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Detailed Case Studies - a closer look at cost effective energy and carbon emission optimization in Europe

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Abstract

Renovating the European building stock shows high potential for energy and greenhouse gas reductions. Thereby the optimum balance between energy conservation or efficiency measures and renewable energy generation on-site has to be found, regarding the primary energy and greenhouse gas reductions as well as the renovation costs. The whole life cycle of the building has to be considered and therefore Life Cycle Cost (LCC) calculations and Life Cycle Impact Assessment (LCIA) are of importance.
This paper shows some results to these issues and was prepared within the frame of the IEA EBC Annex 56 research project [1].

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Keywords: Energy and Carbon Optimization, LCC, LCIA, Co-Benefits, high performance renovation, renewable energy generation on-site

1. Introduction

Reducing the carbon emissions in the building sector requires corresponding measures. The use of renewable energy sources generated on-site or off-site, can be such measure as well as energy conservation and efficiency measures. From economic perspective energy conservation and efficiency measures can be as effective as the use/generation of renewable energy. So following questions arise: Where is the balance point between these two types of measures in a cost/benefit perspective? What is the best building performance in terms of less energy consumption, less carbon emissions and attainment of co-benefits with the lowest effort?

For that reason a new methodology for energy and carbon emission optimized building renovations was developed within the IEA EBC Annex 56 research project [2].

The developed methodology provides the basis for the assessment and evaluation of energy related renovation options. A comprehensive analysis of the different renovation options is necessary to find the appropriate measures for each individual building. Energetic, ecological and economic criteria are part of this comprehensive analysis, including also co-benefits as overall added values. The goal is to develop cost effective energy and carbon emissions

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optimizations in building renovations with the help of Life Cycle Cost (LCC) calculations, Life Cycle Impact Assessments (LCIA) and with the identification of co-benefits as an added value to the energy and carbon emissions reduction.

In a first step the methodology was tested with generic single-family and multi-family residential buildings from Austria, Denmark, Norway, Portugal, Spain, Sweden and Switzerland which are typical for the corresponding building stock in those countries. In total ten different renovation packages were defined and parametric calculations were performed. The goal was to identify the impacts of the renovation measures on the building envelope on the primary energy use, the carbon emissions and the costs, testing also the influence of three different heating systems.

In a following step the methodology is validated on the basis of real building renovations. Therefore seven Detailed Case Studies of major energy renovations from six European countries (see Table 1) were compiled and analyzed within the IEA EBC Annex 56, in order to evaluate the impact and relevance of different renovation measures and strategies on the Primary Energy Demand and Global Warming Potential as well as on the Life Cycle Costs. Those Detailed Case Studies are residential and non-residential buildings, which serve as role model projects in each individual country.

For the Detailed Case Studies parametric studies were performed based on the developed methodology. Each partner could define the characteristics of the investigated renovation packages according to what is feasible in each country. The idea was to include different thermal standards (insulation of building envelope) and different energy sources for heating and domestic hot water preparation (fossil fuels and renewables), different ventilation situations (mechanical and natural) as well as also renewable energy generation on-site.

Table 1: Overview of analyzed Detailed Case Studies within the IEA EBC Annex 56 project

Country	Site	Building type	Year(s) of construction	Year(s) of renovation	Gross heated floor area after renovation
Austria	Johann-Böhmstraße, Kapfenberg	Multi-family building	1960 – 1961	2012 – 2014	2845 m²
Czech Republic	Kamínky 5, Brno	Elementary School	1987	2009 – 2010	9909 m²
Denmark	Traneparken, Hvalsø	Multi-family building	1969	2011 – 2012	5293 m²
Portugal	Neighborhood RDO, Porto	Two-family building	1953	2012	123 m²
Portugal	Montarroio, Coimbra	Single-family building	XIVth – XVIth (late medieval)	(2015) Ongoing	48 m²
Spain	Lourdes Neighborhood, Tudela	Multi-family building	1970	2011	1474 m²
Sweden	Backa röd, Gothenburg	Multi-family building	1971	2009	1357 m²

This paper gives a short insight into the work and results of the performed parametric studies, by way of example shown on hand of the Austrian Detailed Case Study.

2. Investigated renovation packages of the Austrian Detailed Case Study

The reference case includes only renovation measures which don´t result in an energetic improvement of the building. Only a new oil heating system is included. The renovation package v1 represents a minimum thermal renovation according to the Austrian national regulations. Renovation package v2 includes the high thermal insulation of all building components and a mechanical ventilation system with heat recovery. The renovation package v3 is the actually executed building renovation including in addition also pre-fabricated façade elements and a renewable energy generation on-site by a solar thermal installation and photovoltaic modules. By varying the energy source for heating and domestic hot water, in the renovation packages v1 and v2, in total 10 renovation options could be defined. Figure 1 shows an overview of the investigated renovation packages and measures.

Renovation package	Building envelope	Mechanical ventilation	Heating and domestic hot water	Energy generation on-site
Reference case	**NO** energetic improvement of the building components	**NO** mechanical ventilation	Fuel oil	**NO** energy generation on-site
V1	Min. required thermal insulation of all building components	**NO** mechanical ventilation	fuel oil natural gas district heating biomass	**NO** energy generation on-site
V2	High thermal insulation of all building components	Mechanical ventilation with heat recovery	fuel oil natural gas district heating biomass	**NO** energy generation on-site
V3	High thermal insulation of all building components	Mechanical ventilation with heat recovery	District heating based on renewables, solar thermal	Photovoltaic and solar thermal installations

Figure 1: Investigated renovation packages for the Detailed Case Study “Kapfenberg”, Austria (source: AEE INTEC)

3. Main findings of the Detailed Case Study “Kapfenberg”, Austria

Figure 2 shows the calculation results of the Austrian Detailed Case Study “Kapfenberg”. On the left side the comparison of the Life Cycle Costs (y-axis) with the Global Warming Potential (x-axis), on the right side with the total Primary Energy Demand (renewable and non-renewable share included) on the x-axis.

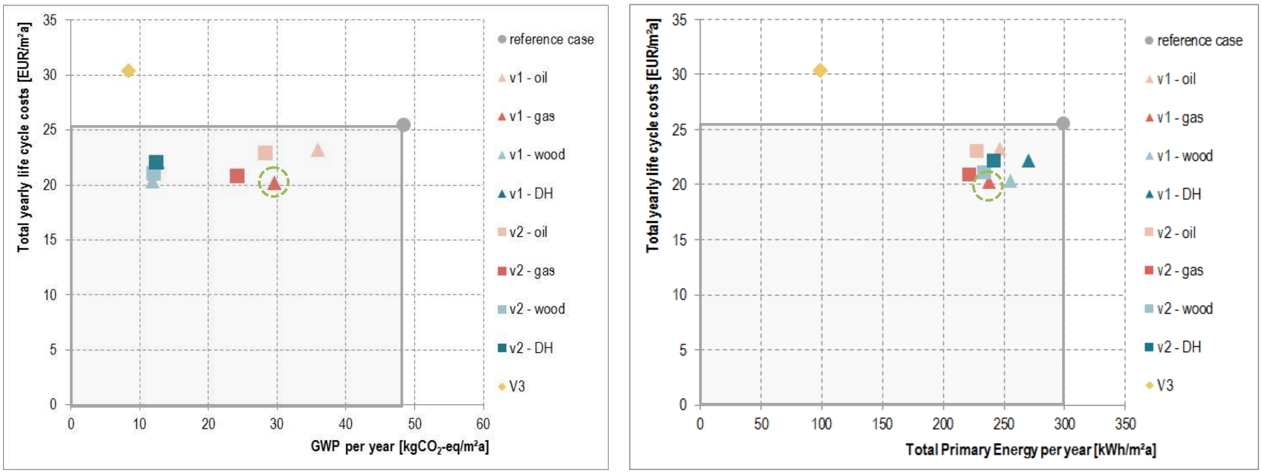

Figure 2: Life Cycle Costs in comparison with Global Warming Potential (left chart) and total Primary Energy Demand (right chart) of the Detailed Case Study “Kapfenberg”, Austria (source: econcept AG and AEE INTEC)

The results show that all renovation packages v1 and also all renovation packages v2 are cost-effective (grey marked area). That means the yearly specific Life Cycle Costs of each renovation package are lower than the Life Cycle Costs of the reference case (grey dot in Figure 2). The exceptional case is the executed renovation package v3, which is not cost-effective, since the yearly specific Life Cycle Costs are higher than the Life Cycle Costs of the reference case.

Following reasons for these higher Life Cycle Costs were identified:

- Higher investment costs for the building envelope due to the new developed pre-fabricated façade elements.
- Higher investment costs for the building services due to the energy generation on-site (solar thermal and photovoltaic installations).
- Higher annual costs for the building envelope and the building services due to the pre-fabricated façade elements and the energy generation on-site.
- Lower energy consumption costs due to the on-site generated renewable energy, which cannot fully compensate the higher investment and annual costs of the building renovation.

Figure 2 shows that the lowest Global Warming Potential, and still cost-effective solution, is achieved by the renovation packages v1 and v2 with heating and domestic hot water preparation based on wood and district heating. Those four renovation packages achieve annual Global Warming Potentials of about 12 kg_{CO2-eq}/m^2a, which is a reduction of nearly 36 kg_{CO2-eq}/m^2a or 75%, compared to the reference case.

The executed renovation package v3 would achieve an annual Global Warming Potential of 8.4 kg_{CO2-eq}/m^2a. This would be a reduction of 40 kg_{CO2-eq}/m^2a or 83%, compared to the reference case.

The lowest total Primary Energy Demand, and still cost-effective solution, is achieved by renovation package v2 with natural gas as energy source for heating and domestic hot water preparation. This renovation package achieves a total Primary Energy Demand of 222 kWh/m²a. This is a reduction of about 77 kWh/m² or 26% compared to the reference case.

The executed renovation package v3 would achieve a total Primary Energy Demand of 100 kWh/m²a which would be a reduction of 200 kWh/m²a or 67%, compared to the reference case.

The cost optimal solution for the Austrian Detailed Case Study is renovation package v1 with heating and domestic hot water preparation based on natural gas (see green circle in Figure 1). This cost optimal solution achieves a Global Warming Potential of 30 kg_{CO2-eq}/m^2a, a total Primary Energy Demand of 238 kWh/m²a and annual Life Cycle Costs of 20.19 €/m²a.

In relation to the most ambitious, but sill cost-effective solution, the gap to the cost optimal solution is:

- Global Warming Potential: with additional annual Life Cycle Costs of 0.14 €/m²a the Global Warming Potential could be reduced from 30 kg_{CO2-eq}/m^2a (cost optimal solution) to 12 kg_{CO2-eq}/m^2a (lowest Global Warming Potential). In other words, with Life Cycle Costs which are 1% higher than the Life Cycle Costs of the cost optimal solution, the Global Warming Potential could be reduced by 60%.
- Total Primary Energy Demand: with additional annual Life Cycle Costs of 0.66 €/m²a the total Primary Energy Demand could be reduced from 238 kWh/m²a (cost optimal solution) to 222 kWh/m²a (lowest total Primary Energy Demand). 3% higher annual Life Cycle Costs would result in a 7% lower total Primary Energy Demand.

To have in further consequence a more detailed understanding of the influence of the different renovation measures on the results, an analysis of the influence of improving the thermal quality of the building envelope, the modification of the energy source for heating and domestic hot water preparation and the renewable energy generation on-site was conducted.

Following Table 2 includes the main findings of this analysis. The results are divided into the main parameters Global Warming Potential, total Primary Energy Demand and Life Cycle Costs and presented for each of the investigated energy sources for heating and domestic hot water preparation.

The influence of improving the thermal quality of the building envelope is given in the first results column. The numbers represent the change of the results when the thermal quality of the building envelope is improved. Negative values mean reductions; positive numbers display an increase due to the renovation measures. The numbers in the brackets express the relative changes.

The second and third columns give the results for the influence of modifying the energy source for heating and domestic hot water preparation. In the left column the numbers represent the savings potentials due to the change of the energy source on the Global Warming Potential, the total Primary Energy Demand and the Life Cycle Costs as absolute and relative saving potentials (in brackets), always compared with the energy source which achieves the highest value in each individual category, when the thermal quality of the building envelope is lower. The right column shows the same results but for an improved thermal quality of the building envelope.

The fourth and last results column shows the influence of the renewable energy generation on-site. The numbers represent the change of the results when a renewable energy generation on-site is taken into account (+ is increase, - is reduction).

Table 2: Analysis of the influence of the different renovation measures – absolute and relative changes and savings potentials

	Influence of improving the thermal quality of the building envelope	Influence of modifying the energy source for heating and domestic hot water preparation left: lower thermal quality of the building envelope right: higher thermal quality of the building envelope		Influence of renewable energy generation on-site
Parameter	change	savings potential	savings potential	change
Global Warming Potential (GWP)				
Oil	-7.6 kg_{CO2-eq}/m^2a (-21%)	-	-	n/a
Natural gas	-5.5 kg_{CO2-eq}/m^2a (-19%)	6.3 kg_{CO2-eq}/m^2a (18%)	4.2 kg_{CO2-eq}/m^2a (15%)	n/a
Wood	+0.1 kg_{CO2-eq}/m^2a (+1%)	24.0 kg_{CO2-eq}/m^2a (67%)	16.3 kg_{CO2-eq}/m^2a (58%)	n/a
District heating	-0.2 kg_{CO2-eq}/m^2a (-2%)	23.3 kg_{CO2-eq}/m^2a (65%)	15.9 kg_{CO2-eq}/m^2a (56%)	-4.0 kg_{CO2-eq}/m^2a (-33%)
Total Primary Energy Demand (PED)				
Oil	-33 kWh/m^2a (-13%)	23 kWh/m^2a (9%)	14 kWh/m^2a (6%)	n/a
Natural gas	-30 kWh/m^2a (-13%)	23 kWh/m^2a (12%)	20 kWh/m^2a (8%)	n/a
Wood	-35 kWh/m^2a (-14%)	15 kWh/m^2a (5%)	8 kWh/m^2a (3%)	n/a
District heating	-42 kWh/m^2a (-16%)	-	-	-143 kWh/m^2a (-59%)
Life Cycle Costs (LCC)				
Oil	-0.34 €/m^2a (-1%)	-	-	n/a
Natural gas	+0.66 €/m^2a (+3%)	3.06 €/m^2a (13%)	2.06 €/m^2a (9%)	n/a
Wood	+0.72 €/m^2a (+4%)	2.92 €/m^2a (13%)	1.86 €/m^2a (8%)	n/a
District heating	-0.08 €/m^2a (±0%)	1.12 €/m^2a (5%)	0.86 €/m^2a (4%)	+8.24 €/m^2a (+27%)

4. Conclusions

When looking at the results in Table 2 it is evident that the influence of improving the thermal quality of the building envelope on the Global Warming Potential is very low for renewable energy sources like wood and district heating but higher for fossil fuels like oil and natural gas. Reductions of the total Primary Energy Demand are given and are quite similar for all energy sources. The influence on the Life Cycle Costs is also quite similar for all energy sources but not really relevant.

The Global Warming Potential savings, due to the modification of the energy source for heating and domestic hot water preparation, is higher for the renewable energy sources than for the fossil fuels. However vice versa, the total Primary Energy Demand savings potential is higher for the fossil fuels and lower for the renewable energy sources. The main reasons for that are the Global Warming and Primary Energy conversion factors and the efficiency of the heating systems. Regarding the Life Cycle Costs natural gas and wood show the highest reduction potentials and district heating a lower value.

The influence of the energy generation on-site is quite high. Significant reductions of the Global Warming Potential and the total Primary Energy Demand can be achieved by the renewable energy generation on-site but with the highest Life Cycle Costs of all investigated renovation packages.

Summarized following conclusions can be drawn:

- The Global Warming Potential reduction is highest when changing the energy source for heating and domestic hot water preparation from fossil fuels to renewables. Furthermore the reduction potential due to the renewable energy generation on-site is higher than the reduction potential of the improved building envelope.
- The total Primary Energy Demand reduction is higher when improving the thermal quality of the building envelope than when changing the energy source for heating and domestic hot water preparation. However, the highest total Primary Energy Demand savings potential is given when generating renewable energy on-site.
- The influence of improving the thermal quality of the building envelope on the Life Cycle Costs is relative low. It is higher when the energy source for heating and domestic hot water preparation is modified. For the Austrian Detailed Case Study the large solar thermal and photovoltaic installations increase the Life Cycle Costs more than all other investigated renovation measures on the building envelope and the building services.

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