Energy and Buildings 100 (2015) 20–26

Contents lists available at ScienceDirect

Energy and Buildings

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

Cost-optimal renovation and energy performance: Evidence from existing school buildings in the Alps

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ARTICLE INFO

Article history:
Available online 10 April 2015

Keywords:
Cost optimal analysis
Heating energy performance
School buildings
Austria

ABSTRACT

This paper reports a study of cost-optimal building renovation arrangements regarding the heating energy performance. The study is based on 8 different primary schools with different building ages and therefore different constructions. The schools are located in the Alps and thus in a region which is in the antagonism between high energy standards and particular climatic conditions. The calculation method is oriented on standard energy demand and life cycle cost methods. The results show that the cost-optimal performance is between a heating energy demand of 50 to 60 kW h/m^2 p.a. Furthermore the building age has a high effect on the results of the net present value. Also the investment costs of the different building renovation arrangements show a high effect on the results concerning the cost optimal renovation measurements. Where the insulation thicknesses of the envelope have proposed thicknesses of about 10–12 cm the windows only reach the highest *U*-value of 1.2 because of the higher investment costs. Also the heating energy system with their energy efficiency was considered in the study and the change into a more efficient system is proposed in every case.

1. Introduction

To reduce the energy dependency and greenhouse gas emissions, it is important to (i) achieve a reduction of energy consumption and (ii) develop the use of energy from renewable sources. In this context, the building sector becomes an important and appropriate role. In Europe, 40% of total energy consumption and 36% of CO_2 emissions account to this sector [1,2]. According to Marszal and Heiselberg [3] buildings are durable and buildings decisions have long-term consequences but the building owners or investors mostly focus on the investment costs only and subsequently neglect future operation or replacement costs. With this praxis, they lack the holistic view of actual cost of a building, and this can result in not choosing the cost-effective solution [3]. In doing so, the European Building Directive (EPBD) call among others for the cost-optimal balance between the investments and the energy costs throughout the lifecycle of a building [4]. While in the past, the energy saving measures are mostly evaluated by their impact on the energy consumption only, the EPBD establishes a strong step forward into the economic evaluations of the solutions diversity [2]. Thereby, the cost optimal level refers to the energy performance that leads to the lowest cost during the estimated economic lifecycle [2].

A broad strand of literature tries to capture economic passable strategies and scenarios for more energy efficiency by a cost optimal level. Thereby, different methods of life cost analysis are used. But the great majority of these studies focus on the new buildings area. Hasan et al. [5] analyzed the minimized life cycle cost of a detached house regarding on different insulation thicknesses, windows and heat recoveries by using a combined simulation and optimization method. Compared with the reference case, the results show a realistic reduction in thermal energy by 39–50%. Marszal and Heiselberg [3] run a life cycle cost analysis for a multi-storey residential net zero energy building. Thereby, they use different study cases with three levels of energy demand and three alternatives of energy supply systems. Kneifel [6] shows that conventional energy efficiency technologies can be uses to decrease the energy use in new commercial buildings by 20–30%. Kurnitski et al. [7] analyze the cost optimal performance levels for nearly zero energy residential buildings. Also Gustafsson and Karlsson [8] studied the optimal retrofit combination for multi-family houses. They discussed their results on a case study of a real building in Sweden. Sesana and Salvalai [1] give an overview on life cycle methodologies and economic feasibility for nearly zero-energy buildings in the new building sector. While Marszal and Heiselberg [3] run a life cycle cost analysis of a multi-storey residential net zero energy building in Denmark. Also Morrissey and Horne [9] studied different life cycle cost

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http://dx.doi.org/10.1016/j.enbuild.2015.04.005
0378-7788/

implications of energy efficiency measures in new residential buildings and Corgnati et al. [2] focused on the methodology of definition and application of reference buildings for further cost optimal analysis. Regarding to the measurement on the impact of renovation, the main focus of these studies are based on different energy performance levels, including current minimum energy requirements, low and nearly zero energy standards [10,11].

While the focuses on the new building area is in line with the targets of the EU climate and energy objectives (e.g. all buildings constructed after 2020 should reach nearly zero energy levels) and leads to important results and findings in connection to the construction and operational costs of new buildings, the following paper promises an enlargement in respect to the existing building stock. The large savings potential can be located in the existing building stock. This can be attributed to technical restrictions. Simultaneously, in alpine regions as Tyrol, it is a particular challenge to bring the energy demand and energy efficiency in harmony. This may be underpinned by the fact, that due to the climate conditions in the Alps, the energy demand is rather high. Hence, it is of particular interest to accomplish energy efficiency measures by a cost optimal renovation. So, our study results are important from several perspectives. Better understandings of the parameters, which affect the cost of renovation in school buildings, lead us to cost-optimal renovation measures while maximizing the energy performance. Simultaneously we get the information, whether the renovation steps, the equipment or the cost parameters for (public) school buildings differ to residential buildings. With the sensitivity analysis, we are able to show how energy price changes, changes in the proportion of window areas, changes in the interest rate, price variation and changes in the investment costs shift the cost-optimal renovation measures.

The structure of the paper is as follows. Section 2 presents the methodological framework, variables and data used in the paper. Section 3 presents the empirical results for the cost optimized renovations and the results out of the sensitivity analysis. A discussion of the limitations, directions for future research and concluding remarks are offered in the final section.

2. Methodology and data

Followed by Corgnati et al. [2] the main reference for the economic calculation methodology is the global cost calculation from the European Standard EN 15459 [12]. In particular the global cost calculation allows to compare different energy saving measures, applied to different buildings, taking into account both (i) the energy consumption and (ii) the economic performance [2]. For life cycle costing the ISO 15686-5 is the main relevant standard [13]. Next to these standards there are also guidelines available, which are based on the cost optimality requirements in general [14] and due to the framework of the European Building Directive [15,16]. The cost-optimal balance includes the investment costs and the operating costs over the life time of the building. This method could be used for new buildings as well, as for retrofit situations. Furthermore, we use the data out of the scientific report from the Institut Wohnen und Umwelt [17] and from the BMVBS [18] to specify our cost functions. These data are based on the requirements due to the EnEV 2012 (Energy saving regulation 2012).

In a next step, we define our school buildings which are used in the case study. The specific data for the eight primary school buildings are shown in Table 1.

It is apparent; that our sample consists of one school building constructed in the time period 1919–1944, three buildings out of 1945–1960, one building was constructed in 1961–1970, two in 1971–1980 and one during the time period of 1981–1990.

Table 1
Building data.

Case	GFA[1]	Number of floors	Ratio	Ratio	U-values envelope					Space heating system		Heating energy demand [kWh/m² a]
			Surface to Volume	Windows to Wall	Construction period	Wall	Roof	Floor	Window	Energy source	Efficiency	
1	787	2	0.55	0.26	1945–1960	1.7	0.8	1.2	2.3	Oil	0.80	133.2
2	992	2	0.53	0.29	1945–1960	1.7	0.8	1.2	2.3	Oil	0.80	128.7
3	1.756	2	0.63	0.18	1961–1970	0.8	0.7	0.8	2.7	Oil	0.80	109.4
4	936	2	0.53	0.30	1919–1944	1.7	0.8	1.2	2.3	Gas	0.80	126.2
5	2.311	3	0.48	0.21	1981–1990	0.5	0.4	0.5	2.5	Oil	0.80	76.5
6	1.351	3	0.43	0.28	1945–1960	1.7	0.8	1.2	2.3	Oil	0.80	114.7
7	5.513	5	0.30	0.37	1971–1980	0.8	0.7	0.8	2.7	Gas	0.80	76.4
8	6.090	3	0.37	0.42	1981–1990	0.5	0.4	0.5	2.5	Gas	0.80	68.5

[1] GFA: gross-floor-area.