# Effect of implementing building energy efficiency labeling in China: A case study in Shanghai

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## Abstract

The building energy efficiency labeling (BEEL) scheme has been adopted in China in 2008. During its implementation, some achievements have been made, but its effect on building energy efficiency is still not well justified. This study has investigated the effect of implementing the BEEL scheme in the city of Shanghai, with a further analysis of potential barriers for other areas of China. From the case study, it was found that 1) the energy use intensity of labeled commercial office buildings in Shanghai followed a normal distribution, with an average value of 79.14 $kWh/m^2 \cdot a$; 2) energy-saving rate and energy consumption showed an inverse proportional relationship for residential buildings but this relationship is not applicable for commercial office buildings; 3) for Shanghai, ground source heat pump (GSHP) and variable refrigerant volume systems are more effective for commercial office buildings, and GSHP and split air-conditioners are more appropriate for residential buildings. The study justified the benefits of such practice on the energy efficiency of buildings in Shanghai, providing a useful reference for the implementation of the BEEL scheme in other cities. Additionally, potential barriers of implementing the BEEL scheme in China were identified and corresponding solutions were provided.



**Keywords:**

Building; Energy efficiency labeling; Chinese labeling scheme; Energy efficient building; Barrier analysis

## 1. Introduction

### *1.1 Development of Building Energy Efficiency Labeling (BEEL)*

It is well acknowledged that buildings are responsible for over 30% of the society's final energy consumption and over 55% of electricity demand (IEA, 2017). With the continues increase of both global population and people's living standards, energy demand by buildings will continue to rise, placing growing pressures on the energy and environment systems (IEA, 2013). Under this circumstance, promoting the energy efficiency of buildings has become a major task of most countries. The building energy efficiency labeling (BEEL) has been considered as an effective tool to help achieve energy efficient buildings, being used by a number of countries in the world.

The BEEL, also named as building Energy Performance Certificate (EPC), firstly emerged in Europe in early 1990s (Pe, 2009). It is an informative tool for building owners, occupiers and real estate developers/agents to achieve energy efficient buildings, providing useful recommendations on cost-effective measures in terms of building energy performance. The successful implementation of the BEEL scheme in developed countries has proven BEEL as a powerful tool to help government promote energy efficient buildings (Arcipowska et al., 2014). Thereafter, it has also been adopted by developing countries such as India (Yu et al., 2017), Brazil (Andrea et al., 2015) and South Africa (Martin, 2013).

China, one of the biggest developing countries in the world, is also facing serious challenges with respect to reduction of energy consumption (Huo et al., 2018). With economic development and living standard improvement, the building and construction industry in China keeps a steady and fast growth. In 2016, China's total floor area has reached to approximately 58.1 billion square meters ($m^2$), in which urban residential, rural residential and public floor areas were 23.1 billion, 23.3 billion and 11.7 billion $m^2$ respectively (Jiang et al., 2018). In China, nearly 25% of the total primary energy was consumed by buildings (Yan et al., 2017). To reduce the energy consumption from the building sector, the Ministry of Housing and Urban–Rural Development (MoHURD) has launched various policies to promote the energy efficiency of buildings, and the BEEL is one powerful mechanism.

The Chinese BEEL scheme started since 2008, with a focus on compulsory standard compliance and energy-saving technology promotion. As shown in Table 1, it is a comprehensive system covering many aspects in terms of building energy consumption evaluation, just like many other countries in the world. This scheme is applicable to both new and existing buildings, except for those still in the design phase. Additionally, the object building under labeling can be either residential or public, with a consideration of both their design and operational energy consumptions. Like many other countries, in China the system adopts a voluntary approach for residential buildings and small-scale public buildings, while it is legally required for government owned office buildings and large-scale public buildings. The Chinese BEEL scheme mainly concerns the energy performance of the building, such as its envelope, heating ventilation and air conditioning (HVAC) system and lighting system. This is different from the Energy Star (USEPA, 1998) and the CASBEE (JSBC, 2001) systems, which consider indoor environment quality (IEQ) and the water system as well.

Table 1 BEEL schemes in different countries.

| Country | Labelling scheme | Sponsor | Object | Phases | Method | Content of assessment | Status | References |
|---|---|---|---|---|---|---|---|---|
| United States | Energy Star (1998) | EPA (U.S.) | Commercial, industrial & residential | In operation | Operational rating | Energy and water system, IEQ etc. | Voluntary | (USEPA, 1998) |
| | HERS Index (2002) | DOE (U.S.) | Residential | In operation | Operational rating | Envelope and mechanical system | Voluntary | (RESNET, 2002) |
| | Building EQ (2011) | ASHRAE | Commercial | As-designed & In-operation | Combined asset rating & operational rating | Energy and water system, IEQ etc. | Voluntary | (ASHRAE, 2011) |
| Canada | EnerGuide (1998) | Natural Resources Canada | Residential | As-designed & In-operation | Combined asset rating & operational rating | Envelope and mechanical system, water and sewer. | Voluntary | (NRC, 1998) |
| United Kingdom | DEC (2015) | DCLG | Public | In-operation | Operational rating | Fabric and associated services such as heating, ventilation and lighting | Mandatory | (DCLG, 2015) |
| Spain | Royal Decree 235 (2013) | Ministry of Presidency of the Spanish Gov. | dwellings & small tertiary sector | In operation | Operational rating | Envelope, HVAC, lighting (tertiary buildings) and hot water energy use | Voluntary | (López-gonzález et al., 2016) |
| Australia | NABERS (1999) | The New South Wales Government | Public & residential | In operation | Operational rating | Energy and water system, IEQ etc. | Voluntary | (NSW, 1999) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Japan | CASBEE (2001) | JSBC | Public & residential | As-designed & In-operation | Combined asset rating & operational rating | Energy and water system, IEQ etc. | Voluntary | (JSBC, 2001) |
| South Korea | BEER-certification (2001) | Korea Gov. | Public & residential | As-designed | Asset rating | Heating, hot water, electricity, and water | Voluntary | (Jeong et al., 2017a) |
| | BECC (2016) | Korea Gov. | multi-family | In operation | Operational rating | Heating, cooling and lighting | Voluntary | (Jeong et al., 2017b) |
| China | JGJ/T 288-2012 (2012)[1] | MoHURD | Public & residential | As-built & In-operation | Combined asset rating & operational rating | Envelope, HVAC, and lighting energy use. Renewable energy generators. | Voluntary | (MoHURD, 2012) |
| India | SVAGRIHA (2007) | Ministry of New and Renewable Energy, government of India | Residential | As-built | Asset rating | Lighting, heating, cooling, auxiliary, and hot water energy use. Renewable energy generators. | Voluntary | (Chandel et al., 2016) |
| Brazil | RTQ-C (2009) | Brazilian Federal Gov. | Public & residential | As-designed & As-built | Asset rating | Envelope, lighting and air conditioning system | Voluntary | (Fossati et al., 2016) |
| South Africa | Energy Barometer (2010) | South Africa Gov. | Commercial | As-designed & In-operation | Combined asset rating & operational rating | Lighting, heating, cooling, auxiliary etc. | Voluntary | (Martin, 2013) |

Notes: [1] the MoHURD has released "Technical Guidelines for Energy Efficiency Labeling for Civil Buildings (Trial Implementation)" (BS [2008] No. 118) (MoHURD, 2008) in 2008 and updated it to "Standard for Building Energy Performance Certification" (JGJ/T 288-2012) in 2012.

The implementation of the BEEL scheme in China, however, was not smooth. Hong et al. (2015) revealed that the Chinese standard for BEEL (JGJ/T 288-2012) was often overlooked by authorities, resulting in a limited improvement of building energy efficiency in public buildings. Potential reasons could be various, but an important one was the lack of follow-up investigations and summaries (Zhang et al., 2013), leading to poor understanding of the effect from using the BEEL scheme.

*1.2 Pioneer work on the implementation of BEEL*

After almost 30 years of development, the BEEL scheme has become relatively mature in developed countries, and some existing literatures have analyzed its impact on the building performance. Murphy (2014) has examined the impact of the EPC by comparing various differences between EPC-rated dwellings with other unrated dwellings, and argued that the former dwellings showed no better energy performance than the latter dwellings Las-heras-casas et al. (2018) have developed a correction algorithm for region-dependent energy performance certificates for assessing residential buildings. Herrando et al. (2016) established a systematic approach for analyzing the discrepancies between the estimated and operational energy consumption of 21 faculty buildings located on the campus of the University of Zaragoza. To better understand the value of energy efficiency labels from an economic perspective, Zhang et al. (2018) developed a hedonic pricing model for the metropolitan Atlanta area in the U.S. and found that houses with energy certificates resulted in a sale price premium of 11.7%. In 2013, the European Commission funded a study (Mudgal et al., 2013) on the impact of energy performance certificates. Based on an analysis of residential housing market in Europe, the study revealed that higher energy saving resulted in substantially higher sale or rental prices on average.

Besides the work introduced above, researchers also expanded their investigation of BEEL implementation from national level to international level. Mlecnik et al. (2010)

investigated the characteristics of existing labels in European developed countries and recommended that these labels' complexity need to be lowered and trialability, observability, and compatibility need to be increased. Furthermore, they discussed the compatibility in the development of the European Energy Performance of Buildings Directive (EPBD) and advocated official recognition of existing voluntary labels in the framework of the recast of the EPBD. The Buildings Performance Institute of Europe has evaluated the implementation status of the EPC scheme in EU countries and found out that the EPCs' quality, credibility and usefulness were varying significantly among member states (Arcipowska et al., 2014). Evans et al. (2017) identified key elements and practices in implementing building energy codes in 22 countries.

Based on the above review of literatures, some main research directions in terms of the BEEL can be summarized: 1) evaluating the effectiveness of different rating methods (Johansson et al., 2016; Las-heras-casas et al., 2018; Rajagopalan and Tony, 2012; Siew and Priyadarsini, 2008); 2) verifying building energy performance of labeled projects (Herrando et al., 2016; Majcen et al., 2013); 3) investigating practical benefits of energy efficiency labeling for building owners, real estate actors and governments (Collins and Curtis, 2018; Olaussen et al., 2017; Zhang et al., 2018); 4) comparing domestic labeling schemes with foreign schemes (Evans et al., 2017; Liang and Krüger, 2017; Lopes et al., 2016). Through these studies, the value of BEEL has been explored extensively in developed countries and the implementation process of BEEL has been improved significantly.

### *1.3 Recent studies on promoting BEEL in China*

In China, some studies have been conducted, with a focus on promoting BEEL for Chinese buildings. For example, Shan et al. (2012) have done an investigation on 82 pilot projects obtaining theoretical BEEL values in China, with most were government-led projects. The investigation revealed that projects in cold climate performed a higher average building energy-saving rate than those in other climates. Mcneil et al. (2016) have used a bottom-up modeling approach to estimate the potential impact of BEEL on reducing carbon emissions in China. From the study, they found that the carbon emission rate of projects with BEEL could be 6% lower than the baseline. Zhang et al. (2007) analyzed the relationship between different participants, such as government, building owner and rating institution, in the BEEL scheme for residential buildings, and suggested that the government should perform as a good manager and supervisor of the whole scheme and all participants should be monitored to ensure the accuracy of the labelling. Waltner et al. (2012) updated efforts made by both U.S.A and China in BEEL and commented upon existing collaborations between the two countries, such as the U.S.A-China Clean Energy Research Center (CERC) project for promoting building energy efficiency. Most of these studies focused on the development of the labeling system and its pilot use, with a lack its effect in the implementation stage.

### *1.4 Problem statement*

Studies in terms of the development and implementation impact of the BEEL scheme have been widely carried out in developed countries. In China, however, relevant studies are still not sufficient to provide evidence on its positive effects to build confidence of relevant authorities in China. To fill this gap, the authors of this paper have investigated the effect of implementing the BEEL scheme in China from completed projects, aiming to identify advantages and disadvantages of this scheme in the Chinese market. The study was designed to answer the following research questions:

(1) How effective of the labeling process to the energy-efficiency of buildings in China?

(2) Can energy-saving rate be reliably used for evaluating the building's energy efficiency?

(3) To what level this labeling scheme will benefit the energy efficiency of future buildings in China?

(4) What are the potential barriers of implementing this labeling scheme in China, with a consideration of geographical variations?

The paper was divided into six sections. Following this introduction session, Section 2 provided a detailed overview of the BEEL system in China and described its development. Section 3 introduced the data collection and analysis method. Section 4 analyzed a case study carried out in Shanghai through statistical methods to answer the first three questions listed above. Section 5 discussed potential barriers of implementing the labeling scheme through an additional literature search and interviewing relevant professionals to answer the fourth question. Section 6 was formed by a thorough conclusion of this research paper.

## 2. Development of the BEEL scheme in China

In China, the MoHURD released a series of policies and regulations since 2008 to guarantee the implementation of the BEEL scheme. These included "Regulation on Energy Conservation in Civil Buildings" (CSC [2008] No. 530), "Interim Civil Buildings Energy Efficiency Rating and Labeling Management Regulations" (BS [2008] No. 80), and "Technical Guidelines for Energy Efficiency Labeling for Civil Buildings (Trial Implementation)" (BS [2008] No. 118). These documents specified basic framework, operational mechanism, supervision and management, process and technical systems of the labeling work. Based on results obtained from pilot projects completed between 2008 and 2012, it was realized that the technical guidelines were not well formed, and therefore an updated version was developed in 2012, named as JGJ/T 288-2012. It is currently the prevailing regulation in guiding the labeling activities in 21 provinces, 3 autonomous regions and 4 municipality directly under central government in China.

## 2.1 Labeling method and process

### 2.1.1 Labeling method

The labeling is including three aspects of evaluation content, i.e. basic option, prescribed options and alternative options. The basic option refers to the calculation of energy-saving rate, which can be obtained either by simulation or measurement. Prescribed options refer to minimum performance requirements for both building's envelope and HVAC systems. Alternative options refer to the application of renewable energy and other innovative energy efficient technologies, which can help to enhance the rating level. An example (IMT, 2013) of the Chinese label is shown in Fig. 1, containing a building information box, a theoretical rating box and a measured rating box. The final rating was determined under each rating box related to the above three categories.

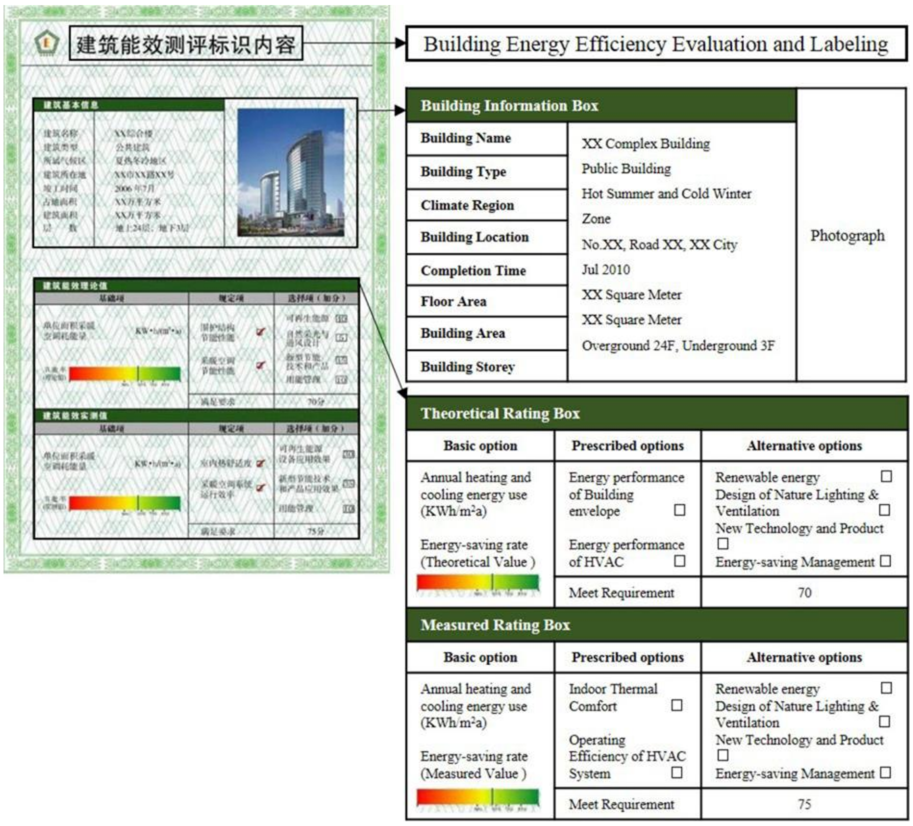


Fig. 1 An example of a national energy conservation label for public and residential buildings in China.

Since there is no established building energy consumption database in China, there is no benchmark energy consumption data of similar buildings available for comparative evaluation. Therefore, a self-reference method is used. In this method, a reference building, whose parameters meet the conditions and characteristics for the desired level of efficiency in the design standard (generally 50% energy saving than baseline building), will be generated from an actual building. In this case, comparison of energy performance with the reference building will be done on the basis of a labeling index (energy-saving rate), as defined below,

$$\eta' = (\frac{B_0 - B_1}{B_0}) \times 100\% \quad (1)$$

where $\eta'$ represents energy-saving rate, $B_1$ represents the energy use intensity (EUI) value of the labeling building, and $B_0$ represents the EUI value of the reference building.

At the beginning, the guideline (BS [2008] No. 118) used a normative label which has a scale of one to five stars to indicate the level of energy efficiency of a building. The number of stars given to the building was based on the reduction of energy consumption comparing to that of baseline buildings built in 1980s. The comparison was built upon percentage, and the regulation required a minimum of 50% reduction for obtaining a one-star label. If a building attempted to obtain the most efficient five-star rating, it should achieve at least 85% energy saving than baseline buildings. Consequently, very few buildings could get a five-star certification, and therefore the rating was changed to a three-star system in the updated version in 2012, which was the JGJ/T 288-2012. In this new standard, the relative energy saving rate "$\eta$" calculated based on the reduction of energy consumption comparing to the current energy-saving design standards which require 50% or 65% energy saving is used, the relationship of these two indexes is shown in Fig. 2. The evaluation interval was cut down and buildings achieving 65% energy saving or more than baseline buildings could obtain a three-star level (the highest level in the new version), as illustrated in Fig. 3.

| Star Level | $\eta'$ (Compared to the building in the 1980s) | $\eta$ (Compared to the building which meet the requirement of current energy-saving design standards) |
|---|---|---|
| ★ | 50%≤ $\eta'$ <57.5% | 0%≤ $\eta$ <15% |
| ★★ | 57.5%≤ $\eta'$ <65% | 15%≤ $\eta$ <30% |
| ★★★ | $\eta'$ ≥65% | $\eta$ ≥ 30% |

Note: the source of the table is from the "JGJ/T 288-2012", p 53.

Fig. 2 Level of the BEEL (Compared to the energy saving 50% standard).

<table>
<tr><th colspan="4">Technical Guidelines for Energy Efficiency Labeling for Civil Buildings</th></tr>
<tr><th>Energy-saving rate ($\eta'$) of Basic Option</th><th>Prescribed Options</th><th>Alternative Options</th><th>Star Level</th></tr>
<tr><td>50%≤ $\eta'$ <65%</td><td rowspan="5">Satisfy all requirements</td><td rowspan="5">Add one more star when score over 60 points. Maximum is 100 points. The highest level is five star.</td><td>★</td></tr>
<tr><td>65%≤ $\eta'$ <75%</td><td>★★</td></tr>
<tr><td>75%≤ $\eta'$ <85%</td><td>★★★</td></tr>
<tr><td rowspan="2">$\eta'$ ≥85%</td><td>★★★★</td></tr>
<tr><td>★★★★★</td></tr>
</table>

⇩

<table>
<tr><th colspan="4">Standard for building energy performance certification</th></tr>
<tr><th>Relative energy-saving rate ($\eta$) of Basic Option</th><th>Prescribed Options</th><th>Alternative Options</th><th>Star Level</th></tr>
<tr><td>0%≤ $\eta$ <15%</td><td rowspan="3">Satisfy all requirements</td><td rowspan="2">Add one more star when score over 60 points. Maximum is 130 points for residential buildings and 150 points for public buildings .</td><td>★</td></tr>
<tr><td>15%≤ $\eta$ <30%</td><td>★★</td></tr>
<tr><td>$\eta$ ≥30%</td><td></td><td>★★★</td></tr>
</table>

Fig. 3 Development of the BEEL rating system in China.

### *2.1.2 Labeling process*

In order to obtain a building energy efficiency label, the building owner needs to find a third party, i.e. a government-approved institution (either a national or provincial assessment institution), to submit an application. If the building is new or recently refurbished, the third party will check relevant information by evaluating the model of the building or auditing the actual building. These may include software simulation, document review, on-site inspection and performance test. After these processes are completed, the building owner can get a rating report from the third-party institution and needs to submit the report to the local construction commission for application the label. If the application approved, the commission will provide final approval of the label for publication and issuing an asset rating certificate. This asset rating determines the overall star level achieved by the building and is valid for 1 year after the building is occupied. Once occupied, the owner is supposed to get an operational rating, which is valid for 5 years. The operational rating is based on data from metering various energy end-uses, including HVAC, lighting, plug loads, domestic hot water and process energy. The on-site measurement must be carried out for more than one year. The whole labeling process has be visualized in Fig. 3.

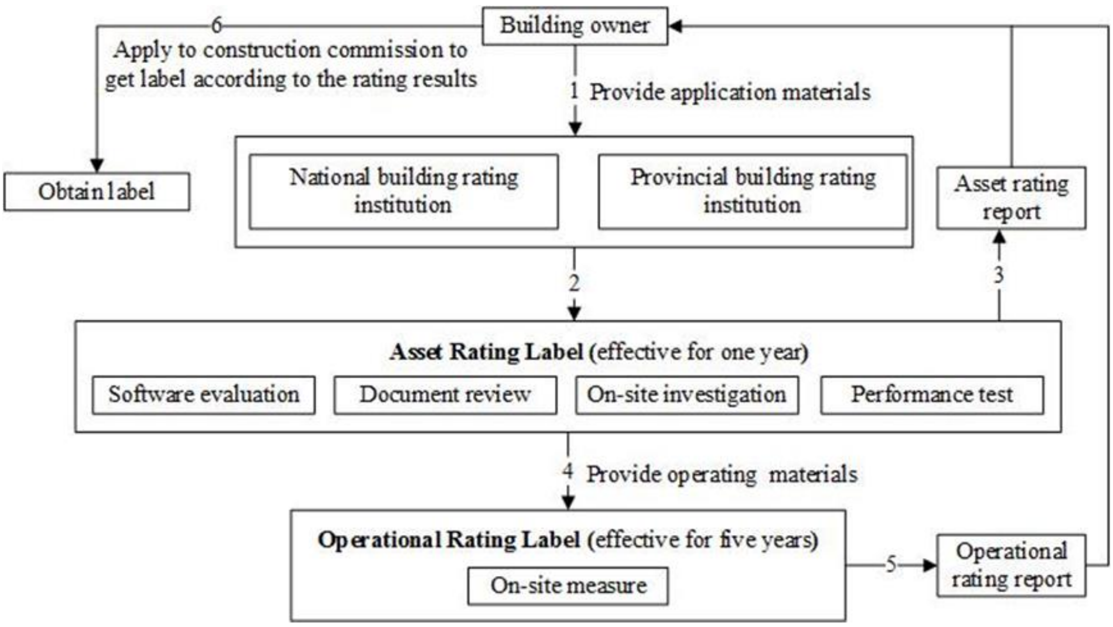


Fig. 3 Whole process of obtaining energy efficiency building labels in China.

*2.2 Implementation development*

To establish a technical support system for the BEEL scheme, the MoHURD has confirmed seven national building rating institutions, and the provincial construction commission has certified more than one hundred provincial rating institutions. Only national building rating institutions can evaluate applications for three star labels, and provincial institutions can only evaluate one-star and two-star applications.

Meanwhile, provinces and cities, such as Shanxi, Shandong, Jiangsu, Hubei, Guangdong, Guangxi, Hainan, Beijing, Shanghai, Tianjin, Shenzhen and Xiamen, have all published provincial management approaches and local technical standards/guidelines according to their local conditions.

## 3. Research methodology

### *3.1 Data collection*

By 2013, the MoHURD has disclosed 387 labeled projects (based on technical guidelines). All specific information (rating report) of these projects were centrally submitted to the Center of Science and Technology of Construction (CSTC) from the project owner. As the great number of projects in the city of Shanghai caught our attention, the CSTC made a field research in the city to obtain more necessary messages, such as the data of energy consumption, and to examine the BEEL development in Shanghai.

The total number of these projects in Shanghai were 164, far more than other cities. This outstanding quantity is highly linked to Shanghai's economic vitality and supporting policy from the local government. Currently, Shanghai is the center of finance of China and its annual growth rate in economy is much higher than the national average level. Investment in real estate in Shanghai has reached 49 billion dollars, almost 3–5 times of those in other large and midsize cities in China (Zhu et al., 2016). With superior economic foundation and governmental supporting policies (listed in Table 2), the quantity of labeling projects in Shanghai is of course growing much faster than any other cities.

Table 2 Summary of energy efficiency policies related to BEEL in Shanghai.

| No. | Policy | Year | Description |
|---|---|---|---|
| 1 | Shanghai energy saving special funds management approach | 2008 | ✧ List support items but does not reflect the specific subsidy amount |
| 2 | Interim Measures for Special Support for Building Energy Efficiency Projects in Shanghai | 2012 | ✧ New residential and public building demonstration projects (least two-star), subsidy ≤ 50 CNY/$m^2$.[1]<br>✧ Existing residential building energy-saving renovation demonstration project (least one-star), subsidy ≤ 100 CNY/$m^2$, existing public building energy-saving renovation demonstration project, subsidy ≤ 50 CNY/$m^2$. |
| 3 | Special Support Measures for Building Energy Efficiency and Green Building Demonstration Projects in Shanghai | 2016 | ✧ Green building demonstration projects, two-star operational label, subsidy ≤ 50 CNY/$m^2$; three-star operational label, subsidy ≤ 100 CNY/$m^2$.<br>✧ Existing residential building energy-saving renovation demonstration project, subsidy ≤ 50 CNY/$m^2$, existing public building energy-saving renovation demonstration project, subsidy ≤ 25 CNY/$m^2$. |

Notes: [1] CNY= Chinese Yuan.

As mentioned above, Shanghai has a total of 164 labeled projects (83 public buildings and 81 residential buildings). The type and quantity of public buildings and the labeling levels of public and residential buildings are listed in Table 3. The listed information indicates that no public building has got a three-star level, but some residential buildings have, which proves the necessity to change the evaluation system used in technical guidelines. In the following analysis, two important parameters, i.e. the EUI level and the energy-saving rate, will be mainly used. With a consideration of available sample size, commercial office buildings and residential buildings were finally used in the analysis.

Table 3 Star level distribution of labeled projects in Shanghai.

| Building type | | Total number | Star level | | |
|---|---|---|---|---|---|
| | | | ★ | ★★ | ★★★ |
| Public Building | Hotel | 9 | 9 | 0 | 0 |
| | Hospital | 3 | 3 | 0 | 0 |
| | University | 2 | 2 | 0 | 0 |
| | Gymnasium | 2 | 2 | 0 | 0 |
| | Department Store | 6 | 5 | 1 | 0 |
| | Commercial Office Building | 56 | 40 | 13 | 0 |
| | Government Office Building | 5 | 5 | 0 | 0 |
| Residential Building | | 81 | 48 | 27 | 6 |

### *3.2 Analysis method*

In order to comprehend the EUI level of commercial office buildings in Shanghai, validity samples and the EUI statistical distribution were needed. For acquiring valid samples, the Inter Quartile Range (IQR) (Gliedt and Hoicka, 2015; Xiao et al., 2012) of the EUI was calculated. The IQR is a measure of statistical dispersion, which is equal to the difference between the 75$^{th}$ and the 25$^{th}$ percentiles. If the difference between the sample data and the 75$^{th}$ quartile or the 25$^{th}$ quartile is larger than 1.5 IQR, the data will be considered as abnormal and hence rejected to be used.

To observe the frequency distribution features of the EUIs of the samples, the energy use data was divided into groups and the interval ($k$) was determined using the equation given by H.A. Sturges (Sturges, 1926):

$$k = [\log_2 n] + 1 \quad (2)$$

where $n$ is the sampling size.

Meanwhile, the Kolmogorov-Smiromov (K-S) test (Daniel, 1990) was used to further explore the distribution of EUIs of these samples. The K–S test is a nonparametric test of one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution. To obtain the relationship between the EUI and the energy-saving rate for different type of buildings in Shanghai, the curve fitting was applied to denote the relationships between these two variables.

For promoting the effect of the scheme in future projects, potential barriers were analyzed and discussed in this study as well. The research team has reviewed domestic literatures in terms of current practices of implementing BEEL. In addition to this, thirty experts in building related areas were interviewed by telephone calls and they were coming from building design institutes (ten), government (ten) and real estates (ten). To promote the information obtained from the study, open questions were adopted by the telephone interview.

## 4 Results and Discussion

### *4.1 The EUI and energy-saving rate*

#### *4.1.1 The EUI level for commercial office building in Shanghai*

The EUI level for commercial office buildings in Shanghai was demonstrated in this section. Through the data filtration, three sample buildings, with EUIs exceeding the upper limit of the data, were removed from the analysis, with 53 samples finally used in the analysis. (By further observations, those three buildings containing spaces used as dedicated data centers, industrial manufacturing and laboratory space, hence not typical office buildings.)

Fig. 4 shows the frequency distribution characteristics of the EUIs for labeled commercial office buildings in Shanghai. The EUIs of labeled buildings presented a normal distribution, as shown in Fig. 4(a). This is similar to the EUI distribution of unlabeled commercial office buildings in Shanghai, monitored at the same period, as shown in Fig. 4(b) (BERC, 2014). Comparing Fig. 4(a) and Fig. 4(b), the mean EUI of labeled commercial buildings in Shanghai was 79.14 kWh/$m^2$a, while it was 129.79 kWh/$m^2$a for unlabeled commercial office buildings.

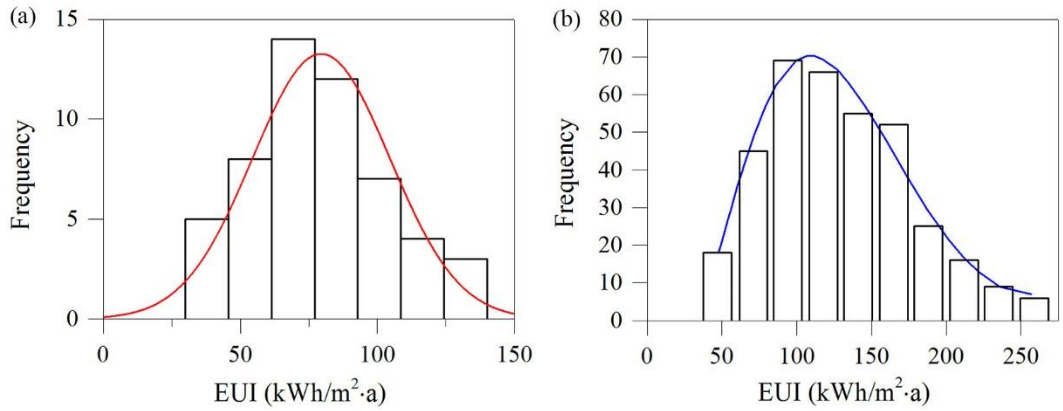


Fig. 4 Distribution of the EUIs for commercial office buildings in Shanghai (a) labeled buildings; (b) unlabeled buildings.

*4.1.2 Relationship between the energy-saving rate and the EUI*

Unlike most developed countries, which have their own database with information about the energy performance of a significant number of buildings, China adopts the self-reference approach when evaluating a building's energy efficiency. In this approach, the labeling index, i.e. energy-saving rate, shows the saving percentage towards to the performance of the reference building. The statement that buildings having high energy-saving rate have low energy consumption, as advocated by many real estate actors, often leads to a confusion to the tenants (even experts). In order to understand the energy-saving rate in the same type of buildings when compared with benchmarking approaches, the relationship between the energy-saving rate and the EUI was developed for the selected samples. The samples were divided into two classifications, i.e. commercial office buildings and residential buildings, and the data are shown in Fig. 5 and Fig. 6, respectively, with fitted correlation curves.

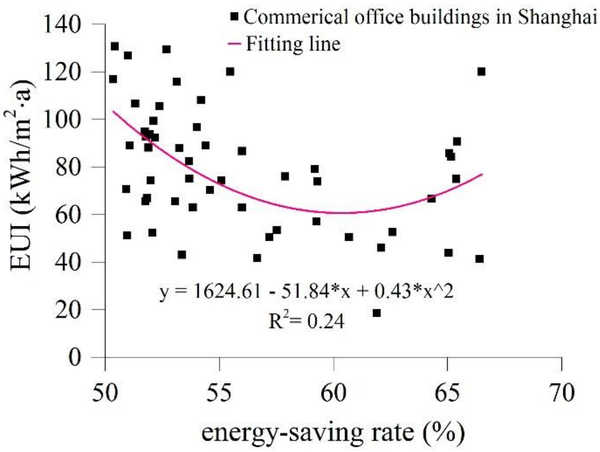


Fig. 5 Relationship between the EUI and the energy-saving rate for commercial office buildings in Shanghai.

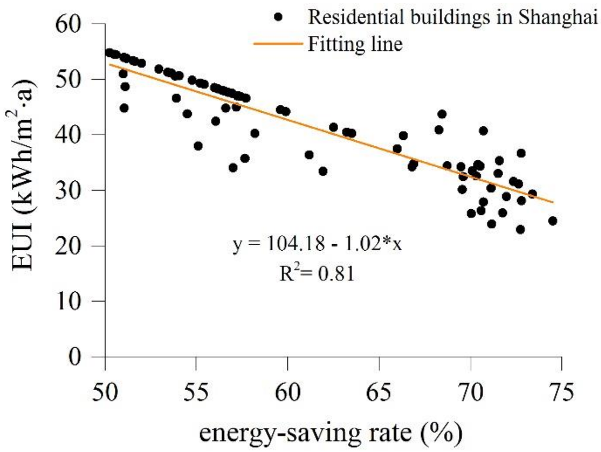


Fig. 6 Relationship between the EUI and the energy-saving rate for residential buildings in Shanghai.

In Fig. 5, the relationship between the energy-saving rate and the EUI is presented more as a quadratic form, meaning that buildings with higher energy-saving rate does not necessarily have a lower EUI. In Fig. 6, however, it can be obviously observed that for residential buildings the energy-saving rate is inversely proportional to the EUI. The phenomenon could be attributed to the variation of system selection for a certain type of building. For commercial office buildings, many factors may affect the system selection, such as floor area, system style, operation schedule and occupant density

(Deng et al., 2018). For residential buildings, however, the energy systems are often selected in similar ways in the same city (in Shanghai, 60% are using split air conditioners).

Previous studies (BERC, 2014; P. Xu et al., 2013) have shown that the energy consumption of public buildings was related to the building's volume and scale, and 20000 $m^2$ has been selected as a threshold. In this study, the influence of the gross floor area (GFA) on the EUI was analyzed as well. As shown in Fig. 7, the EUI of commercial office buildings with GFA smaller than 20000 $m^2$ was more likely to be lower than 80 kWh/$m^2$a (the benchmark value for new buildings, given by the "Chinese standard for energy consumption of building", GB/T 51161-2016), but that with GFA higher than 20000$m^2$ was higher. Most commercial office buildings with GFA higher than 20000$m^2$ have a relatively higher EUI and lower energy-saving rate (cases in blue dashed frame), indicating higher energy saving potential.

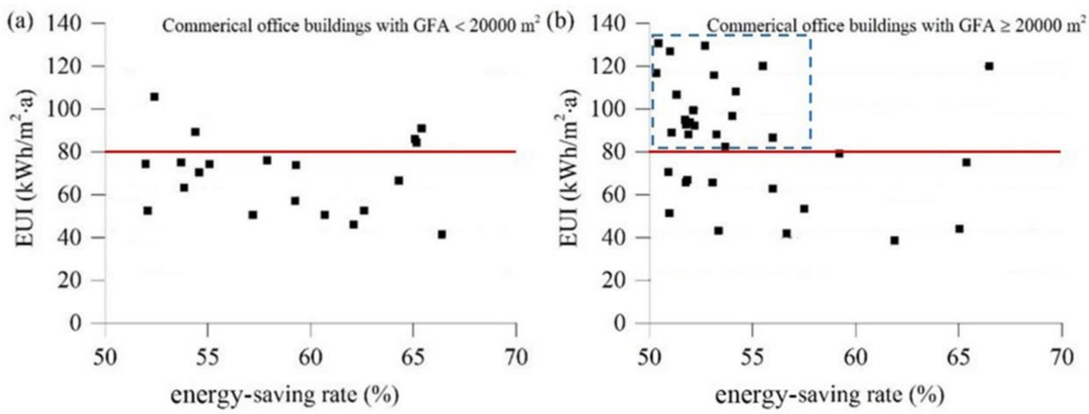


Fig. 7. The EUI of commercial office buildings in Shanghai (a) buildings with GFA lower than 20000 $m^2$; (b) buildings with GFA higher than 20000 $m^2$.

*4.2 Recommended technologies for energy-efficient buildings*

The HVAC, domestic hot water, lighting and appliances systems account for most energy consumption of a building. Particularly, the HVAC system can consume about 50%-70% energy for residential buildings and about 40%-60% energy for public buildings in China, demonstrating great energy saving potential (Cao et al., 2016; L. Xu et al., 2013). The selection of HVAC systems and energy-efficient technologies is influenced by various local factors, such as climate, renewable energy distribution and economic level. In order to identify the most cost-effective measures to reduce the building's energy consumption under local conditions, building designers need to do a number of simulation work with different technologies and systems during the design stage, resulting in a huge workload. To solve this issue, analyzing these labeled projects may provide some hints about mostly suitable technologies for different geographical areas, hence reducing the workload of designers.

*4.2.1 Recommended technologies for public buildings*

Through the analysis of alternative options in these labeled public buildings, the most frequently utilized technologies in public buildings in Shanghai are shown in Fig. 8. The top three ranked technologies are building automation system (BAS), heat recovery and variable water volume. A further analysis on the 28 labeled commercial office buildings with EUIs lower than 80 kWh/m$^2$a was also conducted and the result (Fig. 9(a)) showed the most widely adopted energy-efficient HVAC systems in those buildings were ground source heat pump (GSHP), variable refrigerant volume (VRV) system and boiler combined with chiller. Furthermore, a comparison between Fig. 9(a) and Fig. 9(b) reveals that GSHP and VRV give better energy performance than other systems for commercial office buildings.

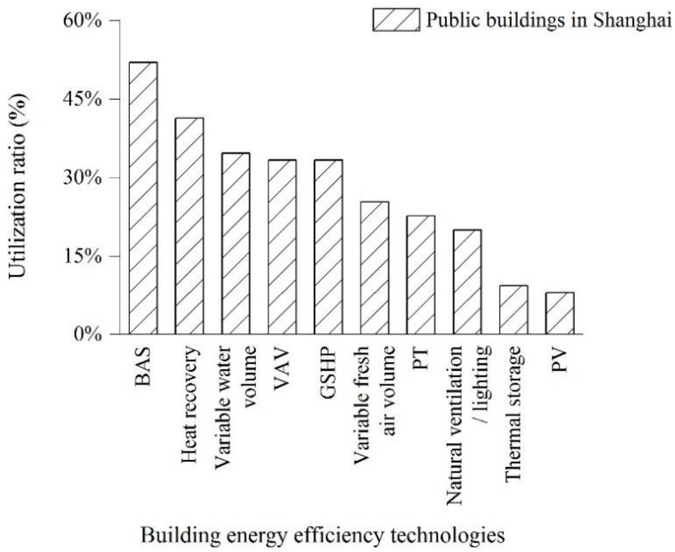


Fig. 8 The proportion of renewable energy and energy-efficient technologies used in public buildings in Shanghai

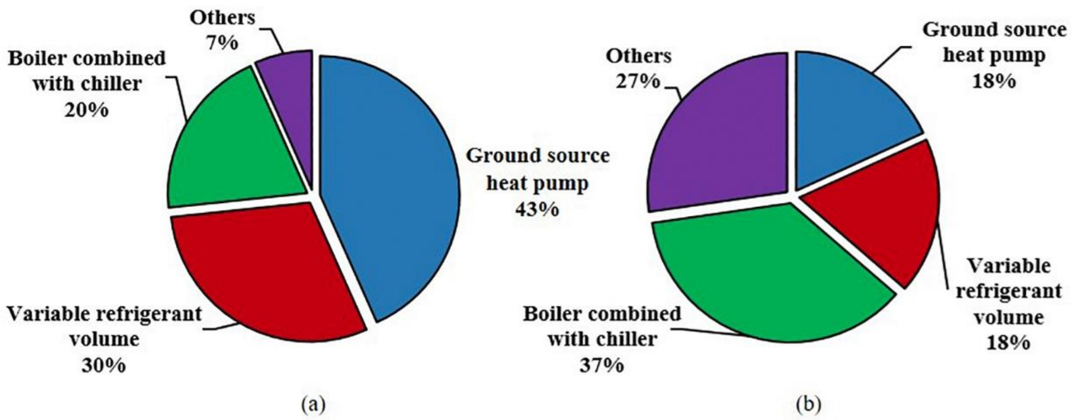


Fig. 9. HVAC systems of labeled commercial buildings in Shanghai (a) buildings with EUI lower than 80 kWh/m$^2$a; (b) buildings with EUI higher than 80 kWh/m$^2$a.

*4.2.2 Recommended technologies for residential building*

As shown in Fig. 10, natural ventilation, daylighting, GSHP and photo-thermal (PT) utilization device were preferred when designing energy-efficient residential buildings in Shanghai. The HVAC systems of 34 labeled residential buildings with EUI lower than 40 kWh/m$^2$a in Shanghai were also analyzed (shown in Fig. 11). Popularly selected technologies included heat pump, split air-conditioners, inverter air-conditioners, boilers and chillers. The utilization proportion of GSHP was the highest, followed by split air-conditioners and inverter air-conditioners. In the remaining 47 labeled residential buildings with EUI higher than 40 kWh/m$^2$a, the proportion of split air-conditioners was the highest, followed by inverter air-conditioners and GSHP. Although the application of GSHP helps to save more energy, the most commonly used HVAC system in labeled residential buildings in Shanghai was split air-conditioners, as it is more convenient to be installed and controlled.

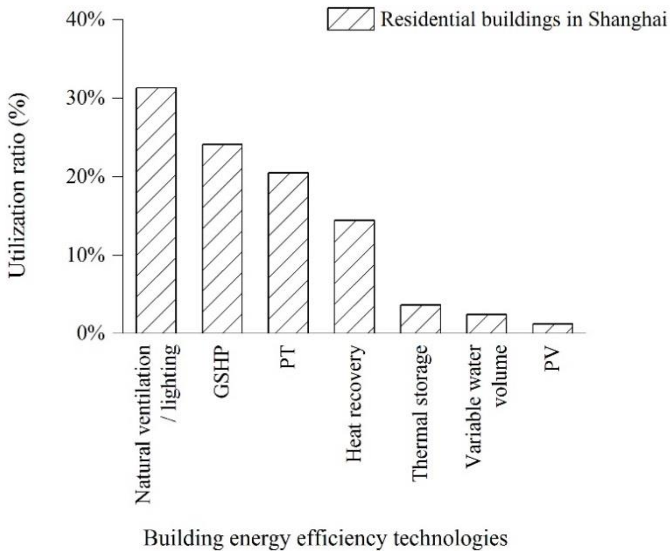


Fig. 10 The proportion of renewable energy and energy efficiency technologies used in Shanghai residential buildings

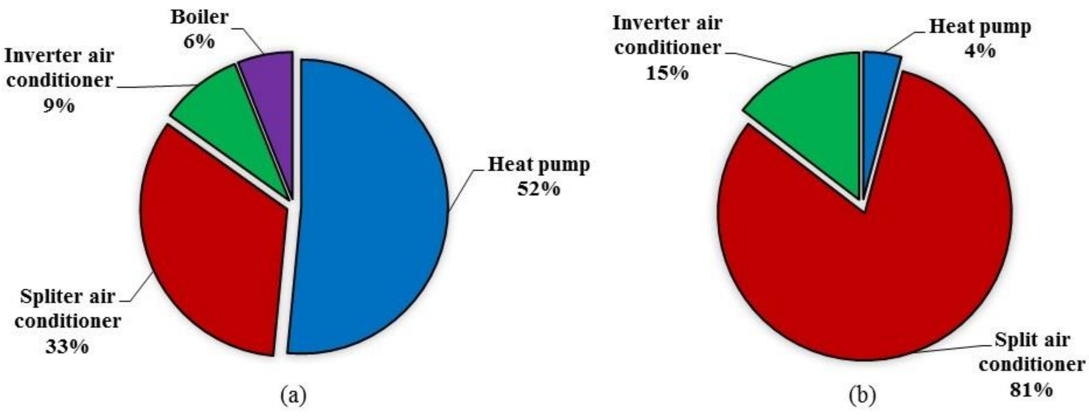


Fig. 11. HVAC systems of labeled residential buildings in Shanghai (a) buildings with EUI lower than 40 kWh/m$^2$a; (b) buildings with EUI higher than 40 kWh/m$^2$a.

The utilization of these energy-efficient technologies is not only affected by their energy efficiency but also depends on their operational cost and local policy. Benefited from the industrial development in the Yangtze River Delta region and subsidy policies, the use of renewable energy in this region is very active. The distribution of solar PV industry, solar water heater industry and GSHP industry in China are shown in Fig. 12 (Wang et al., 2017). However, according to the data shown in Table 4 (Huang and Mauerhofer, 2016), the economic cost of using PV, PT and GSHP are still higher than other technologies used in building. With the further development of these technologies, their cost will definitely reduce, and there is no doubt that renewable energy will be more popularly used in building services systems in the future.


Fig. 12 Distribution of solar energy and GSHP industrial bases.

Table 4 Data collection of the energy-efficient technologies in building sectors.

| **Technologies** | | **Economic** | |
|---|---|---|---|
| **Terminal energy Consumption** | **Energy-efficient technologies** | **Microeconomic efficiency (CNY/t$CO_2$)** | **Energy saving potential** |
| Space heating and cooling | Building insulation | 204 | 50%-80% |
| | Split air-conditioner | 465 | 30%-50% |
| | Geothermal heat pump | 756 | 30%-70% |
| Lighting | Lighting energy | 352 | 10%-70% |
| Water heating | Solar thermal | 1010 | 10%-65% |
| | Electric water heater | 160 | 23%-30% |
| Others | Solar PV | 1510 | 85% |

## 5. Barrier analysis

As a result of the domestic literature review and relevant professionals' interview, potential barriers were classified into three categories, i.e. technical, political and awareness aspects.

For the technical aspect, the barriers can be mainly summarized as follows:

(1) The current rating method focuses on construction and operation stages, not design stage. This reduces the impact of the energy-saving rate of selected systems.

(2) The certification process is complicated. It involves many relevant building codes regarding to energy efficiency and operation process, but the descriptions in both guidelines and standards are not clear and well structured.

(3) The building energy simulation software is not comprehensively designed. Some functions and parameters are still missing and not unified. For instance, the central heating and LiBr absorption heat pump are both used in building services systems, but in national simulation software only district boilers are available.

(4) The materials used for labeling are difficult to collect. Various materials are required in the labeling process, such as engineering drawings, product performance test reports and equipment's parameters. This significantly reduces the enthusiasm of building owners for labelling their buildings.

For the political aspect, the barriers can be mainly categorized as follows:

(1) There is no sufficient attention paid by the Chinese government and institutions to investigate the implementing effect of the BEEL scheme. In other countries, various studies have been conducted for the building energy-efficient labeling, with respect to aspects such as housing price, location, energy consumption, costs of rating and investment value of building labeling. However, such investigations are rare in China.

(2) Integration of asset rating and operational rating has not yet been formed. There are very few projects requesting operational labelling at this stage. One reason is high cost of measuring energy consumption during the operational stage. How to make the measurement more cost effective still needs further explorations.

(3) Local governments, especially in middle and western regions of China, are lack of certified rating institutions and training on practitioners, leading to limited capacities in terms of both technology and human resource to implement energy efficiency policies, projects and standards.

(4) Incentives for builders are inadequate. Most cities have relatively low investment in BEEL market cultivation, which needs to be improved. Meanwhile, if there is little budget available from the local government, giving penalties to those buildings with poor energy efficiency may also be applicable.

From the awareness aspect, the barriers can be mainly classified as follows:

(1) Lack of sufficient information and understanding from consumers/tenants/building owners for making well-informed consumption and investment decisions.

(2) Lack of information about the energy performance of buildings.

(3) Energy information may not be provided or analyzed by end-users, energy providers, or other rating institutions.

(4) Conventional perceptions on energy-efficient measures increasing the cost of the building.

Regarding to these barriers, suggestions for the future promotions of the BEEL scheme include: 1) improving and simplifying the evaluation method; 2) subsidizing to the projects which obtained the operational label; 3) establishing database of building energy consumption and usable benchmarks; 4) focusing on researching long-term mechanism of actual impact of the labeling scheme to stakeholders; 5) strengthening policy support and market cultivation; and 6) raising awareness among general public.

## 6. Conclusions and Policy Implications

As the BEEL scheme has been advocated as "Key points of work of the Building Energy Conservation and Technology Division of the Ministry of Housing and Urban-Rural Development in 2018" by the MoHURD, it is necessary to investigate its effect of implementation in China.

This paper introduced the development of the BEEL scheme in China and used a case study in Shanghai to investigate the energy-efficient effectiveness of labeled buildings, the relationship between energy-saving rate and the EUI, as well as recommended technologies for energy-efficient buildings under different local conditions and requirements. The barriers for implementing the BEEL scheme over the whole country were also analyzed. The results from this study will help to better understand the positive effect of implementing the BEEL scheme in China and provide a reference for other cities and even for other developing countries. Main conclusions from this study can be drawn as follows:

(1) With the development of Shanghai and its implementation of energy-efficient policies for buildings, the EUIs of labeled commercial office buildings followed a normal distribution, similar to the distribution of unlabeled commercial office buildings during the same period, but with a lower mean EUI.

(2) In Shanghai, the energy-saving rate and energy consumption followed an inverse proportional relationship for residential buildings. For commercial office buildings, however, a high energy-saving rate did not mean low building energy consumption. Therefore, this labeling index cannot be used for benchmarking, but can help to achieve the scheduled goals of declared building energy-efficient policies.

(3) Through analysis of labeled projects, suitable energy-efficient technologies (HVAC

systems) for Shanghai were summarized. BAS, heat recovery and variable water volume were preferred technologies for public buildings, and natural ventilation, daylighting, ground source heat pump and solar energy utilization device were useful technologies for residential buildings. The GSHP and VRV systems showed a better energy performance in commercial office buildings, and GSHP and split air-conditioners in residential buildings.

(4) There is a lack of comprehensive analysis of the effectiveness of the BEEL scheme across China and only limited information is available for some cities. There are still lots of barriers for promoting the BEEL scheme, coming mainly from three main aspects, i.e. technical, political and awareness. More detailed information from completed projects needs to be collected, and follow-up investigations and evaluations are also urgently desired.

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