Energy Policy 37 (2009) 140–149

Contents lists available at ScienceDirect

Energy Policy

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

Economic analysis of energy-saving renovation measures for urban existing residential buildings in China based on thermal simulation and site investigation

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ARTICLE INFO

Article history:
Received 15 April 2008
Accepted 14 July 2008
Available online 23 September 2008

Keywords:
Energy-saving renovation
Site investigation
Electricity price

ABSTRACT

Energy-saving renovations of existing residential buildings have proven to be very helpful in alleviating the pressure of energy shortages and CO_2 emission, but an economic analysis of the measures by using a life cycle cost (LCC) method is very important and necessary to determine whether to implement them or not. Based on thermal simulation and site investigation, the paper uses one urban existing residential building in Hangzhou city of China as the subject building, and analyzes the economic benefits from the energy-saving renovation measures through the LCC method.

The findings clearly show that the investigation of the factual electricity consumption of the subject building is very important to predict accurately the energy-saving effects and financial benefits of the measures for the building, because of the great discrepancy between in fact and in thermal simulation of the heating and cool loads, and the too cheap electricity price may hamper the development of energy-saving implementations in residential sector in China.

1. Introduction

Both the abroad environmental and the domestic energy crisis pressures had made energy savings one of basic national policies in the 11th Five-year Economic Growth Plan of China. Along with the rapid economic development, urbanization and improvement of people's living conditions in the past decade, residential energy consumption has risen sharply in Hangzhou city of China. Hangzhou Statistical Yearbook (2007) shows that the total urban residential electricity consumption in Hangzhou city increased by 93.75% while the population growth was only 9.22% from 2001 to 2006. In contrast, energy shortage in the city had been restricting the economic development seriously. To make matters worse, almost all existing residential buildings in the city were built with poor thermal quality. Such statistics clearly reveal that renovation (upgrading the condition) with energy-saving measures that can improve the energy performance of those buildings will be highly valuable to alleviate the pressures of energy shortages and CO_2 emissions of the city.

However, the initial investments make the decision-makers think twice about applying energy-saving measures to renovate those buildings. In fact, the economic benefits of the measures from the life cycle assessment (LCA) viewpoint may be the most critical factor in the energy-saving renovations. A number of studies had addressed the issue. Kohler (1999) thought that the renovation (upgrading the condition) of existing buildings should be a priority as it offered an opportunity to take cost-effective measures to transform the residential structures into resource-efficient and environmentally sound buildings. Equally important was the fact that renovation costs were significantly lower than demolition and reconstruction. Gustafsson (2000) used life cycle cost (LCC) to optimize the retrofit measures and minimize the cost of them for renovating the existing residential buildings in Sweden. Papadopoulos et al. (2002) concluded that the issue of energy renovation measures in the existing buildings of Greece was important and complex, and the energy potential was significant. Verbeeck and Hens (2005) proved the insulation of the envelope of the existing buildings in Belgium as the most effective and durable measures, also economically feasible depending on the available retrofit budget and the underlying motivation (limited investment, economic benefit at long term). Arslan and Kose (2006) showed the cost-effectiveness when optimum insulation in renovating the existing buildings in Kutahya city of Turkey was applied, moreover, energy consumption and air pollutants decreased. Tommerup and Svendsen (2006) illustrated how a profitable 80% savings potential of energy used for space heating could be identified over 45 years within the Danish residential building stock if the energy performances were upgraded through proper renovation. Lollini et al. (2006) demonstrated that significant economic advantages

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doi:10.1016/j.enpol.2008.07.041

resulted from high-performance building envelope if the life cycle of the building was taken into account.

Although the total energy consumption of China is the second in the world, the per capita or per square meter residential energy consumption is much less than that of the developed countries for different lifestyles or customs, residential policies (Long, 2007). And the energy price system in China is also different from that of developed countries, so the experience or results for those countries cannot be applied directly and simply in China, but LCC is an effective method to take the economic analysis of such an issue. Some preliminary studies available in China also proved the advantages of energy-saving renovation for the existing buildings, but only through thermal simulation or, in theory; their results should be checked further. Zhao and Lin (2005) demonstrated that the energy and economic efficiency of residential flats could be achieved with the application of appropriate energy-efficiency designs. Liu and Li (2005) showed that the increase of initial investment of the external wall insulation was acceptable and the energy effect was quite obvious. Hao and Yang (2007) showed that the initial investment (cost) would be paid back during the operational phase through less electricity consumption for energy-saving renovation of the existing residential buildings in Shanghai city. Zhao et al. (2007) analyzed the technology of energy-saving reform of existing residential buildings, and compared the energy consumptions calculated from thermal simulation by the Chinese Doe version software (CHEC), before and after the energy-saving reform. The outputs of those studies may be exaggerated and not convincing enough, for not further being analyzed by combining with the factual electricity consumption of the existing residential buildings.

Some researchers in China were aware of the importance of the factual electricity consumption of residential buildings to the energy-saving study. But it is very regretful that most of the prior researchers just wanted to make clear the status quo on electricity consumption and that for cooling load and/or heating load of residential buildings through investigation. Zhong and Long (2003) investigated the cooling load of the residential buildings in Shanghai city by a survey undertaken in July 2002, and found the value was 7.94 kWh/(m^2 year) in summer. Ren et al. (2003) investigated the cooling load of urban residential buildings in summer in Guangzhou city from 1997 to 1999, and found the value was 7.9 kWh/(m^2 year). Hu et al. (2004) investigated the electricity consumption and cooling load of urban and rural buildings in Hubei province, and found the values were, respectively, 9.0–36.9 and 1.0–9.8 kWh/(m^2 year). Wu (2005) investigated the electricity consumption of residential buildings in Hangzhou city from 2001 to 2004 and calculated the total heating and cooling loads to be 11.10 kWh/(m^2 year), about one-third of the total electricity consumption of residential buildings. Only Lam (1998) applied the monthly electricity consumption to analyze the climatic and economic influence on residential energy consumption.

This study will analyze the economic benefits from the energy-saving renovations of the existing residential buildings in Hangzhou city of China through the simplified LCC method, based on the energy-saving effects of the measures calculated by thermal simulation and further revised by the factual electricity consumption of residential buildings.

2. Methodology

2.1. Research subject

The first national energy-saving standards (Ministry of Construction P.R. China, 2001) in the hot summer and cold winter region were published in 2001 for the energy efficiency of new and rebuilt residential buildings. Most eastern and western areas of China are part of the region, which represents less than 20% in area, but accounts for more than 40% of the Chinese population and nearly 50% of the country's economy.

Hangzhou city is a typical city in the region (see Fig. 1). Its economy is very well developed while the energy shortage problem is very serious relative to most other cities of China. Although the relative governments had published more detailed energy-saving standards (Zhejiang Province Architectural Design and Research Institute, 2003; Hangzhou Construction Committee, 2002) for new and rebuilt residential buildings in the city, the real-estate developers were reluctant to comply with the codes due to increased costs and uncertain benefits for buyers. Additionally, buildings with large-area windows, complicated shapes, etc. were very popular in the city's real-estate market. As a result, the market was strongly against energy-saving standards in recent years and at least 95% (e.g., 47.5 million m^2) of residential buildings in the city had been designed and built without considering energy-saving measures and with poor thermal quality. In the next decade, buildings constructed in the 1980s and 1990s are subject to future refurbishment due to the contaminative urban environment and the relatively poor protective systems in Chinese cities, and the buildings will be refurbished with energy-saving measures taken into account (thereby adhering to the residential energy-saving standards) before being demolished. It is therefore necessary and meaningful to examine valid and rational measures for, and co-benefits from, energy-saving renovations of existing urban residential structures in the city.

As a result, a golden opportunity now exists to improve the energy performance of residential buildings through refurbishment in the city. This paper attempts to identify the most effective renovation measures for these buildings by comparing the energy-saving performance among the variables advanced by the standards. Additionally, a cost comparison of each measure will be made in order to make a compelling argument for their successful implementation if possible.

This study uses a seven-story building (see Fig. 2) built in 1995 in the Zijin neighborhood of the city as a typical building in the case study. The area of the households in every floor is about 355 m^2 (see Fig. 3). The subject building has 28 households and there are no vacancies. The building is chosen as it represents 51.9% of the type of residential buildings built before 2001 and will have to be renovated in the near future. It holds particular value in helping to determine rational energy-saving measures while increasing social and financial values.

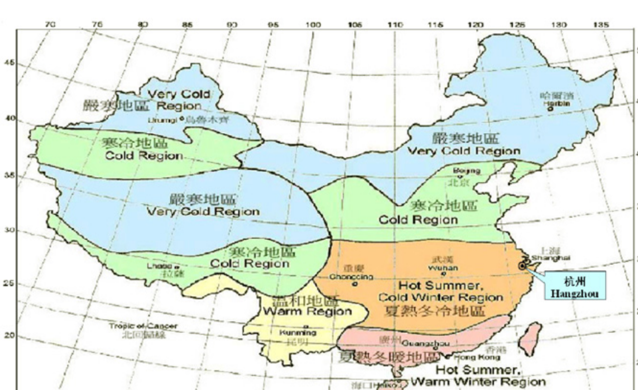

Fig. 1. Climatic regions in China and Hangzhou city's location.