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Estimating energy savings in Chinese residential buildings from 2001 to 2015: A decomposition analysis

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Abstract

Evaluating energy savings in Chinese residential buildings (ESCRB) plays an important role in Chinese building energy–efficiency work. However, the said work is currently challenged by the lack of effective method for estimating ESCRB data by summarizing all the quantifiable and unquantifiable impact factors. To overcome this problem, this study employed the equation of Human Impact, Population, Affluence, and Technology (IPAT), and the index decomposition of Logarithmic Mean Divisia Index (LMDI) to establish an effective ESCRB estimation method, and then calculated ESCRB data during the period of 2001–2015. Results of this study reflect that ESCRB has significantly accumulated with the rapid development of Chinese building energy–efficiency work in the past 15 years. In particular, ESCRB data in 2001–2005, 2006–2010, and 2011–2015 are 118, 79, and 96 million tons of standard coal equivalent, respectively. This study proves the feasibility of calculating ESCRB data and fills the lack of research on effective ESCRB estimation methods. Moreover, this method is also applicable for estimating energy savings in residential buildings at a provincial or regional level.

Keywords: Energy savings in Chinese residential buildings, Chinese residential energy consumption, Building energy–efficiency policy, IPAT equation, LMDI decomposition

1. Introduction

The building sector is one of the top three fields in total national energy consumption and creates an incredible energy demand explosion. As China becomes the largest emitter of greenhouse gas worldwide [1], Chinese building energy–efficiency work has faced strict challenges given that Chinese building sector is the second largest sector in Chinese national energy consumption. Chinese residential energy consumption (CREC) is a typical type of building energy consumption and accounts for over 80% of Chinese national building energy consumption in the current stage [2]. If the growth trend of CREC continues, then CREC is expected to exceed 1.2 billion tons of standard coal equivalent (tce) in 2030 [3]; this condition can lead to severe environmental pollution and hinder China's sustainable development strategy. Therefore, energy savings in Chinese residential buildings (ESCRB), including energy savings in Chinese urban residential buildings (ESCURB) and energy savings in Chinese rural residential buildings (ESCRRB), has aroused public concern. ESCRB reflects the building energy–saving benefits, which come from the operation stage of Chinese existing residential buildings nationwide under the influence of numerous relevant impact factors, such as policy, technological progress, and user behavior.

However, the quantification of CREC and ESCRB significantly lags behind, thereby seriously affecting Chinese building energy–efficiency work as this task requires evaluating the said data. In addition, reliable and accurate CREC data are required in obtaining ESCRB data. Although Chinese building energy–efficiency work has largely progressed in several aspects, such as laws, incentive policies, and building energy–efficiency technology, several shortages still exist in quantifying basic building energy consumption data [2]. The main reasons are as follows. (i) The statistical system of CREC data is still a work in process. In the statistical system of Chinese energy consumption, CREC has been ignored separately as an independent division of energy consumption but is scattered in different energy consumption statistics of various societal divisions. Thus, concrete CREC data are unavailable. (ii) Considering the lack of reliable supporting data of CREC, studies on the accurate calculation of ESCRB are still inadequate seriously. Namely ESCRB data are in a missing status at the current stage.

ESCRB should be considered in quantitatively verifying the achievements of building energy–efficiency goals in the residential building sector and in evaluating the completion of relevant policies. For example, the government established the goal of 93 million tce for the officially planned ESCRB during the period of 2011–2015 [4]. The actual ESCRB in the said period should be determined and compared with the officially planned one. This examination can help the government formulate and implement targeted goals and policies for the upcoming stage of Chinese building energy–efficiency work. In a word, it is an urgent and significant work to establish a method to estimate

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ESCRB and launch an operation of performance appraisal on the basis of the calculation results.

This study aimed to establish an effective method for estimating ESCRB through relatively mature and credible CREC data. Subsequently, ESCRB data from 2001 to 2015 were determined and checked.

2. State of the art

As a prerequisite in estimating ESCRB, numerous published works have documented varied approaches for assessing CREC data since Chinese building energy consumption supervision system is hard to completely achieve nationwide namely the data statistical system of Chinese building energy consumption at the national level is a work in progress. Thus, official CREC data are still unavailable at the current stage [2]. The results of the said methods are also significantly different. The vast majority of early scholars focused on primary CREC data estimation methods. To simplify the complex calculation process, some works directly replaced CREC approximation as living energy consumption of Chinese households because the data source of living energy consumption of Chinese households is clearly published in China Energy Statistical Yearbook [5, 6, 7, 8, 9].

A small percentage of research teams established relatively systematic and sustainable CREC data estimation models to improve the accuracy of CREC data in the last 10 years. The Building Energy Conservation Research Center of Tsinghua University built the China Building Energy Model in 2007; the model is the first systematic estimation approach for national building energy consumption data in China, and its updated data in 2014 indicated a national building energy consumption value of 819 million tce, accounting for 21.06% of Chinese national energy consumption [10]. Meanwhile, Chongqing University built the China Macroscopic Building Energy Consumption Statistical System in 2010, which is based on relevant data promulgated by China Energy Statistical Yearbook. China Macroscopic Building Energy Consumption Statistical System implemented weight combination and error correction to integrate the distributed energy consumption related to national building energy consumption, and this system effectively estimated the national building energy consumption from 1985 to 2009 [11]. The updated data of this system in 2014 indicated a national building energy consumption value of 814 million tce, accounting for 19.12% of Chinese national energy consumption in the said year. The value of residential energy consumption in urban China is 326 million tce, accounting for 40.05% of national building energy consumption, while the value of residential energy consumption in rural China is 201 million tce, accounting for 24.69% of national building energy consumption [12].

Considering the lack of reliable supporting data of CREC, studies on the accurate calculation of ESCRB are still inadequate seriously. Namely ESCRB data are in a missing status at the current stage.

The said studies introduce various estimation methods for CREC data with different performance. The rationality and accuracy of the simplified CREC estimation approaches are disputable because CREC and living energy consumption of Chinese households are two different concepts. However, the data shown in China Macroscopic Building Energy Consumption Statistical System and China Building Energy Model are relatively credible, as the two systematic estimation methods have been widely accepted and referenced by numerous relevant studies. Notably, studies on ESCRB data estimation methods are still missing which means it is an urgent task to develop an effective ESCRB estimation method at the current stage. Accordingly, this study mainly aimed to establish an effective approach for estimating ESCRB data and to fill the lack of research direction. On the basis of the modified residential energy consumption per unit area, this study established equations of CREC to estimate ESCRB through an extended equation of Human Impact, Population, Affluence and Technology (IPAT) and an index decomposition of Logarithmic Mean Divisia Index (LMDI). Subsequently, this study calculated ESCRB data from 2001 to 2015.

The remainder of the paper is organized as follows. Section 3 introduces the principles of the IPAT equation and the LMDI decomposition. Subsequently, the effective ESCRB estimation method is developed. Then, the model variables are explained. Furthermore, the sources of corresponding data are introduced. Section 4 provides the results of ESCRB estimation model and a further discussion of these results. Section 5 presents the conclusions of the study.

3. Methodology

3.1 IPAT equation and LMDI decomposition

The proposed approach for achieving ESCRB data estimations used the IPAT equation and the LMDI decomposition. Several previous studies proved the development of the two methods. Ehrlich and Holdren [13] established a famous method called the IPAT equation to uncover the influence among population growth, economic development, and technological advancements. The method is shown as Eq. (1).

$$I(\text{Human Impact}) = P(\text{Population}) \times A(\text{Affluence}) \times T(\text{Technology}) \quad (1)$$

The IPAT equation has been widely appreciated and applied in energy economics, environmental science, and many relevant fields since its introduction [14, 15]. Notably, the equation is still an important research tool in the said research fields.

Index decomposition is a method used to study environmental changes and the interaction mechanism, and this approach has achieved increasing attention from researchers in relevant fields. Using index decomposition, a research target can be quantitatively decomposed into a series of factors. A quantitative study is then conducted on the effect of the said factors on the target, that is, the contribution rate. Finally, the key factors with high contribution rates are highlighted. The LMDI decomposition is a classic form of index decomposition [16], and this approach exerts a good effect, entails a simple process, and produces results without a residual value in practice. Thus, the method is an excellent research tool for identifying and examining impact factors on carbon emissions [17]. The model structure of the LMDI decomposition is as follows:

$$\Delta V_x = \sum_{i=1}^{n} \frac{V_i|_t - V_i|_0}{lnV_i|_t - lnV_i|_0} ln\left(\frac{x_i|_t}{x_i|_0}\right) \quad \left(i = 1, 2, 3, \ldots, n\right) \quad (2)$$

3.2 ESCRB estimation model

The combination of the IPAT equation and the LMDI decomposition enables researchers to conduct quantitative analyses on the contribution of the relevant impact factors to the rise in carbon emissions [18]. The IPAT equation and the LMDI decomposition are mostly applicable for analyzing carbon emissions and energy consumption. Given that CREC is a typical type of energy consumption, the two methods are applied equally in the CREC field.

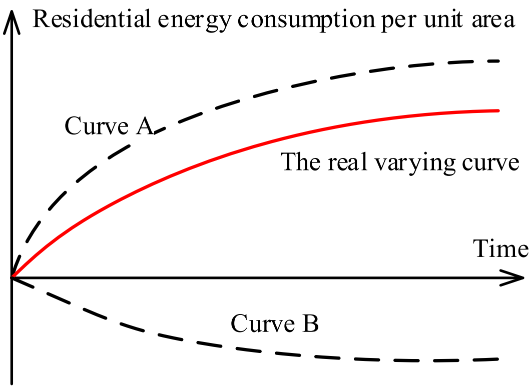

Fig. 1. Schematic of residential energy consumption per unit area with residential building service level and residential building energy–efficiency level

Notice: Curve A − the curve under the influence of residential building service level

Curve B − the curve under the influence of residential building energy–efficiency level

Fig. 1 indicates that residential energy consumption per unit area is influenced by residential building energy–efficiency level and residential building service level. Residential energy consumption per unit area decreases with the increase in residential building energy–efficiency level and increases with the increase in residential building service level. Therefore, under the influence of the two factors, residential energy consumption per unit area increases annually. On the basis of the analysis above, this study obtained a feasible method for estimating ESCRB. The residential building service level was assumed to be in the baseline and reporting periods remained unchanged, and then modified residential energy consumption per unit area was calculated. Modified residential energy consumption per unit area is an important index to measure the actual residential building energy–efficiency level and a crucial prerequisite in estimating ESCRB data. Modified residential energy consumption per unit area reflects the changes in residential energy consumption per unit area in the actual residential building energy–efficiency level, which is calculated from a constant residential building service level.

$$re_m = \frac{re}{I_{rs}} \tag{3}$$

In this case, re_m is the modified residential energy consumption per unit area, r_e is the residential energy consumption per unit area, and I_{rs} is the residential building service level index reflecting the changing value in residential building service level of all existing residential buildings in urban and rural regions at the national and provincial levels over a period. Given that residential building service level is an abstract concept and is difficult to measure quantitatively, quantifying I_{rs} is challenging. Thus, mathematical processing was applied under the assumption that a functional relation exists between I_{rs} and residential energy consumption per capita index, as shown in Eq. (4).

$$I_{rs} = \alpha I_{rp} \tag{4}$$

In this case, I_{rp} is the residential energy consumption per capita index and α is an unknown coefficient ($\alpha > 0$). α is unquantifiable and re_m cannot be calculated directly. Through further research, an effective ESCRB estimation method based on the IPAT equation and the LMDI decomposition was established.

As shown in Eq. (5), on the basis of an extended version of the IPAT equation, two equations of residential energy consumption in urban China (RE_1) and residential energy consumption in rural China (RE_2) were developed by summing up the correlative impact factors.

$$RE_i = P_i \times A_i \times I_{rs} \times re_{m_i} \quad (i = 1, 2) \tag{5}$$

In this case, P_1 and P_2 are the Chinese urban and rural population, respectively. A_1 and A_2 are the building areas of Chinese existing urban and rural residential buildings, respectively. I_{rs} and re_{mi} are the same as those shown above. In accordance with Eq. (5), the LMDI decomposition was employed to decompose residential energy consumption in urban and rural China. In a period about [0, t], residential energy consumption in urban China and residential energy consumption in rural China changes from $RE_i|_0$ to $RE_i|_t$, and ΔRE_i can be defined as the sum of comprehensive effect factors as follows:

$$\begin{aligned} \Delta RE_i &= RE_i|_t - RE_i|_0 \\ &= \Delta RE_{P_i} + \Delta RE_{A_i} + \Delta RE_{I_{rsi}} + \Delta RE_{re_{mi}} \quad (i = 1, 2) \end{aligned} \tag{6}$$

In this case, ΔRE_{Pi}, ΔRE_{Ai}, ΔRE_{Irsi}, and $\Delta REre_{mi}$ are defined as the contribution of P_i, A_i, I_{rs}, and re_{mi} to the changes in residential energy consumption in urban and rural China, respectively.

Eqs. (7) to (10) reveal the contributions of each driving factor to the residential energy consumption in urban and rural China through the LMDI decomposition, as shown below.

$$\Delta RE_{P_i} = \frac{RE_i|_t - RE_i|_0}{lnRE_i|_t - lnRE_i|_0} ln\left(\frac{P_i|_t}{P_i|_0}\right) \tag{7}$$

$$\Delta RE_{A_i} = \frac{RE_i|_t - RE_i|_0}{lnRE_i|_t - lnRE_i|_0} ln\left(\frac{A_i|_t}{A_i|_0}\right) \tag{8}$$

$$\begin{aligned} \Delta RE_{I_{rsi}} &= \frac{RE_i|_t - RE_i|_0}{lnRE_i|_t - lnRE_i|_0} ln\left(\frac{I_{rs_i}|_t}{I_{rs_i}|_0}\right) \\ &= \frac{RE_i|_t - RE_i|_0}{lnRE_i|_t - lnRE_i|_0} ln\left(\frac{I_{rp_i}|_t}{I_{rp_i}|_0}\right) \end{aligned} \tag{9}$$

$$\Delta RE_{re_{mi}} = \frac{RE_i|_t - RE_i|_0}{lnRE_i|_t - lnRE_i|_0} ln\left(\frac{re_{m_i}|_t}{re_{m_i}|_0}\right) = \frac{RE_i|_t - RE_i|_0}{lnRE_i|_t - lnRE_i|_0} ln\left(\frac{re_i|_t \times I_{rp_i}|_0}{re_i|_0 \times I_{rp_i}|_t}\right) \quad (10)$$

Thus, the estimation results of ESCURB and ESCRRB can be defined as follows:

$$\text{ESCURB} = \sum\left|\Delta RE_{1,j}\right| \quad (\Delta RE_{1,j} \in \left\{\Delta RE_{P_1}, \Delta RE_{A_1}, \Delta RE_{I_{rs1}}, \Delta RE_{re_{m1}}\right\}, \Delta RE_{1,j} < 0) \quad (11)$$

$$\text{ESCRRB} = \sum\left|\Delta RE_{2,k}\right| \quad (\Delta RE_{2,k} \in \left\{\Delta RE_{P_2}, \Delta RE_{A_2}, \Delta RE_{I_{rs2}}, \Delta RE_{re_{m2}}\right\}, \Delta RE_{2,k} < 0) \quad (12)$$

3.3 Variables and data sources

Eqs. (7) to (10) involve five main variables, as shown in Table 1.

Table 1. Declaration of model variables

Variable	Symbol	Unit
Residential energy consumption in urban China	RE_1	10^4 tce
Residential energy consumption in rural China	RE_2	
Population in urban China	P_1	10^6 persons
Population in rural China	P_2	
Building area of existing residential buildings in urban China	A_1	10^6 m^2
Building area of existing residential buildings in rural China	A_2	
Residential energy consumption per capita index	I_{rp}	1
Residential energy consumption intensity in urban China	re_1	tce / 100 m^2
Residential energy consumption intensity in rural China	re_2	

All the data used in this study were obtained from China Statistical Yearbook for the period 2000–2015, except for the CREC data. Given that the statistical system of Chinese building energy consumption is still a work in progress, official CREC data are unavailable. Hence, this study referred to our previous studies that are relatively mature and credible [12]. The data of the main variables are shown in Tables 2 to 4.

4. Results analysis and discussion

4.1 Estimation results of ESCRB

With MATLAB R2014a, the time–series data involved in the five types of variables in Section 3.3 were introduced to Eqs. (7) to (10). The results prove that only $\Delta REre_{mi}$ is less than 0, which reflects that the contributions of re_{mi} to residential energy consumption in urban and rural China are definitely negative. Therefore, $|\Delta REre_{mi}|$ can be regarded as the values of ESCURB and ESCRRB. Table 5 indicates the estimation results of ESCRB during the period of 2001–2015. The results prove that this method is also applicable for estimating energy savings in residential buildings at a provincial or regional level if the credible residential energy consumption data at these levels exist.

4.2 Root cause of the considerable achievement of ESCRB

Fig. 2 shows that the calculated ESCRB is more than the officially planned ESCRB in 2006–2010 [19] and 2011–2015 [4]. China did not publish the officially planned ESCRB in 2001–2005; thus, this study could not compare the calculated ESCRB with the officially planned ESCRB in the said period.

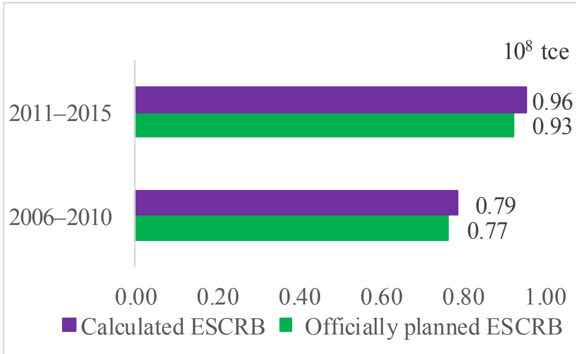

Fig. 2. Calculated ESCRB and officially planned ESCRB in 2006–2015

The abovementioned comparison shows that, in the third stage of Chinese building energy–efficiency work (2006–2015), the building energy–efficiency policies obtained a good implementation effect in the residential building sector. In this period, the government deepened the building energy–efficiency policy system in a series of ways, such as laws and regulations, technical standards, propaganda and training, market mechanism, economic incentives, and technological innovation [2]. On the basis of considerable officially published information [2, 4, 20], this study summarized the completion status of the main targets and main relevant building energy–efficiency policies in the third stage of Chinese building energy–efficiency work (2006–2015), as shown in Table 6.

Table 2. Data involved in ESCRB estimation method in 2001–2005

Variable \ Year	2000	2001	2002	2003	2004	2005
RE_1 (10^4 tce)	13,777.22	15,126.87	17,018.80	18,863.28	20,435.36	22,424.63
RE_2 (10^4 tce)	8,734.30	9,046.85	9,821.09	11,064.21	12,400.20	13,386.92
P_1 (10^6 Persons)	459.06	480.64	502.12	523.76	542.83	562.12
P_2 (10^6 Persons)	808.37	795.63	782.41	768.51	757.05	745.44
A_1 (10^6 m^2)	5,722.48	6,651.92	8,184.61	8,911.15	9,616.17	10,769.00
A_2 (10^6 m^2)	20,134.91	20,447.69	20,733.87	20,903.47	21,121.70	22,139.57
I_{rp}	1.000	1.085	1.199	1.349	1.463	1.584

re_1 (tce/100m^2)	2.408	2.274	2.079	2.117	2.125	2.082
re_2 (tce/100m^2)	0.434	0.442	0.474	0.529	0.587	0.605

Table 3. Data involved in ESCRB estimation method in 2006–2010

Variable \ Year	2005	2006	2007	2008	2009	2010
RE_1 (10^4 tce)	22,424.63	24,090.24	25,944.63	27,073.53	28,128.31	29,213.11
RE_2 (10^4 tce)	13,386.92	14,153.25	15,085.64	15,477.83	16,157.25	17,538.44
P_1 (10^6 Persons)	562.12	577.06	593.79	606.64	621.74	636.93
P_2 (10^6 Persons)	745.44	737.42	727.50	721.38	712.76	703.98
A_1 (10^6 m^2)	10,769.00	11,289.12	11,971.43	12,496.79	13,241.41	14,082.16
A_2 (10^6 m^2)	22,139.57	22,460.12	22,592.74	22,809.28	23,163.17	22,885.53
I_{rp}	1.000	1.063	1.125	1.177	1.229	1.314
re_1 (tce/100m^2)	2.082	2.134	2.167	2.166	2.124	2.074
re_2 (tce/100m^2)	0.605	0.630	0.668	0.679	0.698	0.766

Table 4. Data involved in ESCRB estimation method in 2011–2015

Variable \ Year	2010	2011	2012	2013	2014	2015
RE_1 (10^4 tce)	29,213.11	29,413.70	31,121.66	33,309.67	34,385.35	35,964.51
RE_2 (10^4 tce)	17,538.44	18,685.50	19,782.61	21,221.22	21,457.83	22,146.53
P_1 (10^6 Persons)	636.93	690.79	711.82	730.71	749.16	771.16
P_2 (10^6 Persons)	703.98	656.56	642.22	630.01	618.66	603.46
A_1 (10^6 m^2)	14,082.16	14,868.99	15,677.25	16,589.79	17,382.97	18,543.66
A_2 (10^6 m^2)	22,885.53	23,767.47	23,826.36	24,305.12	24,623.59	25,248.74
I_{rp}	1.000	1.045	1.113	1.177	1.196	1.220
re_1 (tce/100m^2)	2.074	1.978	1.985	2.008	1.978	1.939
re_2 (tce/100m^2)	0.766	0.786	0.830	0.873	0.871	0.877

Table 5. Estimation results of ESCRB in 2001–2015

2001–2005	Energy savings (10^4 tce)	2006–2010	Energy savings (10^4 tce)	2011–2015	Energy savings (10^4 tce)
ESCRB	11,786.92	ESCRB	7,909.26	ESCRB	9,644.82
ESCURB	10,487.75	ESCURB	7,421.17	ESCURB	8,358.88
ESCRRB	1,299.17	ESCRRB	488.09	ESCRRB	1,285.94
Annual ESCURB		Annual ESCURB		Annual ESCURB	
2001	1,999.41	2006	847.14	2011	2,689.79
2002	3,038.37	2007	1,041.89	2012	1,798.57
2003	1,795.49	2008	1,199.43	2013	1,435.99
2004	1,514.54	2009	1,743.14	2014	1,049.38
2005	2,139.94	2010	2,589.58	2015	1,385.16
Annual ESCRRB		Annual ESCRRB		Annual ESCRRB	
2001	548.11	2006	270.21	2011	338.47
2002	297.34	2007	–11.28	2012	160.90
2003	72.79	2008	439.62	2013	115.88
2004	–264.68	2009	252.12	2014	384.42
2005	645.61	2010	–462.57	2015	286.26

Table 6. Completion status of main targets and relevant policies of Chinese building energy–efficiency work in 2006–2015

Targets \ Projects	Newly built buildings	Building energy–efficiency retrofit of existing residential buildings	Renewable energy applied in buildings
Target requirements	(1) The new mandatory building energy–efficiency design standards should be fully implemented in northern severe cold zone, cold zone and hot–summer–cold–winter zone, and the implementation rate should be above 95% during the construction stage. (2) Northern mega cities (i.e., Beijing, Tianjin) should perform higher building energy–efficiency design standards. (3) A bunch of low/ultra–low building energy consumption demonstration buildings should be built.	550 million m^2 in northern heating zones	2.5 billion m^2 of building area applying new renewable energy should be established.
Completion statuses	(1) The implementation rate of mandatory building energy–efficiency design standards	＞1,200 million m^2 in northern heating zones	2.90 billion m^2 of building area applying new renewable

		during the construction stage of newly built buildings reached 97.19% at the national level. (2) The said rate was 100% in northern mega cities. (3) 1017 low/ultra–low building energy consumption demonstration buildings at the national level have been built.		energy were established.
Main relevant building energy–efficiency policies	General policies	(1) The Law of PR China on Promoting Clean Production (2003) (2) The Law of PR China on Energy Conservation (1998, 2008) (3) Regulation on Energy Conservation in Civil Buildings (2008) (4) The 11th Five–Year Plan (2006) (5) The 12th Five–Year Plan (2011) (6) China building energy–efficiency Plan (1996–2010) (7) The 12th Five–Year building energy–efficiency Special Plan (2012)		
	Special policies	(1) JGJ 26–1995 (2) JGJ 26–2010 (3) JGJ 134–2001 (4) JGJ 134–2010 (5) JGJ 75–2003 (6) JGJ 75–2012 (7) GB/T 50824–2013 (8) GB 50189–2005 (9) GB 50189–2015 (10) GB/T 50378–2006 (11) GB/T 50378–2014 (12) GB 50411–2007	(1) JGJ 129–2000 (2) JGJ/T 129–2012 (3) CJ[2007] No.957 (4) CJ[2012] No.148	(1) CJ[2006] No.460 (2) CJ[2009] No.305 (3) CJ[2009] No.306 (4) CJ[2011] No.061 (5) CJ[2012] No.604

Table 6 shows that the tasks related to Chinese building energy–efficiency work have achieved significant results, and these achievements impelled our calculated ESCRB to exceed the officially planned ESCRB in the third stage of Chinese building energy–efficiency work. As mentioned in the Introduction, ESCRB data lay a foundation for Chinese building energy–efficiency work. Given that effective ESCRB estimation method is deficient, the government should launch an operation of performance appraisal based on building energy–efficiency load, such as checking the building area of building energy–efficiency retrofit of existing buildings. This implementation may force the government to concentrate on one–side pursuit for additional areas of building energy–efficiency retrofit, instead of increased energy savings. Accordingly, the actual energy–saving benefits can be reduced. Thus, establishing a method for assessing ESCRB and launching an operation of performance appraisal based on the goal checking of energy savings in residential buildings nationwide are necessary. These tasks are significant for the development of Chinese building energy–efficiency work. To a certain extent, the results of the present ESCRB data estimation can help the government formulate and implement suitable and targeted building energy–efficiency policies in consideration of China's special national condition.

5. Conclusions

In order to achieve a method for effectively estimating ESCRB data, this study developed an approach based on the IPAT equation and the LMDI decomposition for effectively estimating ESCRB data. The main conclusions of the study are as follows:

(1) The calculation results reflect that ESCRB has significantly accumulated with the rapid development of Chinese building energy–efficiency work in the past 15 years. Specifically, ESCRB data in 2001–2005, 2006–2010, and 2011–2015 are 118, 79, and 96 million tce, respectively.

(2) The proposed ESCRB estimation method is also applicable for estimating energy savings in residential buildings at a provincial or regional level if the credible residential energy consumption data at these levels exist. Given that the model structure of ESCRB estimation method does not require the extra data involving specific regional characteristics, this method reflects universal calculation rules on estimating energy savings in residential buildings at a regional level.

This study proves the feasibility of calculating ESCRB data and fills the lack of research on effective ESCRB estimation methods. However, future works should consider additional relevant impact factors to further improve the accuracy of ESCRB estimation.

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