Energy and Buildings 86 (2015) 608–618

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A study on the energy rebound effect of China's residential building energy efficiency

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ARTICLE INFO

Article history:
Received 16 July 2014
Received in revised form 3 October 2014
Accepted 21 October 2014
Available online 30 October 2014

Keywords:
Building energy efficiency
Energy rebound effect
LA-AIDS model

ABSTRACT

China's building energy efficiency design standards have been always treated as the base of national energy conservation planning and industrial investment. However, they cannot fully achieve the expected benefits due to the energy rebound effect. This paper verifies the energy rebound effect in China's urban and rural residential buildings based on the LA-AIDS theory, and further estimates the building energy conservation by counterfactual analysis, catching the specific influences of rebound effect on building energy conservation and the corresponding residential building energy conservation potentials of China. The empirical results reveal that: (i) The rebound effect in the rural residential buildings is much larger than that in the urban residential buildings, where presenting the "back-fire" effect. (ii) The rebound effect in the rural residential buildings is weakening while it is enhancing in the urban residential buildings. (iii) Nationally, if energy policies including price polices, technological improvements as well as some other measures were implemented to avoid the rebound effect, we could have conserved about 20% electricity consumption in China's residential buildings each year. The magnitude increased by time to the highest level (107.66 GWh) in 2011, equivalent to the CO_2 emission reduction of 0.1 billion tons.

1. Introduction

Energy rebound effect refers to the idea that some or all of the anticipated energy conservation due to energy efficiency improvement are offset. The reason is that demand for energy services increases as effective price of these services declines after energy efficiency improves [1]. It is one of the most important subjects in energy economics field. Energy rebound effect of China's residential building efficiency studied in this paper means that the expected energy conservation designed by China's building energy efficiency standards cannot be fully achieved because the occupants might demand for more comfortable lifestyles with more energy services in buildings as building energy efficiency improves.

Building energy consumption mostly depends on the occupants' behaviors, thus, the study on building energy rebound effect can help us make more accurate assessment of energy conservation effect through building energy efficiency improvement. At the macro level, it contributes to more accurate energy conservation plannings and more reasonable incentive polices. At the micro level, it is greatly important for building materials investment analyses. For example, in Shanghai, China, it is considered that we can conserve heating and air-conditioning electricity by 16 kWh/m^2 each year in standard mode by applying a 20 mm thick polystyrene as building exterior wall thermal insulation. Thus, theoretically, the energy used in producing this kind of material can be restored by building energy efficiency improvement in only 8 years. However, in the actual living mode of the occupants, the electricity conservation is no more than 7 kWh/m^2 each year, which means we actually need 19 years to compensate the energy consumed in producing the polystyrene material [2].

The acceleration of China's urbanization process is accompanied by the increase of a large number of new residential buildings. China's building energy consumption accounts for nearly 1/3 of the country's total energy consumption and keeps increasing rapidly. Overall, China's current building energy consumption presents the following characteristics: (i) The magnitude of building energy consumption is large and rising year by year. (ii) Its proportion to the total energy consumption is at a low level compared to the developed countries, indicating a large growth potential. (iii) Electricity

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http://dx.doi.org/10.1016/j.enbuild.2014.10.049
0378-7788/

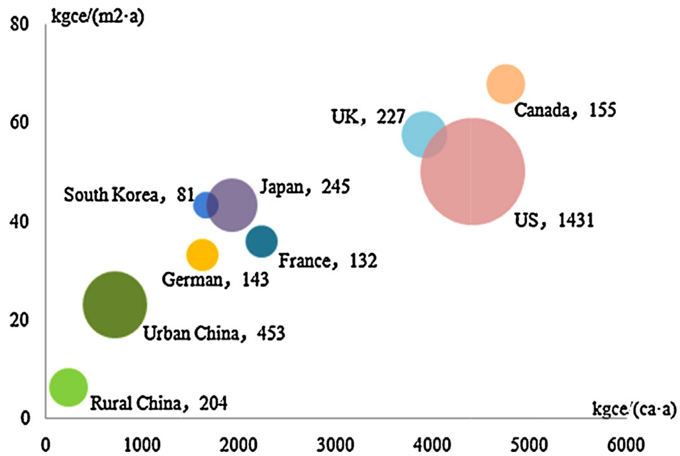

Fig. 1. Building energy consumption of several countries in the world. Data source: [2].

is the main energy consumed in buildings while heating and air-conditioning are the main energy services in buildings. (iv) Energy consumption in rural buildings is much lower than that in urban buildings, and commodity energy used in rural buildings gradually increases. Fig. 1 shows building energy consumption of several countries around the world. The horizontal axis represents building energy consumption per capita of each year. The vertical axis represents building energy consumption per unit area of each year. The size of the circles represents total building energy consumption of each year. The figure clearly shows that China's building energy consumption is still at a low level both per capita and per unit area compared to the developed countries. Considering the huge population and land area of China, the magnitude of building energy consumption and growth potential are rather large. The building sector will undoubtedly become a crux of energy conservation and emission reduction as well as climate and environment management both nationally and globally.

Building energy efficiency has become one of the priorities for Chinese government since early 1980s. According to *the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD)*, the newly constructed residential buildings should achieve energy efficiency improvement by 30% stage by stage based on the building energy consumption situations in 1980–1981. Such design standard is usually used to estimate building energy conservation in practice even it has not taken the change of occupants' lifestyles into consideration. It might bring large inaccuracy into the related estimation and prediction results [3].

The rest of the sections of this paper are arranged as follows: Section 2 reviews the related study literatures in this field. Section 3 introduces theories and methodologies used in this paper. Section 4 presents the empirical analyses, including data and descriptions, results and discussions, as well as further discussion by a counterfactual analysis method. Section 5 summarizes achievements and limitations of this study.

2. Literature review and methods

2.1. Literature review

The earliest research about the relationship between energy consumption and energy efficiency can date back to the 19th century. Jevons [4] found that we cannot absolutely reduce energy consumption by energy efficiency improvement since the accompanying economic growth with efficiency improvement usually results in more energy consumption. As for another reason, energy efficiency improvement reduces the effective prices of energy, leading to more energy demand according to economic price theories. In recent years, energy rebound effect receives large amounts of attention as energy conservation and emission reduction has become the focus of the international society. There we can find a growing number of literature discussing energy rebound effect both from the perspective of theoretical analyses and empirical studies.

The theoretical analyses are trying to explain energy rebound effect with economic theories. Brooks [5] pointed out energy efficiency improvement caused by technological advancement would result in the increase of energy consumption in two ways. One of them is the price effect, i.e., energy price becomes relatively cheaper comparing to other production factors due to the efficiency improvement. The other is the income effect, i.e., the improvement accelerates economic growth so that more energy are demanded. Moreover, whether the energy policies can achieve their conservation goals or not largely depends on the rebound effect. Saunders [6] also indicates that technological advancement can improve energy efficiency, i.e., less energy is needed for the same amount of output. It means that capital, labor and other input factors might be substituted by energy. Meanwhile, improved energy efficiency makes energy relatively cheaper, leading to more consumption. Thus, technological advancement cannot achieve its expected energy conservation. Wirl [7] came up with a precise and detailed explanation about energy rebound effect. He firstly admitted that technological advancement could save energy through efficiency improvement. However, the advancement effectively enhances the equipment efficiency which remarkably reduces the enterprise's production cost and accelerates economic growth, thus increasing energy demand. Finally, the saved energy from efficiency improvement is probably partly or totally offset by the additional energy needed from economic growth. There is even, in fact, the additional energy demand exceeds the saved energy through efficiency improvement, i.e., the "backfire" effect. As Birol and Keppler [8] figured out, technology is undoubtedly effective for energy efficiency and conservation in the long term, but some of them might be offset due to the rebound effect. Thus, price polices should be fully considered to avoid the substitution of other input factors by energy, encouraging consumers to use other factors instead of energy. Only in this way, can we ensure that energy can really got conserved by technological measures.

The empirical studies are more common. They collect real data to estimate the magnitude of rebound effect at different levels. However, the results might turn out to be inconsistent with different data or methods. It is a point in dispute about the rebound effect which still has not to be settled yet. Berkhout et al. [9] rigorously defined energy rebound effect and figured out that the magnitude of energy rebound effect in Netherlands is between 0 and 15% according to every definition. Roy [10] figured out that the rebound effect for lighting and cooking in some Indian rural households reached up to 200% in his paper. Bentzen [11] found the magnitude of rebound effect for the US manufacturing sector is approximately 24% with asymmetric price effects. Jin [12] calculated the long-term result 30% and short-term result 38% of rebound effect at the macro level in South Korea, while the magnitude of electricity rebound effect for air-conditioning is between 57% and 70%. Hens et al. [13] showed the magnitude of rebound effect for heating in residential buildings is 31–86% as respect to the indoor temperatures by engineering approaches. Sorrell et al. [14] provided a comprehensive review on the empirical estimates of direct rebound effect and concluded that the magnitude of the direct rebound effect for household energy services in the OECD should generally be less than 30%.

Researches on the rebound effect in China have not got much attention until Zhou and Lin [15]. Those two authors made an empirical test in their paper using China's macro energy consumption data. Liu and Liu [16] estimated the rebound effect of energy