Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 00 (2015) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

6th International Building Physics Conference, IBPC 2015

Pitfalls in the economic and ecological evaluation of energy related building renovation strategies and measures

Ott W.[a], Bolliger R.[b]*

[a]econcept AG, Gerechtigkeitsgasse 20, 8002 Zürich, Switzerland
[b]econcept AG, Gerechtigkeitsgasse 20, 8002 Zürich, Switzerland

Abstract

The relevance of a correct and comprehensive impact assessment methodology for determining costs, primary energy and carbon emissions reductions of energy related renovation options is demonstrated for the case of a Swiss multi-family building. For this case building, a reference scenario was defined which does not improve the energy performance. 9 different options to renovate the building envelope were investigated, in combination with 3 different options for the heating system. The need for the definition of an appropriate and correct reference renovation option which creates a level playing field for the assessment of the impacts of different energy related renovation options is emphasized. The significance of the initial energy performance of a building before renovation on economic viability and resulting energy and carbon emissions reductions is illustrated. Furthermore, the need and the relevance for integrating expectations on future energy prices in the cost assessment options is demonstrated. .

Keywords: Building renovation; energy savings; carben emissions reductions; green house gas reductions; cost assessment; cost optimal building renovation; cost effective building renovation; energy performance of buildings; assessment methodology; anyway renovation

1. Introduction

Tapping within building renovation the vast potential for reductions of energy use and carbon emissions in existing buildings is one of the major challenges of energy and climate policy. Currently there is widespread uncertainty if and to what extent renovation measures, which increase energy performance of buildings towards an

* Corresponding author. Tel.: +41 44 286 75 86; fax: +41 44 286 75 76.
E-mail address: walter.ott@econcept.ch.

ambition level of zero or nearly zero energy buildings (NZEB), are economic viable. This is a relevant barrier for deploying far reaching energy related retrofit measures within building renovation. Advanced analyses of the costs and benefits of energy related building renovation measures disclose that the methodology of the cost evaluation matters and influences the outcome of cost/benefit analyses crucially.

The impact of some important methodological issues and assumptions will be demonstrated for a multi-family building (MFB) in Switzerland, which has been one of the examples which have been assessed within IEA EBC Annex 56 "Cost effective energy and carbon emissions optimization in building renovation" [1]. For residential buildings IEA Annex 56 explores the range of cost effective energy related renovation measures by parametric calculations for generic buildings in 8 European countries (AT, DK, IT, NO, PT, ES, SE, CH). These assessments aim at illustrating the reductions of primary energy consumption and of carbon emissions which are feasible with cost effective energy related retrofit measures as well as at demonstrating the synergies and trade-offs between energy efficiency measures and renewable energy deployment [2].

Subsequently, the methodology to determine comprehensively the impacts of energy related renovation measures is described, including the definition of a reference scenario. For a Swiss multi-family building, which is investigated here in more detail, and 9 packages of energy related renovation measures, the related characteristics are indicated. The impact of the following factors for the assessments and methodological aspects are highlighted and demonstrated for the case of this building:

- Energy performance of the building before renovation, especially energy performance of the building envelope (insulation of roof and walls as well as U-value of windows before renovation)
- Assumed energy prices: Current prices as well as their future development during the lifetime of the renovation measures (time range of 30 years)

2. Methodology of cost based impact assessment of energy and carbon emissions related building renovation

2.1. Impact indicators

The assessment of the buildings is done for the subsequent impacts:

- Costs: The assessment is based on a life-cycle cost approach, comprising all cost elements which are relevant, i.e. initial investment costs (including planning costs, professional fees, taxes and other project contingencies), energy costs and other running costs (operational and maintenance costs during the lifetime of the building element), replacement costs (if a building element has to be replaced during the assessment period), disposal costs for replaced building elements and possibly energy and carbon emission taxes.
- Primary energy use for heating, domestic hot water, ventilation and auxiliary electricity consumption: Net delivered primary energy, whereby on-site generated renewable energy reduces energy consumption of the building and thus net delivered energy respectively. Primary energy use of net delivered energy carriers is determined with the help of national conversion factors for the different energy carriers consumed. The conversion factor for electricity is based on the national mix of electricity sources consumed.
- Carbon emissions: Carbon emissions are determined by the energy carriers consumed and the corresponding carbon emission factors according to the Kyoto protocol. These emission factors comprise also upstream emissions and take into account the country specific mix of electricity consumed.

2.2. Methodology and input values for the life-cycle cost assessment

The cost assessment is performed dynamically for real costs (without inflation) applying a real discount and interest rate of 3% p.a., taking into account national standard life-times for the renovated building elements.

Table 1 illustrates the estimated average energy prices for the upcoming 30 years which are used to take into account energy cost savings due to higher energy performance of the renovated Swiss MFB.

Table 1. Assumed average (discounted) energy prices for the upcoming 30 years (for a Swiss MFB)

Energy carrier	Unit	**Standard scenario**	Low price scenario	High price scenario
Oil	EUR / kWh	**0.1**	0.07	0.13
Electricity	EUR / kWh	**0.2**	0.16	0.24
Wood pellets	EUR / kWh	**0.1**	0.07	0.13

2.3. Reference renovation option

To correctly and fairly determine the impacts of energy related renovation measures on costs, primary energy use and carbon emissions, it is necessary to define one or more reference renovation options which comprise all measures which are necessary to fully re-establish the functionality of the building, not aiming at improving its energy performance yet. For the assessment it was assumed that the building originally has an oil heating system. In the reference renovation option, this is replaced too, to also have a new heating system with a lifetime of 20 years as in the case of energy related options changing the heating system. The reference renovation is called "anyway renovation". In contrast, the energy related renovation options may comprise or be an alternative to the measures of the anyway renovation and go in any case beyond the reference renovation to have a better energy performance as a result (e.g. for windows: Reference option: Repainting and repairing; energy related option: New windows).

3. Specification of the Swiss multi-family building and of 9 packages of energy related renovation measures

For a generic Swiss multi-family building (MFB) 9 different packages of energy related renovation measures (M1 – M9) are assessed in comparison with two reference "anyway renovation" options (R1/2; see Table 2).

Table 2. Description of different packages of renovation measures M1 to M9 and of the reference cases 1 and 2 for a MFB in Switzerland

Renovation Package	Description
Ref 1/2	The plastering of the wall is restored, the wall is repainted, and the roof is refurbished, yet all those measures do not improve energy performance of the building. In the reference case 2 there is already some pre-existing insulation of the roof and the walls.
M1	The wall is insulated with 12 cm of rock wool.
M2	The wall is insulated with 30 cm of rock wool.
M3	Additionally to M2, the roof is insulated with 12 cm of rock wool.
M4	Additionally to M2, the roof is insulated with 36 cm of rock wool.
M5	Additionally to M4, the cellar ceiling is insulated with 10 cm of rock wool.
M6	Additionally to M4, the cellar ceiling is insulated with 16 cm of rock wool.
M7	Additionally to M6, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.3.
M8	Additionally to M6, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.
M9	Additionally to M6, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 0.8.

Table 3 provides an overview on two different reference cases with "anyway renovation" measures as well as on the measures and their properties for 9 packages of renovation measures with increasing ambition and impact on the energy performance. Reference case 2 represents a building which has already windows with a better U-value and some roof and wall insulation before renovation.

Table 3. Data for different packages of renovation measures M1 to M9 and two different reference cases Ref 1 and Ref 2 for a Swiss MFB.

Parameter	Unit	Reference 1/2 (new heating)	M1	M2	M3	M4	M5	M6	M7	M8	M9
Wall - Costs	EUR/m^2 wall	58	128	140	140	140	140	140	140	140	140
Wall - thickness of insulation material	cm	0/8	12	30	30	30	30	30	30	30	30

Parameter	Unit	Reference 1/2 (new heating)	M1	M2	M3	M4	M5	M6	M7	M8	M9
Wall - λ of insulation material	W/mK	- /0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Wall - lifetime of renovation measure	a	40	40	40	40	40	40	40	40	40	40
Window - Costs	EUR/m^2 window	33	33	33	33	33	33	33	763	832	875
Window - U-Value	W/m^2K	2.7/2.1	2.7	2.7	2.7	2.7	2.7	2.7	1.3	1	0.8
Window - g-value		0.75/0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.55	0.45	0.45
Window - lifetime	a	-	30	30	30	30	30	30	30	30	30
Roof - Costs	EUR/m^2 roof	58	58	58	146	188	188	188	188	188	188
Roof - thickness of insulation material	cm	0/10	-	-	12	36	36	36	36	36	36
Roof - λ of insulation material	W/mK	- /0.04	-	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Roof - lifetime of renovation measure	a	30	30	30	30	30	30	30	30	30	30
Cellar ceiling - Costs	EUR/m^2 cellar ceiling	-	-	-	-	-	87	93	93	93	93
Cellar ceiling - thickness of insulation material	cm	-	-	-	-	-	10	16	16	16	16
Cellar ceiling - λ of insulation material	W/mK	-	-	-	-	-	0.04	0.04	0.04	0.04	0.04
Cellar ceiling - lifetime	a	-	-	-	-	-	40	40	40	40	40
Energy demand for heating	kWh/m^2	158	107	99	77	73	58	57	32	27	23
Peak heating capacity required	kW	45/40	33	31	26	25	22	21	15	14	13
Conversion efficiency of oil heating		0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Conversion efficiency of geothermal heat pump		3.2	3.5	3.5	3.7	3.7	3.8	3.8	4	4.1	4.1
Conversion efficiency of wood pellets heating		0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85

Calculation of energy demand is based on the input parameters for the different elements of the building envelope, taking into account both the original U-values of the building and their changes due to the renovation.

4. Methodological impacts on the assessment of the effects of 9 different renovation packages

For the case of the generic Swiss MFB the following paragraphs illustrate on the one hand the effects of the initial energy performance of buildings before renovation on the impacts of 9 different energy related renovation packages on yearly primary energy consumption, carbon emissions and life-cycle costs. On the other hand, the impact of different future energy prices is highlighted.

4.1. Influence of initial energy performance of building envelope on economic viability of energy related measures

Figures 1 and 2 illustrate the significance of the initial energy performance of a MFB before renovation on the cost effectiveness of energy related measures as well as on their impact on primary energy demand and GHG emissions. The better is the initial energy performance of the MFB, the poorer are the achievable reductions of primary energy demand and GHG emissions. Since marginal benefits of additional insulation are distinctly decreasing it is less cost effective or might even be not cost effective any more to further improve energy performance of the building.

Measures are cost effective if resulting annual life-cycle costs are lower than in the case of an anyway renovation. In the case poor initial energy performance of the MFB (Ref 1), all measures are cost effective, since resulting annual costs are lower than in the anyway renovation case of Ref 1. Renovation package M6 is the cost optimal package for Ref 1. This holds also if the oil heating system is substituted by a ground source heat pump system or by a wood pellets system (green and blue curves in Figures 1 and 2). Beyond the cost optimum, M7 to M9 yield further reductions in primary energy demand and carbon emissions. They are still cost effective compared to the anyway renovation case Ref 1. Replacement of the oil heating system by a geothermal heat pump reduces costs and allows for further reductions of energy and carbon emissions by the measures M1 - M9.

If the MFB has a better energy performance before renovation (Ref 2), only the insulation of the cellar ceiling (M5 and M6) and of the roof (M3 and M4) are still cost effective compared to the anyway renovation of Ref 2. The better insulation of the walls and the roof are only slightly or nearly cost effective since the walls and the roof have already some insulation in Ref 2. Better windows with lower U-values are definitively not cost effective any more. Cost optimal renovation option is still M6, especially if combined with a geothermal heat pump.

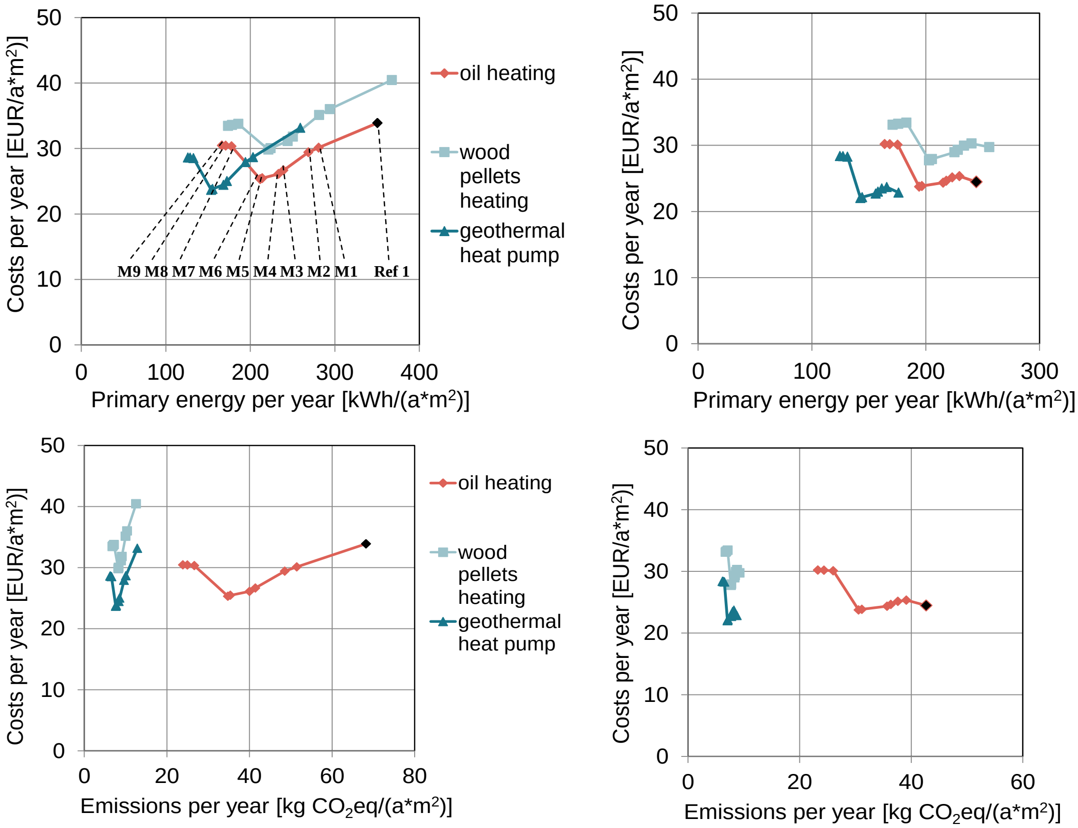

Fig. 1. Swiss MFB: Annual life-cycle **costs** and resulting **primary energy demand** (top figures) and **carbon emissions** (bottom figures) per m^2 conditioned gross floor area for a reference "anyway" renovation, replacing the oil heating (black square dot) as well as for additionally carrying out 9 energy related renovation options M1-M9 (red curves). Blue and green curves: Instead of an oil heating system a wood pellets heating system and a geothermal heat pump system is initially installed respectively.
Left side figures: Reference case 1 (low initial energy performance). **Right side figures**: Reference case 2 (higher initial energy performance of the building undergoing renovation)

4.2. Influence of future energy prices on economic viability of energy related measures

Figure 2 illustrates the fact that energy prices matter very much for resulting life-cycle costs and hence for economic viability of energy related renovation measures. Instead of the standard price scenario of Table 1 which starts from actual energy prices and assumes a price increase of 30% for the upcoming 30 years, a high price and a low price scenario (see Table 1) are assumed in Figure 2. M6 is still the cost optimal option. But with low energy prices M7-M9 are not cost effective any more. Therefore it is crucial to think aboout future energy price development and to integrate resulting expectations into the economic assessment of renovation options.

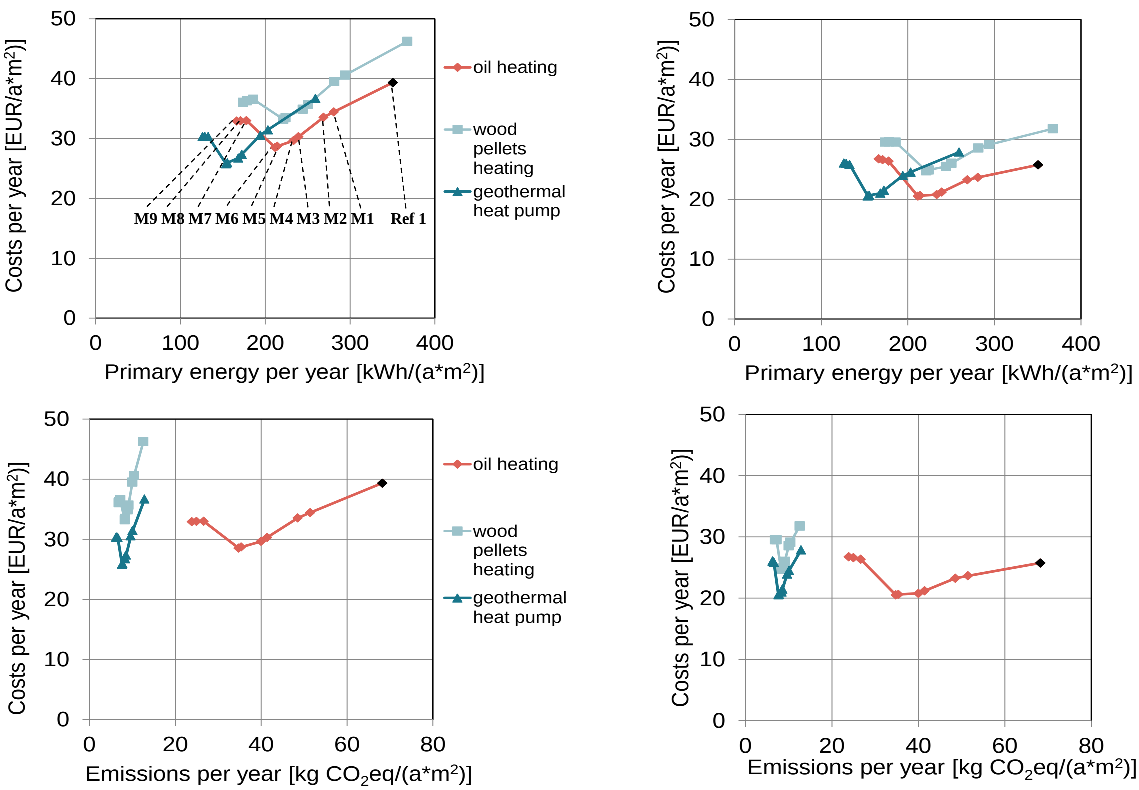

Fig. 2. Swiss MFB: Annual life-cycle costs and resulting **primary energy demand** (**top figures**) and **carbon emissions** (**bottom figures**) per m^2 conditioned gross floor area for the reference "anyway" renovation (reference case 1: Low initial energy performance of the MFB), replacing the oil heating system (black square dot) as well as for additionally carrying out 9 energy related renovation options M1-M9 (red curve). Blue and green curves: Instead of a replacement of the oil heating a wood pellets heating system (blue curves) and a geothermal heat pump system (green curves) is initially installed respectively.
Left side figures: **High** energy price scenario (see Table 1). **Right side figures**: **Low** energy price scenario (see Table 1)

5. Concluding remarks

To get to a realistic impact assessment for energy related renovation measures a comprehensive approach applying a correct methodology is important. While impact assessment comparing the renovation project with a situation in which no measures are carried out might be appropriate for indicating energy and emissions reductions of the renovation project, this is not correct for determining the cost of energy related renovation measures. The cost of the energy related renovation has to be compared with the cost of an anyway renovation that would be necessary to maintain the same functionality and life expectancy of the building elements concerned also in the absence of the renovation project, in order to recognize the additional costs and to get a fair comparison.

Acknowledgements

The research has been carried out within the framework of Annex 56 of the Energy in Buildings and Communities programme of the IEA. Support from the Swiss Federal Office of Energy is gratefully acknowledged. The use of a tool from the FP7 Eracobuild programme's INSPIRE project and related data for developing and carrying out generic calculations is gratefully acknowledged.

References

[1] IEA EBC Annex 56 "Cost effective energy and carbon emissions optimization in building renovation"; http://www.iea-annex56.org/
[2] Ott W, Bolliger R, Ritter V, Citherlet St, Périsset B, Favre D, de Almeida M, Ferreira M. Methodology for Cost-effective energy and carbon emissions optimization in building renovation. Preliminary report, IEA EBC-programme; April 2014