of energy use in the residential sector. Filippini and Pachauri (2004) examined the influence of factors such as income, prices, household size and other household specific characteristics on electricity consumption in the household sector of urban areas in India. They found that electricity demand is income and price inelastic whilst household, demographic and geographical variables are significant determinants of household electricity consumption. Brounen et al. (2012) focused on the relationship between economic behavior and household energy consumption. The research revealed that the residential gas consumption is mainly dependent on structural dwelling characteristics and the electricity consumption is largely determined by income and family composition. Longhi (2015) further tested the influence of changes in household socio-economic characteristics on changes in energy expenditures and the results showed that dwelling characteristics, especially house size have the most significant impact on the energy consumption. Based on a case study in Italy, Besagni and Borgarello (2018) concluded that building, social-demographic and appliances variables are important determinants of residential energy expenditure.

Existing literature also shed lights on the rebound effects to assess the reduction in expected

benefits resulting from increase in energy efficiency. Sorrell (2007) asserted that the energy savings achieved from improved energy efficiency are generally not realized in practice due to behavioral responses such as greater use of energy services. Such behavioral responses are referred to as the rebound effect. By analyzing the nature, operation and importance of rebound effects, the research called for an explicit treatment of rebound effects when assessing the potential impact of energy efficiency policies. Wolff and Schubert (2017) strengthened the point that the energy savings achieved from thermal retrofit are far less than expectation because of the rebound effects. Freire-González (2010) proposed a methodology to assess the magnitude of rebound effects in household and found that the existence of rebound effects reduces the effectiveness of energy efficiency policies. In addition to the studies commissioned to estimate the extent and magnitude of “economy-wide” macroeconomic rebound effects, Galvin (2015), Broadman (2010) and Hong et al. (2006) argued that energy poor households show larger rebound effects after energy efficiency retrofits. There is a tendency toward higher rebound effects in lower socio-economic groups (Chitnis et al., 2014).

### **2.3 Methodologies for assessing implementation effects of BEE’s Special Planning**

A number of studies were performed to explore the methodology for assessing the implementation effects of BEE policies. Xin et al. (2014) established an evaluation method with the application of the multi-level expert evaluation method, and the evaluation indexes cover the aspects of policy mechanisms, financing modes and technical measures. McNeil et al. (2016) developed a bottom-up modeling framework to quantify the effects of energy efficiency programs in China’s building sector on potential energy savings and emission reduction. They found that the implementation of building codes provides the largest savings opportunity, leading to an overall 17% reduction in overall space heating and cooling demand. Zhao et al. (2009) established a three-grade evaluation system for heat metering and EER of existing residential buildings in northern heating areas of China. Yang et al. (2010) proposed a method to identify and weight indicators for assessing the energy efficiency of residential buildings in China, and set out a list of

indicators of energy efficiency assessment in residential buildings in the hot summer and cold winter zone. Although previous studies have made considerable progress to evaluate the BEE policies and recommend on policy directions, prior research did not offer an appropriate methodology to conduct an ex-post assessment of BEE Special Planning.

### **3 Description of the Methodology for an Ex-post Assessment of BEE Special Planning**

#### **3.1 Ex-post assessment framework**

This research aims to develop a robust and systematic methodology for an ex-post assessment of BEE Special Planning in the context of China. An ex-post assessment framework is an essential pre-requisite for the development of the methodology. The framework of an ex-post assessment of BEE Special Planning is presented in Fig.2, which includes target, criteria and index layers. The target layer (A) relates to the main purpose of the ex-post assessment framework. The criteria layer (B) represents the dimensions based on which the assessment is carried out. The index layer (C) refers to the indexes pertaining to the identified dimensions. The framework allows a comprehensive ex-post assessment of the implementation effects of BEE Special Planning in Beijing during the past 12<sup>th</sup> FYP period. It also enables the researchers to identify main barriers hindering the implementation of BEE Special Planning and offer meaningful policy recommendations.

This research started with a comprehensive review of existing literature on the evaluation of BEE policies to provide a preliminary list of dimensions and associated indexes. We then held two round-table discussions with in-house experts from Beijing Real Estate Science and Technology Research Institute and Research Center of Construction Science and Technology of Beijing Municipal Commission of Housing and Rural Development, along with external BEE experts to propose a three-dimensional index system for the ex-post assessment framework. In order to validate the dimensions and indexes for the ex-post assessment, a questionnaire was designed to solicit respondents' views on the appropriateness of the indexes selected. The questionnaire also

elicits experts' opinions on the weights of each dimension in the criteria layer and each index in the index layer. The main sections of the questionnaire are presented in Appendix 1. The questionnaire was sent to 32 experts from relevant fields of BEE and 28 valid responses were returned, representing a response rate of 87.5%. The composition of the respondents participating in the survey was shown in Fig.3.

### 3.1.1 Dimensions identification

Based on two rounds of round-table discussions, this research develops a three-dimensional ex-post assessment framework, which includes the realization degree of main planning targets ( $B_1$ , which can quantitatively reflect the effects of the BEE Special Planning), the development level of BEE ( $B_2$ , which qualitatively assesses the effects of BEE Special Planning), the facilitating mechanisms to promote BEE ( $B_3$ , which indicates the extent to which the relevant mechanisms are in place to facilitate the implementation of the BEE Special Planning), as shown in Fig.4. The dimensions can comprehensively evaluate the tasks completed and the effects of BEE Special Planning, and reflect the development level of BEE and facilitating mechanisms to promote BEE.

### 3.1.2 Establishment of the index system

Based on the questionnaire survey result and the subsequent statistical analysis, the composition of indexes under  $B_1$ ,  $B_2$ ,  $B_3$  were adjusted. As for  $B_1$ , ten indexes were reduced to eight indexes, with "Green building" and "Housing industrialization" being removed. The number of indexes under  $B_2$  was kept as ten, but "Index of heat transfer coefficient of building envelope" was adjusted to "Average energy-saving rate of residential building", and "Areas and proportion of green buildings" was adjusted to "Average ranking of green buildings". The number of indexes under  $B_3$  was reduced from ten to nine, with "Implementation of heat metering and charging system" being deleted. The index system under the ex-post assessment framework is shown in Fig.5. The description of each index is presented in Annex 1-3.

### 3.1.3 Determination of the weights for dimensions and indexes

This research adopted the Expert Scoring Method to determine the weight of criteria layer and index layer. Based on the scores given by the experts in the questionnaires survey, the weight of the criteria layer and index layer is obtained (See Table 1).

### 3.2 Establishment of the ex-post assessment model

In this paper, the Fuzzy Synthetic Evaluation Method (FSEM) was applied to build the ex-post assessment model of BEE Special Planning. The FSEM is a widely used and effective multi-factor decision-making method based on fuzzy mathematics (Zhao et al., 2016; Shi et al., 2017; Wu et al., 2017). Detailed steps are described as follows.

#### 3.2.1 Determine the factor sets of evaluation object

The determination of factor sets is the first step to carry out the fuzzy synthetic evaluation. It is assumed that there are  $n$  indicators included in the evaluation object. The  $i^{th}$  indicator can be expressed as  $u_i$ . Thus, the factor sets can be expressed as follows:

$$U = \{u_1, u_2, \dots, u_i, \dots, u_n\} \quad (1)$$

As shown in Fig. 5, the factor sets of the ex-post assessment can be listed as follows:

$$\text{Factor sets of } A = \{B_1, B_2, B_3\} \quad (2)$$

$$\text{Factor sets of } B_1 = \{C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{17}, C_{18}\} \quad (3)$$

$$\text{Factor sets of } B_2 = \{C_{20}, C_{21}, C_{22}, C_{23}, C_{24}, C_{25}, C_{26}, C_{27}, C_{28}, C_{29}\} \quad (4)$$

$$\text{Factor sets of } B_3 = \{C_{31}, C_{32}, C_{33}, C_{34}, C_{35}, C_{36}, C_{37}, C_{38}, C_{39}\} \quad (5)$$

#### 3.2.2 Determine the weight sets of impact factors

The weight quantitatively reflects the relative importance of every index in the ex-post assessment. The weight sets of impact factors can be expressed as follows:

$$W = \{w_1, w_2, \dots, w_i, \dots, w_n\} \quad (6)$$

In Eq. (6),

$$w_i \geq 0, \sum_{i=1}^n w_i = 1$$

According to Table 1, the weight sets of impact factors in criteria layer and index layer can be presented as follows:

$$W_A = \{0.44, 0.28, 0.28\}$$

$$W_{B1} = \{0.28, 0.14, 0.10, 0.09, 0.04, 0.16, 0.16, 0.03\}$$

$$W_{B2} = \{0.19, 0.12, 0.11, 0.10, 0.09, 0.07, 0.09, 0.08, 0.05, 0.10\}$$

$$W_{B3} = \{0.15, 0.15, 0.12, 0.12, 0.12, 0.10, 0.09, 0.05, 0.10\}$$

### 3.2.3 Determine the grade sets of evaluation object

The grade sets of evaluation object can be used to describe the evaluation results. Each grade can correspond to a fuzzy subset of an evaluation object. Here, assume that there are  $m$  grades included in the evaluation grade sets. The  $j^{th}$  grade can be expressed as  $v_j$ . Thus, the evaluation grade sets can be expressed as follows:

$$V = \{v_1, v_2, \dots, v_j, \dots, v_m\} \quad (8)$$

After experts' discussion, evaluation grades about implementation effects' ex-post assessment are divided into five grades: excellent, good, moderate, qualified and unqualified. So, the grade sets of evaluation object can be expressed as follows:

$$V = \{\text{excellent, good, moderate, qualified, unqualified}\} \quad (9)$$

### 3.2.4 Establish the fuzzy relation matrix

The Single Factor Evaluation method was adopted to establish the fuzzy relationship subset, and the Expert Scoring Method was applied to grade each evaluation index. According to Fig.5, the assessment indexes can be divided into quantitative and qualitative indexes. For the grade evaluation of quantitative index, the evaluation grade from different experts should belong to the same grade according to the evaluation standard of each index. That is, if the index  $i$  belongs to

evaluation grade  $v_j$  ( $j=1, 2, \dots, m$ ), its corresponding membership degree to this grade  $r_{ij}$  equals to  $1(r_{ij}=1)$ , and the membership degree to other grade  $v_p$  ( $p \neq j, p=1, 2, \dots, m$ ) is  $0(r_{ip}=0)$ . Meanwhile, for the grade evaluation of qualitative index, the fuzzy subset  $r_i = (r_{i1}, r_{i2}, \dots, r_{im})$  can be established according to the results of different experts scoring. Finally, the fuzzy relation matrix  $R$  can be established through combining  $n$  fuzzy relation subsets of quantitative and qualitative indexes, which is shown in Eq. (10).

$$R = \begin{bmatrix} R & | & u_1 \\ R & | & u_2 \\ \dots & \dots & \dots \\ R & | & u_n \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix} \quad (10)$$

In Eq. (10), the element  $r_{ij}$  of the  $i^{th}$  row and  $j^{th}$  column represents the membership degree of the factor  $u_i$  for the evaluation grade  $v_j$ .

### 3.2.5 Establish the mathematical model

Applying the FSEM method, the mathematical model of ex-post assessment can be established as follows:

$$B = W \times R = (w_1, w_2, \dots, w_n) \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix} = (b_1, b_2, \dots, b_m) \quad (11)$$

In Eq. (11),  $B$  represents the membership degree judgment matrix,  $W$  represents the factor weight coefficient vector, and  $R$  represents the fuzzy relation matrix. After obtaining the synthetic evaluation judgment matrix  $B$ , the evaluation result can be determined according to the principle of maximum membership degree. The evaluation grade can thus be determined to the corresponding grade of maximum  $b_k$  ( $b_k = \max \{b_j\}$ )

## 4 Ex-post Assessment of the BEE Special Planning in Beijing during the 12<sup>th</sup> FYP Period

Following the methodology in Section 3, an ex-post assessment was conducted for the BEE Special Planning in Beijing during the past 12<sup>th</sup> FYP period.

### 4.1 Main contents of BEE Special Planning and the actual implementation effects

According to the BEE Special Planning in Beijing during the 12<sup>th</sup> FYP period, the main contents include: (1) The status of BEC and the progress made of BEE during the past 11<sup>th</sup> FYP period; (2) The building energy demand and energy-saving potential during the 12<sup>th</sup> FYP period; (3) The guiding ideology, working principles and strategic objectives of BEE during the 12<sup>th</sup> FYP period; (4) Eight key programs of BEE during the 12<sup>th</sup> FYP period; (5) Seven safeguards to ensure the achievement of the goals. The relationship of the five parts is provided in Fig.6. The main goals of the BEE Special Planning are to achieve the total energy-saving goal of 6.2 million tce and the energy-saving goal for each key program is shown in Table 2.

During the past 12<sup>th</sup> FYP period, each key program and energy-saving measures had been executed as scheduled with considerable achievements compared with the accomplishments gained during the 11<sup>th</sup> FYP period. Although the energy-saving goal in commercial buildings was not realized, the actual energy savings achieved by other major energy-saving programs had exceeded the expected goals. The actual total energy-saving amounts reached 6.34 million tce by the end of 2015 (See Table 2), which exceeded the planning goal of 6.2 million tce.

### 4.2 The ex-post assessment of the implementation effects of BEE Special Planning

Based on BEE Special Planning and its implementation in Beijing during the past 12<sup>th</sup> FYP period, an ex-post assessment on its implementation effects can be conducted by applying the ex-post assessment model as described in Section 3.2.

#### 4.2.1 Establish the grades evaluation criteria about the index layer

According to the indexes' properties, 8 indexes ( $C_{11} \sim C_{18}$ ) which reflect the realization degree

of main planning targets and 4 indexes ( $C_{20} \sim C_{23}$ ) belonging to the development level of BEE can be regarded as quantitative indicators. The remaining 15 indexes ( $C_{24} \sim C_{29}$ ,  $C_{31} \sim C_{39}$ ) are treated as qualitative indicators. As for the quantitative indicators, the evaluation grade and the membership degree were determined through comparing the actual performance with their expected targets. For qualitative indicators, the evaluation grade and the membership degree were obtained by using the Expert Evaluation Method. The grades evaluation criteria of the index layer are shown in Table 3. If the actual performance of a quantitative indicator exceeds its expected target, its grade can be evaluated as excellent.

#### 4.2.2 Establish the fuzzy evaluation subset of single factor

Applying the grades evaluation criteria for two types of indicators in Table 3, a single factor fuzzy comprehensive evaluation of 27 indexes is conducted, and the evaluation subsets are summarized in Table 4.

#### 4.2.3 Establish the fuzzy relation matrix

The fuzzy relation matrix  $R_{B1}$  can be developed through combining the fuzzy evaluation subsets of implementation effects for the indexes ( $C_{11} \sim C_{18}$ ). The fuzzy relation matrix  $R_{B2}$  for the indexes ( $C_{20} \sim C_{29}$ ) and  $R_{B3}$  for the indexes ( $C_{31} \sim C_{39}$ ) can also be obtained.

$$R_{B1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$$R_{B2} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0.88 & 0.12 & 0 & 0 & 0 \\ 0.13 & 0.62 & 0.25 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0.13 & 0.74 & 0.13 & 0 & 0 \end{bmatrix}$$

$$R_{B3} = \begin{bmatrix} 0.37 & 0.63 & 0 & 0 & 0 \\ 0.37 & 0.63 & 0 & 0 & 0 \\ 0.12 & 0.64 & 0.12 & 0.12 & 0 \\ 0 & 0.37 & 0.5 & 0.13 & 0 \\ 0.13 & 0.63 & 0.24 & 0 & 0 \\ 0.13 & 0.5 & 0.37 & 0 & 0 \\ 0.13 & 0.37 & 0.25 & 0.25 & 0 \\ 0.13 & 0.25 & 0.37 & 0 & 0.25 \\ 0.13 & 0.25 & 0.13 & 0.37 & 0.13 \end{bmatrix}$$

#### 4.2.4 The results of ex-post assessment on implementation effects

Applying the Eq. (11), the result of ex-post assessment on the realization degree of main planning targets ( $B_1$ ) can be calculated as follows:

$$\begin{aligned} B_1 &= W_{B1} \times R_{B1} \\ &= (0.28 \quad 0.14 \quad 0.1 \quad 0.09 \quad 0.04 \quad 0.16 \quad 0.16 \quad 0.03) \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \\ &= (0.51, 0.30, 0.03, 0, 0.16) \end{aligned}$$

Similarly, the results of ex-post assessment on the development level ( $B_2$ ) and facilitating mechanisms to promote BEE ( $B_3$ ) can be calculated as follows:

$$B_2 = W_{B2} \times R_{B2} = (0.5376, 0.2494, 0.093, 0, 0.12)$$

$$B_3 = W_{B3} \times R_{B3} = (0.1889, 0.5129, 0.1942, 0.0895, 0.0255)$$

Finally, according to the calculation results of  $B_1$ ,  $B_2$  and  $B_3$ , the results of the ex-post assessment of the implementation effects of BEE Special Planning in Beijing during the 12<sup>th</sup> FYP period (A) can be calculated by applying the Eq. (11) as follows:

$$\begin{aligned} B_A &= W_A \times R_A \\ &= (0.44 \quad 0.28 \quad 0.28) \begin{bmatrix} 0.51 & 0.30 & 0.03 & 0 & 0.16 \\ 0.5376 & 0.2494 & 0.093 & 0 & 0.12 \\ 0.1889 & 0.5129 & 0.1942 & 0.0895 & 0.0255 \end{bmatrix} \\ &= (0.428, 0.345, 0.093, 0.025, 0.111) \end{aligned}$$

According to the result vector  $B_A$ , it can be seen that the membership degree of grade  $V_1$  is 0.428, which is the maximum value of  $B_A$ . Applying the principle of maximum membership degree, the grade of ex-post assessment is  $V_1$ , which indicates that the implementation effects of BEE Special Planning in Beijing during the 12<sup>th</sup> FYP period are excellent.

### 4.3 Comprehensive score evaluation of implementation effects

#### 4.3.1. Establish the evaluation formula of comprehensive score

Assigning different scores to five evaluation grades in Table 3, which are  $T=[100, 90, 80, 60, 0]^T$ . Thus, the comprehensive score evaluation formula of implementation effects can be deduced as follows:

$$S = B \times T \quad (12)$$

#### 4.3.2. Calculate the comprehensive score of implementation effects

Applying the Eq. (12), the comprehensive score of implementation effects for the target layer (A) can be calculated as follows:

$$S_A = B_A \times T$$

$$= (0.428 \quad 0.345 \quad 0.093 \quad 0.025 \quad 0.111) \begin{bmatrix} 100 \\ 90 \\ 80 \\ 60 \\ 0 \end{bmatrix} = 83$$

The comprehensive score of the target layer is 83, locating between moderate grade and good grade, which indicates that the BEE Special Planning still has room for further improvement.

Likewise, the comprehensive scores of the criteria layer (B) can be calculated respectively as follows:

$$S_{B1} = B_1 \times T = 80$$

$$S_{B2} = B_2 \times T = 84$$

$$S_{B3} = B_3 \times T = 86$$

The comprehensive scores of the criteria layer are 80, 84 and 86 respectively, locating between moderate grade and good grade. This suggests that the criteria layer has room for improvement during the 13<sup>th</sup> FYP period in Beijing.

Combining the Eq. (12) and Table 4, the comprehensive scores of 27 indexes for the index layer can be calculated, which are listed in Table 5. And the radar plot of scores' distribution of 27 indexes is shown in Fig.7.

## 5 Discussions

### 5.1 Performance analysis of the 27 indexes

#### 5.1.1 Achievements of the BEE Special Planning

As shown in Table 5, apart from the  $C_{16}$ ,  $C_{21}$ ,  $C_{38}$  and  $C_{39}$  with relatively low scores, other indexes generally receive a score higher than 80. It is notable that  $C_{11}$ ,  $C_{13}$ ,  $C_{14}$ ,  $C_{15}$ ,  $C_{20}$ ,  $C_{23}$  and  $C_{24}$  score 100, indicating that the BEE Special Planning in Beijing during the 12<sup>th</sup> FYP period is

generally effective in terms of realizing the main planning targets, reaching the desired development level of BEE and ensuring the facilitating mechanisms to be in place.

(1) Substantial increase of the proportion of energy efficient buildings

During the 12<sup>th</sup> FYP period, the areas of newly constructed urban residential buildings with a level of energy-saving ratio of 65% are 94.24 million m<sup>2</sup>. The accumulated areas of urban energy efficient residential buildings have reached 451.25 million m<sup>2</sup>, which accounts for 92.2% of the total areas of urban residential buildings. The newly constructed urban commercial buildings with a level of energy-savings ratio of 50% are 74.37 million m<sup>2</sup>. The accumulated areas of energy efficient commercial buildings have reached 148.12 million m<sup>2</sup>, which represents 46.8% of the total areas of urban commercial buildings. By the end of 2015, the total areas of urban energy efficient civil buildings are 599.37 million m<sup>2</sup>, accounting for the 74.4% of the total areas of urban civil buildings (805.70 million m<sup>2</sup>). The proportion of energy efficient buildings has increased by 17.3% from 57.1% in 2010.

(2) Considerable effects of energy saving and carbon emission reduction

Based on the relevant documents (BMCHURD, 2006; BMCHURD, 2011; BMCHURD, 2016), this paper provides a comparative analysis of the implementation effects of the latest three BEE Special Planning in Beijing (See Table 6). Table 6 shows that heating energy consumption per unit building area has continually decreased and the total amounts of energy savings rose on a gradual basis. Obviously, considerable effects of energy saving and carbon emission reduction have been achieved by latest three BEE Special Planning.

It is notable that despite the considerable energy savings per unit building area, the total energy consumption of civil buildings in Beijing grows at a rapid rate as a result of significantly increased building areas. The total energy consumption amounts in 2004, 2009 and 2014 were 14.44 million tce, 19.456 million tce and 31.14 million tce respectively, accounting for 28.1%, 29.6% and 45.6% of the total energy consumption (BMCHURD, 2006; BMCHURD, 2011;

BMCHURD, 2016). The rapid growth in demand for energy has imposed considerable pressure on energy supply. Meanwhile, in order to reduce carbon emissions, the Beijing Municipal Government largely encourages the use of clean energy (gas, thermal energy, new and renewable energy) to replace coal consumption. For example, as shown in the Table 6, the natural gas heating area in Beijing has increased from 35.6% in 2005 to 54.9% in 2015, whilst the coal heating area decreasing from 42.1% to 18.7%. Since 2016, the Beijing Municipal Government mandated the use of natural gas for district heating, which further exacerbates the problem of deficiency in gas supply. With respect to the gap between the energy demand and supply, it is essential that the government invest more in infrastructures to increase the gas supply, and in the meantime, continually commit to energy efficiency upgrades.

### (3) Beijing's BEE development level close to the advanced level of developed countries

During the 12<sup>th</sup> FYP period, Beijing took the lead in China to implement the new "Design Standard for Energy Efficiency of Residential Buildings (DB 11/891-2012)" with an energy saving ratio of 75%, where heating energy consumption index for new residential buildings has dropped from 8.82kgce/m<sup>2</sup> to 6.3kgce/m<sup>2</sup>. Since Germany's climate conditions and energy structure is relatively similar to that of Beijing, this paper presents a comparison of heat transfer coefficient (**also referred to as *U-value***) of building envelope between Beijing and Germany (See Table 7). From Table 7, it can be seen that Beijing's BEE development level is close to the advanced level of developed countries under the same climate zone (e.g., Germany).

#### 5.1.2 "Short bucket" of the BEE Special Planning implementation

As shown in Table 5, the comprehensive scores of  $C_{16}$  and  $C_{21}$  are 0, and the comprehensive scores of  $C_{38}$  and  $C_{39}$  are below 70, which indicate that these four indicators' objectives had not been realized during the 12<sup>th</sup> FYP period. These are the "short buckets" in the implementation of the BEE Special Planning in Beijing during the 12<sup>th</sup> FYP Period.

According to the relevant documents (BMCHURD, 2011; BMCHURD, 2016), the mean

electricity consumption per unit area of commercial building should have been reduced by 12% by the end of 12<sup>th</sup> FYP Period. However, by the end of 2014, the index value of mean electricity consumption reached 103.8kWh/m<sup>2</sup>, which had increased by about 22.55% compared to the baseline value (84.7kWh/m<sup>2</sup>) in 2009. Thus, the expected target of C<sub>21</sub> was not realized and further the total energy saving goal of C<sub>16</sub> was also not realized. Fig. 8 shows the variation trend of mean electricity consumption index of large-scale (more than 20000 m<sup>2</sup>), medium-sized (between 3000 m<sup>2</sup> and 20000 m<sup>2</sup>) and small-sized (less than 3000 m<sup>2</sup>) commercial buildings during the 12<sup>th</sup> FYP period in Beijing.

As shown in Fig. 8, if the electricity consumption index of commercial buildings in 2009 is taken as the baseline, by the end of 12<sup>th</sup> FYP period, the electricity consumption per unit area in large-scale office building, hotel and restaurant, shopping mall had been reduced by 23.94%, 23.15% and 37.83%, respectively. Electricity consumption per unit area in small and medium-sized office building, hotel and restaurant, shopping mall had increased by 25.82%, 28.85% and 110.69%, respectively. The mean electricity consumption per unit area of small-sized commercial building was 93.16kWh/m<sup>2</sup> by the end of 12<sup>th</sup> FYP period, which had increased by 9.99% on the basis of 84.7kWh/m<sup>2</sup> in 2009. It is clear that despite the decrease of electricity consumption in large-scale commercial building, the overall electricity consumption of commercial building increased as a result of the significant rise of electricity consumption in small and medium-sized commercial building.

The gap between the actual electricity savings and the expected value specified in the BEE Special Planning may be explained by the rebound effects, as highlighted in existing literature (Frank, 2001; Sorrell and Dimitropoulos, 2008). It has been widely recognized that energy improvements do not generally lead to the estimated amount of reductions in energy consumption (Saunders, 2013). One explanation is that improvements in energy efficiency encourage greater use of energy because the increase in efficiency reduces the price of energy which makes

additional energy services affordable (Sorrell and Dimitropoulos, 2008). This research reinforced that such behavioral responses, known as rebound effects, compromise the quantity of energy saving that are expected to be achieved through energy efficiency upgrades (Galvin, 2014). The increase in electricity consumption in small and medium-sized commercial buildings resonate with previous findings that energy poor households show larger rebound effects (Wolff et al., 2017; Boardman, 2010). This may be due to the reason that the increase in energy efficiency lead to higher energy service demand, which was largely unmet prior to the energy efficiency improvement (Chakravarty et al., 2013). The users of small and medium-sized commercial buildings may take advantage of the energy efficiency upgrade to pursue other energy services (e.g. new ventilation systems, better air-conditioning equipment) to fulfill the unmet demand and improve their comfort of living. We agree with Boardman (2010) and Galvin (2015) that high rebound effects among groups initially consuming disproportionately small quantities of energy services do not necessarily compromise the overall energy and climate goals. It is important to take social justice into account when designing policy instruments tackling with rebound effects.

## 5.2 Evaluation grade standards of the indexes

Assume that the evaluation grade standards for quantitative indicators are improved and those for qualitative indicators remain unchanged in Table 3. Thus, a new evaluation scheme, named Scheme II, is formed, and the initial scheme in Table 3 is named Scheme I. The grade standards' comparison of the two schemes is listed in Table 8.

According to the evaluation grade standards of Scheme II and adopting the same calculation process similar to Scheme I, the result of the ex-post assessment of implementation effects about BEE Special Planning in Beijing during the 12<sup>th</sup> FYP period can be calculated as follows.

$$B_A = W_A \times R_A = (0.316, 0.213, 0.164, 0.053, 0.256)$$

Based on the result vector  $B_A$ , the grade of post-assessment is also  $V_1$ , which represents excellent. The comparison of the evaluation results based on Scheme I and Scheme II are shown in

Fig. 9.

According to the principle of maximum membership degree, although the evaluation grades of two schemes are both  $V_1$  in Fig.9, the proportion belonging to excellent and good grades in Scheme I is higher than that of Scheme II, while the proportion belonging to moderate, qualified and unqualified grades in Scheme I is lower than that of Scheme II. The reason for this result is that the evaluation grade standards for quantitative indicators in Scheme II are relatively stricter than those of Scheme I in Table 8. Therefore, it can be deduced that as the indexes' evaluation standards are improved, the proportion belonging to excellent and good grades will decline and that belonging to qualified and unqualified grades will rise. The ex-post assessment result may change if the indexes' evaluation standards are raised to a certain level. Therefore, the indexes' evaluation standards are an important factor affecting the ex-post assessment result when applying the FSEM.

### 5.3 Main barriers hindering the implementation of BEE Special Planning

Through conducting an ex-post assessment of implementation effects of BEE Special Planning in Beijing, the following main barriers during the past five-year process were identified, which are discussed under following sub-headings.

#### 5.3.1 High electricity consumption of large-scale commercial buildings

As shown in Fig. 8, mean electricity consumption index in commercial building, especially in shopping mall is too high during the 12<sup>th</sup> FYP period in Beijing. This may be because that large glass curtain walls acting as building envelopes are very popular in commercial buildings. Due to lack of technical measures of shading and heat insulation, the internal space of commercial buildings can gain too much heat by glass curtain walls. Also, the internal space is difficult to interchange fresh air and the buildings cannot effectively use outdoor low temperature air, which causes too much heat gathering inside the buildings. Furthermore, lack of energy efficient management during the operation process of large-scale commercial buildings may also the reason

for high electricity consumption.

### 5.3.2 Insufficient data information

The reason causing the low score of the index  $C_{39}$  is that the database of BEC lacks of adequacy. Such problem is mainly reflected on the facts that the principles for data collection of BEC were inconsistent, the types of data needed were not confirmed and data collection sources are not clear. These factors lead to the inadequacy of actual BEC data and further influence the quality of subsequent statistical analysis.

### 5.3.3 Slow uptake of modern information technology

During the past 12<sup>th</sup> FYP period, several information platforms, such as on-line monitoring platform of electricity consumption of large-scale commercial buildings and on-line monitoring system of heating energy consumption, were successively established by the Beijing Municipal government. Some local governments of Beijing Municipality have built their energy consumption monitoring platforms. However, these were not fully integrated with relevant data effectively. The monitoring coverage was not wide enough and the types of BEC being monitored were not comprehensive. Moreover, there were no consistent standards and technology supports for the monitoring platform.

### 5.3.4 Lack of market participation

Currently, the BEE program is predominately driven by administrative forces from the government. The market has not played an important role in promoting BEE. Limited market participation may be due to a lack of attractiveness of the BEE activities to investors. This is in line with prior findings that actual energy savings in thermal retrofit is far less than theoretical calculations, which greatly compromise the economic viability of thermal retrofit of buildings (Galvin and Sunikka-Blank, 2013; Michelsen and Müller-Michelsen, 2010). It is even more difficult to attract market investment for low-income tenants due to the uncertainty in demand and

investment returns (Großmann et al. 2014). Without effective market participation, it is very difficult to promote further development of BEE.

### 5.3.5 Lack of wider social recognition of BEE

Although Beijing has made considerable achievements and plays a leading role in the implementation of BEE in China, the promotion of BEE mainly relies with the government's administrative power, lacking of the participation of wider community. Meanwhile, due to lack of effective publicity and popularization of BEE, the public perception about BEE remains at a preliminary stage, with some individuals even casting doubt on the value of BEE. In absence of wider social recognition of BEE, the large-scale promotion of BEE during the 13<sup>th</sup> FYP period will be hindered.

## 6 Conclusions and Policy Recommendations

The BEE Special Planning is characterized by multi-objective, multi-dimensional and large-long time span. It is a great challenge to conduct an ex-post assessment of the completed BEE Special Planning. This paper was the first attempt to examine the implementation effects of BEE Special Planning, which is a special policy instrument set out in China. In this paper, a synthetic ex-post assessment methodology was developed. In the development of the methodology, an ex-post assessment framework including target layer, criteria layer and index layer with 27 indexes describing implementation effects was first identified. The weight of criteria layer and index layer were then determined by applying Expert Scoring Method. Based on the FSEM, the ex-post assessment model of BEE Special Planning was established.

By applying the methodology to conduct the ex-post assessment of the implementation effects of BEE Special Planning in Beijing during the 12<sup>th</sup> FYP Period, we found that generally speaking, the overall implementation effect of the policy document is excellent. When examining individual index, we found that the indexes  $C_{16}$  and  $C_{21}$  are the “short bucket” of BEE which needs more resource investment during the 13<sup>th</sup> FYP period in Beijing, and the indexes  $C_{38}$  and  $C_{39}$  also

need more attention in the future. We further identified the main barriers that will hinder the further development of BEE in Beijing such as high electricity consumption of large-scale commercial buildings, insufficient data information, slow uptake of modern information technology, lacking of market participation and wider social recognition of BEE. It is also notable that the indicators' evaluation standards are important factors affecting the ex-post assessment result when applying the FSEM method.

The ex-post assessment methodology offers a useful and systematic framework to evaluate the implementation effects of BEE Special Planning, and other BEE policies. By applying the methodology to the ex-post assessment of BEE Special Planning in Beijing during the "12<sup>th</sup> Five-Year Plan" Period, the implementation effects of the policy document are evaluated. The challenges that the BEE work face and shortcomings of policy instruments can be identified, which provide important reference for policy makers to adjust the policy directions and further facilitate informed and effective policy making.

It is hoped that the methodology presented in this paper can provide a generic framework for conducting an ex-post assessment of BEE policies. However, adjustments may be required when evaluating future policy documents due to the evolvement of contextual factors. For example, when evaluating the implementation effects of the BEE Special Planning during the "13<sup>th</sup> Five-Year Plan" period, the indexes identified in this research and the weights given to the indexes may be modified to accommodate the evolving scope of the BEE work. It is therefore essential that the methodology to be applied elsewhere by taking unique contextual elements into account.

The policy recommendations for improved BEE Special Planning in future are provided as follows:

- Since an information management system of BEC is essential to conduct the energy consumption testing and perform data collection, transmission and analysis, this research suggests that energy management centers of large-scale commercial buildings should be

established and get connected to the Beijing Building Energy Consumption Information Platform so that the BEC's information management system during the period of 13<sup>th</sup> FYP can be improved. Also, a statistical analysis system of BEC for individual building and groups of buildings needs to be established, and the index system should be refined according to the features of different types of buildings. Relevant departments in the Beijing Municipal government should establish and continuously update the BEC database of different types of buildings to provide detailed data about BEC of each type of buildings and analyze the energy-saving potential and the benefits arising from the EER through energy consumption simulation.

- This research suggests that an over-pricing mechanism should be designed when energy consumption of the building exceeds the energy consumption threshold. Currently, residents in Beijing pay for annual heat fee based on their apartment floor areas, rather than on actual heat consumption amounts. The heat metering has not been installed in most residential areas of energy efficiency buildings. A charging approach based on energy consumption has not been applied. As such, residents lack the motivations to engage energy-saving behaviors. This results in a situation that “energy efficiency building does not save energy”. This research thus suggests that heat metering and charging system should be implemented as soon as possible in new constructed residential area and existing residential areas after being retrofitted.
- Considering the increasing demand for technology and management professionals for BEE, this research recommends that BEE specialty may be set up in relevant universities in order to cultivate the professionals. In the meantime, vocational training institutions are encouraged to actively carry out specialized technical training for BEE practitioners to improve their professional skills. Strengthening the research and development of key technologies and technology integration innovation are important for the professional cultivation and the improvement of core competence in the field of BEE.

- In order to raise the public awareness of BEE, this research recommends a “Publicity Week of BEE” to facilitate basic knowledge sharing. Various forms of publicity activities, such as public service advertising, experts preaching, communication and discussion through the Internet and social media are recommended to be carried out. Good demonstration of a pilot project of BEE technology application is necessary to showcase how the BEE can actually be implemented and associated benefits. Also, a low-carbon lifestyle needs to be actively advocated to the whole community.
- During the 13<sup>th</sup> FYP period, it is recommended that the contractors should provide all BIM data and information when handing new buildings over to the owner. Also, it is useful to adopt the IoT (Internet of Things) technology to build an energy monitoring information platform for buildings, and embed the BIM data of each building to the platform. By integrating the BIM data and the information provided by the platform, buildings’ spatial information and dynamic energy consumption monitoring data can be well matched. With the application of big data analysis, the actual level of energy consumption can be monitored, analyzed and diagnosed, based on which buildings’ energy use strategies and parameters can be adjusted and optimized so that the overall level of energy efficiency management will be improved.

## Acknowledgment

The authors would like to express great appreciation to the Beijing Municipal Commission of Housing and Urban-Rural Development for financially supporting this research (Grant No.: B15L00240), and thank the Science and Technology Institute of Beijing Real-Estate as the cooperation unit. Also, the authors wish to acknowledge Ms. Zhang Changjie for her help in collecting the questionnaires.

## A list of abbreviations

No.	Abbreviations	Explanation
1	BEE	building energy efficiency
2	BEC	building energy consumption

3	EER	energy efficiency retrofitting
4	FSEM	fuzzy synthetic evaluation method
5	FYP	five-year plan
6	tce	tons of standard coal

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Annex 1 The explanation of C<sub>11</sub>- C<sub>18</sub> indexes

Number	Index	Index explanation
1	C <sub>11</sub>	<ul style="list-style-type: none"> <li>➤ Fully implementation of 75% energy-saving design standards in newly constructing residential buildings;</li> <li>➤ Completing the revision of <i>commercial Building Energy Efficiency Design Standards</i>;</li> <li>➤ The proportion of new green building area reaches 10% of total new building area, a total of 35 million square meters of green building are newly built;</li> <li>➤ The proportion of industrialized construction residential buildings reaches more than 30% of total construction area of that year.</li> </ul>
2	C <sub>12</sub>	<ul style="list-style-type: none"> <li>➤ Demolishing urban and rural energy inefficient buildings, and rebuilding as energy efficient buildings.</li> </ul>
3	C <sub>13</sub>	<ul style="list-style-type: none"> <li>➤ The EER areas of envelope structure on energy inefficient residential buildings and commercial buildings reach 60 million square meters.</li> </ul>
4	C <sub>14</sub>	<ul style="list-style-type: none"> <li>➤ Applying shallow geothermal or sewage source heat pump heating and cooling in civil building;</li> <li>➤ Solar photovoltaic integrated building;</li> <li>➤ Application of solar water heating system in civil building;</li> <li>➤ Application of solar-thermal system on civil building heating.</li> </ul>
5	C <sub>15</sub>	<ul style="list-style-type: none"> <li>➤ Newly constructing peasants' energy efficient buildings;</li> <li>➤ Carrying out EER in existing rural residential buildings;</li> <li>➤ Adjustment of rural area energy consumption structure.</li> </ul>
6	C <sub>16</sub>	<ul style="list-style-type: none"> <li>➤ Electricity consumption itemized metering and monitoring platform in large-scale commercial building;</li> <li>➤ Implementation of energy consumption quota and ladder electricity price;</li> <li>➤ Establishing the BEE management systems involving itemized metering measurement of energy consumption, dynamic monitoring, energy consumption statistics, energy audits, energy efficiency public announcement etc. in large-scale commercial building.</li> </ul>
7	C <sub>17</sub>	<ul style="list-style-type: none"> <li>➤ Heating system integration;</li> <li>➤ EER of heating system;</li> <li>➤ Structure adjustment of heating energy.</li> </ul>
8	C <sub>18</sub>	<ul style="list-style-type: none"> <li>➤ Implementing heat metering and charging system;</li> <li>➤ Mobilize the energy-saving enthusiasm of building user and operation management staff through economic incentive policies, administrative measures and education publicity.</li> </ul>

### Annex 2 The explanation of C<sub>20</sub>- C<sub>29</sub> indexes

Number	Index	Index explanation
1	C <sub>20</sub>	<p>➤ <math>\sum</math> The heating area proportion of different types of energy <math>\times</math> Corresponding heating energy consumption per unit area</p> <p>Different types of energy heating refer to gas heating (include wall hung gas boiler), coal-fired central heating and urban central heating.</p>
2	C <sub>21</sub>	<p>➤ <math>\frac{\text{The total electricity consumption of urban public building}}{\text{The total area of urban public building}}</math></p>
3	C <sub>22</sub>	<p>➤ <math>\frac{\sum \text{Energy - saving ratio of different types of residential buildings} \times \text{Corresponding residential area}}{\text{Total residential area}}</math></p> <p>In Beijing, residential buildings can be divided into energy inefficient buildings, energy efficient buildings of the first step, energy efficient buildings of the second step, energy efficient buildings of the third step and energy efficient buildings of the fourth step, and their energy-saving ratios are 0%, 30%, 50%, 65% and 75% based on BEC baseline in 1981 respectively.</p>
4	C <sub>23</sub>	<p>➤ Energy conversion efficiency of the boiler;</p> <p>➤ Heating pipe network efficiency.</p>
5	C <sub>24</sub>	<p>➤ <math>\frac{\sum \text{Application area of different types of renewable energy}}{\text{Total Residential Area}}</math></p>
6	C <sub>25</sub>	<p>➤ <math>\frac{\sum \text{Ranking of green building} \times \text{Corresponding building area}}{\text{Total green building area}}</math></p> <p>Ranking of green building refers to one-star, two-star and three-star green building.</p>
7	C <sub>26</sub>	<p>➤ Heat transfer coefficient of exterior windows and doors;</p> <p>➤ Heat efficiency index of heat source and pipe network;</p> <p>➤ Heating energy consumption index of unit building area;</p>

		➤ Unit electricity consumption index of air conditioning in commercial building.
8	C <sub>27</sub>	➤ Comprehensive result of new materials, new equipment, new technology and new construction process.
9	C <sub>28</sub>	➤ Application of greening construction technology in constructing process; ➤ Construction technology application of housing industrialization, which includes design standardization, prefabricated parts, construction of the assembly, specialization of transportation and IT application in management; ➤ Application of other new technologies and new processes in constructing process.
10	C <sub>29</sub>	➤ Advanced technologies application of solar collector heating, geothermal heat pump, cogeneration central heating etc.; ➤ Advancement of heat metering technology; ➤ Advancement of heat source and heating pipe network.

### Annex 3 The explanation of C<sub>31</sub>- C<sub>39</sub> indexes

Number	Index	Index explanation
1	C <sub>31</sub>	<ul style="list-style-type: none"> <li>➤ Formulate specific implementation rules or management measures based on <i>Beijing Municipality's Implementation Method about Energy Conservation Law of People's Republic of China</i>;</li> <li>➤ Revise <i>Building Energy Efficiency Management Regulations of Beijing</i> to further clarify the principles of implementation, promoting policies, operating subject, supervision and administration, legal responsibility.</li> </ul>
2	C <sub>32</sub>	<ul style="list-style-type: none"> <li>➤ Revise <i>Design standard for energy efficiency of residential buildings of Beijing</i> and <i>Design standard for energy efficiency of commercial buildings of Beijing</i> in order to make the energy-saving ratio of new residential building reaches 75%;</li> <li>➤ Formulate <i>Design Standard for Green Building of Beijing</i> and <i>Assessment Standard for Green building of Beijing</i>;</li> <li>➤ Compile design standard for BEE and anti-seismic in rural residential building of Beijing;</li> <li>➤ Formulate and revise relevant energy efficiency regulations and standards for commercial building and heating systems.</li> </ul>
3	C <sub>33</sub>	<ul style="list-style-type: none"> <li>➤ Formulate and perfect related incentive policies to promote the development of green</li> </ul>

		building and housing industrialization;
		➤ Improve support policies and establish fund guarantee mechanism of BEE.
4	C <sub>34</sub>	➤ Establish market supervision system for construction quality, materials and products of BEE; ➤ Establish market supervision system for BEE operation management of commercial building and heat-supply enterprises; ➤ Establish market supervision system for BEE testing and certification organizations; ➤ Establish market supervision system for financial funds application on BEE.
5	C <sub>35</sub>	➤ Strengthen the research and popularization of new materials, new technologies, new equipment and new process; ➤ Strengthen the promotion mechanism of science and technology development; ➤ Enhance the market supply capacity of BEE materials and products; ➤ Strive to develop the service industry of BEE.
6	C <sub>36</sub>	➤ Strengthen the unified leadership to each county government of Beijing; ➤ Strengthen the coordination of relevant departments in charge of BEE; ➤ Strengthen the construction of administrative institutions and law enforcement agencies; ➤ Perfect the evaluation methods of responsibility goal of BEE work.
7	C <sub>37</sub>	➤ Strengthen the personnel training of technique and management of BEE; ➤ Cultivate the technology and management team for BEE work in rural areas of Beijing.

8	C <sub>38</sub>	<ul style="list-style-type: none"><li>➤ Propagandize related laws and scientific knowledge of BEE through media and exhibitions, public service advertising, exchange seminars, on-site experience etc.;</li><li>➤ Carry out the systematic education about energy-saving scientific knowledge at all levels of schools and universities.</li></ul>
9	C <sub>39</sub>	<ul style="list-style-type: none"><li>➤ Establish the monitoring platform for building information and energy consumption information of large-scale commercial building;</li><li>➤ Realize the sub-metering and wireless transmission of BEC with the utilization of information technology;</li><li>➤ Establish the BEE database and realize the automatic analysis of BEC with big data technology;</li><li>➤ Carry out BEE public announcement with the Internet.</li></ul>

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**Table 1 A summary of index weight**

Criteria layer	Weight (%)	Index layer	Relative weight (%)	Absolute weight (%)
B <sub>1</sub>	44	C <sub>11</sub>	28	12
		C <sub>12</sub>	14	6
		C <sub>13</sub>	10	4
		C <sub>14</sub>	9	4
		C <sub>15</sub>	4	2
		C <sub>16</sub>	16	7
		C <sub>17</sub>	16	7
		C <sub>18</sub>	3	1
B <sub>2</sub>	28	C <sub>20</sub>	19	5
		C <sub>21</sub>	12	3
		C <sub>22</sub>	11	5
		C <sub>23</sub>	10	3
		C <sub>24</sub>	9	3
		C <sub>25</sub>	7	2
		C <sub>26</sub>	9	3
		C <sub>27</sub>	8	2
		C <sub>28</sub>	5	1
		C <sub>29</sub>	10	3
B <sub>3</sub>	28	C <sub>31</sub>	15	4
		C <sub>32</sub>	15	4
		C <sub>33</sub>	12	3
		C <sub>34</sub>	12	3
		C <sub>35</sub>	12	3
		C <sub>36</sub>	10	3
		C <sub>37</sub>	9	3
		C <sub>38</sub>	5	1
		C <sub>39</sub>	10	3

**Table 2 The expected and actual energy-saving amounts of each key program for BEE during the 12<sup>th</sup> FYP period**

No.	BEE program	Objective	Expected energy- saving amount/tce	Actual energy –saving amount /tce
1	New buildings	New buildings of 200 million square meters will be built with BEE design standard, and design standard for new residential buildings will be further improved to reach the energy-saving ratio of 75%.	171.97	230.08
2	Demolishing energy inefficient buildings and rebuilding	Demolishing energy inefficient buildings of 10 million square meters in urban areas and 40 million square meters in rural areas respectively, and rebuilding them with the new BEE design standard.	89.46	87.20
3	EER of existing buildings	The areas of EER are 30 million square meters in existing residential buildings and public buildings respectively.	60.6	63.20
4	Renewable energy application in buildings	Shallow layer geothermal and sewage-source heat pump are adopted for space heating and cooling up to 18 million square meters of civil buildings	14	20.2
		The building roof areas of solar photovoltaic integration will reach up to 1 million square meters, which will produce 40,000 kW photovoltaic power generation capacity	2.97	14.85
		The building areas of using solar water heating systems will reach up to 110 million square meters and the areas of solar collector will reach up to 5.5 million square meters.	39.6	24.48
		The building areas of using solar thermal heating will reach up to 0.16 million square meters and the areas of solar collector will reach up to 40,000 square meters.	0.37	0.46
5	BEE in rural residential buildings	The total quantities of newly-construction energy efficient residential buildings and existing residential buildings retrofitted with energy efficient standard will reach up to 200,000 households in rural areas.	24	74.04
6	BEE in commercial	Electricity consumption per unit area of commercial building will reduce by	97.06	0

	building operation	12% through the implementation of energy consumption quota and ladder electricity price.		
7	BEE in heating system	Including heating resources integration, EER of heating system and structure adjustment of heating energy.	99.1	98.25
8	Behavior energy-saving	The building areas implementing heat metering and charging system will reach up to 200 million square meters.	20.87	16.7
9	Green buildings	-	-	3.67
10	Energy saving through residential industrialization	-	-	1.134
	Total		620	634

**Table 3 The Grades evaluation criteria of the index layer**

Type of indicator	Evaluation grades				
	V <sub>1</sub>	V <sub>2</sub>	V <sub>3</sub>	V <sub>4</sub>	V <sub>5</sub>
Qualitative indicators	excellent	good	moderate	qualified	unqualified
Quantitative indicators	≥100%	≥90%	≥75%	≥60%	< 60%

**Note:** 100% represents the ratio of actual completion amount divided by expected completion amount.

**Table 4 The summary of fuzzy evaluation subset of single factor**

Single factor indicator	Realization degree of quantitative indicators	Single factor evaluation				
		V <sub>1</sub>	V <sub>2</sub>	V <sub>3</sub>	V <sub>4</sub>	V <sub>5</sub>
		≥100%	≥90%	≥75%	≥60%	<60%
		excellent	good	moderate	qualified	unqualified
Fuzzy evaluation subsets of implementation effects for realization degree of main planning targets						
C <sub>11</sub>	133%	1	0	0	0	0
C <sub>12</sub>	97%	0	1	0	0	0
C <sub>13</sub>	104%	1	0	0	0	0
C <sub>14</sub>	105%	1	0	0	0	0
C <sub>15</sub>	309%	1	0	0	0	0
C <sub>16</sub>	0%	0	0	0	0	1
C <sub>17</sub>	99%	0	1	0	0	0
C <sub>18</sub>	80%	0	0	1	0	0
Fuzzy evaluation subsets of implementation effects for the development level of BEE						
C <sub>20</sub>	130%	1	0	0	0	0
C <sub>21</sub>	−22%	0	0	0	0	1
C <sub>22</sub>	——	0.5	0.5	0	0	0
C <sub>23</sub>	100%	1	0	0	0	0
C <sub>24</sub>	170%	1	0	0	0	0
C <sub>25</sub>	——	0	0.5	0.5	0	0
C <sub>26</sub>	——	0.88	0.12	0	0	0

C <sub>27</sub>	——	0.13	0.62	0.25	0	0
C <sub>28</sub>	——	0	0.5	0.5	0	0
C <sub>29</sub>	——	0.13	0.74	0.13	0	0
<b>Fuzzy evaluation subsets of implementation effects for facilitating mechanisms to promote BEE</b>						
C <sub>31</sub>	——	0.37	0.63	0	0	0
C <sub>32</sub>	——	0.37	0.63	0	0	0
C <sub>33</sub>	——	0.12	0.64	0.12	0.12	0
C <sub>34</sub>	——	0	0.37	0.5	0.13	0
C <sub>35</sub>	——	0.13	0.63	0.24	0	0
C <sub>36</sub>	——	0.13	0.5	0.37	0	0
C <sub>37</sub>	——	0.13	0.37	0.25	0.25	0
C <sub>38</sub>	——	0.13	0.25	0.37	0	0.25
C <sub>39</sub>	——	0.13	0.25	0.13	0.37	0.13

**Note:** “——” represents unable to measure the realization degree for qualitative indicator.

**Table 5** The comprehensive scores of 27 indicators for the index layer

Index	Score	Index	Score	Index	Score
C <sub>11</sub>	100	C <sub>20</sub>	100	C <sub>31</sub>	93.7
C <sub>12</sub>	90	C <sub>21</sub>	0	C <sub>32</sub>	93.7
C <sub>13</sub>	100	C <sub>22</sub>	95	C <sub>33</sub>	86.4
C <sub>14</sub>	100	C <sub>23</sub>	100	C <sub>34</sub>	81.1
C <sub>15</sub>	100	C <sub>24</sub>	100	C <sub>35</sub>	88.9
C <sub>16</sub>	0	C <sub>25</sub>	85	C <sub>36</sub>	87.6
C <sub>17</sub>	90	C <sub>26</sub>	98.8	C <sub>37</sub>	81.3
C <sub>18</sub>	80	C <sub>27</sub>	88.8	C <sub>38</sub>	65.1
		C <sub>28</sub>	85	C <sub>39</sub>	68.1
		C <sub>29</sub>	90		

**Table 6 Implementation effects of the latest three BEE Special Planning**

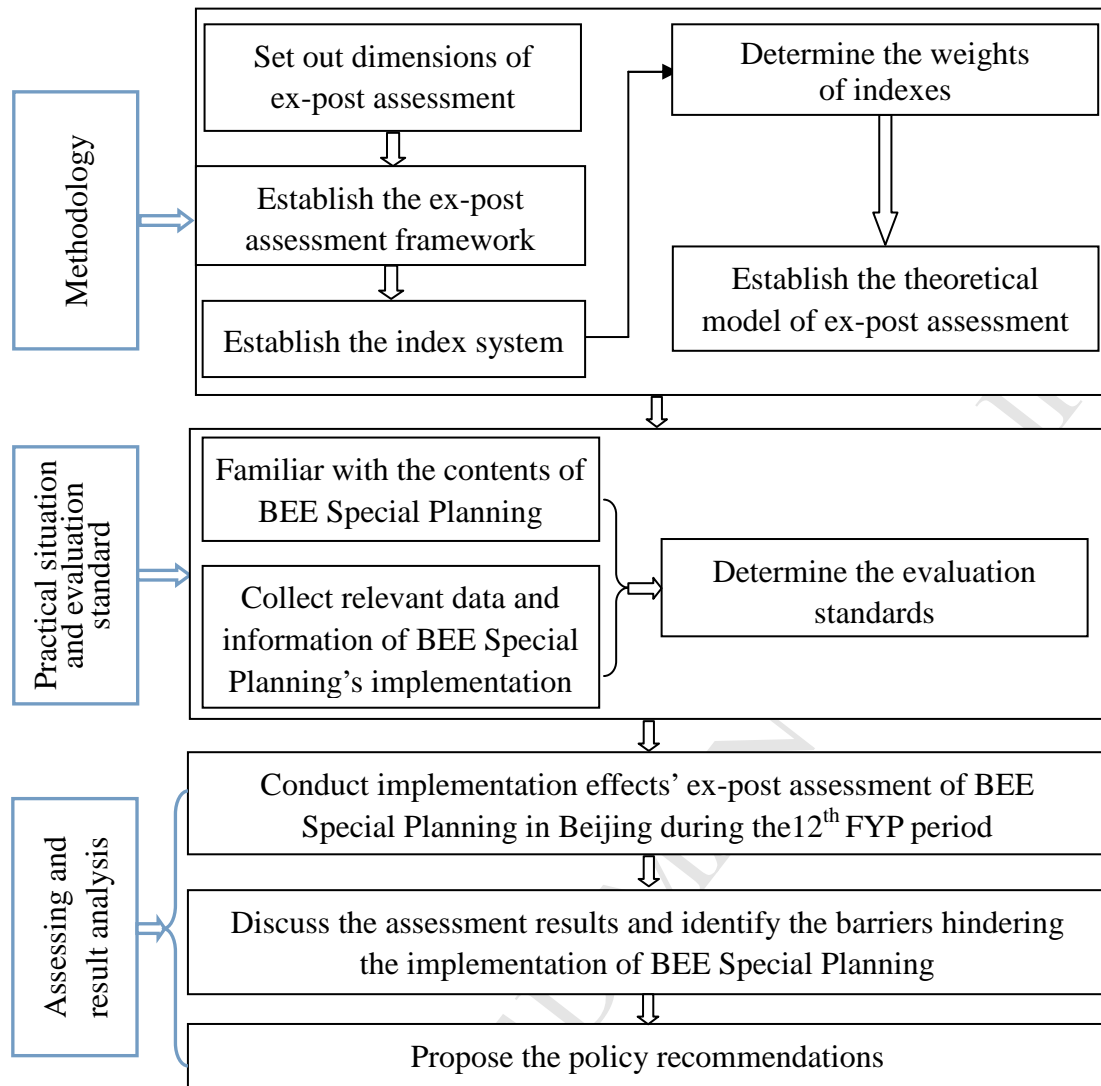
Indicator \ Time	By the end of 10 <sup>th</sup> FYP of BEE (2001-2005)	By the end of 11 <sup>th</sup> FYP of BEE (2006-2010)	By the end of 12 <sup>th</sup> FYP of BEE (2011-2015)
Total energy savings (Mtce)	100	396	634
Total CO <sub>2</sub> emission reduction (Mtce)	250	990	1585
The average heating energy consumption per unit area (kgce/m <sup>2</sup> )	20.8	16.49	13.9
The proportion of heating areas by gas (%)	35.6	43.5	54.9
The proportion of heating areas by municipal central heating (%)	19.8	23	25.1
The proportion of heating areas by coal (%)	42.1	31	18.7
The proportion of heating areas by new and renewable energy (%)	—	—	1.5

**Table 7 A comparison of heat transfer coefficient of building envelope  
between Beijing and Germany**

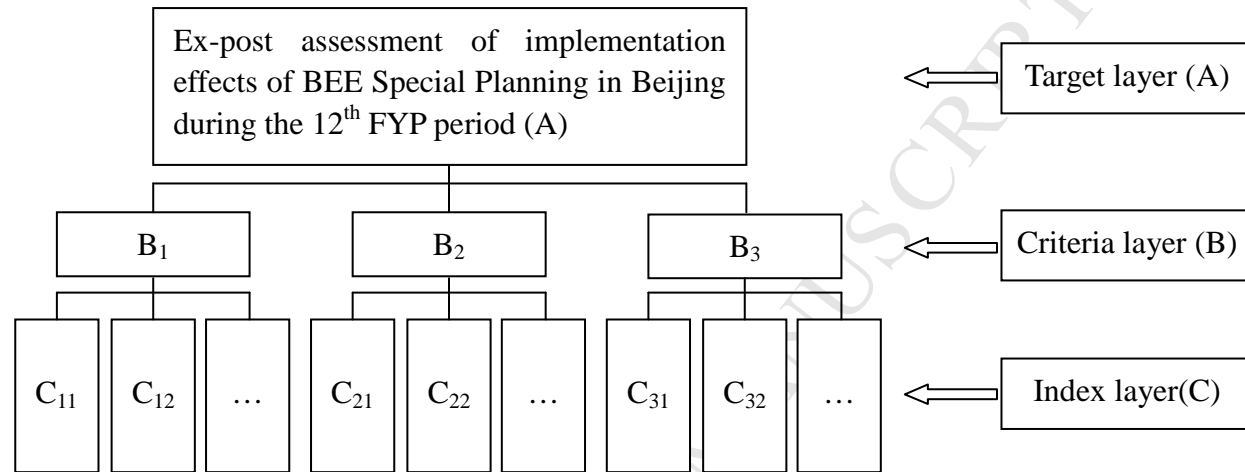
Building envelope		Roof $U(W/(m^2.K))$	External wall $U(W/(m^2.K))$	External window $U(W/(m^2.K))$	The top slab of basement $U(W/(m^2.K))$
Beijing regulation in DB 11/891-2012	$\leq 3$ storey	0.30	0.35	1.5~1.8	0.5
	4~8 storey	0.35	0.40	1.8~2.0	
	$\geq 9$ storey	0.40	0.45	1.8~2.0	
Germany regulation in 2009		0.20	0.28	1.3	0.35

**Table 8 The grade standards' comparison of the two schemes**

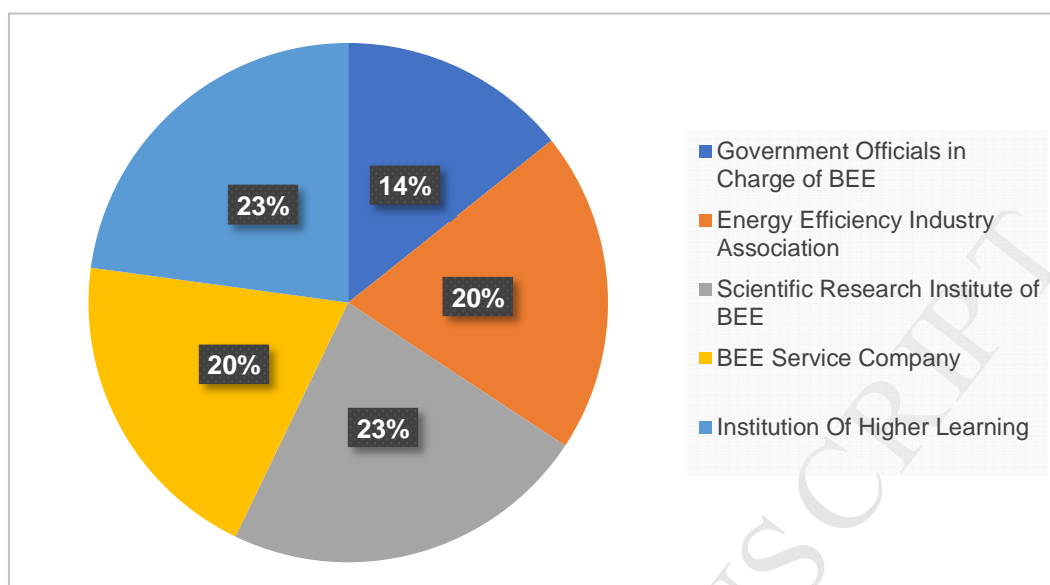
Type of indicator		Standards of evaluation grade				
		$V_1$	$V_2$	$V_3$	$V_4$	$V_5$
Scheme I	qualitative	excellent	good	moderate	qualified	unqualified
	quantitative	$\geq 100\%$	$\geq 90\%$	$\geq 75\%$	$\geq 60\%$	$< 60\%$
Scheme II	qualitative	excellent	good	moderate	qualified	unqualified
	quantitative	$> 120\%$	$> 110\%, \leq 120\%$	$> 100\%, \leq 110\%$	$= 100\%$	$< 100\%$



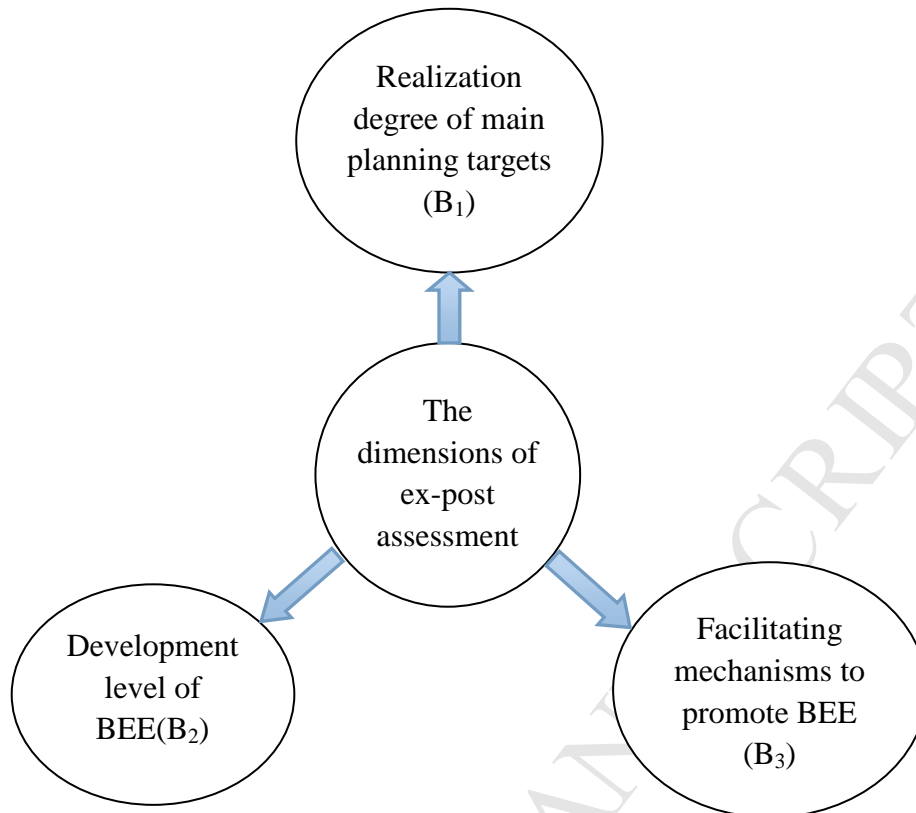
**Fig.1 Technology road-map for implementation effects' ex-post assessment of BEE Special Planning**



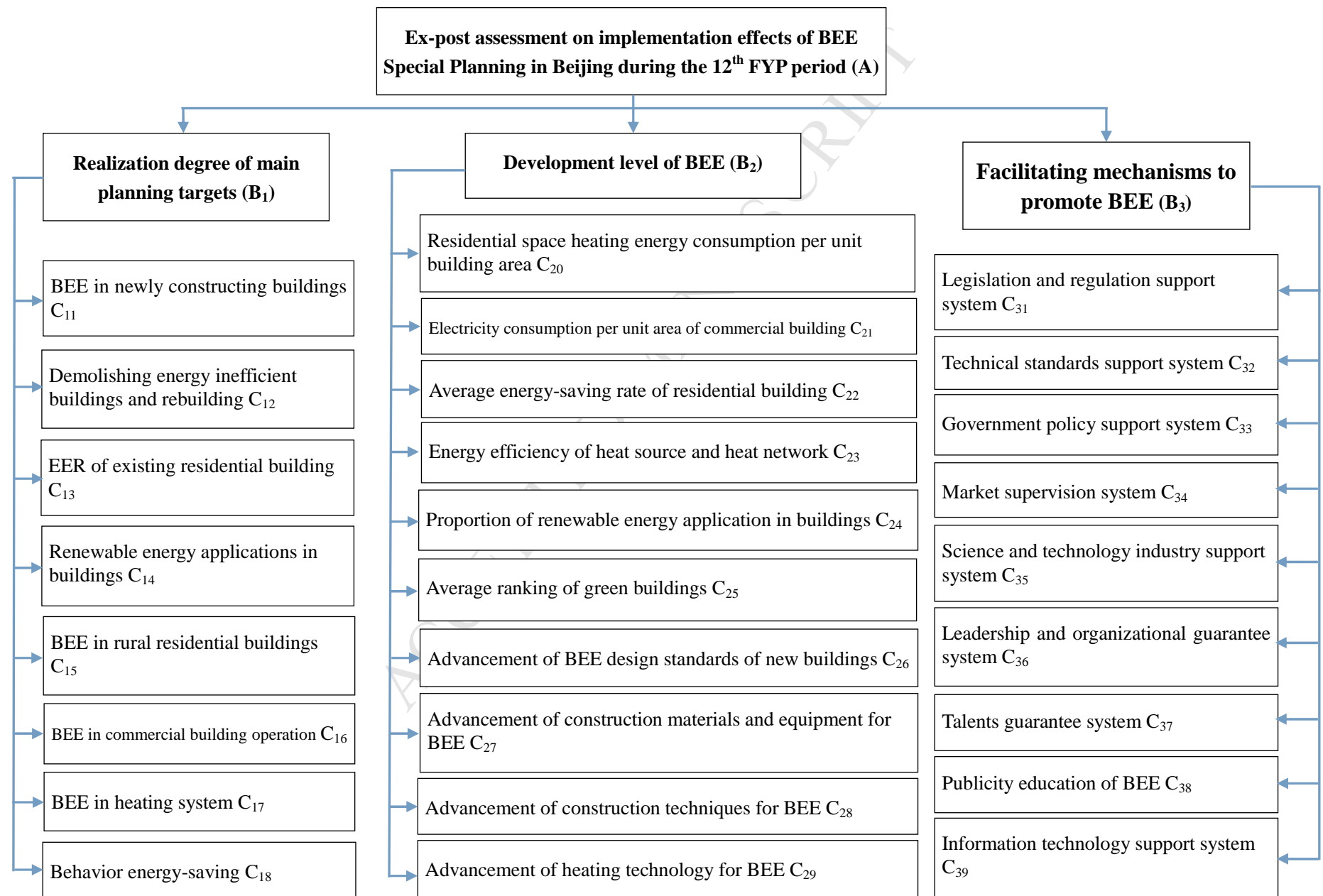
**Fig.2 Ex-post assessment framework of BEE Special Planning**



**Fig. 3 The Composition of Expert Panel**



**Fig. 4 The dimensions of ex-post assessment system**



**Fig.5 The index system of ex-post assessment on BEE Special Planning in Beijing during the 12<sup>th</sup> FYP period**

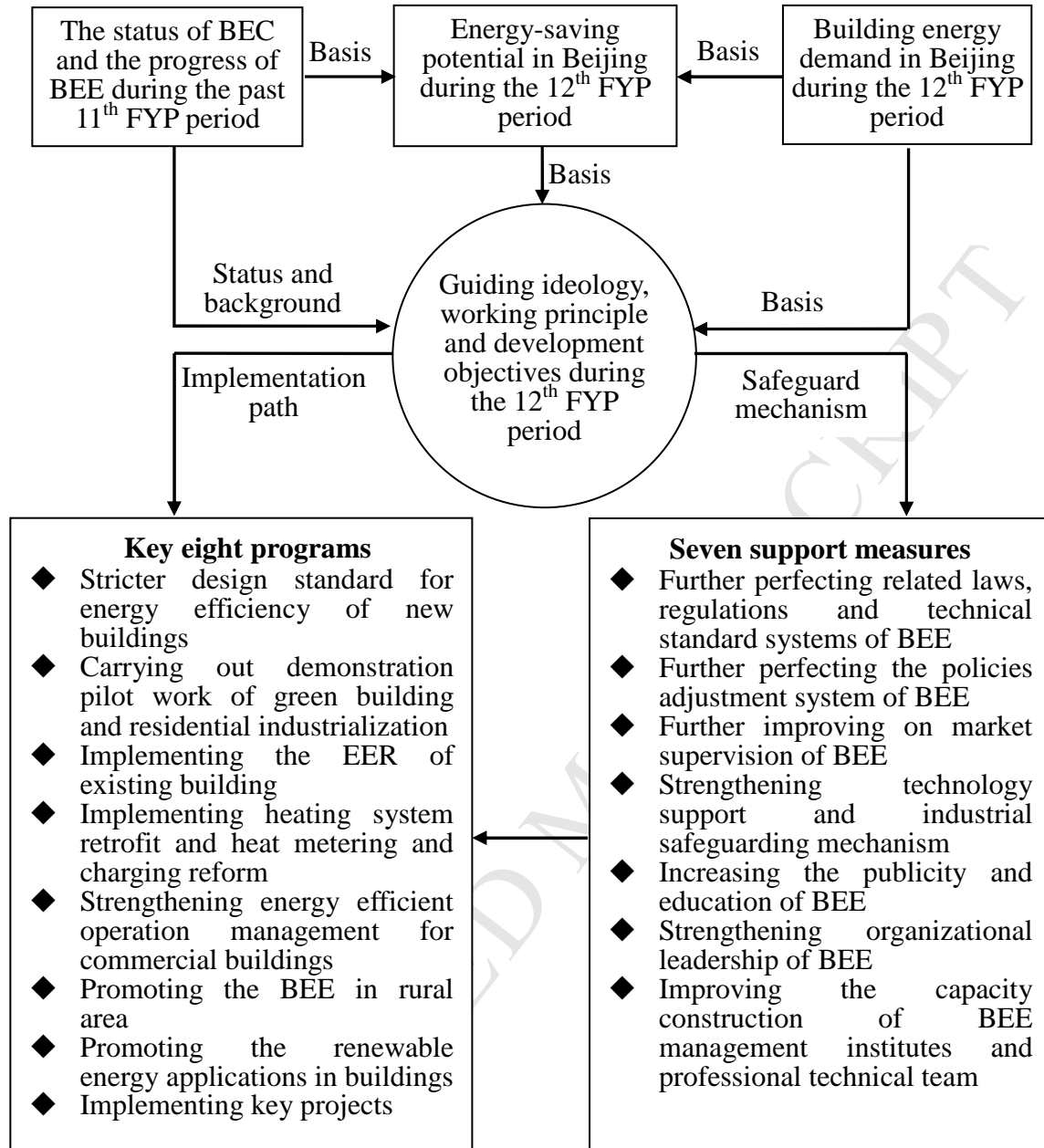
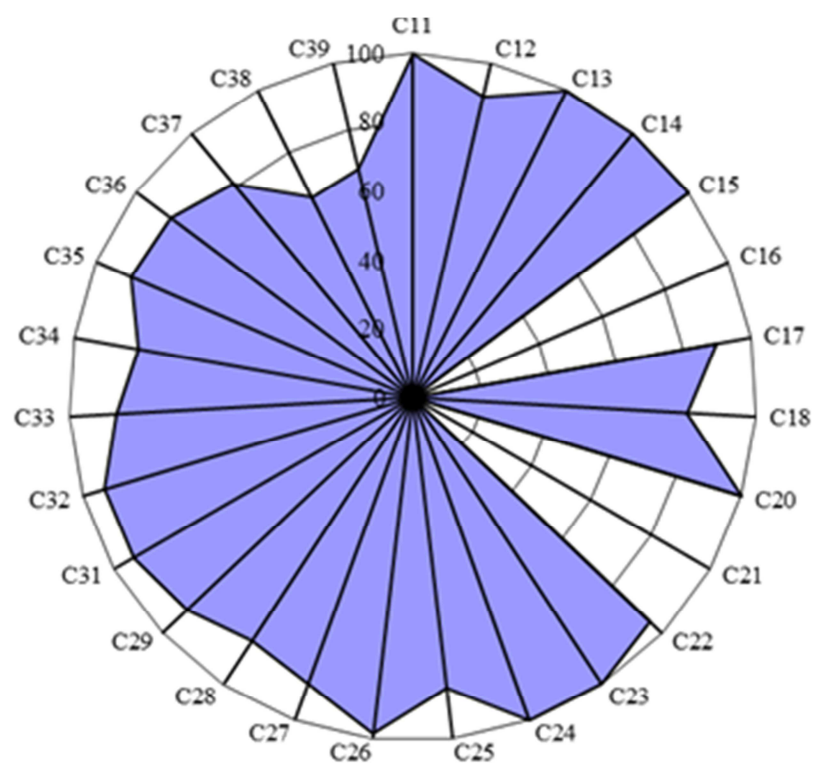
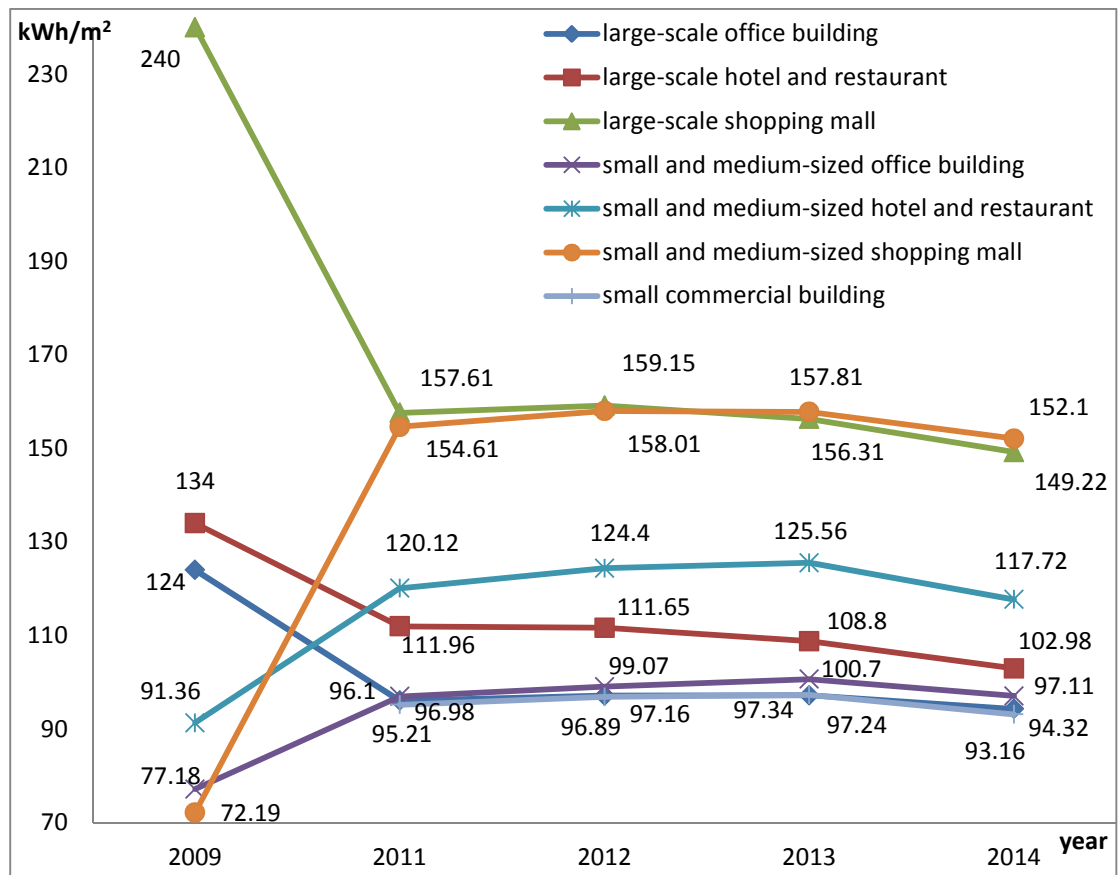


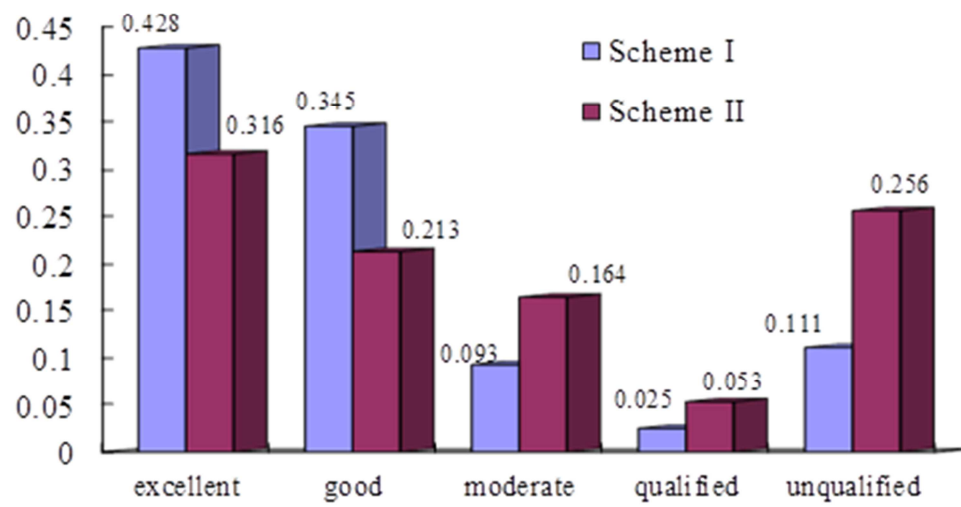
Fig.6 Main contents and their relationship of BEE Special Planning in Beijing



**Fig.7** The radar plot of scores' distribution of 27 indexes for the index layer



**Fig.8 The variation trend of mean electricity consumption index of commercial buildings during the 12<sup>th</sup> FYP period in Beijing**



**Fig.9 Comparison of the evaluation results based on Scheme I and Scheme II**

### Highlights

- ◆ We set out the ex-post assessment criteria from three dimensions;
- ◆ Establish the ex-post assessment framework from target layer, criteria layer and index layer, and 27 indexes are identified;
- ◆ Establish the ex-post assessment model by applying the FSEM;
- ◆ The indicators' evaluation standards are the important factors affecting the ex-post assessment result;
- ◆ Identify the main barriers to BEE implementation in Beijing and propose policy recommendations.