Cost effective energy and carbon emission optimization of buildings renovation shown in an Austrian case study

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ABSTRACT: The European building stock shows high potential for energy and greenhouse gas reductions. At the same time the current renovation rates are too low and high performance renovations are not always achievable.
The optimum balance between the primary energy / greenhouse gas reduction and the renovation costs has to be found. The whole life cycle of the building has to be considered and therefore Life Cycle Cost (LCC) calculations and Life Cycle Impact Analysis (LCIA) are of importance.
Furthermore the optimum balance between energy conservation or efficiency measures and renewable energy generation on-site has to be defined as well.
This paper shows some suggestions to answer these issues and was prepared within the frame of the IEA EBC Annex 56 research project.[1]

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

1 INTRODUCTION

The recasting of the EPBD [2] forces the re-evaluation of energy conservation and efficiency measures. This approach implies a strong investment on the building envelope and in energy efficient building services (demand side approach) as well as on the use of on-site renewables (supply side approach). Additionally present standards and requirements are mainly focused on new buildings (e.g. passive house standard). Although specific conditions of renovation projects require comprehensive measures, recommendations for the renovation of existing buildings are rare.

Reducing the carbon emissions in the building sector requires overarching 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 is needed. The objective of the IEA EBC Annex 56 research project includes the development of this

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new methodology to enable cost effective renovations of existing buildings, finding the right balance between energy efficiency measures and the renewable energy use.

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

This paper gives a short insight into the work of the IEA EBC Annex 56, shown on hand of an Austrian case study.

2 METHODOLOGY AND TOOLS

2.1. Life Cycle Costs (LCC)

Calculating the Life Cycle Costs requires the definition of a reference situation (baseline) to properly determine the effects of an energy related renovation.

For each renovation measure or entire renovation package that is applied to the building the full costs of the renovation and the following use of the building are calculated. But the focus is only on energy related measures, which have an influence on the energy performance of the building. Costs related to building renovation measures, which do not improve the energy performance are not regarded (e.g. new flooring). So therefore it is not the assessment of the total renovation costs!

The defined reference case is a so-called “anyway renovation” and comprises only measures which have to be carried out “anyway”. Such anyway renovation measures can occur because the technical lifetime of the building element has been achieved or the functionality or service quality of the element is not sufficient any more.

The time range for the cost calculation is defined as the whole lifetime of the building or the particular building element. The exchange, replacement, demolition and the disposal of the building (elements) should be included also.

Following costs are taken into account in the LCC calculation:

- Investment costs
- Replacement costs during the lifetime of the building
- Running costs, including energy costs, possible costs for carbon emissions, costs for auxiliary energy consumption, operational costs and maintenance costs.

Detailed definitions for the cost evaluation can be found in the draft results report of STA “Methodology” of the IEA EBC Annex 56 project.[3]

In the IEA EBC Annex 56 the global cost method is used to calculate the (global) costs for the different renovation measures based on a life cycle approach. Future developments of interest rates and energy prices are considered.

In this context three specific terms should be mentioned, which are also illustrated in Figure 1. These are:

- Cost optimum
- Cost neutrality
- Cost efficiency

The starting point of the global cost curve in Figure 1 is the point “requirements in force”. This point represents the global costs of the reference situation where only renovation measures are carried out that have no influence on the energy performance of the building.

From that point on the different energy related measures reduce the primary energy consumption and also the global costs right up to the cost optimum (point O).

Further renovation measures still reduce the primary energy consumption but increase the global costs. The point N describes the cost neutrality. It is the situation where the global costs of the energy related renovation measures are equal to the costs of the requirements in force.

The range from the point requirements in force to the cost optimum and to the cost neutrality is defined as the cost efficiency.

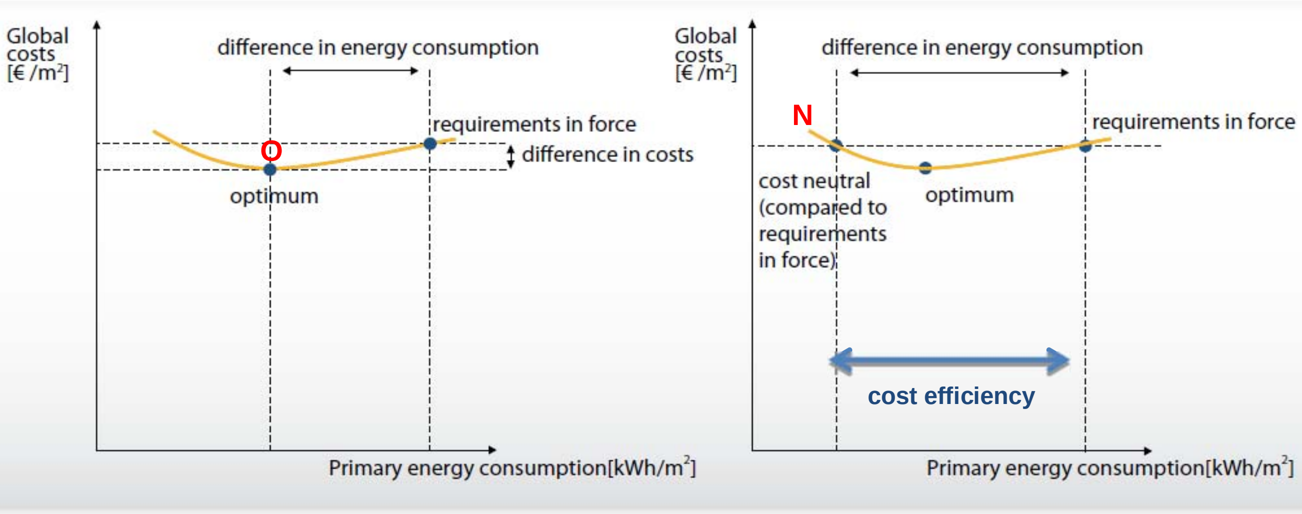

Figure 1. Global cost curve – illustration of cost optimality (O), cost neutrality (N) and cost efficiency[5]

2.2. Life Cycle Impact Analysis (LCIA)

Performing an LCIA requires the definition of the temporal and the physical system boundaries:

The temporal system boundary describes the elementary stages of the building life cycle which should be included in the calculation. According to IEA EBC Annex 56 following stages should be included:

- Material production
- New materials transportation between the production site and the building site
- Material replacement
- Energy consumption during the building operation
- End of life transportation of wasted materials
- Waste management of removed materials

Following stages however are neglected:

- Maintenance
- Repair
- Building construction and deconstruction

The physical system boundary defines all materials and energy flows which have to be included in the analysis. In order to perform a LCIA of a renovated building according to IEA EBC Annex 56 the contributions of construction elements and building-integrated technical systems (BITS) should be taken into account.

The category “construction element” includes the materials of the building elements which have an influence on the energy performance of the building. Each element (roof, façade, etc.) is made of one or more layers and to each layer a certain material can be assigned.

The category “BITS” includes the installed technical equipment for the operation of the building. BITS include different systems, such as heating or mechanical ventilation. It also includes the on-site energy generation of renewable energy sources. Each system again consists of different components (boiler, pumps,…) and each component is made of different materials and may consume energy.

To display the LCIA results different parameters exist. In this paper following parameters are used to analyze the Life Cycle Impact:

- PED – Primary Energy Demand. It represents the total primary energy used and includes the non-renewable part (fossils, nuclear, primary forests) as well as the renewable part (hydro, solar, wind, and biomass). PED is expressed in [kWh].
- GWP – Global Warming Potential. This value is related to the emissions of greenhouse gases. The potential of these greenhouse gases is compared to the global warming potential of CO_2 and expressed in [$kg_{CO2\text{-}Equ}$].

2.3. Co-Benefits

In the IEA EBC Annex 56 it is of prime importance to include also side effects or co-benefits of the renovation measures in the considerations and recommendations and not only regard the energy /greenhouse gas savings and the costs. Thereby it is necessary to differentiate the co-benefits that arise from the different renovation measures.

A special attention is on the elaboration of the differences between co-benefits that arise from energy efficiency measures and co-benefits which come from measures regarding the use of on-site renewable energy. As already mentioned is the objective also to identify the optimal balance between “minimization of demand” and “generation of renewable energy” measures. In further consequence co-benefits can play an important role in the decision making process besides the global costs, the primary energy demand and the greenhouse gas emissions.

The main regarded co-benefits are:

- Thermal comfort
- Natural lighting
- Air quality
- Condensation and mold control
- Noise
- Operational comfort
- Reduced exposure to energy price fluctuations
- Aesthetics/Architectural integration
- Useful living area
- Safety (intrusion and accidents)
- Pride/Prestige
- Ease of installation

3 AUSTRIAN CASE STUDY

3.1. Description of the existing building before the renovation

The Austrian case study is a residential building which was built between 1960 and 1961. The four-story building has a length of 65 m (east and west oriented façade) and a depth of 10 m (north and south oriented façade). On each floor nine apartments were located which varied from 20 m² to 65 m^2 living area. These apartments didn´t meet the current way of living because they were too small and for this reason not all flats were rented.

The existing building was a typical Austrian building from the 1960’s made of sandwich concrete elements without an additional insulation. The basement ceiling was insulated with approx. 6 cm polystyrene. The old roof was a pitched roof with no insulation. The ceiling to the unheated attic was insulated with 5 cm wood wool panels. The existing windows were double glazed windows with an

U-value of 2.50 W/m²K. The missing airtightness of the existing windows caused high infiltration losses. Figure 2 shows the existing building before the renovation.

Figure 2. Picture of the building before the renovation (source: AEE INTEC)

In the table 1 the U-values of the main building elements of the existing building before the renovation are stated:

Table 1. U-values of the building elements before the renovation

Building element	U-value before renovation
Façade	0.87 W/m²K
Basement Ceiling	0.39 W/m²K
Windows, doors	2.50 W/m²K
Roof	0.74 W/m²K

A variety of different heating systems was installed in the existing building: a central gas heating system, decentralized electric furnaces, electric night storage heaters, oil heaters, wood-burning stoves and coal furnaces. No mechanical ventilation system was installed in the existing building.

Table 2 shows the most important project data (climate data, energy consumption) of the Austrian case study before the renovation.

Table 2. Parameters of the existing building

Parameter	Value
Heating degree days	3794 (base temp. 20°C)
Cooling degree days	-
Gross heated floor area (GHFA)	2845 m²
Calculated heating energy demand (excl. hot water)	105.50 kWh/m²y
Calculated hot water energy demand	12.78 kWh/m²y
Actual heating energy consumption (excl. hot water)	150.97 kWh/m²y
Actual hot water energy consumption	23.78 kWh/m²y
Actual electricity consumption (excl. hot water and heating)	58.62 kWh/m²y
Installed heating capacity	135.85 kW

3.2. Objectives of the renovation

The main objectives of the building renovation were the upgrade of the Indoor Environmental Quality, the living area and the heating system. The objectives of the national research project [4] were the development of prefabricated active and passive façade and building service modules which should be implemented, tested and evaluated in this case study. It should be possible to achieve a plus-energy building after renovation by integration of on-site renewable energy generation. In detail following specific renovation objectives were defined:

- Development of prefabricated active and passive façade modules and of prefabricated modules for the building services.
- 80% reduction of the heating energy demand of the existing building.
- At least 80% of the final energy demand of the renovated building should be covered by renewable energy sources.
- 80% reduction of the CO_2 emissions of the existing building.
- Integration of the building into existing thermal and electricity grids to handle the temporarily occurring mismatches, peaks and storage necessities to achieve plus-energy after the renovation.
- Changing the layout of the apartments to adapt them to the requirements and needs of the future residents.
- Raising awareness of the residents and the property management for sustainable energy efficient usage of the apartments.

3.3. Description of the renovated building

On one hand the overall energy saving concept was based on energy efficiency measures (reduction of transmission, infiltration and ventilation losses as well as energy efficient building services) and on a high ratio of renewable energy sources on the other hand. Additionally an intelligent integration of the building in the existing grids enables the achievement of a plus-energy building after the renovation.

Building envelope

Instead of conventional insulation systems the façade of the Austrian case study was covered with large-sized active and passive façade elements. The idea was to create a prefabricated façade element which allowed the use of different surfaces with the same substructure. The surface materials could vary between wood, stone or fiber cement boards, e.g. or active components like solar thermal or photovoltaic panels.

The supply and disposal ducts of the building services were also integrated in the building envelope (in separate elements). This enabled an easier installation as well as the possibility to access the supply and disposal ducts from outside without the disturbance of the residents.

The existing old pitched roof was removed and a new flat roof was installed. The old roof has to be removed because of two main reasons: the old truss was not able to carry the charges of the photovoltaic power plant and the orientation of the old pitched roof was not ideal for the active energy generation.

The new flat roof is highly insulated with approximately 35-40 cm insulation. On the new roof the photovoltaic panels and also the mechanical ventilation units were installed.

Although a higher insulation would have been desirable for energetically reasons, due to the low room height no more than 6 cm of insulation at the basement ceiling was mounted.

The new windows were already integrated in the prefabricated façade modules and were of high thermal quality (triple glazing). To avoid overheating of the rooms in the warm periods of the year an external shading device was installed.

The U-values of the described building elements after the renovation can be seen in following Table 3.

Table 3. U-values of the building elements after the renovation

Building element	U-value after renovation
Façade	< 0.17 W/m²K
Basement Ceiling	< 0.30 W/m²K
Windows, doors	< 0.90 W/m²K
Roof	< 0.10 W/m²K

With these renovation measures a heating energy demand (excl. hot water) of 16.90 kWh/m²y after the renovation was calculated. This is a reduction of nearly 84% compared to the existing building.

Building services

The local district heating was the main energy source for heating and domestic hot water supply. Additionally 144 m² solar thermal panels were installed on the south façade. Heat provided by district heating and solar thermal system is stored in a 7500 liter buffer storage. From the buffer storage a 2-pipe-system (flow and return) brings the heat to the 32 flats where the heat for domestic hot water is stored in a small boiler. Radiators emit the heat in the flats.

A new mechanical ventilation system with heat recovery was installed in the renovated building (65% heat recovery efficiency / SFP = 0.45 Wh/m³). The ventilation units were positioned on the flat roof and the existing stacks and installations ducts of the building were used for the ventilation ducts. In one half of the flats the ventilation system is controlled automatically based on the CO_2 concentration, in the other half of the flats the residents can control the ventilation system by a three-stage controller individually.

For additional energy generation on-site photovoltaic panels with a size of 550 m² resp. 80 kW were installed on the roof on a steel construction in form of a wing. 80 m² resp. 12 kW were also installed on the south façade.

During the renovation of the case study a monitoring system was also installed to monitor and analyze the most important energy parameters (thermal energy and electricity) as well as comfort parameters.

Figure 3 shows the west oriented façade of the building after the renovation with the solar thermal and photovoltaic modules in front and with the photovoltaic elements on the roof.

Figure 3. Picture of the building after the renovation (source: AEE INTEC)

4 DEFINITION OF THE INVESTIGATED RENOVATION PACKAGES

To compare the realized renovation with other possible renovations three different renovation packages were defined and analyzed in the frame of the IEA EBC Annex 56 research project. Those three renovation packages range from the minimum required renovation measures to the high thermal insulation of the building envelope including mechanical ventilation with heat recovery right up to the high performance renovation of the building including also renewable energy generation on-site. For comparison a reference case was also defined. In the following chapters the four different packages are described.

Reference case

In this renovation package only anyway measures were carried out which don´t result in an energetic improvement of the building. It was just assumed that the existing heating and domestic hot water system had to be renewed and therefore a new oil boiler was installed.

Renovation package v1

The objective of renovation package v1 was to fulfill only the minimum requirements of the Austrian OIB guideline 6[3]. These minimum requirements pertained to the U-values of the components, the heating energy demand and the final energy demand.

In this renovation package v1 neither mechanical ventilation nor a solar thermal system nor a photovoltaic system were included. Renovation measures included the thermal insulation of the roof and the façade, the mounting of new windows with an external shading system and the renewal of the heating and domestic hot water system. For the heating and domestic hot water system four different energy sources were evaluated: oil, natural gas, wood pellets and the local district heating system.

Renovation package v2

In renovation package v2 the building had the same U-values as the actually realized renovation package. The difference between these two renovation packages was that in renovation package v2 the thermal insulation was done by a conventional thermal insulation composite system instead of a prefabricated façade system.

Like in renovation package v3 also in renovation package v2 a mechanical ventilations system with heat recovery was installed. But in contrast no solar thermal system and no photovoltaic system were included. This means that renovation package v2 did not have active energy generation from renewable energy sources on-site.

The renovation package v2 therefore included renovation measures regarding roof, façade, windows, mechanical ventilation and the renewal of heating and domestic hot water system. Again oil, natural gas, wood pellets and the local district heating were defined as the four evaluated energy sources for heating and domestic hot water.

Renovation package v3

Renovation package v3 represented the actually realized renovation of the Austrian case study as described in chapter 3.3.

5 RESULTS

5.1. LCC and LCIA

Following Figure 4 shows the results of the Global Warming Potential calculation, compared with the calculated costs of each renovation package (bases on a time period of 60 years). This comparison helps to identify the cost optimum, regarding the GWP.

3) OIB guideline 6 of the national Austrian Institute of Construction Engineering (OIB), which focuses on energy efficiency and thermal insulation [6], defines requirements and limits and refers to relevant norms as well as the OIB calculation guidelines on "Energy-Related Behaviour of Buildings" [7] for determining energy target values. Directive 6 also defines the contents and form of energy certificates.

Looking at the results it is obvious that the reference case has the highest Global Warming Potential with a value of about 45 $kg_{CO2\text{-}Equ}/m^2y$. All defined renovation packages achieve an improvement. Considering the costs all renovation packages, except the renovation package V3, are cost efficient, which means that the yearly specific (life cycle) costs are lower than the (life cycle) costs of the reference case.

In detail four different scenarios achieve similar good results. Renovation packages v1 and v2 with heating and domestic hot water supply based on wood pellets and district heating achieve a GWP of about 5-7 $kg_{CO2\text{-}Equ}/m^2y$. The yearly specific costs of these four varieties range between 19 €/m²y to 21 €/m²y. The cost optimum renovation would be renovation package v2 with a wood pellets based heating and domestic hot water supply.

The Global Warming Potential of renovation package v3 is admittedly lower than of all the other renovation packages, but with a value of 26 €/m²y the costs of this renovation package are about 35% higher than the cost optimum.

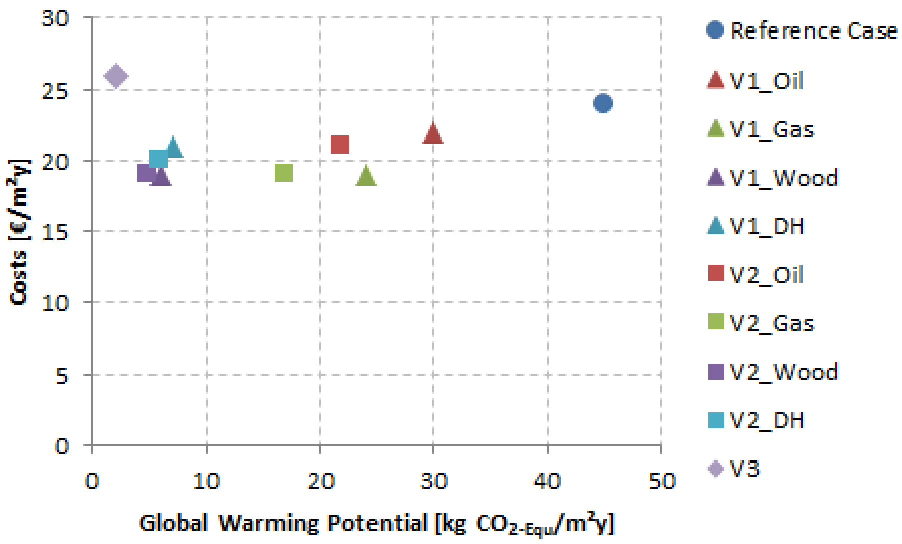

Figure 4. Annual specific costs compared to the Global Warming Potential of the different renovation packages (source: econcept AG and AEE INTEC)

Figure 5 shows the calculation results of the different renovation packages regarding the Primary Energy Demand and the Cost. By comparison of the two parameters the cost optimum renovation regarding the Primary Energy Demand can be identified.

The detailed analysis of the calculation results shows that the Primary Energy Demand of the reference case is the highest with a value of about 225 kWh/m²y. The PED of the renovation packages v1 and v2 ranges between 125 kWh/m²y and 190 kWh/m²y. The best result regarding the PED is achieved by renovation package v3. The Primary Energy Demand of the realized renovation is 50 kWh/m²y. This is a reduction compared to the reference case of nearly 80% and compared to the other renovation packages of about 60-70%.

But regarding also the costs of each renovation package it is obvious that the cost optimum renovation is renovation package v2 with heating and domestic hot water supply based on natural gas. The Primary Energy Demand of this renovation packages is about 128 kWh/m²y and the annual specific cost are about 19 €/m²y.

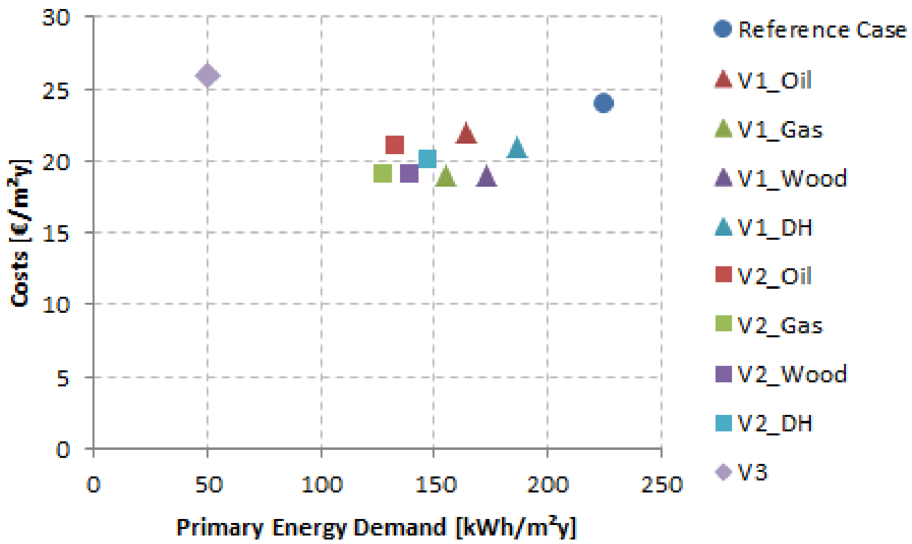

Figure 5. Annual specific costs compared to the Primary Energy Demand of the different renovation packages (source: econcept AG and AEE INTEC)

Summarized it can be said that the cost optimum renovation package is depending on the parameter chosen. If the key parameter is the Global Warming Potential than renovation package v2 with a wood pellets based heating and domestic hot water supply would be the cost optimum renovation. But if the Primary Energy Demand is the key parameter it changes to renovation package v2 with a heating and domestic hot water supply based on natural gas.

Renovation package v3, which represents the actually realized renovation package, achieves the lowest Global Warming Potential and Primary Energy Demand but the costs of the renovation are higher than the annual specific costs of all other renovation packages.

5.2. Co-benefits

Besides the reduction of the energy demand and the greenhouse gas emissions, the renovation of the building implicates further improvements and co-benefits. At this point only the co-benefits of the actually realized renovation are presented.

Through integration of all renovation measures in an overall architectural planning and design process the renovation of the building increases the pride/prestige and the reputation of the building which also affects user satisfaction.

The thermal insulation of the building envelope and the installation of the new windows with an external shading system brings following co-benefits:

- Due to the thermal insulation higher inner-surface temperatures are achieved in winter. This increases the thermal living comfort for the residents.
- New and airtight windows improve the thermal living comfort and the noise protection from the outside.
- Reduced solar inputs in the warm periods of the year, as a result of the installation of an external shading system, increase also the living comfort in the apartments.

The installation of a mechanical ventilation system with heat recovery brings following improvements and co-benefits:

- Improvement of the air quality by a reduction of the CO_2-concentration in the apartments.
- Reduction of the humidity in the rooms and therefore reduction of the condensation and mold.

The installation of a centralized and automatic heating and domestic hot water supply system results in an improved operational comfort.

The reduction of the energy demand as well as the renewable energy generation on-site by the solar thermal and photovoltaic systems reduces the exposure to energy price fluctuations.

The new constructed balconies have following advantages:

- Contribution to the improvement of the reputation of the building by integration in an overall architectural planning and design process.
- New functional area for the residents is available.
- Improved thermal quality of the building envelope by reducing thermal bridges of the balcony construction.

A barrier-free access to the building is possible after the renovation by the installation of an elevator and an arcade.

6 CONCLUSION

Historically the renovation of residential buildings in Austria were exempt from achieving energy requirements often resulting in high energy costs as well as low thermal comfort and low Indoor Environmental Quality. Additionally the apartments were too small for today´s requirements and needs, the access to the building was not barrier-free and the buildings were often run down.

A high performance renovation of these buildings, including the improvement of the energy efficiency, changes to the design and adaptations to modern ways of living has been carried out in limited cases.

The renovation concept, included prefabricated façade elements, new windows, a new roof, new building services (centralized heating and domestic hot water supply as well as a new mechanical ventilation system with heat recovery) and renewable energy generation on-site (solar thermal and photovoltaic).

Especially the renovation of the building with prefabricated façade elements had the advantages that the construction time at the construction site could be reduced and the renovation works could be done independently of the weather conditions.

The first feedback of the tenants was quite good: Most of the tenant´s expectations of the retrofit were fulfilled. The tenants were satisfied with the housing association and the different companies which carried out the renovation. The tenants were pleased with the information they received regarding the mechanical ventilation system and the heating and domestic hot water supply.

The comparison of the defined renovation packages and the calculation of the cost optimum demonstrate the importance of certain key parameters. If the key parameter is the Global Warming Potential the renovation package v2 with a wood pellets based heating and domestic hot water supply would be the cost optimum renovation. In this case a GWP of 5 $kg_{CO2\text{-}Equ}/m^2y$ and annual costs of 19 €/m²y were calculated. The Global Warming Potential of the other renovation packages ranges between 45 $kg_{CO2\text{-}Equ}/m^2y$ (reference case) as the worst result and 2 $kg_{CO2\text{-}Equ}/m^2y$ (renovation package v3) as the best result.

But if the Primary Energy Demand is chosen as the key parameter the cost optimum renovation changes to renovation package v2 with heating and domestic hot water supply based on natural gas. In this cost optimum renovation a Primary Energy Demand of 128 kWh/m²y and annual costs of 19 €/m²y were calculated. Summarized the calculated PED of the different renovation packages ranges between 225 kWh/m²y (reference case) as the worst result and 50 kWh/m²y (renovation package v3) as the best result.

The renovation package v3, which represents the actually realized renovation package, achieves the lowest calculated Global Warming Potential and also the lowest calculated Primary Energy Demand but the highest annual specific costs of all renovation packages. Therefore the renovation package v3 is not the cost optimum renovation in this comparison.

Although the calculation results show that the realized renovation is not the cost optimum renovation, all involved partners are aware of the project´s potential for future innovative renovation strategies. The project has to be seen as an Austrian flagship project, developing and testing new technologies and concepts for the near future and showing that renovation to plus-energy standard is possible. Only the additional funding of different authorities in Austria facilitated this renovation. Without this funding the renovation would not have been possible in this way.

But at this point it has to be highlighted that only this realized high performance renovation achieves the described co-benefits and these represent an important added value compared to the reference case and to the other renovation packages.

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Many thanks to all colleagues and project partners who have participated in these two projects and in this way contributed to the success of the work. A special thanks is dedicated to Roman Bolliger from econcept AG in Switzerland for performing the calculations of the Austrian case study and the different renovation packages.

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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].

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.

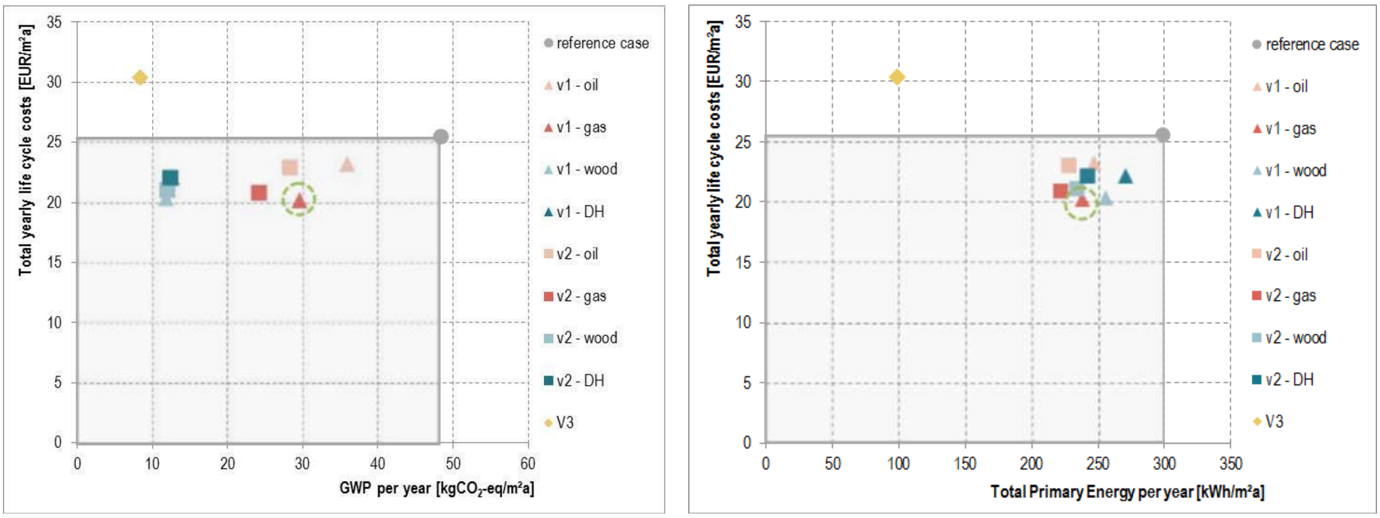

Figure 2: Life Cycle Costs in comparison with Global Warming Potential (left chart) and total Primary Energy Demand (right chart) of the Detailed Case Study "Kapfenberg", Austria (source: econcept AG and AEE INTEC)

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 $kg_{CO2\text{-}eq}$/m²a, which is a reduction of nearly 36 $kg_{CO2\text{-}eq}$/m²a or 75%, compared to the reference case.

The executed renovation package v3 would achieve an annual Global Warming Potential of 8.4 $kg_{CO2\text{-}eq}$/m²a. This would be a reduction of 40 $kg_{CO2\text{-}eq}$/m²a 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 $kg_{CO2\text{-}eq}$/m²a, 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 $kg_{CO2\text{-}eq}$/m²a (cost optimal solution) to 12 $kg_{CO2\text{-}eq}$/m²a (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/m²a (-13%)	23 kWh/m²a (9%)	14 kWh/m²a (6%)	n/a
Natural gas	-30 kWh/m²a (-13%)	23 kWh/m²a (12%)	20 kWh/m²a (8%)	n/a
Wood	-35 kWh/m²a (-14%)	15 kWh/m²a (5%)	8 kWh/m²a (3%)	n/a
District heating	-42 kWh/m²a (-16%)	-	-	-143 kWh/m²a (-59%)
Life Cycle Costs (LCC)				
Oil	-0.34 €/m²a (-1%)	-	-	n/a
Natural gas	+0.66 €/m²a (+3%)	3.06 €/m²a (13%)	2.06 €/m²a (9%)	n/a
Wood	+0.72 €/m²a (+4%)	2.92 €/m²a (13%)	1.86 €/m²a (8%)	n/a
District heating	-0.08 €/m²a (±0%)	1.12 €/m²a (5%)	0.86 €/m²a (4%)	+8.24 €/m²a (+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.

Acknowledgements

The work and results presented in this paper have been carried out within the frame of the IEA EBC Annex 56 project and the Austrian research project "e80^3-Buildings" [3] which was funded by the Federal Ministry for Transport, Innovation and Technology in the frame of the "Building of Tomorrow Plus" program.

Many thanks to all colleagues and project partners who have participated in these two projects and in this way contributed to the success of the work. Special thanks are dedicated to Roman Bolliger from econcept AG in Switzerland for performing the calculations of the Austrian Detailed Case Study and the different renovation packages.

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[1] IEA EBC Annex 56 – Cost-effective energy and carbon emission optimization in building renovation, http://www.iea-annex56.org, accessed at 09 February 2015.

[2] Ott, W., Bolliger, R., Ritter, V., Citherlet, St., Favre, D., Perriset, B, de Almeida, M., Ferreira, M.: Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56) – Methodology and Assessment of Renovation Measures by Parametric Calculations; report within the IEA EBC Annex 56; (2014)

[3] e80^3-Buildings – renovation concepts towards plus-energy building standard with prefabricated active roof and facade elements, integrated building services and grid integration; project funded by the Federal Ministry of Transport, Innovation and Technology in the frame of the "Building of Tomorrow Plus" program; see http://www.hausderzukunft.at/results.html/id7005, accessed at 15 January 2015

COST-EFFECTIVE ENERGY AND CARBON EMISSIONS OPIMISATION IN BUILDING RENOVATION – IEA EBC ANNEX 56

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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 Development and test of methodology

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 optimizations in building renovations with the help of Life Cycle Cost (LCC) calculations, Life Cycle Assessments (LCA) and with the identification of co-benefits as an added value to the energy and carbon emissions reduction (Ott et al.).
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. These generic buildings 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, the Carbon Emissions and the Life Cycle Costs, testing also the influence of three different heating systems.
Furthermore the methodology is also validated on the basis of real building renovations, so-called Detailed Case Studies (see Table 1). Therefore six major energy renovations from six European countries were compiled and analysed within the IEA EBC Annex 56. 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 generation (fossil fuels and renewables), different ventilation situations (mechanical and natural) as well as renewable energy generation on-site (PV and solar thermal installations).

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**	**GHFA*) 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
Spain	Lourdes Neighborhood, Tudela	Multi-family building	1970	2011	1474 m²
Sweden	Backa röd, Gothenburg	Multi-family building	1971	2009	1357 m²

*) GHFA…Gross Heated Floor Area

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 buildings.

3 Generic building calculations

Figure 1 shows the calculation results for the Austrian generic multi-family building. Different renovation measures on the building envelope were tested, including insulation of the exterior wall, the roof and the cellar ceiling as well as the replacement of the windows. In Figure 1 the generic building is equipped with an oil heating system.

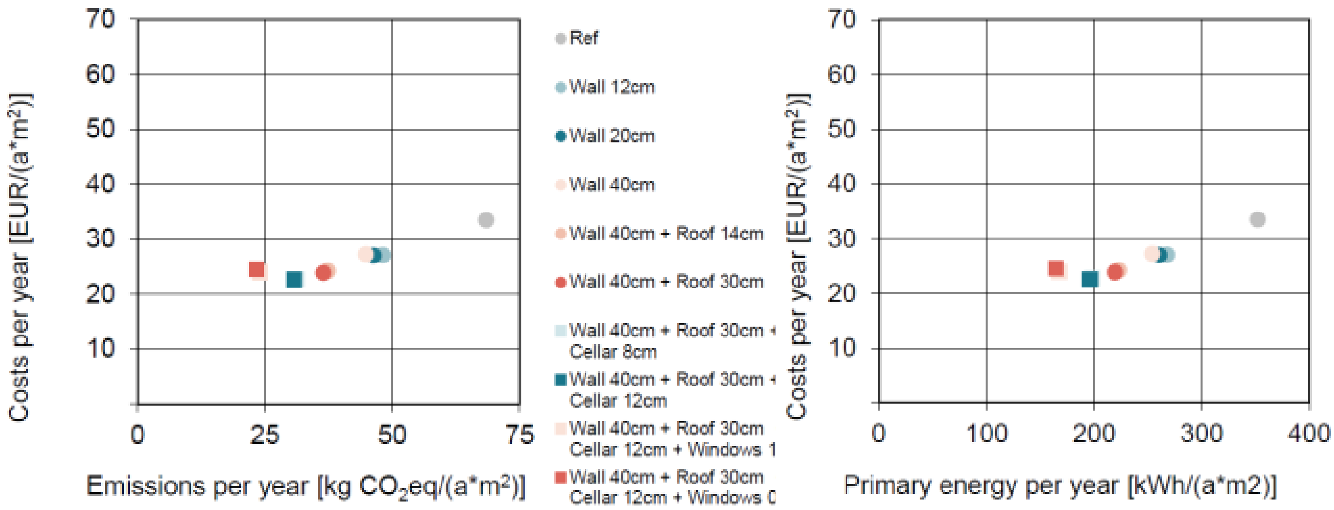

Figure 1: Comparison of cost-effectiveness of energy efficiency renovation measures for the generic multi-family building in Austria (source: IEA EBC Annex 56)

For the different renovation measures the Life Cycle Costs, the total Primary Energy (renewable and non-renewable part included) and the Carbon Emissions were calculated and compared. The left chart shows the LCC and Carbon Emissions results, the right chart the results of the LCC and the Primary Energy.

The results in Figure 1 show that all investigated renovation measures are cost-effective. 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 1). In further consequence the results also show that the number of building elements renovated is more important than the energy efficiency level of a single building element. For instance the Carbon Emissions savings due to the increase of the insulation thickness on the exterior wall from 12 cm to 40 cm are only very small compared to the savings due to the additional insulation of the roof.
The cost-optimum renovation would be the insulation of the exterior wall, the roof and also of the cellar ceiling. The replacement of the windows, to more energy efficient ones, would further reduce the Carbon Emissions and Primary Energy but would also increase the Life Cycle Costs slightly. Nevertheless, this additional measure would also be cost-effective over the whole building life cycle.

The renovation measures on the building envelope were also tested with different heating systems. For the Austrian generic buildings also wood pellets and geothermal heat pump were considered. The following graphs in Figure 3 summarize the cost curves for those investigations.

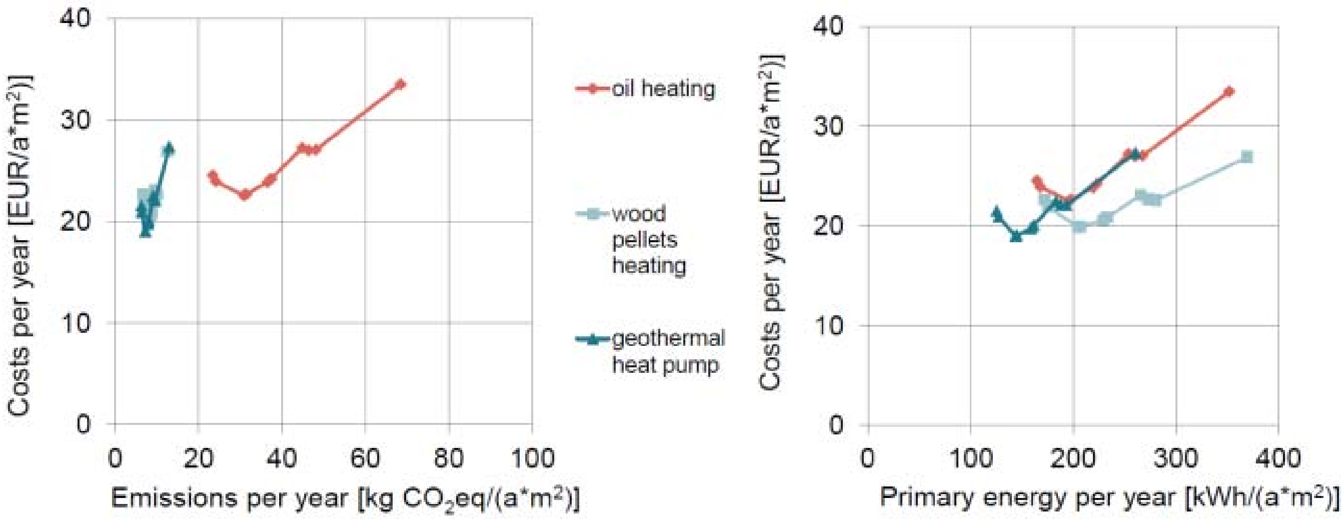

Figure 2: Aggregated comparison of cost-effectiveness of energy efficiency renovation measures for different heating systems and related impacts on Carbon Emissions and Primary Energy use, for the generic multi-family building in Austria (source: IEA EBC Annex 56)

The results show that a switch to Renewable Energy Sources (RES) reduces the Carbon Emissions more significantly than energy efficiency measures on the envelope. Even in the reference cases of the two RES the Carbon Emissions are lower than in all renovation packages of the oil heating. Otherwise have the energy efficiency measures on the envelope a larger impact on the reduction of the Primary Energy than the switch to RES.
Furthermore, the results show that the change of the heating system doesn’t change the cost-effectiveness of energy efficiency measures on the envelope. The cost optimal package of the renovation measures on the envelope remains the same in all three cases (heating systems).

4 Detailed Case Studies

4.1 Investigated renovation packages of the Austrian Detailed Case Study

For the Detailed Case Studies different renovation packages were defined. Thereby the most feasible renovation solutions for this building were investigated. 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 total 10 renovation options could be defined. Table 2 shows an overview of the investigated renovation packages and measures.

Table 2: Investigated renovation packages for the Detailed Case Study “Kapfenberg”, Austria

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 and solar thermal	Photovoltaic and solar thermal installations

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

Figure 3 shows the calculation results of the Austrian Detailed Case Study “Kapfenberg”. On the left side the comparison of the Life Cycle Costs with the Carbon Emissions and on the right side with the total Primary Energy.

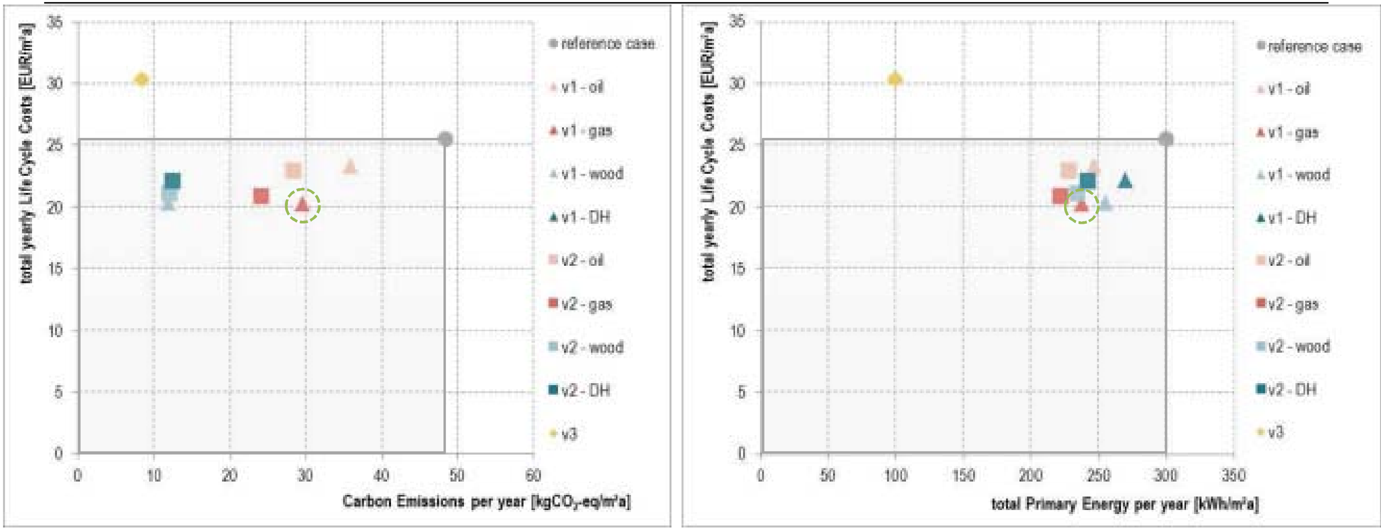

Figure 3: Comparison of cost-effectiveness of energy efficiency renovation measures for the Detailed Case Study “Kapfenberg”, Austria (source: econcept AG and AEE INTEC)

The results show that all renovation packages v1 and also all renovation packages v2 are cost-effective (grey marked area). 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 3 also shows that the lowest Carbon Emissions, and still cost-effective solution, are achieved by the renovation packages v1 and v2 with heating and domestic hot water generation based on wood and district heating (DH). Those four renovation packages achieve annual Carbon Emissions of about 12 kgCO2-eq/m²a, which is a reduction of nearly 36 kgCO2-eq/m²a or 75%, compared to the reference case.
The executed renovation package v3 would achieve annual Carbon Emissions of 8.4 kgCO2-eq/m²a. This would be a reduction of 40 kgCO2-eq/m²a or 83% compared to the reference case.

The lowest total Primary Energy, and still cost-effective solution, is achieved by renovation package v2 with natural gas as energy source for heating and domestic hot water generation. This renovation package achieves a total Primary Energy of 222 kWh/m²a. This is a reduction of about 77 kWh/m²a or 26% compared to the reference case.
The executed renovation package v3 would achieve a total Primary Energy 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 generation based on natural gas (see green circle in Figure 3).

This cost optimal solution achieves Carbon Emissions of 30 kgCO2-eq/m²a, a total Primary Energy 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:

- Carbon Emissions: with additional annual Life Cycle Costs of 0.14 €/m²a the Carbon Emissions could be reduced from 30 kgCO2-eq/m²a (cost optimal solution) to 12 kgCO2-eq/m²a (lowest Carbon Emissions). In other words, with Life Cycle Costs which are 1% higher than the Life Cycle Costs of the cost optimal solution, the Carbon Emissions could be reduced by 60%.
- Primary Energy: with additional annual Life Cycle Costs of 0.66 €/m²a the total Primary Energy could be reduced from 238 kWh/m²a (cost optimal solution) to 222 kWh/m²a (lowest total Primary Energy). 3% higher annual Life Cycle Costs would result in a 7% lower total Primary Energy.

5 Conclusions

The generic calculations have shown that it is important to act on as many envelope elements as possible. The number of building elements renovated is more important than the energy efficiency level of a single building element. A switch to RES reduces the Carbon Emissions more significantly than energy efficiency measures on the envelope but the energy efficiency measures on the envelope have a larger impact on the reduction of Primary Energy needs. Furthermore the change of the heating system does not influence the cost-effectiveness of energy efficiency measures on the envelope. The cost optimal package of renovation measures on the envelope remains the same. Another finding was that the impact of embodied energy use in the renovation process is quite low.

From the analysis of the Detailed Case Study following conclusions can be drawn:
The Carbon Emissions reduction is highest when changing the energy source for heating and domestic hot water generation 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 reduction is higher when improving the thermal quality of the building envelope than when changing the energy source for heating and domestic hot water generation. However, the highest total Primary Energy 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 generation 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.

6 Acknowledgements

The work and results presented in this paper have been carried out within the frame of the IEA EBC Annex 56 project and the Austrian research project “e80^3-Buildings” which was funded by the Federal Ministry for Transport, Innovation and Technology in the frame of the “Building of Tomorrow Plus” program.
Many thanks to all colleagues and project partners who have participated in these two projects and in this way contributed to the success of the work. Special thanks are dedicated to Roman Bolliger from econcept AG in Switzerland for performing the calculations of the Austrian generic building and the Austrian Detailed Case Study.

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Primary Energy and Carbon Emissions reductions in building renovation

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ABSTRACT:

Within the framework of the IEA EBC Annex 56 research project six different Detailed Case Studies from six European countries were compiled and analysed. Such Detailed Case Studies are residential and non-residential building renovations, which serve as model projects in each individual country.

For each Detailed Case Study different renovation packages with sets of measures were tested, including Life Cycle Cost and Life Cycle Assessment. Main issues were primary energy use and related carbon emissions of such buildings as well as the costs incurred by investments in energy related renovation measures and by the building use during the estimated life cycle period.

The calculation results within the Detailed Case Studies have shown that high carbon emissions and Primary Energy reductions are possible, where the corresponding renovation measures are also cost effective, which means that the Life Cycle Costs of the individual measures are lower than the Life Cycle Costs of the reference case.

1. INTRODUCTION

Several standards regarding energy consumption have emerged in the last decade, defining increasing requirements, and culminating with the recent emergence of the “nearly-zero energy” buildings concept. However, these standards are mainly focused on new buildings ignoring, most of the time, the existing ones that represent the least efficient, the largest consumers and the largest share of the building stock.

Having in mind the overall objective of slowing down climate change, measures for the use of renewable energy can be as effective as energy conservation and efficiency measures and sometimes be obtained in a more cost effective way. In existing buildings, the most cost-effective renovation solution is often a combination of energy efficiency measures and measures for utilizing renewable energy.

Within the framework of the IEA EBC Annex 56 six different Detailed Case Studies from six European countries were compiled and analysed. Such Detailed Case Studies are residential and non-residential buildings, which serve as model projects in each individual country.

Table 1 shows an overview of the investigated buildings, including information to the building type, the years of construction, the years of renovation and the gross heated floor areas.

Table 1: Overview of the Detailed Case Studies in the IEA EBC Annex 56 (source: IEA EBC Annex 56)

Country	Site	Building type	Year(s) of construction	Year(s) of renovation	Gross Heated Floor Area
Austria	Johann-Böhmstraße, Kapfenberg	Multi-family building	1960 - 1961	2012 - 2014	2845 m²
Czech Republic	Kaminky 5, Brno	Elementary School	1987	2009 - 2010	9909 m²

Country	Site	Building type	Year(s) of construction	Year(s) of renovation	Gross Heated Floor Area
Denmark	Traneparken, Hvalsø	Multi-family building	1969	2011 - 2012	5293 m³
Portugal	Neighborhood RDL, Porto	Two-family building	1953	2012	123 m²
Spain	Lourdes Neighborhood, Tudela	Multi-family building	1970	2011	1474 m²
Sweden	Backa röd, Gothenburg	Multi-family building	1971	2009	1357 m²

2. METHODOLOGY

Each Detailed Case Study describes and tests several renovation packages with sets of measures regarding:

- Building envelope - measures to improve the thermal quality of the building envelope, i.e. insulation of the façade, the roof and the floor as well as new windows
- Building Integrated Technical Systems – measures on technical systems for heating, domestic hot water, cooling, auxiliaries, lighting, ventilation and common appliances
- Energy sources for heating, cooling and domestic hot water preparation
- Renewable energy generation on-site – measures for the renewable energy generation on-site, e.g. solar thermal installation or photovoltaic modules

The renovation measures range from minimum respectively average renovation measures to high performance, comprehensive measures. The definition of the investigated packages was up to each country and was performed according to what is feasible in each country. Variations of different energy sources for heating and domestic hot water were considered to evaluate the influence of the energy source on the total results.

Besides those renovation measures which lead to a reduction of the energy demand of the building also a reference case was defined, which represents the starting point on the global cost curve and which represents the basis for the comparison with the other defined renovation packages.

The reference case should include only renovation measures which have to be carried out anyway. Therefore this reference case can also be named as “anyway renovation”.

The assessment of all renovation packages was performed according to the methodology developed within the IEA EBC Annex 56, including Life Cycle Costs (LCC) and Life Cycle Assessment (LCA). Main issues are primary energy use and related carbon emissions of such buildings as well as the costs incurred by investments in energy related renovation measures and packages and building use during the estimated life cycle period.

The analysed parameters were the carbon emissions, as an indicator related to the emissions of greenhouse gases, expressed in kgCO_2-eq, the total Primary Energy, which represents the total primary energy used, including the non-renewable part as well as the renewable part, expressed in kWh and the Life Cycle Costs, including investment costs and annual costs, expressed in €.

3. RESULTS

3.1 CARBON EMISSIONS REDUCTIONS

Figure 1 shows the carbon emissions reduction potentials of the six Detailed Case Studies. The reduction potentials are shown as absolute values and as relative reduction potentials. The filled parts of the columns represent the reduction, which can be achieved independently of the chosen renovation package (henceforth called “minimum reduction”). The arrows indicate the ranges between the lowest and the highest possible reduction potentials. The top of each column stands for the highest possible reduction potential.

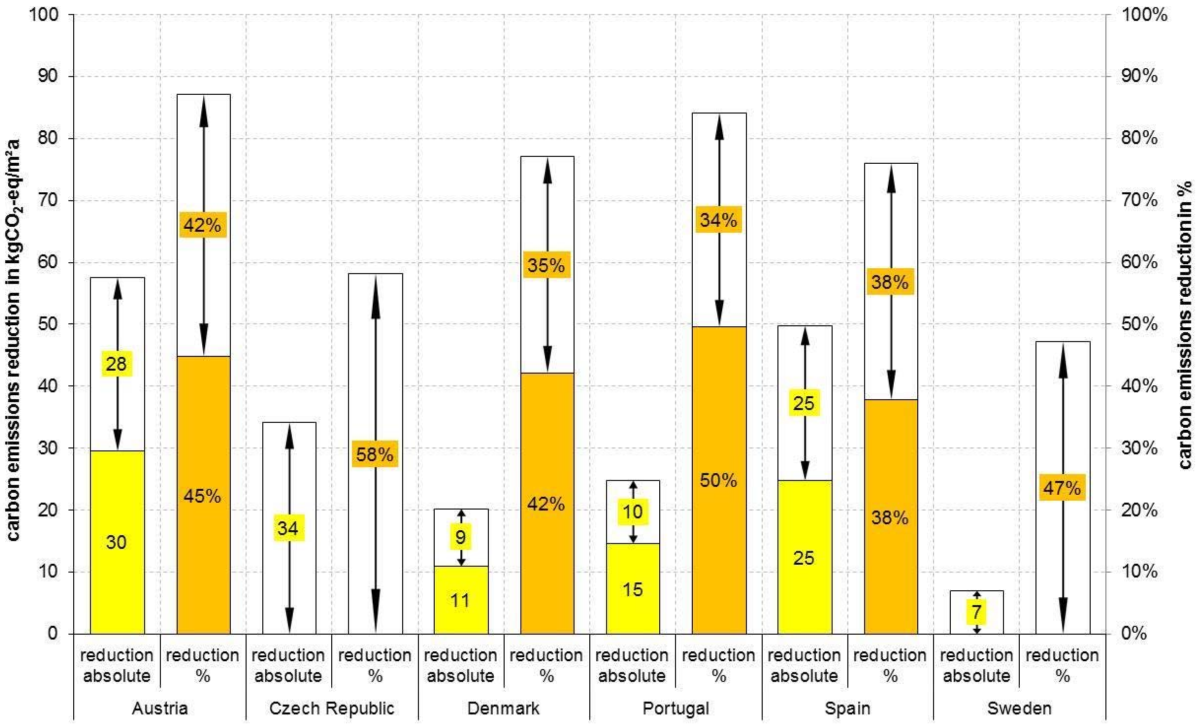

Figure 1: Carbon emissions reduction potential of the six Detailed Case Studies. The absolute and the relative reduction potentials are presented as minimum reduction and also as range between the minimum and maximum reduction. (source: IEA EBC Annex 56)

The chart shows that the Austrian Detailed Case Study achieves the highest minimum reduction of all investigated buildings with a value of 30 $kgCO_2$-eq/m² a and also the highest possible savings with 58 $kgCO_2$-eq/m² a, corresponding to a reduction of 87% compared to the reference case.

The Danish Detailed Case Study shows the smallest absolute reduction potential with values between 11 $kgCO_2$-eq/m² a and 20 $kgCO_2$-eq/m² a. The reason for that low absolute reduction is the quite low carbon emissions of the reference case. However looking at the relative reduction potential the values are high and range between 42% and 77% reduction, which is a result of the energy related renovation measures on the building envelope.

The investigation of the different renovation packages in the Portuguese Detailed Case Study shows a very high relative reduction potential with more than 50% (up to 84% possible). This is the highest value of all six Detailed Case Studies. To achieve this high relative reduction a combination of both, improving the energy performance of the building envelope and the change of the energy source for heating and domestic hot water preparation, is necessary. But the calculations have shown that for these significant reductions the insulation thickness of each building component is not that important. The addition of more insulation on the building envelope doesn´t result in higher carbon emissions reductions.

The Spanish Detailed Case Study reaches similar results as Austria. The absolute savings potential ranges between 25 $kgCO_2$-eq/m²a and 50 $kgCO_2$-eq/m²a which is a reduction of 38% to 76% compared to the reference case. Also in the Spanish case the high carbon emissions of the reference case lead to those high reductions of the investigated renovation packages.

For the Swedish and the Czech Detailed Case Studies no minimum reduction is given. That means the reduction potentials range between 0 $kgCO_2$-eq/m²a and 34 $kgCO_2$-eq/m²a (Czech Republic) and 7 $kgCO_2$-eq/m²a (Sweden). Compared to the reference case these are reductions of up to 58% in the Czech case and up to 47% in the Swedish case.

In addition to the carbon emissions reductions the analysis of the corresponding Life Cycle Costs is shown in Figure 2. The chart demonstrates the possible Life Cycle Cost reductions, when bringing the carbon emissions to the lowest value. That means for each Detailed Case Study the LCC of the renovation package with the lowest annual carbon emissions was compared to the LCC of the individual reference cases.

The analysis shows that the LCC can be reduced from 2 €/m²a in the Austrian Detailed Case Study up to 67 €/m²a in the Swedish Detailed Case Study. In relative value these are reductions of 6% in Austria to 50% in Sweden. The reasons for the low reduction in Austria are the quite low LCC of the reference case and much more important the high investment costs of the executed renovation, due to the prefabricated façade and the large photovoltaic and solar thermal installations. Therefore the LCC are higher than they would be without these particular measures.

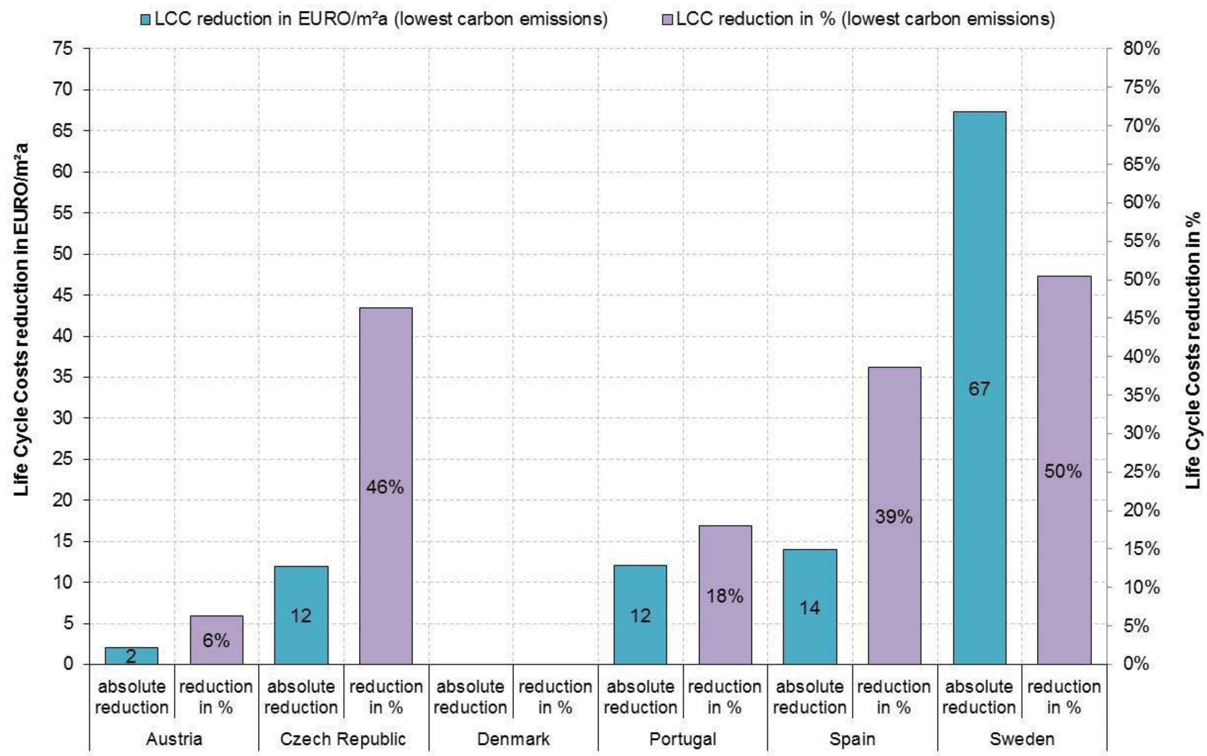

Figure 2: Life Cycle Costs reduction potentials of the six Detailed Case Studies. The absolute reduction potential and the relative reduction potential are presented as values between the reference case and the renovation package which achieves the lowest carbon emissions. (source: IEA EBC Annex 56)

3.2 TOTAL PRIMARY ENERGY REDUCTIONS

Similar to the analysis of the carbon emissions reduction potentials of the six Detailed Case Studies in Figure 1, the total Primary Energy reduction potentials are shown in Figure 3. Again the absolute values and the relative reduction potentials are presented for each Detailed Case Study.

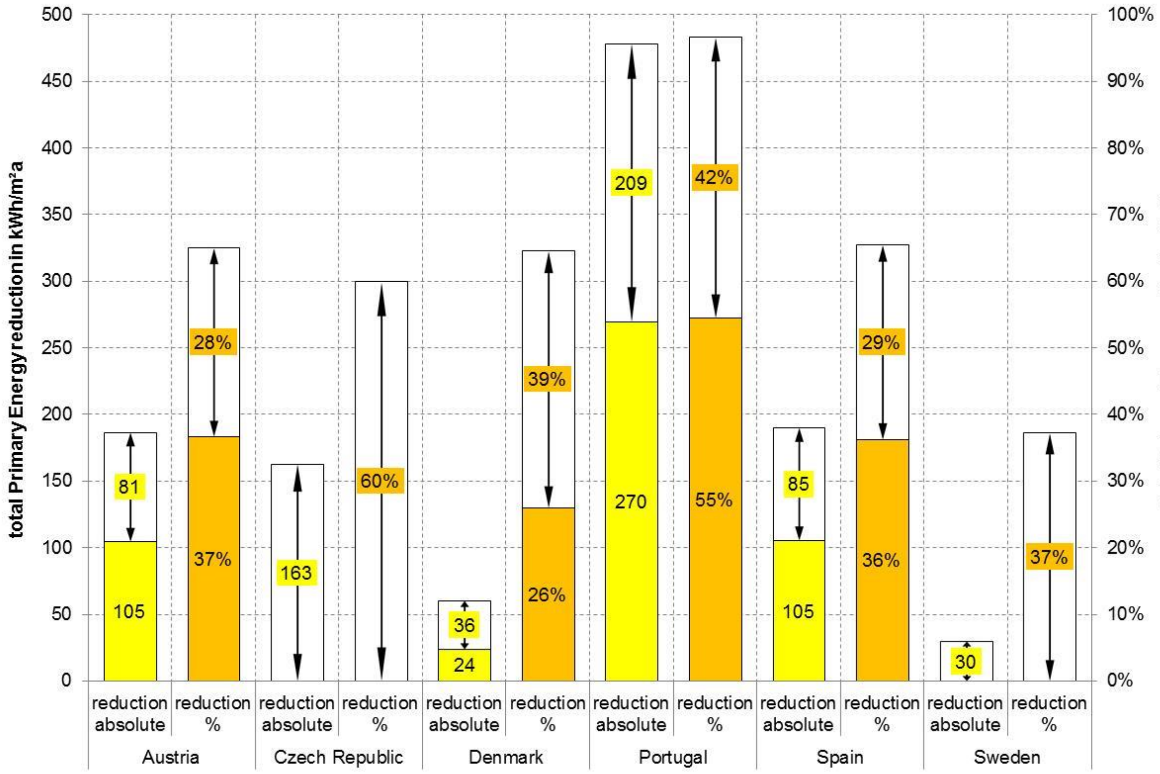

Figure 3: Total Primary Energy reduction potential of the six Detailed Case Studies. The absolute and the relative reduction potentials are presented as minimum reduction and also as range between the minimum and maximum reduction. (source: IEA EBC Annex 56)

The chart shows that the Portuguese Detailed Case Study achieves the highest reduction potentials (of all investigated buildings) with at least 270 kWh/m²a up to 479 kWh/m²a. In relative numbers this reduction represents a minus of 55% to 97% compared to the Portuguese reference case. The reasons for this significant reduction potential are the very high total Primary Energy of the reference case and the combination of the thermal insulation of the building envelope and the switch of the energy source to HVAC. The highest reductions are possible when improving the thermal envelope and changing to heat pump supply.

The results in Austria and Spain are quite similar. The absolute reduction potentials range between 105 kWh/m²a and 186 kWh/m²a in Austria, in Spain between 105 kWh/m²a and 190 kWh/m²a. In relative terms in Austria and Spain reductions between 36% and 65%, compared to the individual reference cases, can be achieved.

65% reduction can be also achieved in the Danish Detailed Case Study, even if the absolute reductions are smaller (between 24 kWh/m²a and 60 kWh/m²a) due to the lower total Primary Energy of the Danish reference case.

For the Swedish and the Czech Detailed Case Studies no minimum reduction is given. That means the reduction potentials range between 0 kWh/m²a and 163 kWh/m²a (Czech Republic) and 30 kWh/m²a (Sweden). Compared to the reference cases these are reductions of up to 60% in the Czech case and up to 37% in the Swedish case. This also means that in the Czech and Swedish Detailed Case Study high relative reductions of the total Primary Energy are possible but the investigation showed that the renovation measures can also lead to an increase of the total Primary Energy.

Figure 4 shows the LCC reduction potentials when reducing the total Primary Energy to the minimum. For each Detailed Case Study the LCC of the specific renovation package, which achieves the lowest total Primary Energy, was compared to the individual reference cases. The reductions are shown as absolute values in €/m²a and also in relative reductions (in %).

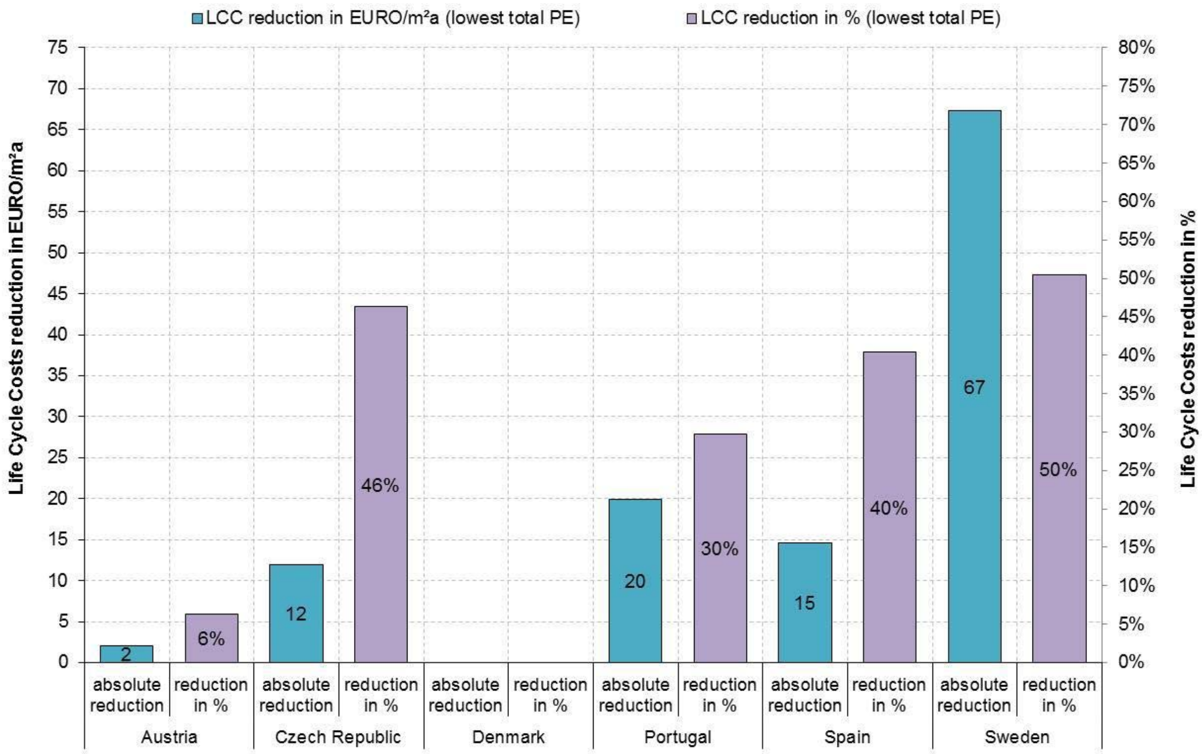

Figure 4: Life Cycle Costs reduction potentials of the six Detailed Case Studies. The absolute reduction potentials and the relative reduction potentials are presented as values between the reference case and the renovation package which achieves the lowest total Primary Energy. (source: IEA EBC Annex 56)

The analysis shows that the LCC can be reduced from 2 €/m²a in the Austrian Detailed Case Study up to 67 €/m²a in the Swedish Detailed Case Study. In relative value these are reductions of 6% in Austria to 50% in Sweden.

Higher LCC reductions are possible in the Swedish Detailed Case Study because of following reasons: The Life Cycle Costs of the reference case are highest in the Swedish Detailed Case Study (compared to all other Detailed Case Studies) and the executed renovation, which achieves the lowest total Primary Energy, also has the lowest LCC (compared to the other investigated renovation packages of the Swedish Detailed Case Study).

Reducing the total Primary Energy in the Czech Detailed Case Study to the lowest possible level reduces the Life Cycle Costs considerably. The absolute reduction is quite small at first glance, with a value of 12 €/m²a, but compared to the LCC of the reference case the relative reduction is 46%. Reasons for this reduction are the combination of the thermal insulation of the building envelope and the switch to gas heating. In general all investigated renovation packages with heating and domestic hot water preparation based on natural gas achieve similar LCC results and savings. The photovoltaic installation could further reduce the Life Cycle Costs.

4. INVESTIGATIONS AND CONFIRMATION OF HYPOTHESES

Based on the defined renovation packages deeper analyses of the influence of the different renovation measures on the Life Cycle Costs, carbon emissions and total Primary Energy were performed. The goal was to test the coherence between renovation measures on the building envelope, the switch of the energy source from non-renewable sources to renewable sources as well as combinations of both.

For each of the residential buildings of the Detailed Case Studies the hypotheses defined in the IEA Annex 56 project were answered.

At this point the confirmation of the hypotheses for the Detailed Case Studies is summarized and shown in following Table 2.

Table 2: Results for the investigated hypotheses for the five residential buildings of the Detailed Case Studies (source: IEA EBC Annex 56)

Hypothesis	Austria	Denmark	Portugal	Spain	Sweden
The number of building elements renovated is more important for the energy performance of the building than the efficiency level of individual elements	✓	✓	✓/✗	✗	✗
A switch to RES reduces emissions more significantly than the deployment of energy efficiency measures	✓	✓	✓	(✓)	✓
A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level	✓	(✓)	(✗)	✓	(✓)
Synergies are achieved when a switch to RES is combined with energy efficiency measures	✓	✗	✓	✓	✓
To achieve high emission reductions, it is more cost effective to switch to RES and carry out less far-reaching renovations on the building envelope than to focus on energy efficiency measures alone.	✓	✓	(✓)	✓/✗	✓

✓…confirmed

✗…not confirmed

(✓)…confirmed with restrictions

✓/✗…for some energy sources confirmed and for some not

5. RECOMMENDATIONS

The investigations of the six Detailed Case Studies allow making recommendations for cost-effective renovations towards nearly zero energy and emissions in future:

- A switch to renewable energy sources reduces the carbon emissions more significantly than the deployment of energy efficiency measures. When the goal is to achieve high carbon emissions reductions, it is more cost-effective to switch to renewable energy sources and carry out less far-reaching renovations on the building envelope than to focus on energy efficiency measures alone.
- Synergies can be achieved when a switch to renewable energy sources is also combined with energy efficiency measures on the building envelope.
- In general, the combination of energy efficiency measures on the building envelope with measures for the use of renewable energy sources does not significantly change the cost optimal efficiency level.
- Whether or not the number of building elements renovated is more important for the energy performance of the building than the efficiency level (insulation thickness) of each particular element has to be checked individually. For some buildings this might be the case, for others however not.

An important step towards cost-effective building renovations is the consideration of the whole building life cycle, which means looking at the Life Cycle Costs of individual renovation measures over the life cycle of the building respectively the single building element, instead of taking only the investment costs of the renovation measure as main decision criterion.

Furthermore it is also important to look at the carbon emissions and/or Primary Energy of different possible renovation measures over the whole building life cycle. The investigations should include different scenarios, to find the optimum renovation. All investigated renovation measures and packages should be compared to a reference situation, where only measures are included that have to be carried out anyway.

The calculation results within the Detailed Case Studies have shown that high carbon emissions and Primary Energy reductions are possible, where the corresponding renovation measures are also cost effective, which means that the Life Cycle Costs of the individual measures are lower than the Life Cycle Costs of the reference case.

However, results have also shown that not all investigated renovation measures bring a reduction of carbon emissions, primary energy and/or Life Cycle Costs. Also higher values, compared to the reference case, were calculated. Therefore a detailed look at different possible renovation measures, including the calculation of the Life Cycle Costs and the Life Cycle Assessment are necessary.

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