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An energy saving retrofit baseline determination method for large scale building based on investigation data

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ABSTRACT

At present, China is implementing large scale building energy efficiency retrofit (LSBEER) due to the constraints of total energy consumption and energy use intensity (EUI). It is vital to determine the baseline of LSBEER. There are some limitations to LSBEER in the current baseline methods, such as lack of exhaustive database, mismatching with actual retrofit potential, inapplicability of physical simulation analysis. The paper proposes a baseline determination model to diminish the uncertainty and improve applicability using the example of 100 buildings in Shanghai. The methodology comprise two indexes of EUI and energy saving rate (ESR) including four methods, based on the bilateral match of retrofit target and the practical retrofit potential combined with design standards for public building energy saving. Meanwhile, evaluation indexes are proposed, such as the energy saving potential matching degree (ESPMD) and retrofit building coverage rate (RBCR). Results show that the ESR-based method has an advantage over the other three methods, with the ESPMD and the RBCR reaching 86% and 95%, respectively.

Keywords：Large scale building; Energy saving retrofit; Baseline model; Energy saving potential matching degree; Virtual energy saving; Energy saving rate

1. Introduction

With the rapid development of our modern society, the proportion of building energy consumption has increased year by year, among which the public buildings are responsible for the major contributors to the total energy consumption. According to the IEA report, the building energy consumption has reached 1/3 of the total energy consumption (IEA, 2014).

Nomenclature

Abbreviation and acronyms

ABVM	Advanced benchmark value method
AES	Amount of energy saving
CRM	Class ranking method
DSEEPBC	Design Standard for Energy Efficiency of Public Buildings in China
EEMs	Energy efficiency retrofit measures
EUI	Energy use intensity
ESPMD	Energy saving potential matching degree
ESR	Energy saving rate
HVAC	Heating, ventilation and air conditioning
IFA	Internal floor area
LSBEER	Large scale building energy efficiency retrofit
RAES	Retrofit amount of energy saving above constrained baseline
RBCR	Retrofit building coverage rate
SHLCPZ	Shanghai Hongqiao low carbon practice zone
UIC	Unit investment cost
VAES	Virtual amount of energy saving
WRM	Whole ranking method
Symbols	
E	Energy consume(GJ)
I	Energy saving investment ($)
N	Total number of buildings in the study area
NC	Number of buildings above constrained baseline
X	Relative ranking position
RI	Energy saving investment above constrained baseline($)
δ	The ratio of baseline to average value
Subscripts	
ad	Advanced value
av	Average value
ba	Energy baseline
g	goal
i	Building type
j	Number of buildings
po	Energy saving potential

1.1 Energy saving retrofit and large scale building requirement in China

In order to achieve global carbon dioxide emission goals, the Chinese government has pledged to reduce the carbon dioxide emissions per unit of gross domestic product by 40-45 percent (i.e. to the level below that of 2005 by 2020). Meanwhile, Chinese government will implement the double-control strategy of total energy consumption and energy intensity during the 13th Five-Year Plan period (2016-2020). The method of building's energy-saving assessment is gradually transformed from technical measures application to total quantity and/or EUI control. For instance, local governments have set up CO_2 emission reduction targets and incorporated them into their annual assessment. In addition, Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD, 2017) has planned the implementation of large scale building energy efficiency retrofit (LSBEER), requiring public buildings energy saving area municipalities to be more than 5 million m^2, sub provincial city of more than 2.4 million m^2. Meanwhile, the energy saving rate of retrofit buildings is required to be beyond 15% before they can obtain policy funding incentives. Since 2007, Chinese government has made a great progress in establishing the energy-saving supervision platform for public buildings. Particularly some cities have carried out the energy retrofit. However, the retrofit was mainly focused on individual public building. As the retrofit scale is enlarged, some cities in China began to promote LSBEER in the administrative regions, which might comprise varieties of buildings. Consequently, the energy-saving incentive policies begin to change from individual building to large scale buildings. Note that the large-scale buildings can be regarded as an integration of multiple functional buildings, including a variety of energy systems, exhibiting different characteristics of energy consumption. Therefore, how to promote LSBEER has become a complex systematic project.

Nowadays, Chinese government starts implementing the double-target control, while some local governments are paying attention to set up a regional retrofit baseline of LSBEER. For example, demonstration projects of LSBEER are being launched in existing central urban area of some cities (Bogach et al. 2013). Thus, some cities have tried to use constraint control indicators to promote building energy efficiency, followed by carrying out the relevant work of building energy baseline.

1.2 previous researches on energy saving retrofit and energy baseline

Building energy performance assessment (such as compare the assessed building with

a self-referenced baseline building) is crucial to ascertain energy efficiency and has been regarded as the basis to make retrofit decision (Wang, et al. 2012). The retrofit of existing buildings will bring remarkable improvements in energy performance. For instance, Penna, et al. (2015) investigated to what extent the incentives on different typologies of energy-efficiency measures can improve the performance of the optimal retrofits solutions. Furthermore, Cremaschi (2018) summarized optimization methods for building energy systems that can bring significant energy saving effect. Moreover, Yang, et al. (2017) developed the prototypical building energy model for urban scale building to evaluate the energy performance, which is capable of evaluating the energy retrofit options of a group of buildings. Patersong et al. (2017) proposed machine learning to predict annual thermal (gas) and electrical energy use of building designs, which could provide basis for energy consumption assessment in the future. In addition, Liang et al. (2016) pointed out that the accuracy of the baseline prediction can significantly impact the energy saving assessment, investment return and payback period. It was shown that energy consumption evaluation can both provide the corresponding foundation and support for energy saving retrofit from previous studies, and that's why energy baseline method has been regarded as the most well-known branch of building energy performance assessment.

For LSBEER, many previous studies have been focused on evaluating retrofit effect (Érika et al. 2013) and cluster analysis for LSBEER (Geyer et al. 2017). Some researchers are targeted at city-scale building stock by discussing the problem of scale retrofit (Chen et al. 2017). In Refs. (Dall'O', et al. 2012), the authors performed an energy cadaster by conducting a large in-field survey for five municipalities, showing that discuses energy retrofit interventions are feasible from a technical, legal and economic point by detecting the characteristics of residential building stocks. Furthermore, Fracastoro et al. (2011) introduced an analytical methodology for determining the statistical distribution of residential buildings according to primary energy consumption at a regional or national scale. Meanwhile, the Refs also introduced mandatory measures and incentives for building energy retrofits as well as evaluating the potential of new technologies, etc. These studies are mainly focused on the residential stock, while very little studies are about the energy saving retrofit baseline of LSBEER.

At present, many literatures have been focused on defining the building energy baseline. For instance, Ellis et al. (2007) proposed the concept of the baseline of the clean development mechanism (CDM), implying that "greenhouse gas emissions from other projects (i.e. baseline projects) be built to provide the same service even in the absence of CDM projects". The Marrakech agreement gave out three baselines, including (1) Levant actual reductions or historical reductions; (2) Emissions generated by a mainstream technology with an investment barrier; (3) In the past 5 years, the average emissions of similar projects with similar performance under the social, economic, environmental and technological conditions were ranked the top 20% in the same category (Kallbekken et al. 2007).

The whole process of predicting baseline and assessing energy saving is called "measurement and verification (M&V)", following which a lot of previous studies had discussed numerous existing models for predicting the baseline of energy usage (xia et al. 2013; Liang et al. 2016). Building energy baseline model has been applied in many aspects of building energy efficiency and plays an important role in determining, evaluating and analyzing the energy efficiency (Energy Foundation, 2011). This model mainly includes two aspects: the energy consumption evaluation of the new building at the design stage and that of the existing buildings at the operational stage. On the one hand, the building energy baseline model is established by using the simulation calculation method. During the design stage, the building energy baseline is generally used for calculating the dynamic energy consumption simulation method. On the other hand, the energy baseline model establishment in operational stage is generally adopted by employing multiple regression methods and special simulation software. In addition, some scholars adopt quartile method, which relies on both mean value and statistical probability distribution for determining the baseline. Basically, the associated research activities contain simple standardization, reference building and simulation methods, and regression model, et al, (Table1).

Table 1 Model and method of building energy consumption baseline

Model/ method	Detailed information	References
Simple Standardization	The simple normalization approach generally relies on simple relative performance indicators, and ratios of single input and outputs. Energy-efficiency indicators are obtained by simply normalizing the energy use based on floor area or operational hours	Filippin (2000) Birtles and Grigg (1997) Chung (2001)
● mean—week model ● day--time--temperature, DTT model ● LBNL model ● multi--parameter change—point model ● Pulse Adaptive model model	(1) the mean-week model depends on day and time (2) DTT model includes time of day ,day of week and two temperature variables for heating and cooling (3) LBNL includes time of week, and a piecewise-continuous temperature with fixed change points. (4) multi-parameter change-point model relate energy use to the ambient (5) Pulse Adaptive model is a proprietary algorithm	Granderson and Price (2014)
Improved LBNL model	This new model is developed from the LBNL model by including the occupancy variable. Besides the outdoor air temperature and the time variables, the occupancy variable is added in this model	Liang et al. (2016)
IPMVP	to provide current practice techniques for verifying energy efficiency in industrial and commercial settings. Using the parameterized baseline model, predict the energy consumption after the energy improvement occurred	Mark et al. (2010)
Support Vector Regression (SVR) model	A new SVR model to forecast the demand response baseline for office buildings	Chen et al.(2017)
Architecture and Simulation methods	Using simulation and reference building classification methods, using EnergyPlus and other special software	Tatiana et al. (2017) Ilaria et al. (2014)
Statistical Regression method	Based on the commercial building energy consumption database, a regression model is used to establish the baseline	Dong et al. (2005) Lei and Hu, (2009) Sharp (1995)
K-means algorithm model	Using cluster analysis method, K-means algorithm model was put forward by using daily energy consumption in office buildings	Ko et al. (2017)

Moreover, the developed countries in both Europe and the United States have established relatively mature evaluation methods and management systems for building energy baseline. Some countries even employed energy baseline for evaluating the performance of buildings.

(1) Energy star in the United States (Scofield, 2013) offers the method of determining the energy consumption baseline of various types of buildings based on mathematical statistics, such as using the least square method, taking the EUI as dependent variable and the influence factor as independent variable, fitting the regression equation between independent and dependent variables, etc.

(2) The British government adopts the "British energy efficiency best practice project" to carry out the energy benchmarking and baseline analysis (BRECSU, 2000). The evaluation method is similar to the Energy Star. It belongs to the mathematical modeling analysis in the way of data statistics, which requires a large volume of data of building's energy consumption, with the top 25% level considered as the ideal level.

(3) Germany adopts the characteristic value of building energy consumption to evaluate energy efficiency in the form of a building passport (Wu, 2006). The energy consumption level of buildings is assessed by comparing the guidance baseline values. Furthermore, the guiding value is the arithmetic average value of EUI in the lower 25% area of the building energy distribution.

In China, some research institutes also put forward the concept of similar baseline. Researchers in Tsinghua University proposed a method of measurement analysis and simulation analysis for energy consumption quota of large public building. Furthermore, Shanghai Institute of Building Science has put forward the idea of dividing energy consumption quota index into both total energy consumption quota index and partial energy consumption quota index through the analysis of sub-metering dada obtained from more than 1000 large public buildings. For example, in Beijing and Shanghai, local authority puts forward rational use of building energy guide for different public building types. Meanwhile, the domestic government, scientific research institutes and property management companies gradually realized the importance of building basic data for energy baseline, and began to collect these data (Xu, et al. 2011).

In summary, there exist several literatures related to the concept, definition, model calculation and factor analysis of building energy baseline. From the current research field of domestic building energy baseline, it is shown that people have realized the importance of supervising the energy consumption in the operation stage of the building, although more research is still at the stage of experimental exploration in China. However, the limitations of the current baseline research methods and models in solving LSBEER reside in follows:

- The work foundation of energy baseline is still inadequate in China, mainly reflected as "no comprehensive data acquisition system", "shortage of building energy consumption and basic fundamental data", etc.
- Few literatures refer to constrain value for LSBEER, which could both promote the energy efficiency retrofit and help to achieve the control goal of regional energy consumption. Meanwhile, the building energy baseline must match the actual amount of energy saving (AES) potential.
- **Considering the type complexity and huge quantity of existing buildings in LSBEER, the number and size of calculation will become very large if we employ simulation analysis method to establish energy consumption baseline through special software for**

each building. Therefore, employing simulation tools to calculate the energy baseline is usually not regarded as a cost-effective way in practice.

1.3 Study goal

To both achieve building energy saving targets and promote the implementation of LSBEER, we must address the limitation of energy baseline in solving the above-mentioned regional LSBEER problems. In this paper, the authors put forward a constraint baseline determination method of LSBEER based on the investigation data by considering both target control and energy saving potential matching. This method comprises two important condition hypotheses:

- The "constraint retrofit baseline" refers to as EUI that a building must achieve by employing energy-saving retrofit. This is similar to the concept of limit values, which means "the minimum EUI value". The goal of the retrofit must be achieved (or closed to the limit index).

- Target control refers to as macro energy saving index control in the retrofit area, in which the realization of goals must rely on the accumulative completion of LSBEER. Different constraint baselines have different effects on the degree of implementation of LSBEER. Therefore, it requires us to match the retrofit potential. Furthermore, establishing the relationship between the baseline and the target is of great significance for decision-maker to promote LSBEER in the administrative area.

Through investigation we can establish basic database of LSBEER, and it is useful to help us in the calculation and analysis of the retrofit baseline. The authors in this paper propose a large-scale building energy saving retrofit baseline model relying on the bilateral matching of target control and energy saving potential. Meanwhile, the authors take 100 buildings in Hongqiao area of Shanghai as an example to demonstrate the feasibility of the proposed method. The remainder of this paper is organized as follows. In section II, we introduce the constraint baseline determination method of LSBEER, followed by a practical case given by section III. Moreover, the application of the baseline method is discussed and analyzed in section IV. Finally, section V concludes this paper and points out the future research directions.

2. Constraint baseline determination method of LSBEER

2.1. Theoretical model

This study assumes that there are totally N buildings in the area of interest with *m* types of buildings, with each type comprising *n* buildings. Among them, EUI of building #j in class #i is $EUI_{i,j}$, with internal floor area $IFA_{i,j}$, and retrofit baseline is $EUI_{i,j,ba}$, the area and energy consumption of each building are known, $EUI_{i,j,po}$ represents the potential value of EUI by the actual energy saving retrofit. And we can solve the optimization baseline index subject to the target constraints. However, when the building is retrofit, there will be differences between the actual energy saving and the expected value. Although we want EUI to reach the expected value, it is actually constrained by the energy saving retrofit potential. The concept of "virtual energy saving" is proposed in this paper, referring to the quantitative index of energy saving effect obtained by the reduction of EUI to the retrofit baseline. In **Figure.1 it shows a schematic diagram of the baseline model, in which** Figure.1(a) implies that the energy saving potential is less than the virtual energy saving, while building energy saving potential is greater than the virtual energy savings, and energy saving gap refers to the deviation between the actual energy saving potential and the virtual energy saving.

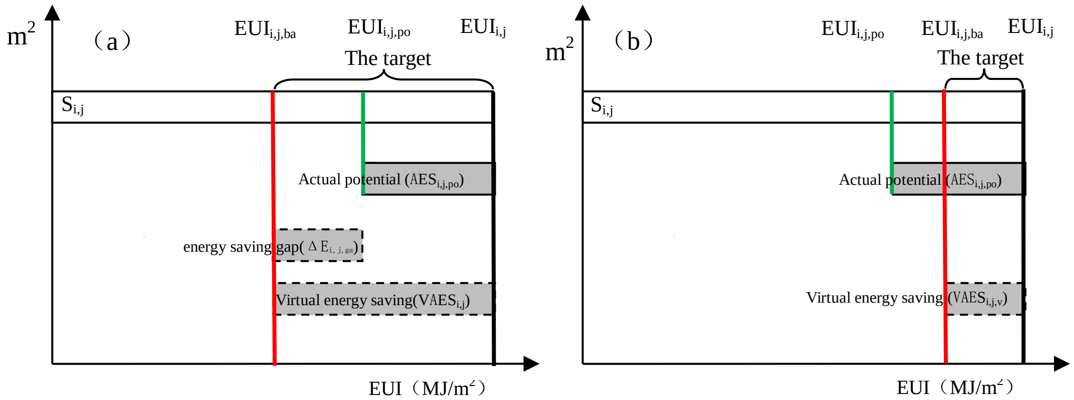


Fig.1. diagram of baseline method

Based on the above hypothesis, large scale buildings' energy consumption baseline model is set up in Equations (1) and (1.1), (2) and (2.1):

$$VAES = \sum_{i=1}^{m}\sum_{j=1}^{n}(EUI_{i,j} - EUI_{i,j,ba}) \times IFA_{i,j} \tag{1}$$

$$EUI_{i,j,k} = \frac{\sum E_{i,j,k}}{IFA_{i,j}} \tag{1.1}$$

Subject to: $VAES \geq AES_g$ (2)

$$AES_g = \sum_{i=1}^{m}\sum_{j=1}^{n} E_{i,j} \times e_g \tag{2.1}$$

where VAES denotes the accumulative virtual amount of energy saving (TJ), AES_g is the regional target energy saving (TJ), **e_g is the reduction percentage target of EUI, and IFA is defined as the floor area of all measured enclosed space to the internal side of enclosing wall (m^2). Finally, E denotes the annual energy consumption (GJ), and k represents the energy type.**

2.2. The selection criteria of baseline method

2.2.1 The selection of baseline index

In view of the previous studies, there were many studies involving energy baseline models (table 1). In these energy baseline analyses, the authors mainly adopted the EUI

index, which is calculated as E divided by IFA (Jing et al. 2017). In recent years, the authors of some references have established reference building models and adopted energy saving rate (ESR) to measure the building's energy efficiency (MOHURD, 2005). Therefore, we propose a baseline calculation method based on two types of energy saving indicators: one is based on EUI and the other ESR index, which will contribute to diminish the gap of the current research methods in solving LSBEER.

2.2.2 The principle of constraint baseline determination method

The principle of selection methods for determining the constraint baseline of LSBEER is mainly based on the following considerations:

- **The principle of applicability: Due to the complexity of building's energy consumption in LSBEER, practical applicability is regarded as one of the most important criteria for baseline model. As compare to it, the other models such as neural network model, regression model, SVR model, Simple Standardization (table 1), all require to collect a large number of relevant factors of data. Furthermore, special simulation software also requires a large number of basic information (such as building drawings, energy systems, etc.). Therefore, for regions where basic databases are shortage, it highly relies on whether the method is operable.**

- **The principle of evaluability: A reasonable "constraint retrofit baseline" should have three characteristics: "highly matching potential" means "maximizing the potential of energy saving retrofit", "Low investment cost" is used to achieve the same goal of saving energy with minimum investment, while "wide coverage of retrofitted buildings" represents the percentage of buildings above the energy baseline, and the higher the**

value, the more buildings will implement energy saving retrofit.

Based on the above-mentioned considerations, we propose a set of methods for determining the baseline for LSBEER, one is based on EUI index, which includes whole ranking method (WRM), class ranking method (CRM) and advanced benchmark value method (ABVM), and the other is based on ESR index. Referring to the energy saving rate index suggested in Design Standard for Energy Efficiency of Public Buildings in China (DSEEPBC), we put forward the requirement of energy saving rate retrofit for existing buildings retrofit.

2.2.3 The evaluation indicators for baseline methods

In terms of the principle of evaluability, the more consistency with the actual situation, the more reasonable of the methods and results are. Therefore, this paper puts forward three evaluation indicators, including energy saving potential matching degree (ESPMD), retrofit building coverage rate (RBCR), and unit investment cost (UIC).

ESPMD is defined as "the ratio between the actual retrofit amount and target expectations". This index reflects the proximity of both the regional energy baseline and the actual EUI after retrofit, as represented in Equations (3) and (3.1).

$$ESPMD = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} RAES_{i,j}}{VAES} \quad (3)$$

$$RAES_{i,j} = \begin{cases} 0, & EUI_{i,j} \le EUI_{i,j,ba} \\ (EUI_{i,j} - EUI_{i,j,ba}) \times s_{i,j}, & EUI_{i,j} > EUI_{i,j,ba} > EUI_{i,j,po} \\ AES_{i,j}, & EUI_{i,j} > EUI_{i,j,po} > EUI_{i,j,ba} \end{cases} \quad (3.1)$$

where $RAES_{i,j}$ denotes the amount of energy saving potential above the constrained baseline(TJ), $AES_{i,j}$ is the technical retrofit potential of building #j in class #i (TJ).

RBCR represents the proportion of the number of buildings above the baseline. This index indicates how many buildings can be constrained to participate in energy saving

retrofit, as calculated by Equations (4) and (4.1).

$$\text{RBCR} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} NC}{N} \quad \textbf{(4)}$$

$$NC_{i,j} = \begin{cases} 0, & EUI_{i,j} < EUI_{i,j,ba} \\ 1, & EUI_{i,j} \geq EUI_{i,j,ba} \end{cases} \quad \textbf{(4.1)}$$

where NC denotes number of buildings above the constrained baseline.

UIC is the economic index to judge baseline. The lower the indicator, the more reasonable the baseline will be, corresponding to "the lower the cost of achieving the same control objective". The calculation of UIC index is shown in Equations (5), (5.1) and (5.2).

$$\text{UIC} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} RI_{i,j}}{\sum_{i=1}^{m}\sum_{j=1}^{n} RIFA_{i,j}} \quad \textbf{(5)}$$

$$RI_{i,j} = \begin{cases} 0, & EUI_{i,j} \leq EUI_{i,j,ba} \\ I_{i,j} \times \frac{VAES_{i,j}}{AES_{i,j}}, & EUI_{i,j} > EUI_{i,j,ba} > EUI_{i,j,po} \\ I_{i,j}, & EUI_{i,j} > EUI_{i,j,po} > EUI_{i,j,ba} \end{cases} \quad \textbf{(5.1)}$$

$$RIFA_{i,j} = \begin{cases} 0, & EUI_{i,j} < EUI_{i,j,ba} \\ IFA_{i,j}, & EUI_{i,j} \geq EUI_{i,j,ba} \end{cases} \quad \textbf{(5.2)}$$

where RI denotes energy saving investment of the building above constrained baseline (\$). RIFA is defined as the IFA of the building above constrained baseline (m^2).

2.3. Baseline method

2.3.1 EUI method

Both WRM and CRM are used to determine the dimensionless parameters, as shown in Equations (6):

$$EUI_{i,j,ba} = \begin{cases} f(\delta, VAES), & WRM \\ f(X, VAES), & CRM \end{cases} \quad (6)$$

where δ denotes the ratio of the base line to the weighted average value of EUI, X is the relative ranking position of EUI in the #j type of building with the range of (0,10).

(1) WRM is the only one baseline for indicating the building's energy consumption for all buildings. We calculate the variation values of VAES under variant δ values, followed by fitting the mathematical relations between VAES and δ. Once Eq. (2) is satisfied, we can derive $EUI_{i,j,ba}$.

(2) CRM is multiple base line of building's energy consumption for different types of buildings. We first calculate VAES under different X values in accordance with Eq. (1), followed by fitting mathematical relation between different VAES and X. Once Eq.(2) is satisfied, we can solve the X value and solve the classification energy baseline under the relative position according to the X value.

(3) According to ABVM, the energy consumption baseline can be determined by the average level of building energy efficiency with high energy efficiency level in the same type of buildings based on the different building types.

2.3.2 ESR method

According to "*the standards for design of energy saving for public buildings*" (GB 50189-2005), taking typical architecture as a reference building in 1980 as an example, it shows that (from North to South in China) the energy saving rate of public building envelope can be up to about 25%-13%, the energy saving rate of the air conditioning heating system is about 20%-16%, and the energy saving rate of the lighting equipment may approach about 7%-18%. Furthermore, according to the "guidelines for the implementation of energy saving design standards for public buildings" (GB50189-2015), the energy consumption of public buildings is reduced by 21.6% through the way of envelope, heating and air conditioning and lighting. Meanwhile, the energy efficiency of public buildings is more than 65% compared with buildings in 80s. In particular, as a hot summer and cold winter area in Shanghai, the contribution of air conditioning and lighting system to 50% of energy saving is more than northern heating area in China, which is equivalent to about 30%.Therefore, by classifying the retrofit of regional building lighting, air conditioning, envelope and renewable energy (referring to the requirement of energy saving rate of public building energy saving design standard), the same requirement of energy saving rate of 50% is put forward for achieving energy saving reconstruction of existing buildings.

2.4. Procedure for strategy implementation

2.4.1 Collection of basic data

In the first steps of baseline determination, we need to collect the basic data that support the baseline determination and the outcome analysis. The kind of data is subdivided into three parts: building basic information, energy consumption data and energy saving potential data.

• Building basic information data includes the types of building type (such as Office, Shopping mall, Hotel etc.), IFA and EUI of each building. This information mainly comes from investigation, based on which we can conduct the collection of necessary information to the model.

• Energy data of buildings of certain function as much as possible (monthly data). Typically, three types of energy data can be differentiated: (1) electricity data; (2) electricity and natural gas data; (3) electricity and diesel oil data. Among them, energy utility bills, building audit data, sub-metering system, and computer simulations are common sources to quantify building energy uses (Wang et al. 2012). For LSBEER,

energy investigation is usually regarded as a cost-effective method in practice.

- **In the proposed energy baseline method, we need to get information about a variety of factors, including the AES date of lighting, air conditioning, building envelope and renewable energy. Based on the energy consumption characteristics of the targeted building, the resource of the AES mainly relies on energy audits and investigation.**

2.4.2 Baseline determination process

Strategy implementation is the process that has the detail steps shown in Fig.2.

Step1: Establishing regional building energy consumption information database, and determining the overall goal of regional retrofit;

Step2: Aattaining EUI_{ba} based on four methods of determining the baseline;

Step3: Preparing procedures to plot analysis curve of $EUI_{ba,}$ according to database information;

Step4: Calculating and evaluating $\Delta E_{i,j,re}$ and λ of two evolution indicators.

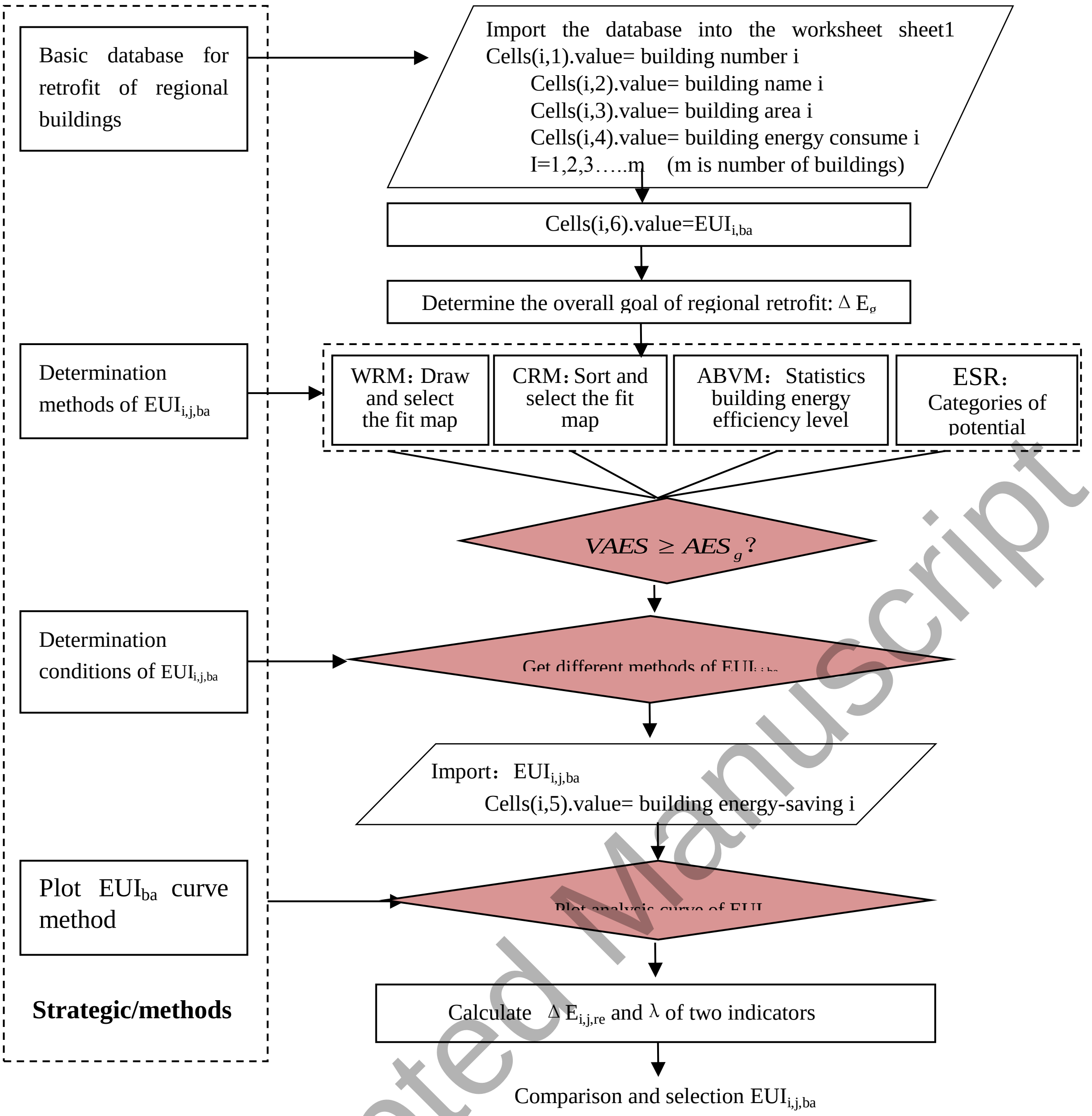


Fig.2. Baseline determination flow chart

According to constrained baseline model, we propose to plot EUI curve, it could be automatically plotted by Visual Basic for Applications + Excel, the plot method see appendix.

3. Case analysis

3.1. Fundamental information

Taking Shanghai Hongqiao low carbon practice zone (SHLCPZ) as the research object (World Bank,2013), it is shown that there exist 100 public buildings in the area of interest, including public institutions, hotels, shopping malls, commercial offices, dual-commercial and other type. The construction years are mostly distributed in 1990s, with the total buildings area 3,917,520m^2 and the total energy consumption 2198TJ (the average EUI is 561MJ/m^2). Currently, we have collected energy data and the potential energy saving of each building through energy audit and investigation, as shown in Table 2.

Table2 Summary statistics data of 100 buildings

	Building numbers	IFA m^2	E TJ	Min EUI MJ/m^2	Max EUI MJ/m^2	AVE EUI MJ/m^2	AES TJ	Investment $
Public institutions	6	86780	51	396	1068	588	15	908
Hotel	13	427816	318	384	1068	744	45	1161
Other	19	863106	261	24	552	300	45	1926
Shopping malls	7	465950	533	720	1536	1140	127	960
Commercial office	46	1473970	600	72	720	408	159	4948
Dual-commercial	9	599898	435	528	1284	720	121	3181
Total	100	3917520	2198	24	1536	561	513	13085

3.2. Reference constraints

Shanghai has carried out demonstration projects for low carbon development in 8 regions. In accordance with the requirements for the development of energy saving and low carbon practice in Shanghai, the total target of EUI is to reduce by 18%. Furthermore, energy saving goal is 396TJ according to Eq. (2).

3.3. Baseline method

3.3.1. Whole Ranking Method

According to the scatter plot of VAES under variant δ values of 100 buildings, we use logarithmic function to fit it. It is shown that R^2 is 0.9927, and the result exhibits a strong correlation, as shown in Fig.3.

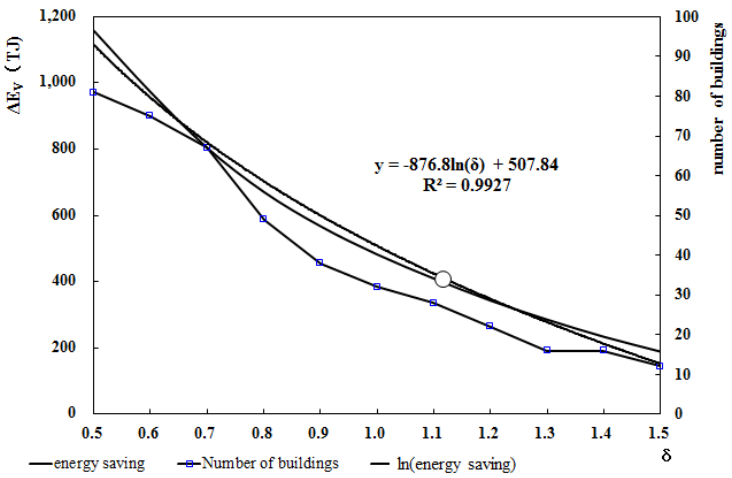


Fig.3 A baseline fitting graph based on whole ranking method

By fitting the result, we obtain the following equation (7):

$$EUI_{i,j,ba} = 561 \times e^{-\frac{1}{876.8}\times(\Delta E_v - 507.84)} \tag{7}$$

When VAES equals 396TJ, $EUI_{i,j,ba}$ will be 637MJ/m^2.

3.3.2. Class Ranking Method

According to the scatter distribution plots of VAES of 100 buildings under different ranking locations, we used the logarithmic function to fit it. It is shown that R^2 is 0.9773, which has strong correlation, as shown in Figure. 4.

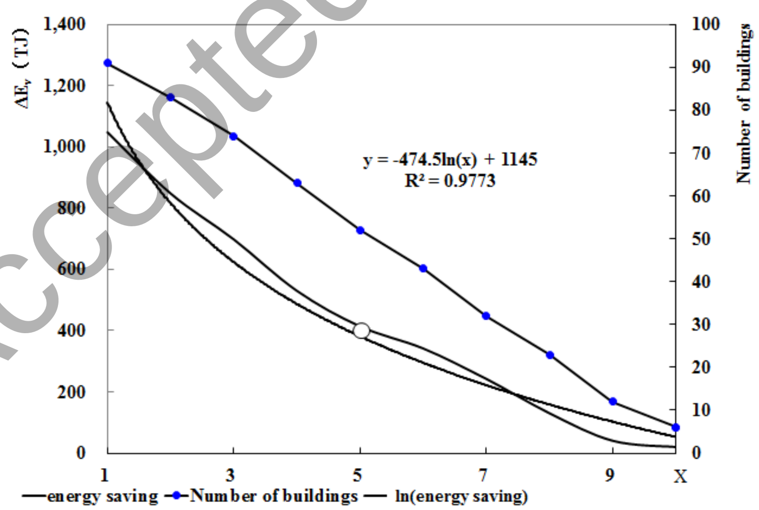


Fig.4 A baseline fitting graph based on classification ranking method

By fitting the result, we get the following equation (8):

$$X = e^{-\frac{1}{39539}\times(VAES - 95418)} \tag{8}$$

When VAES equals 396TJ, X will be 4.85.

In summary, according to the relative ranking position value, different types of building energy baseline can be obtained, as shown in Table 3.

Table3 Building energy consumption baseline based on class ranking method

	Building numbers	The ranking position of building	EUI_{ba},MJ/m^2
Public institutions	6	3	473
Hotel	13	6	665
Other	19	9	185
Shopping malls	7	3	968
Commercial office	46	23	410
Dual-commercial	9	4	710

3.3.3. Advanced Benchmarking Method

In this paper, we classify the energy efficiency of 100 buildings as follows: (1) The building of energy saving design standards for public buildings has been proposed for meeting the energy saving design standards of public buildings; (2) After the retrofit of envelope, air conditioning and lighting, etc., buildings satisfy the energy saving design standard for public buildings. According to the above-mentioned classification principle, we make a summary of the average consumption of different types of buildings (Table 4).

Table4 Building energy consumption baseline based on advanced benchmarking method

	EUI_{av} (MJ/m^2)	EUI_{ad} (MJ/m^2)
Public institutions	588	443
Hotel	744	600
Other	300	302
Shopping malls	1146	604
Commercial office	408	386
Dual-commercial	720	574

Table 4 shows that the total energy saving of the proposed scheme is 576TJ, and the control value of the regional target is reached.

3.3.4. Energy saving Rate Method

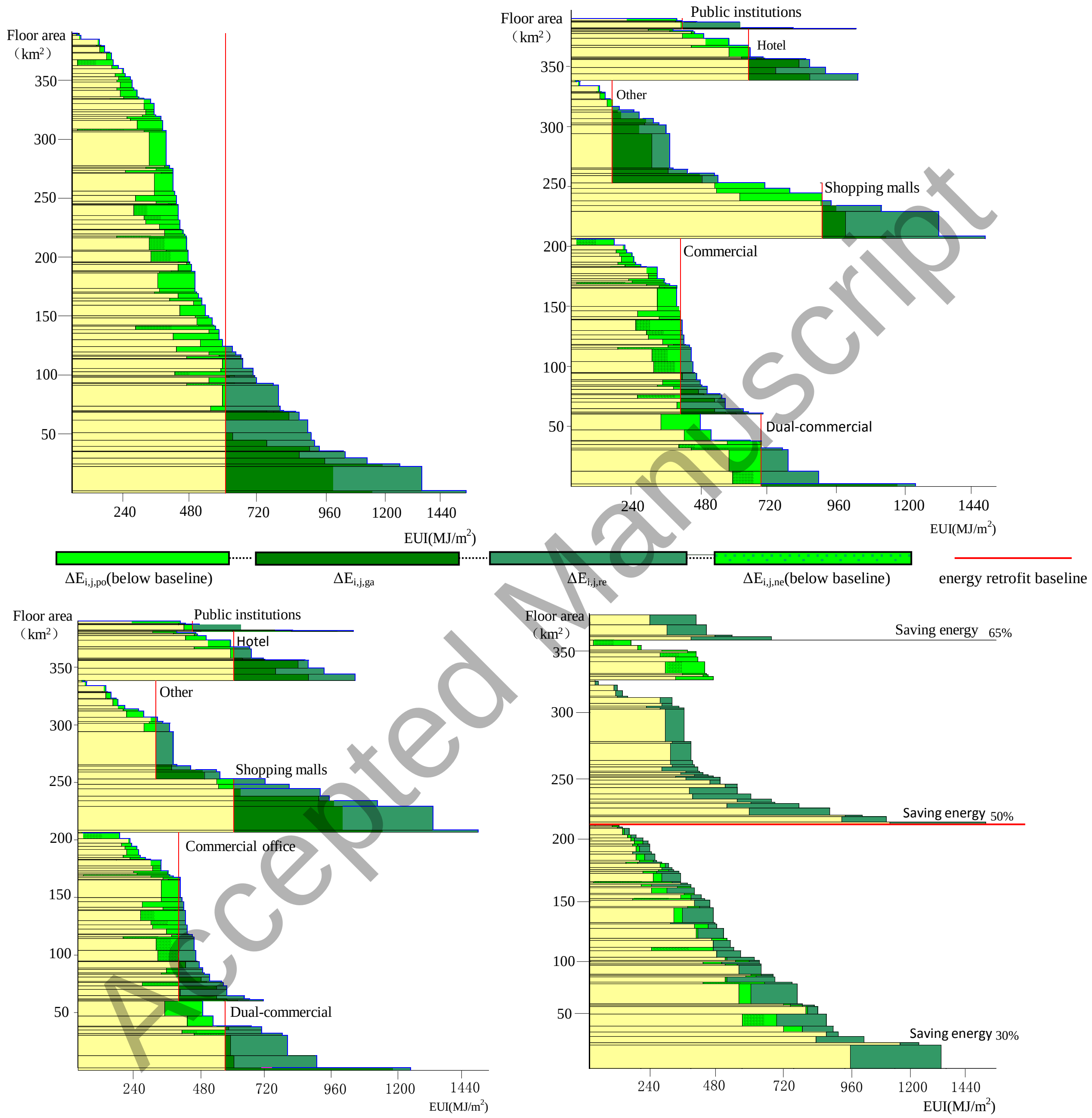
According to the idea of energy saving design standard for public buildings, we also put forward energy savings constraint baseline of 50% for energy saving reconstruction of regional buildings:(1) In accordance with the standards of lighting and air conditioning, the standard of energy saving retrofit is put forward, which is 30% relative to energy saving; (2) on the basis of the standard of lighting and air conditioning equipment, the thermal performance parameters of the enclosure structure are put forward according to the standard, compared with the energy saving 50%. Based on the requirements of variant aspects such as air conditioning, lighting and envelope, more advanced energy conservation measures such as renewable energy and free cooling are adopted, corresponding to an energy saving ratio up to 65%.

4. Results and Discussion

Most of the literatures focusing on energy baseline mainly involve the evaluation and analysis of buildings energy consumption level in operational stage. However, the constraint retrofit baseline aiming at large scale buildings proposed in this paper is different from the existing ones. The proposed one is mainly used for promoting the buildings to implement energy saving retrofit. The establishment of retrofit baseline for LSBEER has a referencing significance for the development of large-scale building energy saving policy in similar regions. Furthermore, data fitting analysis shows that the retrofit baseline and the virtual energy saving have logarithmic function relationship in WRM and CRM (the correlation is strong). Finally, referring to the energy saving design standard of public buildings, the goal of saving energy is also put forward for the existing building energy saving retrofit.

4.1. Calculation results

In this part, the results of four methods are shown in Figure 5, which analyzes the single consumption curve of building energy consumption baseline. The rectangle area indicates the total energy consumption of the building, and the red line represents energy consumption baseline.



(a) WRM (b) CRM (c) ABVM (d) ESR method

Fig.5. EUI curve

From Figure.5, it is shown that:

(1) The RBCR determined by WRM is 27%, the RAES is 216TJ, the value of ESPMD is

55%, and the UIC is 29.4$ /m^2.

(2) The RBCR determined by CRM is 51%, the RAES is 244 TJ, the value of ESPMD is 62%, and the UIC is 23.6$ /m^2.

(3)The RBCR determined by ABVM is 64%, the RAES is 363TJ, the value of ESPMD is 63%, and the UIC is 30.6 $ / m^2;

(4) According to the requirements of the ESR of 50% retrofit baseline, the RBCR is 95%, the RAES is 415.7TJ, the value of ESPMD is 86%, and the UIC is 29.2$ /m^2.

4.2.1 Comparison result

In terms of comparative analysis of a variety of parameters such as ESPMD, RBCR, NIC index and energy saving potential above the baseline (Table 5), the maximum values of ESPMD and RBCR can be up to 86% and 95%, respectively. We find that the ESR method is superior to the other 3 methods. The energy saving potential above the energy baseline is 416TJ, which ensures the realization of energy saving target.

Table 5 The results of comparison baseline methods

Evaluation indicators	The results of comparison
ESPMD	ESR method > ABVM > CRM > WRM
RBCR	ESR method > ABVM > CRM > WRM
UIC	ABVM > WRM > ESR method > CRM
RAES	ESR method > ABVM > CRM > WRM

4.3 The pros and cons of each method

1) WRM

The WRM is regarded as the most simple and easy-to-execute method among the above-mentioned 4 methods. It only requires us to collect the EUI values of each building. Subject to the premise of target constraint, a unified building constraint retrofit baseline is delineated. Furthermore, considering wide differences in the

indicators of AES and EUI between different building types or individual, as a result, the energy saving potential of many buildings cannot support the reduction of EUI to the baseline value. Similarly, although some buildings have great energy saving potential, the EUI is still below the baseline. On the basis of the previous analysis results on 100 buildings, the gap of energy saving is very large (the value of ESPMD is 55%). Meanwhile, the proportion of buildings with EUI above baseline is only 27% under the "one-size-fits-all" model.

2) CRM

Unlike the WRM, the CRM tries to eliminate differences in kinds of building types, requiring us to increase the collection of building types/attributes. Although the essence of CRW is similar to WRM and the execution procedure is a little more complicated than ARW, the accuracy is still higher than that of WRM. From the study cases, it is shown that the index of RBCR has increased by nearly 100%, and the value of ESPMD has increased by 10%. Although WRM outperforms CRM, the RBCR is just over 50%, and the value of ESPMD is still not high enough.

3) ABVM

ABVM's baseline is stricter than that of the CRM. The essence of the proposed method is to employ EUI index of high energy efficiency buildings as energy baseline in the same type of buildings. Note that this method is similar to the advanced benchmarking method. Compared with the above-mentioned two methods, higher requirements for building energy saving retrofit are put forward. In addition to collecting basic data, it is also necessary to classify the energy efficiency of buildings,

such as "whether belong to energy-saving buildings" or "whether meet energy-saving design standards", etc. In the study case, take commercial office buildings as an example, the baseline index determined by WRM, CRM and ABVM are 637MJ/m^2, 410MJ/m^2, and 386MJ/m^2, respectively. Therefore, the baseline of ABVM is 6% lower than CRM (and 39% lower than WRM). The pros of ABVM are that the RBCR, ESPMD indicators are better than both WRM and CRM, while the cons reside in the fact that the cost of retrofit and the VAES are much higher than target. In summary, it is not the best practice method.

4) ESR method

Unlike the above-mentioned 3 methods, the analysis of energy saving potential attributes has been added to the required information in the proposed method. Therefore, the breadth and depth of data quality becomes higher. Meanwhile, the ESR method requires us to master the energy efficiency of buildings, especially the analysis of the gap compared with DSEEPBC. Therefore, its advantages highly match the actual energy saving potential of buildings (In the study cases, the value of ESPMD reached 86% by using the ESR method). However, its disadvantage is reflected in the fact that it is sometimes difficult to judge whether a building can reach 50% energy-saving standard. For all indicators conforming to energy saving design standard, it is easy to do the judgment. However, if individual indicator does not meet the standard requirements, a more complicated trade-off analysis is required.

4.4 The reliability of method

Because the research scope for LSBEER is regional or municipal, the resolution of the requested data is usually high in china. The authors consider the condition of shortage of building energy consumption and basic fundamental data in china; some energy baseline tools are not cost-effective way of application in the large scale buildings. Therefore, on the basis of establishing the basic database of regional energy conservation retrofit, the authors in this paper put forward a statistical calculation and analysis methods for determining the retrofit baseline. In this model, the accuracy and reliability of data are critical to the application of datum line model. There are two main types of data involved in the proposed model, one is high reliability and direct source data, such as energy consumption data from energy bills, fixed information such as IFA, type of buildings, and another is indirect sources date and need to post-processing calculation, such as date of AES which is important to the baseline method. Generally speaking, energy saving retrofit measures and quantification of energy saving potential can be obtained by both energy audit and energy diagnosis (Annunziata, et al., 2014; Munsami, et al., 2017). In the study cases, the acquisition of AES is mainly obtained from the comparative analysis with DSEEPBC based on energy audits and investigation. Considering the fact that energy saving standards is constantly developing, AES also has the attributes of time. Furthermore, there exist uncertain factors in the operational parameters when we calculate AES. Therefore, in the future, reliability estimation of AES will improve the accuracy of the baseline model.

5. Conclusion

This paper discusses the application of energy saving retrofit baseline in large scale buildings. The main conclusion of the paper is as follows:

- **This paper presents the definition and the calculation of baseline for LSBEER to eliminate the limitations and extend the application. The methodology includes three phases: site and building information collection, baseline determination and method evaluation. The results show that the proposed method is suitable for determining baseline for LSBEER.**

- **The proposed evaluable quantitative indicators of ESPMD, RBCR and UIC reflect control strategy of macro energy saving target and provide theoretical guidance for decision makers.**

- **Two baseline calculation modes and four kinds of methods (WRM, CRM, ABVM and ESR method) are suggested, based on 100 buildings samples in Shanghai to verify application and feasibility of the baseline model.**

Building on this work, an integrated framework of constraint baseline for LSBEER is under development aiming to embed constraint indicators into decision making process. The framework includes site and building information collection, quantitative analysis of AES, determination and evaluation baseline methods, as well as analysis of supporting mechanism. Following the framework, the methods will be more systematic and integrity.

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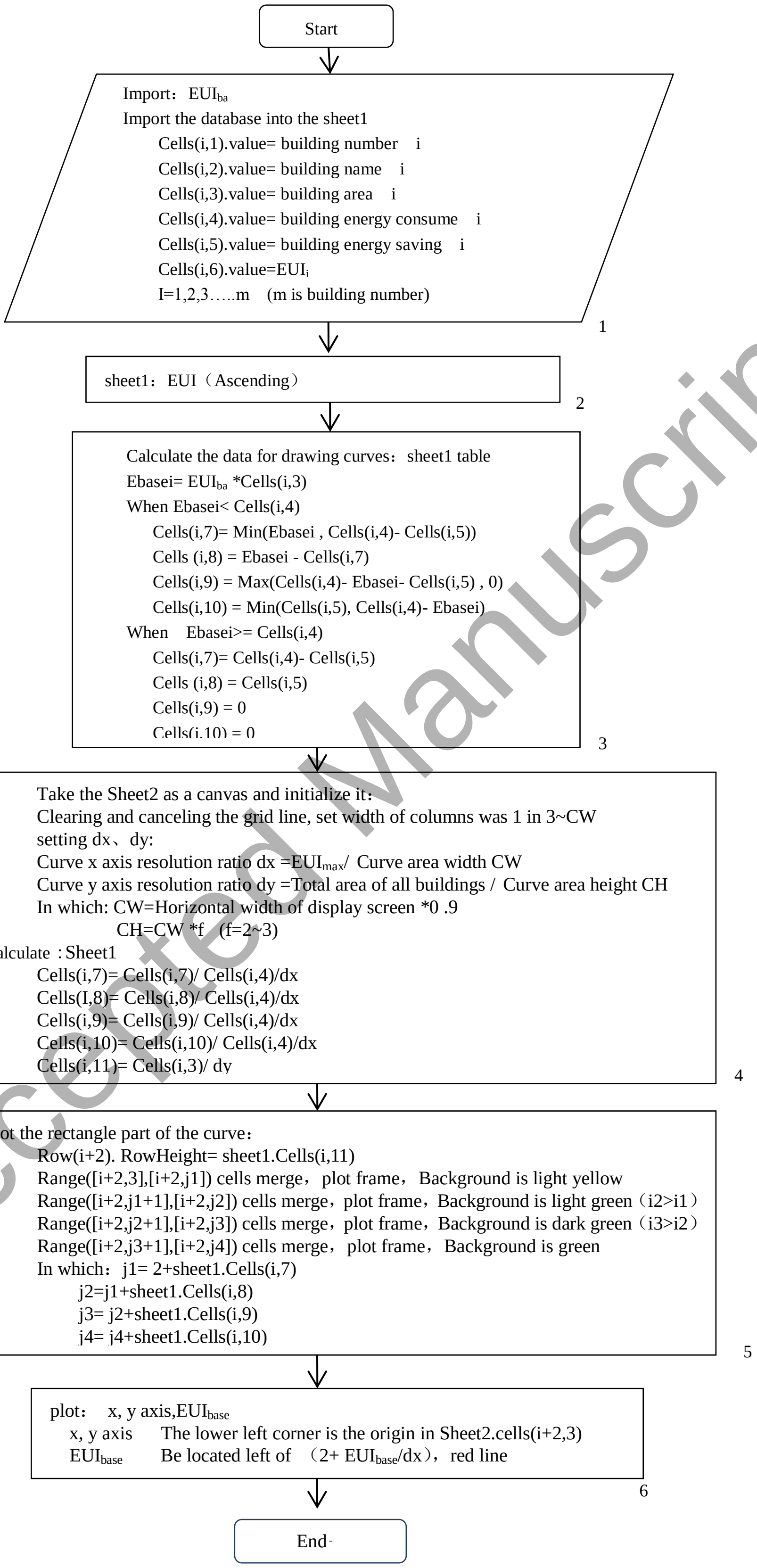
Appendix (Figure is the WRM method process diagram (containing an algorithm), the graph of other three methods to draw similar flow）



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