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Original Research Paper

Potential Analysis of Energy Conservation and Emission Reduction of Existing Buildings Retrofit in Chongqing in Medium and Long Term

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ABSTRACT

Based on current situation and relative plan of energy efficiency of existing buildings, the authors aim to explore the potential of energy conservation and emission reduction of existing buildings retrofit in Chongqing, in medium and long term (2016-2035). Scenario analysis is used to predict energy conservation of existing residential buildings and commercial buildings from 2016 to 2035. The authors create three potential future policy and market scenarios, which include baseline scenario as the Twelfth Five-year (2011-2015) plan, optimism scenario and pessimistic scenario. The results showed that there exists great potential for energy conservation of existing buildings in Chongqing. In the Sixth Five-year (2031-2035), reasonable policy and market intensify will cause energy conservation potential to rise up to 117,100 tons of SCE, and reduce 353,800 tons of CO_2. Existing commercial buildings are the key to promote building energy conservation, while existing residential buildings with increasing energy intensity should be an important issue in long term.

INTRODUCTION

As an inner requirement for sustainable development and objective need of the global warming, energy conservation has been the common topic faced by the world. According to analysis by the United Nations Environment Programme, buildings use about 40% of global energy and resources, and they emit approximately 1/3 of GHG emissions. Yet, buildings also offer the greatest potential for achieving significant GHG emission reductions, at least cost, in developed and developing countries. Furthermore, energy consumption in buildings can be reduced by 30% to 80% using proven and commercially available technologies (UNEP 2009).

In China, building energy consumption has accounted for about 30% of the total energy consumption of the whole society. With the increase of population and total gross floor area, acceleration of urbanization and upturn living standards, this number will rise to about 40% in 2030, which means building area will contribute to the largest portion of energy consumption (Cai et al. 2014, Liu 2012). It is imperative for China to promote energy efficient.

Existing buildings are the major of building energy consumption in China (Fang 2013). However, 95% existing buildings did not achieve building energy efficiency standards. In the era of construction of "two type society" and ecological civilization, energy-saving retrofit of existing buildings can not only improve building energy efficiency by significantly improving the indoor thermal environment, but also contribute to ecological civilization construction in building field to realize green development and environmental protection.

In April 2014, China revised "Environmental Protection Act" for the first time in 25 years. The new version clearly outline that environmental factors should be fully considered when economic and technical policies were made by relevant departments under the State Council and local governments. Chongqing, the youngest municipality of China, launched Building Energy Saving Regulation of Chongqing in 2008, which provides legal basis for Chongqing government to promote energy-saving retrofit of existing buildings. In 2011, Chongqing was selected, by China's Ministry of Finance and Ministry of Housing and Urban-Rural Development, as key demonstration city of energy-saving retrofit of existing commercial buildings promotion. In 2013, Chongqing Urban-Rural Development Committee, the Chongqing Finance Bureau jointly issued the Interim Measures to Manage Energy-Saving Retrofits of Existing Residential Buildings in Chongqing, which means relative work began. At present, energy-saving retrofits of existing buildings in Chongqing is still at the preliminary stage. Immature policy and market, with uncontrollable strength and focus, may lead to extremely varied energy conservation. Therefore, in order to provide scientific basis for work arrangement in Chongqing, it is essential to analyse the potential energy-saving retrofit of existing buildings in medium and long-term.

RESEARCH METHODOLOGIES

Scenario analysis: This paper uses scenario analysis to predict the potential of energy conservation of existing buildings. Scenario analysis is the method that construct reasonable scenarios, which make reasonable assumptions of changing influencing factors in different conditions, to predict possible situations or consequences in the future. According to possible changes, scenario analysis can present different occurrences and outcomes, which is the main difference between scenario analysis and traditional prediction (Cai 2011). The decision-making model can help policy maker to avoid unreasonable estimate of possible changes and outcomes (Zhong et al. 2013).

Scenario analysis method has been widely applied to many fields like energy industry, enterprise decision-making, traffic planning, environmental planning and water resources, etc. Scenario analysis focuses on energy conservation potential trend in different scenarios, instead of accurate predictions. The result not only is the basis for decision-making, but also helps to choose emphasis during policy implementation.

Method to predict energy conservation: In Chongqing, energy-saving retrofit of existing buildings has two dimensions, commercial buildings and residential buildings. In aspect of commercial buildings, retrofits concentrates on substandard systems like envelope, lighting and socket system, power system, heating ventilation and air conditioning and hot water supply system, power supply and distribution system, and other special power systems (Chongqing Urban-Rural Development Committee 2012). As to residential buildings, it means retrofits of one or more systems of external doors and windows, external shading system, roof and exterior wall insulation (Chongqing Urban-Rural Development Committee, the Chongqing Finance Bureau 2013).

This paper picked the current policy in Chongqing as the baseline to analyse the energy conservation potential of existing buildings, and include residential buildings and commercial buildings, in next four five-years (2016-2035). Energy conservation potential is the quantity of energy saving after retrofits in five-years. It can be calculated as follows:

$$E=\sum_{i=1}^{2} E_i=\sum_{i=1}^{2}\sum_{j=1}^{5} E_{ij} \quad (i=1, 2; j=1, 2, 3, 4, 5) \quad ...(1)$$

$$E_{ij}=EI_{ij} \times s_{ij} \times \xi_{ij} \quad (i=1, 2; j=1, 2, 3, 4, 5) \quad ...(2)$$

E is the energy conservation potential in five years, E_1 is the energy conservation potential saved by existing residential buildings, E_2 is the energy conservation potential saved by existing commercial buildings, and E_{ij} is the energy conservation potential saved by the *i* aspect in *j* year in the time unit. EI_{ij} is corresponding building energy intensity, which means the energy consumption per square meter. s_{ij} is corresponding reconstructed area. ξ_{ij} is fractional energy saving, which is the percentage of energy conservation and energy consumption before retrofits.

Scenarios: This paper construct three scenarios with different reconstructed areas and fractional energy saving, baseline scenario (S_1), pessimistic scenario (S_2) and optimistic scenario (S_3).

In baseline scenario (S_1), the strength of policies is the same as that in twelfth five-year plan. With raising energy-saving awareness and gradually improving market mechanism, retrofits area and energy saving rate increase.

In pessimistic scenario (S_2), the strength of policies and market demand has weakened, leading to reducing retrofits area and energy saving rate. However, the building energy intensity will increase as the same as that in S_1.

In optimistic scenario (S_3), the strength of policies and market demand has increased, leading to more retrofits area and higher energy saving rate than that in S_1. Building energy intensity will increase as in S_1.

Energy conservation potential calculation: To avoid the influence of conversion ratio in long time span of prediction, this paper adopts equivalent value to calculate the energy conservation potential. The conversion ratio of electricity and standard coal is 0.1229kgce/kwh.

According to law of urbanization development and current situation in China, urbanization will be nearing completion in 2035. Building energy intensity in China will be the same as or near that in developed countries. Current building energy intensity in America is used as the upper limit of that in Chongqing in 2035 to calculate the future energy consumption of existing buildings each year in Chongqing, combined with the current building energy intensity in Chongqing. Current energy intensity of existing residential building in America is 150kwh/m^2·a (U.S. Energy Information Administration 2009), while that of existing commercial buildings is 287 kwh/m^2·a (U.S. Energy Information Administration 2003).

***Energy conservation potential of existing residential buildings*:** In 2012, Chongqing's urban living energy consumption was 4.37 Mtce. Building-up area per urban resident was 32.17m^2, multiplies by 16.78 million, the total population, to get the total existing residential building area, 539.85 million m^2. Energy intensity of existing residential buildings in Chongqing, calculated by the method of Dong et al. (2008), is 65.94 KWH/m^2·a. Meanwhile, with raising living standard and various energy demands, urban residential intensity will increase 3.6% every year in calculation period.

Table 1: Parameters in different scenarios of existing residential building retrofits in Chongqing.

		2016-2020	2021-2025	2026-2030	2031-2035
S_1	Energy intensity(kwh/m^2·a)	76	91	108	129
	Retrofits area(10000m^2)	400	480	576	691
	Energy saving rate (%)	30	31	32	33
S_2	Energy intensity (kwh/m^2·a)	76	91	108	129
	Retrofits area (10000m^2)	320	384	461	553
	Energy saving rate (%)	23	24	25	26
S_3	Energy intensity (kwh/m^2·a)	76	91	108	129
	Retrofits area (10000m^2)	480	576	691	829
	Energy saving rate (%)	40	41	42	43

Note: The energy intensity in Table is the data of the first year in time unit, and will increase 3.6% every year.

Whereby, the urban residential intensity in 2016 will be $65.94 \times (1+3.6\%)^4 = 76$kwh/m^2·a.

According to the Interim Measures to Manage Energy-Saving Retrofit of Existing Residential Buildings in Chongqing, retrofits area should not be less than 30,000 per district, while 10,000 per county during the twelfth five years (Chongqing Urban-Rural Development Committee and the Chongqing Finance Bureau 2013). There are 21 districts and 17 counties, which means the retrofits area should not be less than 4 million m^2 in five years.

In baseline scenario (S_1), retrofits area will be 400 million m^2 during 13th five year, and will increase 20% every five years. In pessimistic scenario (S_2), retrofits area will be 80% of that in S_1. In optimistic scenario (S_3), retrofits area will be 120% of that in S_1 (Office of Wall Materials Innovation and Building Retrofits in Hebei Province 2012). Retrofits area in each five-year will be apportioned to every year.

As to the energy saving rate, this paper adopts that Wuhan shares the same geographical location and climatic zone. Cases in Wuhan showed that energy saving rate will change depending on the degree of retrofits. Based on the transform content, which includes external wall, roofing, overhead floor, outside the window, shading, etc., retrofits can be divided into three levels: low level, middle level and high level. Low level retrofits include one content only, leading to energy saving rate of 23.43% in shortest static payback time. Middle level retrofits contain two contents, resulting in energy saving rate of 26.93% in shortest static payback time. If buildings are reconstructed, they can reach 50% standard, energy saving rate will be 28.27%, while it would be 42.88% when it can reach 65% standard. High level retrofits contain more than three contents, realizing 36.25% energy saving rate in shortest static payback time. If buildings reconstructed can reach 50% standard, energy saving rate will be 31.11%, while it would be 42.88% when it can reach 65% standard (Hu 2013).

Therefore, this paper reasonably assumes that average energy saving rate from 2016 to 2020 is 30% in baseline scenario (S_1), 23% in pessimistic scenario (S_2) and 40% in optimistic scenario (S_3). Energy saving rate will increase 1% every five years. Parameters in different scenarios are listed in Table 1.

Energy saving potentials in different scenarios are calculated by putting these parameters into formula (2), as given in Table 2.

***Energy conservation potential of existing commercial buildings*: **In 2005, energy intensity of existing commercial buildings in Chongqing is 142kwh/m^2·a (Dong, 2008), increasing 2.4% per calculation period, up to 287 kwh/m^2·a. Therefore, energy intensity of existing commercial buildings in Chongqing in 2016 will be $142 \times (1+2.4\%)^{11} = 184$kwh/m^2·a.

According to the Interim Measures to Manage Energy-Saving Retrofit of Existing Commercial Buildings in Chongqing, retrofits area should not be less than 80,000 m^2 per district, while 30,000 m^2 per county during the twelfth five years (Chongqing Municipal People's Government, 2012). There are 21 districts and 17 counties, which means the retrofits area should not be less than 2.19 million m^2 in five years.

In baseline scenario (S_1), retrofits area will be 400 million m^2 during 13th five year, and will increase 20% every five years. In pessimistic scenario (S_2), retrofits area will be 80% of that in S1. In optimistic scenario (S_3), retrofits area will be 120% of that in S1. Retrofits area in each five-year will be apportioned to every year (Office of Wall Materials Innovation and Building Retrofits in Hebei Province 2012).

The Notice of Further Promote Energy Efficiency of Commercial Buildings shows that, energy intensity of commercial buildings will reduce more than 20%, which is 30% for large commercial buildings, in Chongqing by 2015 (Ministry of Finance, Ministry of Housing and Urban-Rural Development 2011). The practice of energy-saving retrofit of existing commercial buildings in Chongqing showed that the energy saving rate exceeded 20% (Chongqing Daily 2014).

Table 2: Energy saving potentials of residential building retrofits in Chongqing. Unit: 10,000 tons of SCE.

	2016-2020	2021-2025	2026-2030	2031-2035
S_1	1.20	1.78	2.63	3.89
S_2	0.74	1.10	1.65	2.45
S_3	1.93	2.83	4.15	6.08

Table 3: Parameters in different scenarios of existing commercial building retrofits in Chongqing.

		2016-2020	2021-2025	2026-2030	2031-2035
S_1	Energy intensity (kwh/m^2·a)	184	208	234	263
	Retrofits area (10000m^2)	1100	1320	1584	1901
	Energy saving rate (%)	25	26	27	28
S_2	Energy intensity (kwh/m^2·a)	184	208	234	263
	Retrofits area (10000m^2)	880	1056	1267	1521
	Energy saving rate (%)	20	21	22	23
S_3	Energy intensity (kwh/m^2·a)	184	208	234	263
	Retrofits area (10000m^2)	1320	1584	1901	2281
	Energy saving rate (%)	30	31	32	33

Note: The energy intensity in Table is the data of the first year in time unit, and will increase 2.4% every year.

Table 4: Energy saving potentials of commercial building retrofits in Chongqing. Unit: 10,000 tons of SCE.

	2016-2020	2021-2025	2026-2030	2031-2035
S_1	2.00	2.51	3.21	4.20
S_2	1.56	1.89	2.36	3.02
S_3	2.55	3.26	4.25	5.63

Therefore, this paper reasonably assumes that energy saving rate is 25% in baseline scenario (S_1), 20% in pessimistic scenario (S_2) and 30% in optimistic scenario (S_3). Energy saving rate will increase 1% every five years. Parameters in different scenarios are listed in Table 3.

Energy saving potentials in different scenarios are calculated by putting these parameters in formula (2), as given in Table 4.

Potential analysis in medium and long term: Energy saving potentials and proportion in different scenarios are calculated by putting the above results into formula (1), as shown in Fig. 1.

According to calculation results, following conclusions have been made.

Energy conservation from existing buildings is huge: In baseline scenario, energy conservation of existing buildings in Chongqing can achieve 32,000 tons of SCE in 13th five years, while it is 23,000 tons of SCE in pessimistic scenario, and 44,800 tons of SCE in optimistic scenario. In 16th five years, the number will be 80,900 tons of SCE in S_1, 54,700 tons of SCE in S_2, 117,100 tons of SCE in S_3. The gap between energy conservation in 13th five years and 16th five years shows that the conservation potential is so huge that energy conservation could be 3 to 4 times more with tightening policies.

In energy conservation calculation, 1 kg coke goes to 0.9714 kg standard coal. There are 0.8 kg carbon in 1 kg coke, while 0.8236 kg carbon in 1 kg standard coal. As 0.8236 kg carbon will produce 3.02kg CO_2, carbon emission reducing potential of existing buildings in Chongqing in mid and long term has been shown in Fig. 2. At present, residents in Chongqing produce 3.7 tons CO_2 every year. In optimistic scenario, there will be 353,800 tons CO_2, which is equal to that produced by 100,000 residents at current level. In addition, energy conservation and carbon emission will decrease more with the processing and conversion loss.

Commercial buildings should be the key emphasis in next stage: Although the area and energy saving rate of commercial buildings are less than that of residential buildings, but commercial buildings have higher energy intensity in the whole prediction period. As shown in Figs. 1 and 2, commercial buildings will have greater energy conservation potential in all scenarios by 2025. Therefore, commercial buildings should be the emphasis in next stage.

Residential buildings have greater potential in long term: Lower energy intensity though it has, residential buildings

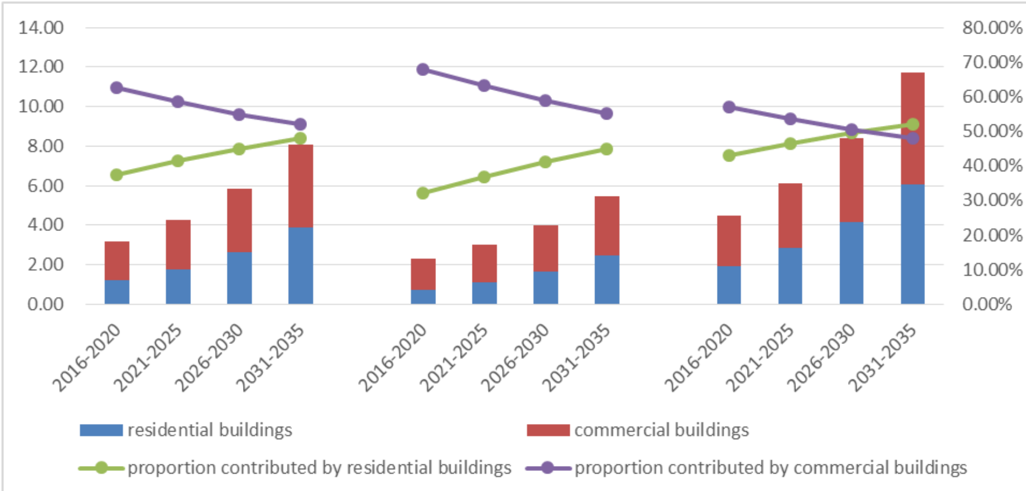

Fig. 1: Energy saving potentials and proportion in different scenarios in Chongqing.
(Left: S_1, Mid: S_2, Right: S_3; Unit: 10,000 tons of SCE)

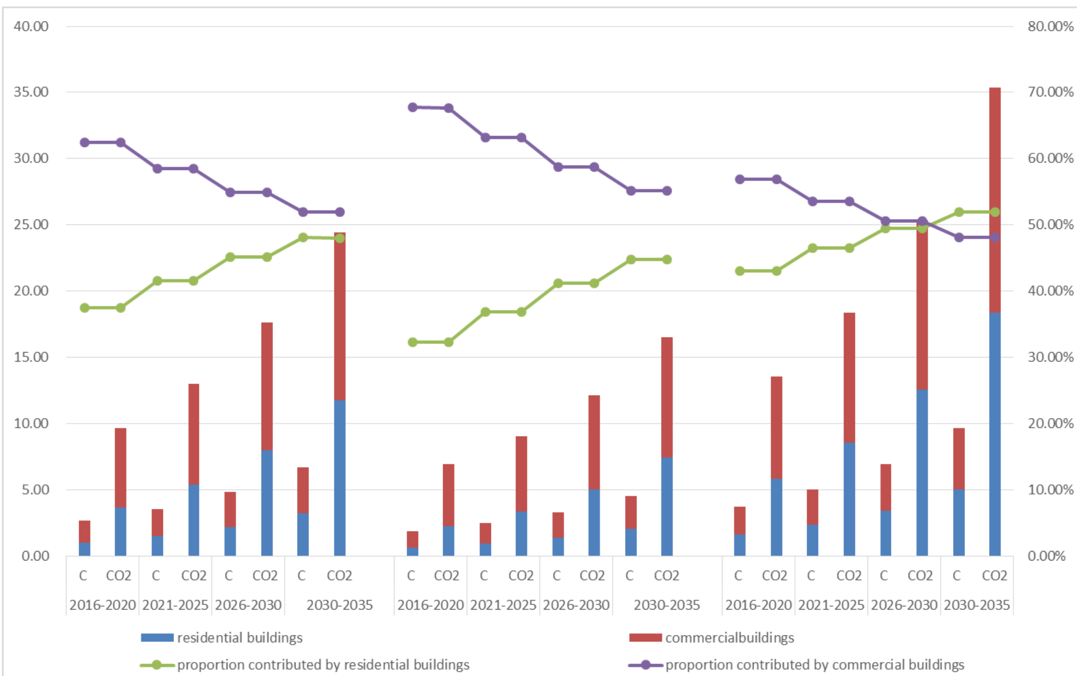

Fig. 2: C and CO_2 emission potential and proportion in different scenarios in Chongqing.
(Left: S_1, Mid: S_2, Right: S_3; Unit: 10,000 tons)

have higher energy saving rate and faster growth. As we can see, the proportion contributed by residential buildings increases gradually, and exceeds that of commercial buildings in optimistic scenario by 2035.

Chongqing's high energy consumption buildings, which are needed to retrofit, are mainly the existing buildings before 2006. The population of Chongqing is 12,659,500 in 2005, multiplied by 22.17 m^2, the average living building area per resident, we can get the total residential building area as 280,661,100 m^2. The commercial buildings account for 25% of all building area (He et al. 2009). In optimistic scenario, there are only 9.2% of residential buildings which will be reconstructed from 2016 to 2035, while the proportion is 75.7% in commercial buildings. Therefore, there is huge potential to improve in residential buildings in long term, which should be paid more attention.

CONCLUSIONS

China is the world's largest construction market (Cai et al. 2014), building energy consumption has become the focus of the world. Energy-saving retrofit of existing buildings will not only help to improve the present situation of Chinese building energy consumption, it also reflects the basic principle of "waste not" of the "two types society", and it is a decisive significance for the sustainable development of energy and environment in China even the world. Take Chongqing as an example, the authors build three different scenarios to calculate the energy saving potential from 2016 to 2035. Results show that there is huge energy conservation potential in existing buildings in Chongqing. Commercial buildings should be the key emphasis in next stage, while residential buildings have greater potential in long term.

The results can help policy makers to obtain a kind of intuitive grasp on energy conservation and emissions reduction potential of different types of existing buildings in medium and long term, thus choose emphasis during policy implementation, and make reasonable arrangements for the future construction energy conservation work.

However, existing buildings are limited, new buildings will contribute to more energy consumption, and should be one important part in next stage. This will be the further research aspect.

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