Energy and Buildings 84 (2014) 662–673

Contents lists available at ScienceDirect

Energy and Buildings

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

Cost-optimum analysis of building fabric renovation in a Swedish multi-story residential building

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ARTICLE INFO

Article history:
Received 24 March 2014
Received in revised form 2 June 2014
Accepted 2 September 2014
Available online 10 September 2014

Keywords:
Building renovation
Building fabric
Energy simulation
Space heating
Insulation
Energy efficiency
Cost-optimum renovation
Sustainability
Windows

ABSTRACT

In this study, we analysed the cost-optimum level of building fabric elements renovation in a multi-story residential building. We calculated final energy use for space heating of the building considering a wide range of energy efficiency measures, for exterior walls, basement walls, attic floor and windows. Different extra insulation thicknesses for considered opaque elements and different *U*-values for new windows were used as energy efficiency measures. We calculated difference between the marginal saving of energy cost for space heating and the investment cost of implemented energy efficiency measures, in order to find the cost-optimum measure for each element. The implications of building lifespans, annual energy price increase and discount rate on the optimum measure were also analysed. The results of the analysis indicate that the contribution of energy efficiency measures to the final energy use reduces, significantly, by increasing the thickness of extra insulation and by reducing the *U*-value of new windows. We considered three scenarios of business as usual (BAU), intermediate and sustainability, considering different discount rates and energy price increase. The results of this analysis suggest that the sustainability scenario may offer, approximately, 100% increase in the optimum thickness of extra insulation compared to BAU scenario. However, the implication of different lifespans of 40, 50 or 60 years, on the optimum measure appears to be either negligible or very small, depending on the chosen scenario. We also calculated the corresponding *U*-value of the optimum measures in order to compare them with the current Swedish building code requirements and passive house criteria. The results indicate that all optimum measures meet the Swedish building code. None of the optimum measures, however, meet the passive house criteria in BAU scenario. This study suggests that the employed method of building renovation cost-optimum analyses can be also applied on new building construction to find the cost-optimum design from energy conservation point of view.

1. Introduction

Buildings account for 40% of total primary energy use [1] and 36% of CO_2 emissions [2] in the European Union (EU). The EU directive on energy performance of building [3] requires member states to set minimum requirements for energy performance of buildings and building elements. That includes existing buildings that are subject to major renovation. This directive demands for considering cost-optimal balance between the investment and the saved energy cost during the lifespan of a building. According to EU Parliament Directive of 2012/27/EU [4], the existing building stock represents the single biggest potential sector for energy savings. It suggests that buildings are crucial to achieve the EU objective of reducing greenhouse gas emissions by 80–95% by 2050 compared to 1990. The Swedish government targets 20 and 50% total final energy use reduction per heated building area by 2020 and 2050, respectively, using 1995 as the reference [5]. Directive 2012/27/ EU urges member states to establish a long-term strategy for mobilising investment in building renovation. This strategy should identify and then include cost-effective approaches to renovation, depending on the building type and climate zone.

Energy is used during the whole life cycle of a building, i.e. construction, operation and end-of-life phases. Various researchers have studied final energy use in the entire life cycle of buildings (e.g. [6–10]) and show that the operation phase contributes, significantly, to the life cycle final energy use of buildings. Ramesh et al. [8] conducted a literature review study on life cycle final energy analysis of 73 residential and office buildings in northern and central Europe, Canada, tropical region of Asia and Australia. Their results suggested that the final operation energy use contributes to about 80 to 90% of life cycle energy use in residential buildings. Space heating of buildings is a substantial part of total operation energy.

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http://dx.doi.org/10.1016/j.enbuild.2014.09.003

According to the European Environment Agency [11] space heating accounts for about 68% of total operation energy use of buildings in European countries. Improved energy efficiency measures for space heating of existing buildings can provide substantial opportunity to reduce the primary energy use and CO_2 emission.

In Sweden, there is a significant potential to reduce primary energy use by decreasing the space heating demand of existing buildings. About 40,000 apartment buildings with almost 920,000 dwellings and about 480,000 single family houses were constructed between 1961 and 1975 in Sweden [12]. Most of these buildings are still in good condition from serviceability point of view and are projected to undergo major renovation within the next 20 years [13].

There are numerous energy efficiency measures that can reduce final operation energy use of buildings. The measures may include ventilation heat recovery systems, efficient hot water taps, efficient electrical appliances and improved thermal performance of building fabric elements. Various researchers have studied energy implication of different energy efficiency measures for building renovation. Gustavsson et al. [14] analysed a multi-story wood-frame residential building constructed in 1995 in southern part of Sweden. They evaluated the effects of various energy efficiency measures on district heated (henceforth DH) buildings. They found that implementing more energy-efficient doors and windows, additional exterior walls insulation and additional roof insulation could reduce the final space heating by 35%. Dodoo et al. [5] analysed the effect of retrofitting a wood-frame building to a passive house standard. They considered improved water taps and building elements as well as ventilation heat recovery. They found that space heating could be reduced by 39% by improving the insulation on external walls and roof and changing doors and windows. The cost-effectiveness of the building energy renovation, however, was not analysed in these studies. In another study, Ouyang et al. [15] analysed a 27-year old residential building in China. They considered six energy efficiency measures including external doors and windows improvement, adding insulation on the exterior walls and the roof, applying light colour on the envelope and applying curtains or blinds to exterior windows. They calculated final energy use and CO_2 emission and analysed the economic implication of considered energy efficiency measures. They suggested that the considered measures are not cost effective unless the government provides subsidy and increase electricity price. The considered information of energy balance and economy analysis, however, has not been provided in details in this study. Dall'O' et al. studied the energy saving potential of retrofitting the residential building stocks in five municipalities of Milan in Italy [16]. They considered windows replacement, facade extra insulation, roof extra insulation and air loss reduction of ventilation. They considered three economic scenarios: no incentive, tax deduction of 36% and tax deduction of 55%. The energy and economic analysis was performed to calculate the simple payback time for considered measures. Wahlström et al. [17] studied the implications of new building regulation on the major renovation of apartment buildings. They also analysed the profitability of energy-efficiency measures of existing multi-family houses. Their analysis involve the optimal life cycle costs of energy-efficiency measures in combination with four types of heating systems, considering 30 years calculation period and 3% discount rate.

Ecofys report of cost-effectiveness climate protection [18] quantified the required investments and cost-effectiveness of energy efficient building envelope elements for cold, moderate and warm climate zones in Europe. In another report of Ecofys [19], the feasibility of deep renovation in European countries was studied. This report used case-studies for deep renovation programme in German low energy building stock. The results were then extrapolated to other European countries. The price level indices, mortgage rates, inflation rates, energy prices and heating degree days were taken into account in this study. They suggested that superficial renovations of buildings increase the risk of missing Europe long term climate target and that immediate deep renovation action is necessary for the European building stock.

In this study, we analysed the optimum level of renovating the building fabric elements. We calculated the marginal difference between the saving of final energy cost for space heating due to energy efficiency measures and the cost of implementing those measures to renovate building fabric elements. Changing the existing windows to the ones with lower *U*-value, implementing extra insulation on exterior walls, basement walls and attic floor were considered, in order to find the optimum *U*-value for windows and thickness for extra insulation. The implication of different parameters such as discount rates, energy price increases and the lifespans of considered energy efficiency measures on cost-optimum measures were then analysed.

2. Methods

2.1. General approach

We considered an existing building and studied the implication of energy renovation measures on final energy use for space heating. We analysed the contribution of thermal performance improvement of the building fabric elements to the final energy demand. The optimum choices of efficiency measures of individual elements were then analysed, from economic point of view. The overall approach of our study consists of the following parts:

(1) Modelling the energy balance of the building to calculate final energy for space heating;
(2) analysing the contribution of each energy efficiency measure to final energy savings;
(3) performing the cost-optimisation analysis for each considered elements;
(4) analysing the sensitivity of optimum measures to discount rates, energy price increase and lifespans of the considered elements.

2.2. Case-study building

This study is based on a 50-year old multi-story residential building located in the city of Växjö in south of Sweden. It was constructed in 1964 as part of the Million Programme, running from 1960s to early 1970s in Sweden [12].

The existing residential building stock of Sweden appears to be relatively old but still in good condition from serviceability perspective. The housing statistics in the European Union [20] indicates that 19, 25 and 39% of the existing residential building in Sweden in 2008 are above 80, 70 and 60 years old, respectively. This report also indicates that 100% of existing buildings in the year 2008 in Sweden were equipped with central heating, hot running water and bath and shower. This may be used as a qualitative indication of building general condition for the existing residential buildings. This indication is, in average, 98, 97 and 83% in the UK, France and Poland, respectively [20].

The case-study building has eighteen apartments in three floors and six flats on ground floor. It is a concrete-frame building with brick cladding. Fig. 1 shows a view of the building. Total heated floor area of the building is 1430 m^2. Total ventilated volume is 3710 m^3 which includes total volume of living space and the volume of common space, e.g. stair case where different temperatures are required. The required information of the building for the analysis was extracted from existing drawings provided by the building