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Economic analysis of upgrading aging residential buildings in China based on dynamic energy consumption and energy price in a market economy

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ABSTRACT

This article employed a standard LCC to conduct economic analysis of upgrading the aging residential buildings in China. According to the current situation, an interest rate of 6%, an inflation rate of 3%, an increase rate of annual energy savings of 2% and an increase rate of electricity price of 2% were assumed in the method. The results indicated that only relying on gradually increasing electricity price and governments' subsidies was not enough. After detailed analysis of the energy saving measures and the distribution of all benefits from building energy retrofit, it was found that actually only 1/3 of original cost was spent only for energy savings, the second 1/3 for both energy savings and good façade appearance and occupants should share the last 1/3 because even if without energy retrofit, they would have to pay the part too. The corresponding results proved that the first 1/3 of investment cost could be drawn back within the residue life cycle, and so the investment could be accepted in a sheer market economy. In the end, a model about distribution of investment cost of and benefits was proposed to adapt the market economy to overcome the financial problems in China.

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1. Introduction

As a large part of total energy consumption of China, the energy consumed by the unaccountable aging residential buildings had been highlighted as a key potential area and drawn much attention and many efforts towards energy efficiency. Upgrading aging buildings through energy retrofit had been widely accepted as the top-priority choice all over the world. Since the residential buildings' energy retrofits would soon become imperative in China, it was very essential to employ economic analysis to evaluate the economic benefits from such real projects, which decision-makers (for example occupants, investors, governments, and so on) were very interested in at any time.

Life cycle cost (LCC) had been regarded as an effective method (Gustafsson and Karlsson, 1988) to take economic analysis of such issue. A standard LCC, with the fundamental criteria for the evaluation of the cost effectiveness—a *net present value* (*NPV*) and an *internal rate of return* (*IRR*), was applicable to have an objective evaluation. In that way, the criteria of *NPV* and *IRR* could estimate the economic benefit resulting from an investment, during a certain period of time, and could completely solve the problem related to the lifetime of measures and its difference. To evaluate the cost of borrowing money the *NPV* and *IRR* were calculated using the discounted cash flows, i.e. a discount rate was introduced, which was usually equated to the economy market's interest rate. The expression of the relationship between *NPV* and *IRR* was shown as Eq. (1):

$$NPV=\sum_{t=0}^{t}(CI-CO)_t(1+IRR)^{(-t)} \tag{1}$$

In Eq. (1), $(CI-CO)_t$ meant the cash flow in t year; CI_t and CO_t respectively meant the cash input and cash output in t year. If *NPV* was more than zero, the investment could be accepted. More *NPV* means that the investment would bring more profits. Vice versa, if *NPV* was less than zero, the investment should be rejected, because the investment could not bring enough economic profits or the economic profits could not be up to expectation.

Using this financial method or the similar variation methods, Gorgolewski (1995) had assessed and compared the performances of various refurbishment measures for renovating a British dwelling, to give an indication of financial benefits over the life of the measures; Gustafsson (2000) had optimized the retrofit measures and minimized the cost of them for renovating the existing residential buildings in Sweden; Papadopoulos et al. (2002) had determined the potential of energy saving renovation measures in a representative sample of building of Greece under realistic

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conditions and the rapidly changing economic conditions; Verbeeck and Hens (2005) had discussed economically feasible ways and means to choose among insulation measures, better glazing, installation measures and renewable energy systems such as solar collectors and PV cells and finally deduced a logical hierarchy of energy saving measures from the results for the existing buildings in Belgium; Lollini et al. (2006) had demonstrated the significant economic advantages by improving performance of building envelope of the Italian residential buildings, if the life cycle of the building was taken into account; Tommerup and Svendsen (2006) had given a short account of the technical energy saving possibilities that were present in existing dwellings and assessed the total savings potential of the energy saving measures in the Danish residential building stock; Amstalden et al. (2007) had analyzed the profitability of energy efficient retrofit investments in the Swiss residential building sector from the house owner's perspective; Atkinson et al. (2009) had explored the relationship between the energy market, the political and regulatory context and energy design decisions for Hellenic existing multi-residential buildings, to determine what form the energy market landscape would take if tailored to encourage low carbon solutions. Their results had indicated that significant economic benefit would come out from energy retrofits of aging residential buildings.

The standard LCC had already been introduced into the field of the building energy retrofits in China (Yu, 2006; Lan et al., 2007; Wang and Liu, 2008; Liu and Liu, 2009; Liu and Liang, 2009; Yu and Yang, 2009; Liu and Liu, 2010), and had been adopted in some pilot studies in the recent years (Jia et al., 2006; Wang, 2007; Hao and Yang, 2007; Wang, 2010; Zhang et al., 2010). As the studies of the European developed countries, the Chinese pilot studies had gained the same conclusion that the initial investment cost would be paid back soon during the operational phase for less energy consumption after energy retrofit. But those studies had a fateful shortcoming that the life cycle economic benefits were only based on thermal simulation, and not combined with the actual energy consumptions of the subject aging residential buildings. So the economic benefits were exaggerated too much, and the above conclusion was not correct in China.

In the previous article (Ouyang et al., 2009), we had done such similar study too. The life cycle economic benefit of energy retrofit was based on thermal simulation and site investigation about the actual energy consumption of the subject building, and drawn a sounder conclusion, which was different to that of these pilot studies of China. Strictly speaking, however, the LCC used in that article had a flaw too. It was not the standard LCC, but a simplified LCC. It had been thought that any added costs due to the interest rate on the loan for the initial and maintenance investment might be counteracted or exceeded by the increased value of the property due to the rapid economic development in China. As a result, the simplified LCC did not include the interest rate and the inflation rate. Additionally, the annually economic benefit from energy retrofit was assumed to be constant in the residual life cycle in the simplified LCC. But the actual situation was opposite in China. The two increased variables (annual energy savings and electricity price) would magnify the annually economic benefit and thereby the life cycle economic benefit.

Different to the high and relatively steady household energy consumptions of the European developed countries, the Chinese household energy consumption was relatively low at present, and it had been experiencing a continual and repaid increasing process, even in the unit: kg standard coal equivalent/annual per capita, to satisfy the higher quality of life in these years (see Fig. 1) (National Bureau of Statistics of China, 2010). This figure also indicated that the increase rate began to reduce since 2005, thanks to the efforts of the whole society towards energy efficiency in the residential sector of China. So the absolute quantity of annual energy savings of any energy saving measure would increase with the increasing household energy consumption, if the relative energy saving effect of the measure kept constant in the residual life cycle.

On the other hand, the price of electricity, which accounted for most of the Chinese household energy source and thus "energy" was referred in particular to "electricity" in this article, was very low (Lam, 2004; Wang, 2007), and the governments of China were gradually increasing the household electricity price to ensure the national energy security in these years. The low household energy consumption level and the low electricity price of China could explain why the European developed countries could gain positive economic benefits from aging residential buildings' energy retrofits, while China could not.

Therefore, this article would attempt to refine the results of the previous article using the standard LCC in a market economy, and the dynamic energy consumption and electricity price would also be taken into account to comply with the particularity of China. With the refined results, it was hoped that we could propose more reasonable suggestions for the governments to adjust the energy policies for upgrading the aging residential buildings of China.

2. Brief review of the previous article

In the previous article, an aging residential building (see Fig. 2) of Hangzhou of China had been selected as a typical building in the case study. The seven-story building had been constructed in 1995, had 28 households with no vacancy, and the area of the 4 households in every floor was about 355 m^2. The building was chosen as it represented about 50% of the type of residential buildings constructed before 2001 in the city of China.

Six energy saving measures had been proposed for renovating the building and the corresponding effects on building energy performance were shown as follows:

M1: installing 2 safety doors (the building's doors, not families' doors) on the first floor and 12 windows on the remaining six floors, thereby separating the stairs from the outside air. This measure would reduce the shape coefficient of building from 0.38 to 0.32, change a little the heat transmission coefficient (*K*, unit: W/(m^2 K)) and thermal inertia index (*D*, no unit) of the exterior walls and the ratio of exterior windows/wall area. The *K* of the exterior doors would be 6.5 W/(m^2 K), because the stairs' two safety doors were steel. All other parameters were not changed.

M2: substituting plastic double windows for old ones. This measure would reduce the *K* and the shadow coefficient (SC, no unit) of the exterior windows respectively from 6.25 to 2.85 W/(m^2 K) and from 0.80 to 0.70. All other parameters were not changed.

M3: applying unfixable fabric, timber curtains and/or aluminum blinds. This measure would reduce the SC of the exterior windows from 0.80 to 0.30 in summer. All other parameters were not changed.

M4: adding insulation material (40 mm extruded polystyrene (XPS)) to the roof. This measure would reduce the *K* of the roof from 3.969 to 0.672 W/(m^2 K) and improve the *D* of the roof from 1.554 to 2.376. All other parameters were not changed.

M5: adding insulation material (10 mm XPS) to the exterior walls. This measure would reduce the mean *K* of the exterior walls from 2.355 to 1.296 W/(m^2 K) and reduce the *D* of the exterior walls from 3.251 to 3.236. All other parameters were not changed.

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