International Energy Agency

Evaluation of the impact and relevance of different energy related renovation measures on selected Case Studies

(Annex 56)

Energy in Buildings and Communities Programme

March 2017

EBC is a programme of the International Energy Agency (IEA)

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 28 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates research and development in a number of areas related to energy. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitant Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilating Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)

Annex 21: Environmental Performance of Buildings (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multizone Air Flow Modelling (*)
Annex 24: Heat, Air and Moisture Transport in Insulated Envelope Parts (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Control Strategies for Hybrid Ventilation in New and Retorfitted Office Buildings (HybVent) (*)
Annex 36: Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures (*)
Annex 37: Low Exergy Systems for Heating and Cooling (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Thermal Insulation (*)
Annex 40: Commissioning of buildings HVAC Systems for Improved Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy-Efficient Future Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (NZEBs)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
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Annex 64: Optimised Performance of Energy Supply Systems with Energy Principles
Annex 65: Long-Term Performance of Super-Insulation in Building Components & Systems
Annex 66: Definition and Simulation of Occupant Behaviour in Buildings
Annex 67: Energy Flexible Buildings
Annex 68: Design and Operational strategies for High IAQ in Low Energy Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in low Energy Buildings
Annex 70: Building Energy Epidemiology
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Public Communities
Annex 74: Energy Endeavour
Annex 75 Cost-effective building renovation at district level combining energy efficiency and renewable

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - Survey on HVAC Energy Calculation Methodologies for Non-residential Buildings

Management Summary

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, as described in the Energy Performance of Buildings Directive[1]. However, these standards are mainly focused on new buildings neglecting, most of the time, the existing ones that represent the least efficient, the largest consumers and the largest share of the building stock.

The IEA EBC Annex 56 project «Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation» intends to develop a new methodology for cost-effective renovation of existing buildings, using the right balance between the energy conservation and efficiency measures on one side and the measures and technologies that promote the use of renewable energy on the other side. It aims to provide a calculation basis for future standards, which aims at maximizing effects on reducing carbon emissions and primary energy use in building renovation. The project pays special attention to cost-effective energy related renovation of existing residential buildings and low-tech office buildings (without air conditioning systems). Apart from including operational energy use, also the impact of including embodied energy is investigated in the project.

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.

To promote energy efficient buildings, with low energy consumption and energy generation on-site, innovative renovation projects are needed that can act as forerunners and inspiration but also serve as best practice examples for the expert audience and the general public.

Within this project six different Case Studies from six European countries were compiled and analyzed (see Table 1). The Case Studies are both residential and non-residential buildings, which serve as model projects for renovations in each individual country. The specific aim of the case study activity of this project is to provide significant and useful feedback from practice on a scientific basis.

1 Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

Table 1: Overview of the investigated Case Studies

Country	Before	After	Site	Building type	Year(s) of construction	Year(s) of renovation	GHFA
Austria			Johann-Böhmstraße, Kapfenberg	Multi-family building	1960 – 1961	2012 – 2014	2,845 m^2
Czech Republic			Kamínky 5, Brno	Elementary School	1987	2009 – 2010	9,909 m^2
Denmark			Traneparken, Hvalsø	Multi-family Building	1969	2011-2012	5,293 m^3
Portugal			Neighborhood RDL, Porto	Two-family Building	1953	2012	123 m^2
Spain			Lourdes Neighborhood, Tudela	Multi-family Building	1970	2011	1,474 m^2
Sweden			Backa röd, Gothenburg	Multi-family Building	1971	2009	1,357 m^2

The assessment of the Case Studies was performed according to the methodology developed within this project[2], including Life Cycle Cost (LCC), Life Cycle Assessment (LCA) and the evaluation of the co-benefits. 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 in building use during the estimated life cycle period, including also the embodied energy of the materials added to improve the energy efficiency of the building.

The impacts of the different renovation packages are illustrated with the help of graphs depicting primary energy use or carbon emissions on the x-axis and costs on the y-axis. Primary energy use, carbon emissions and costs are considered on a yearly and per m² basis. The principle of these graphs is shown in the following Figure 1.

2 see Ott, W. et al. (2015): "Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)", see http://www.iea-annex56.org/Groups/GroupItemID6/STA_methods_impacts_report.pdf

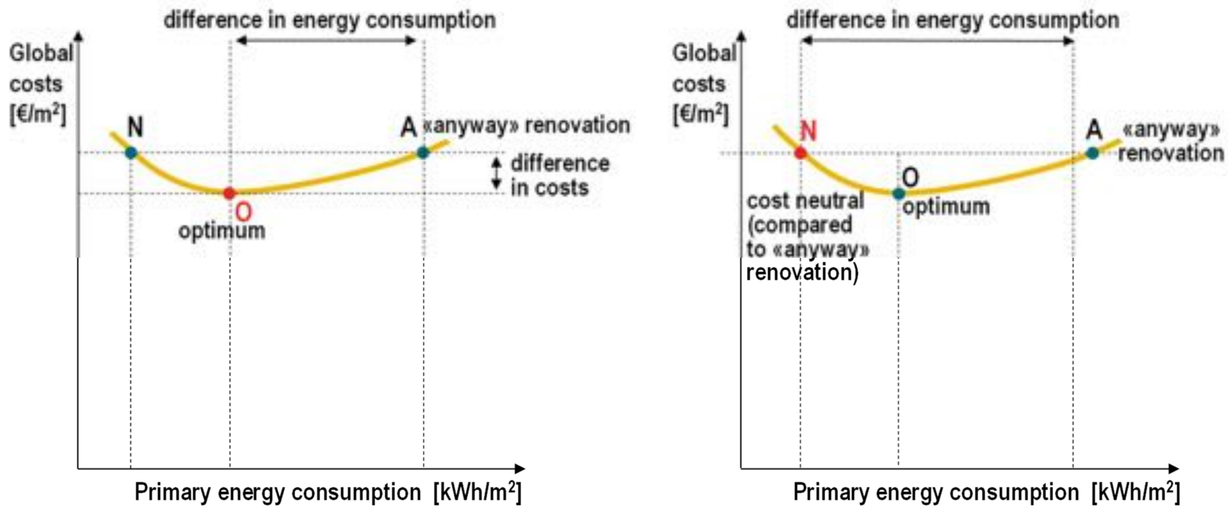


Figure 1: Global cost curve after renovation, starting from the reference case A («anyway renovation») towards renovation options with less primary energy use than in the case of the anyway renovation. Costs comprise annual capital costs, energy costs, as well as operation and maintenance costs. O represents the cost optimal renovation option. N represents the cost neutral renovation option with the highest reduction of primary energy. Renovation options on this curve between A and N are all cost-effective. (BPIE 2010, p. 15, supplemented by econcept).

Objectives

The main objectives of this work are:

- To test the theoretically developed methodology with practical experiences within realized renovations in order to identify possible inconsistencies and providing feedback to refine the methodology;
- To reach an in-depth understanding of the performance of some selected case studies in order to increase the general understanding of the performance of technologies when applied in practice;
- To understand barriers and constraints for high performance renovations by a thorough analysis of case studies and feedback from practice in order to identify and show measures on how to overcome them;
- To support decision-makers and experts with profound, science based information (as a result of thoroughly analyzed case-studies) for their future decisions;
- To show successful renovation projects in order to motivate decision-makers and stimulate the market towards more ambitious renovations.

Parametric calculations

In addition to the actual renovation carried out for the individual projects each Case Study also describes and tests several alternative 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
- **BITS (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 production**
- **RES (renewable energy sources) 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 and 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. Therefore the investigated packages differ from country to country and many differences between the building standards and the climates in each country exist too. Variations of different energy sources for heating and domestic hot water were also 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, establishing also the limit of the cost-effectiveness.

The reference case should include only renovation measures which have to be carried out anyway. Therefore this reference case can also be named “anyway renovation”. Renovation measures included in this package could be the repainting of windows or outside walls or a roof sealing.

As previously mentioned, the assessment of all renovation packages was performed according to the methodology developed within this project, including Life Cycle Cost (LCC), Life Cycle Assessment (LCA) and the co-benefits. Main issues are primary energy use and related carbon emissions of such buildings, including the energy demand for heating, domestic hot water and electricity, as well as also the embodied energy of the materials added to improve the energy efficiency of the building.

This report gives an overview of the defined renovation packages and the calculation results of the six Case Studies. The main results of the investigations are presented on the next pages. The analyzed parameters were the carbon emissions, referring to 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, maintenance costs and energy costs, expressed in EUR.

Carbon emissions reductions

Figure 2 shows the carbon emissions reduction potentials of the six Case Studies. The reduction potentials are shown as absolute values (yellow columns) and as relative reduction potentials (orange columns). The filled parts of the columns represent the minimum 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 hatched columns stand for the lowest carbon emissions which can be achieved by the renovation packages.

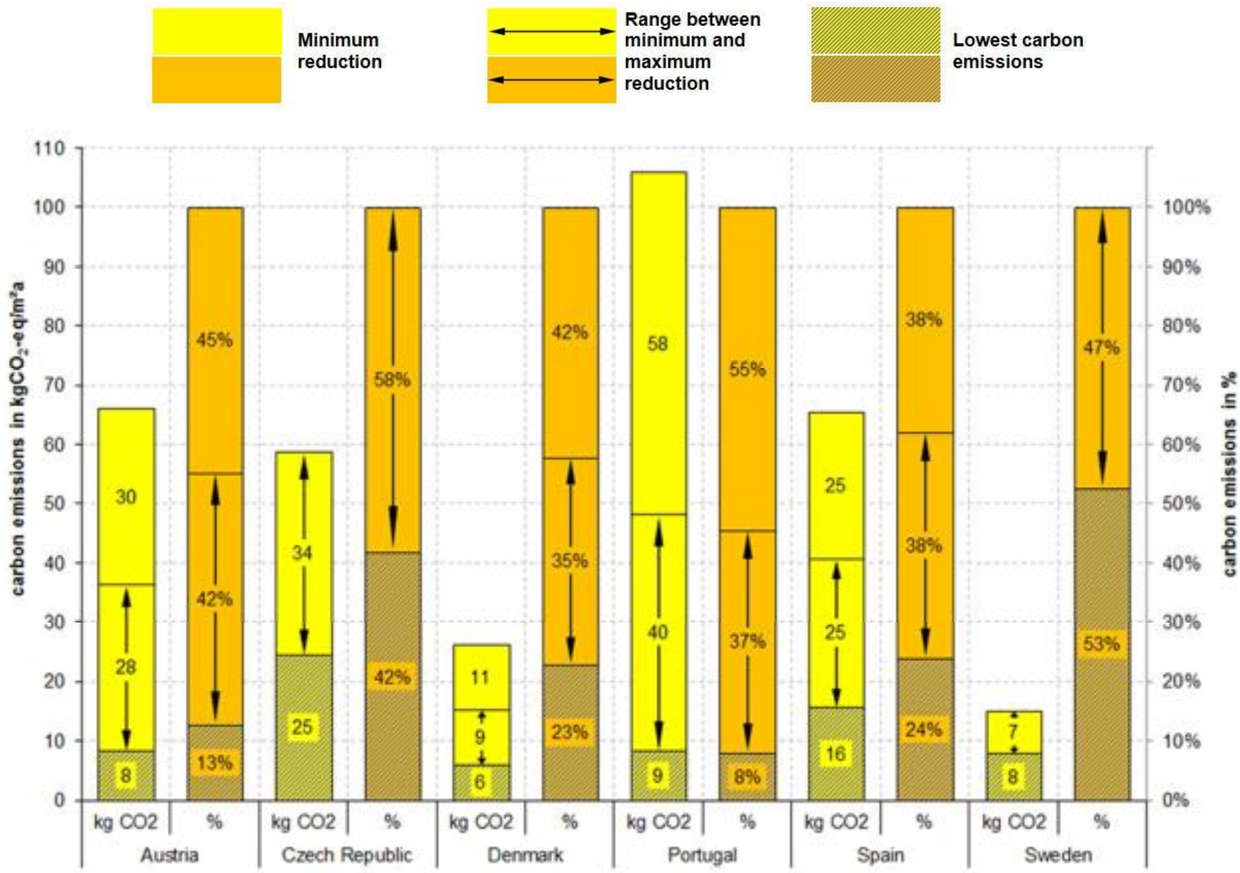


Figure 2: Carbon emissions reduction potential of the six Case Studies. The absolute (yellow columns) and the relative reduction potentials (orange columns) are presented as minimum reduction and also as range between the minimum and maximum reduction, compared with the anyway renovation of each building. The hatched columns represent the lowest possible carbon emissions.

The chart shows that the Portuguese Case Study achieves the highest minimum reduction of all investigated buildings with a value of 58 kgCO_2-eq/m²a and also the highest possible savings with 98 kgCO_2-eq/m²a, which is a reduction of 92% compared to the reference case. 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 production is necessary.

The Danish Case Study shows the smallest absolute reduction potential with values between 11 kgCO_2-eq/m²a and 20 kgCO_2-eq/m²a. The reason for that low absolute reduction is the quite low carbon emissions of the reference case, which is similarly true also in Sweden. 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.

In the Spanish Case Study similar results are achieved as in 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. In the Austrian and the Spanish case the high carbon emissions of the reference case lead to those high reductions.

For the Swedish and the Czech Case Studies no minimum reduction is given due to the fact that some of the investigated renovation packages lead to an increase of the carbon emissions, compared to the reference case. That means the reduction potentials range between 0 kgCO_2-eq/m²a and 34 kgCO_2-eq/m²a (Czech Republic) respectively 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 3. The chart demonstrates the possible LCC reductions, when bringing the carbon emissions to the lowest value. This means for each 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 filled columns represent the LCC reductions, the hatched columns represent the LCC of the renovation package with the lowest carbon emissions.

The analysis shows that the LCC can be reduced from 2 EUR/m²a in the Austrian Case Study up to 17 EUR/m²a in the Portuguese Case Study (in the Danish and Swedish Case Studies no reduction of the LCC is given, therefore no value is shown for these two countries in Figure 3). In relative values these are reductions of 6% in Austria and 22% in Portugal. 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 of the Austrian Case Study are higher than they would be without the prefabrication and the RES generation on-site.

In Czech Republic and Spain the relative reductions are even higher than in Portugal. In the Czech Case Study the relative reduction is 46% and in the Spanish Case Study 39%, always compared to the reference cases.

In the Danish and the Swedish case, the reference case corresponds to the cost optimal solution. The investigated energy renovations decrease the carbon emissions and primary energy use, but are not profitable for the building owners. In the Danish Case Study the reason for this is that the energy demand and the LCC of the existing building are already quite low. The Danish and Swedish buildings nevertheless underwent an extensive energy renovation because the façades were worn down and the external concrete walls were weakened by deterioration. The obtained co-benefits were also an argument for the extensive energy renovation. The costs weren´t the driving force of the renovation, instead attractive flats in a safe and green environment was the main focus. The Swedish renovation was a pilot project to gain knowledge on prerequisites, problems and solutions regarding technology, economy and the experience of the residents from a major renovation.

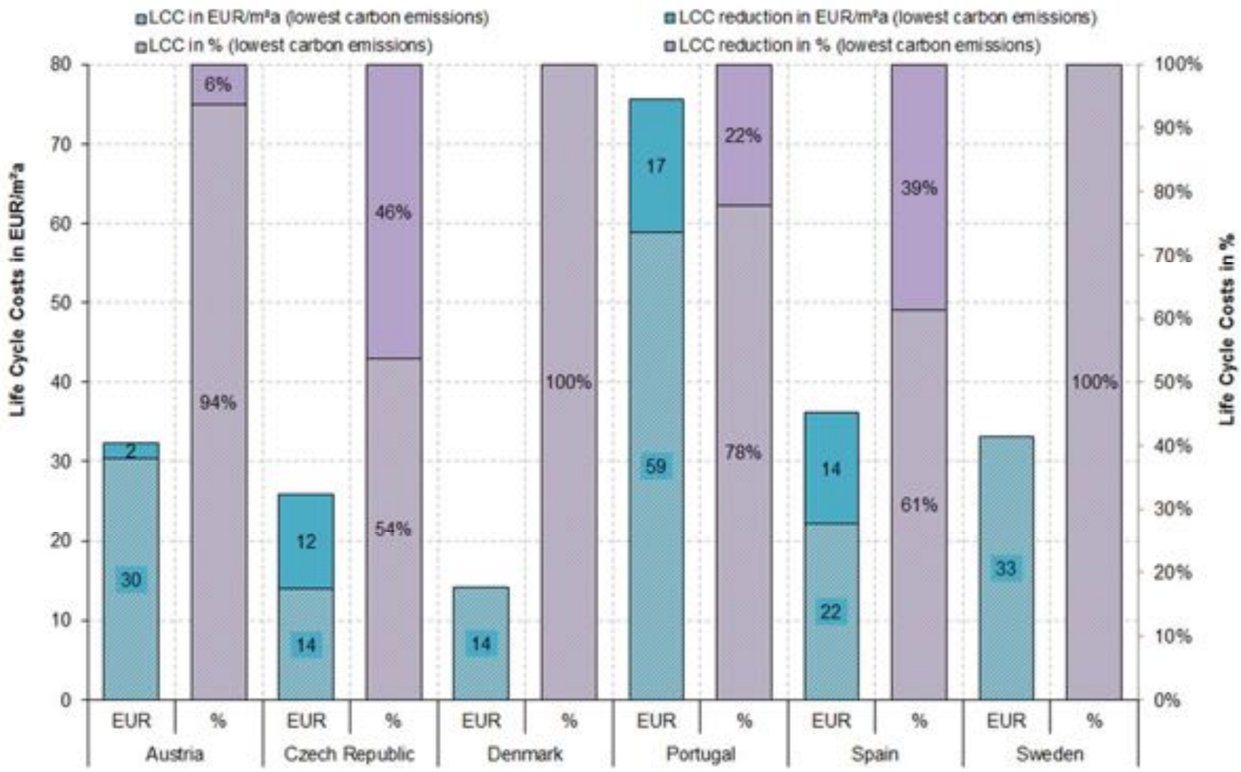


Figure 3: Life Cycle Cost reduction potentials of the six Case Studies. The absolute reduction potential (blue column) and the relative reduction potential (purple column) are presented as values between the reference case and the renovation package which achieves the highest carbon emissions reductions.

Total Primary Energy reductions

Similar to the analysis of the carbon emissions reduction potentials in Figure 2, the total Primary Energy reduction potentials of the six Case Studies are shown in Figure 4. Again the absolute values (yellow columns) and the relative reduction potentials (orange columns) are presented for each Case Study. The filled parts of the columns represent the reduction, which can be at least achieved, independently of the chosen renovation package (here, too, 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 total Primary Energy reduction. The hatched columns stand for the lowest total Primary Energy which can be achieved by the renovation packages.

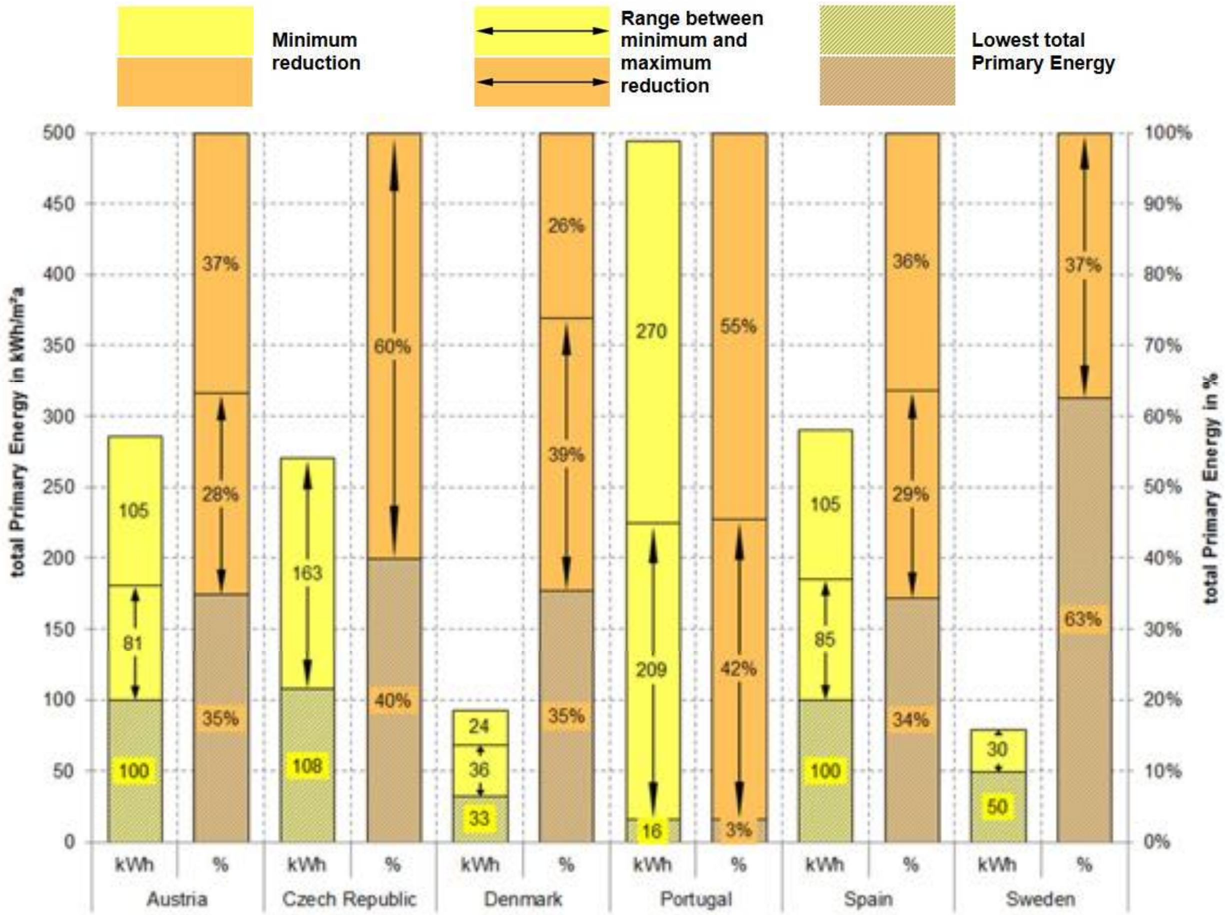


Figure 4: Total Primary Energy reduction potential of the six Case Studies. The absolute (yellow columns) and the relative reduction potentials (orange columns) are presented as minimum reduction and also as range between the minimum and maximum reduction, compared with the anyway renovation of each building. The hatched columns represent the lowest possible total Primary Energy.

The chart shows that the Portuguese 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 is a reduction 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 a multi-split air conditioner for heating and cooling and solar thermal panels backed up by electric heater for DHW. The highest reductions are possible when improving the thermal envelope and changing to heat pump supply.

The results in Austria and Spain are again 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 Case Study, even if the absolute reductions are smaller (between 24 kWh/m²a and 60 kWh/m²a) due to the lower total Primary Energy demand of the Danish reference case.

For the Swedish and the Czech Case Studies no minimum reduction is given due to the fact that some of the investigated renovation packages lead to an increase of the Primary Energy, compared to the reference case. Therefore 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 Case Studies 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 and therefore not always to a reduction.

Figure 5 shows the LCC reduction potentials when reducing the total Primary Energy to the minimum. For each 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 EUR/m²a and also as relative reductions (in %).

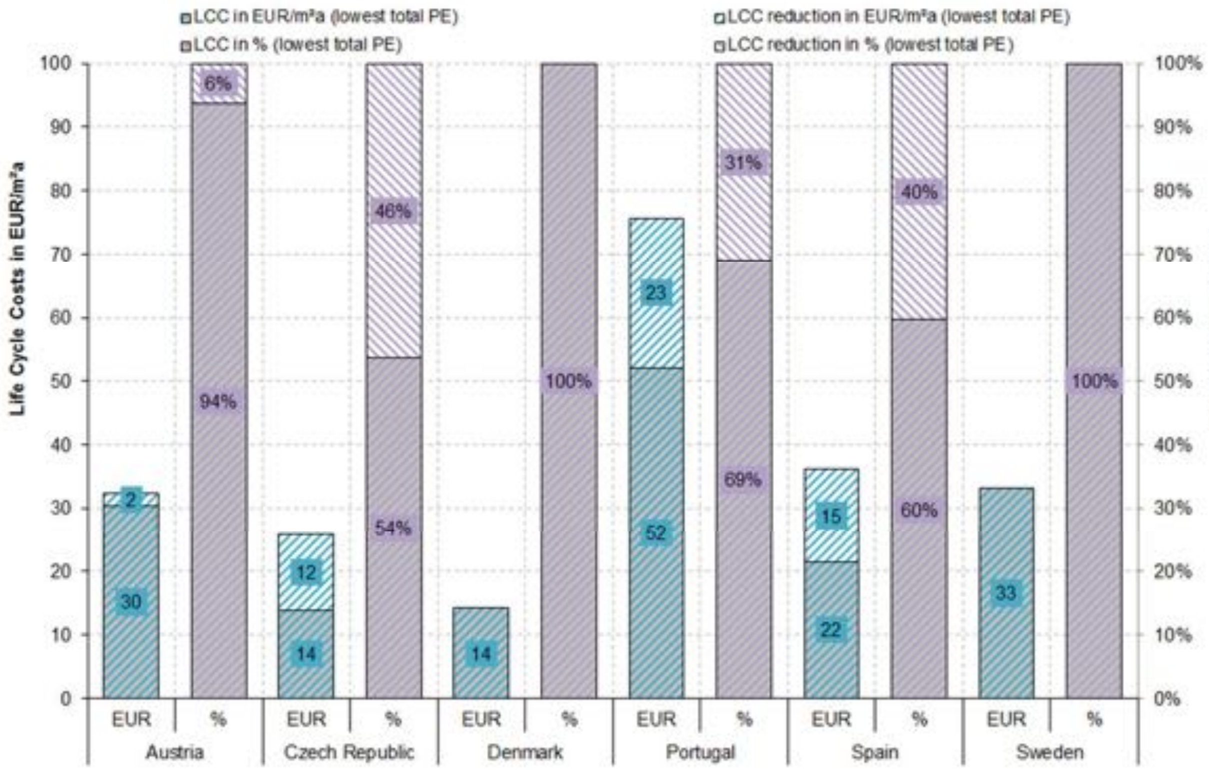


Figure 5: Life Cycle Costs reduction potentials of the six Case Studies. The absolute reduction potentials (blue columns) and the relative reduction potentials (purple columns) are presented as values between the reference case and the renovation package which achieves the lowest total Primary Energy.

The analysis shows that the LCC can be reduced from 2 EUR/m²a in the Austrian Case Study up to 23 EUR/m²a in the Portuguese Case Study (again no values for the Danish and the Swedish Case Studies because for these two buildings no reductions of the LCC were given). In relative value these are reductions of 6% in Austria to 31% in Portugal. 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 package v3, due to the prefabricated façade and the photovoltaic and solar thermal installations.

Reducing the total Primary Energy in the Czech Case Study to the lowest possible level also reduces the Life Cycle Costs considerably. The absolute reduction is quite small at a first glance, with a value of 12 EUR/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 production based on natural gas achieve similar LCC results and savings. The photovoltaic installation could further reduce the Life Cycle Costs.

Investigation 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 Case Studies the hypotheses investigated also for the generic calculations in this project were tested[3]. The hypotheses are:

1. **The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements.**
2. **A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements.**
3. **A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level.**
4. **Synergies are achieved when a switch to RES is combined with energy efficiency measures.**
5. **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.**

At this point the confirmation of the hypotheses for the Case Studies is summarized and shown in following Table 2, with following key: ✓ means that the hypothesis is confirmed, ✗ means that the hypothesis is not confirmed. Symbols in parenthesis or separated by a slash indicate that the hypothesis is only partly confirmed / not confirmed.

3 For the Case Study from the Czech Republic, the small number of renovation packages that was available didn't allow the test of the hypotheses.

Table 2: Results for the investigated hypotheses for the five residential buildings of the Case Studies

Hypothesis	Austria	Denmark	Portugal	Spain	Sweden
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements.	✓	✓	(✓)	✗	✗
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements.	✓	✓	✓	(✓)	✓
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.	✓	✓	(✓)	✓/✗	✓

The hypothesis ***"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements."*** could be completely confirmed for Austria and Denmark and partially for Portugal. In Portugal this hypothesis was only confirmed for the renovation measures roof and wall but not for the remaining measures on the building envelope. For the Spanish and the Swedish Case Study this hypothesis was not confirmed.

The hypothesis ***"A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements."*** was confirmed in all five countries, with limitations in the Spanish Case Study where the hypothesis was confirmed for the switch to district heating with 75% biomass or to biomass heating system, yet not for a switch to heat pump.

The hypothesis ***"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level."*** is completely confirmed for the Austrian, the Portuguese and the Spanish Case Study and confirmed with limitations in Denmark and Sweden. In the Danish Case Study for example the reference case or simply a switch to a different heating system, without energy efficiency measures, is the cost optimum renovation. All investigated energy related renovation measures lead to an increase of the annual Life Cycle Costs. In the Swedish case, the cost-optimum was not changed by a combination of energy efficiency measures with RES measures. However, it can to be noted that in the case of an oil heating system, renovation measures beyond the cost optimum are similarly cost-effective as the cost optimum, whereas for district heating and the RES based heating systems investigated, additional renovation measures on the building envelope beyond the cost optimum make the renovation significantly less cost-effective.

The hypothesis ***"Synergies are achieved when a switch to RES is combined with energy efficiency measures."*** is confirmed in Austria, Portugal and Spain. In Denmark this hypothesis is disproved. The results showed that it is more cost efficient to use district heating or heat pump and not carrying out further energy related renovation measures on the building envelope. In Sweden the hypothesis can be partly confirmed for the insulation of the exterior wall in combination with the change to district heating based on RES. The hypothesis however is disproved for all remaining renovation measures in combination with district heating based on RES and also for all combinations with a pellets heating system.

The hypothesis ***"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."*** is completely confirmed in Austria, Denmark and Sweden. In Portugal and Spain limitations exist. The Spanish Case Study shows a confirmation for the district heating system with 75% biomass and the biomass heating system, yet not for a heat pump. In Portugal it is in general difficult to answer this hypothesis. In fact it cannot clearly be answered. It is more likely to be confirmed but a hundred per cent confirmation is not possible.

Main findings from the generic parametric calculations[4]

In all investigated generic buildings investigated there is a cost optimum, with lower costs than those of an «anyway renovation». Costs are rising for measures going beyond the cost optimum, but many or sometimes all of the measures considered in the assessment are still cost-effective, i.e. lower than the cost of the anyway renovation.

With respect to the energy performance of energy related building renovation measures and the balance between renewable energy deployment and energy efficiency measures, the five main hypotheses have also been investigated. Within this context, some tentative conclusions are made referring to renewable energy sources (RES) in general. However, it is important to note that only specific RES systems were taken into account in the generic calculations. For example the role of solar thermal or small wind turbines has not been investigated and not all types of renewable energy systems were investigated for all reference buildings. In the case of the countries Austria, Denmark, Spain and Sweden, geothermal heat pumps and wood pellet heating systems have been investigated as RES systems; in the case of Portugal an air-water heat pump and its combination with PV were investigated as RES systems. The related findings obtained

4 Taken from the report: "Investigation based on calculations with generic buildings and case studies" (Bolliger and Ott, 2015)

from the parametric calculations with the investigated generic buildings are summarized in the following Table 3.

Table 3: Results for the investigated hypotheses for the generic multi-family buildings

Hypothesis	Austria	Denmark	Portugal	Spain	Sweden
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements.	✓	✓	✓	✓	✗
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements.	✓	✓	✓	✓	✓
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.	✓	✓	✓	✓	✓

The comparison of the results of the Case Studies (Table 2) with the results of the generic buildings (Table 3) shows good correlation.

Small deviations could be found:

- in Austria for the hypothesis **"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level"**
- in Portugal for the hypotheses **"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements."** and **"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."**
- in Spain for the hypotheses **"A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements."** and **"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."**

- in Sweden for the hypothesis **"Synergies are achieved when a switch to RES is combined with energy efficiency measures."**

In the mentioned cases the named hypotheses could be fully confirmed in the generic buildings but only confirmed with limitations in the real Case Studies (exception: in Austria it´s vice versa).

For some hypotheses however, no correlation between the Case Studies and the generic buildings is given:

- in Denmark the hypothesis **"Synergies are achieved when a switch to RES is combined with energy efficiency measures."** was confirmed in the generic building but not confirmed in the Case Study
- in Spain the hypothesis **"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements."** was confirmed in the generic building but not in the Case Study
- in Sweden the hypothesis **"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level."** was partly confirmed in the Case Study but not in the generic building.

Co-benefits

Several notions are used to refer to the benefits that arise from building renovation with energy efficiency and carbon emissions reduction. In this project, the main focus is on energy, carbon emissions and costs, consequently the reduction of energy use, carbon emissions and costs are direct benefits. Though all the benefits that arise from a renovation project besides these direct benefits can be included in the notion of co-benefits, only co-benefits deriving from energy and carbon emissions related renovation measures are considered in this project.

The co-benefits that arise from energy and carbon emissions related building renovation can be independent from energy, carbon emissions and costs (e.g. less exterior noise), or can be a consequence of these (e.g. less risk of exposure to future energy price increases), and the benefits can impact at private level (e.g. increased user comfort) or/and at society level (e.g. impact on climate change or air pollution).

In this context, the notion of co-benefits refers to all benefits (positive or negative) resulting from renovation measures related to energy and carbon emissions optimized building renovation, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction.

For each Case Study the co-benefits, derived from energy related renovation measures were analyzed based on the parametric calculations following the developed methodology and also, for some of the Case Studies, interviews performed among the residents of the buildings.

Following conclusions can be drawn from this analysis:

- At the building level, in the renovation of existing buildings, energy efficiency measures, when compared to measures for the use of renewable energy sources, are the main source of co-benefits, particularly those improving the building quality (reduction of problems with building physics, increase of useful building areas and improved safety against intrusion) and the resident physical wellbeing (increased thermal and acoustic comfort, increased use of daylighting and better indoor air quality).
- To maximize the co-benefits from energy related building renovation, it is more relevant to improve more elements of the building envelope in combination than to significantly improve single elements. As an example, the improvement of a façade with additional 20 cm of insulation instead of improving it with 10 cm of insulation will be much less relevant (from the perspective of co-benefits) than to supplement the improvement of the façade with 10 cm of insulation with the replacement of windows.
- Depending on the original condition of the building, improving all the elements of the building envelope usually means going beyond cost optimality (once the improvement of certain elements may not be cost effective in a comprehensive package of measures). Although, the difference in global costs is usually not relevant and packages of measures remain cost-effective when compared to “anyway renovation”. Furthermore, improving all the elements of the building envelope is usually the way to achieve the maximization of the added value from the co-benefits.
- At the building level, measures for the use of renewable energy sources usually have the co-benefits of reducing the exposure to energy price fluctuations. Residents with systems based on renewables (with the exception of systems based on wood pellets) are more comfortable regarding future variations on the energy prices once they are less dependent on energy from the market. Regarding their implementation, many renewable energy systems present a challenge for their integration on existing buildings. Some of these systems (e.g. photovoltaic or solar thermal) often present a challenge for their integration in the architectural characteristics of the existing buildings, while others (e.g. geothermal heat pump) present technical and often also financial challenges to be implemented. On the other hand, other systems (e.g. air/air or air/water heat pumps or wood pellets burner) are much easier to implement than most of the high efficiency measures and may allow reducing the depth of the interventions on the building envelope.

Challenges to reach nearly zero energy and nearly zero emissions

Besides the technical solutions, which are necessary to reach cost effective nearly zero energy buildings after renovation, including high reductions of carbon emissions and total Primary Energy, it is important to know the challenges that occur when trying to reach this goal and also the measures that can be taken to overcome them.

Therefore participants from following countries have been asked 13 questions on this topic: Austria, Czech Republic, Denmark, Finland, Norway, Portugal, Spain, Sweden, Switzerland and The Netherlands.

The questions asked in the interviews were divided into four main categories: information issues, technical issues, ownership issues and economic issues.

The evaluation of the barriers to reach nearly zero energy buildings can be summarized as follows:

One barrier is relevant for all countries, which is the information asymmetry of differing opinions expressed by professionals.

In 9 out of ten countries it was considered to be a barrier that there is a:

- Lack of examples and inspiration
- Lack of economic incentives or uncertainty about the incentives
- Lack of economic knowledge

In 7-8 countries the following were considered to be barriers:

- Incomplete information from the Energy Performance Certificate of Buildings
- Lack of knowledge about possibilities, potential benefits and added values
- Lack of well proven systems, total solutions and information about these
- Lack of clear requirements
- The structure of ownership (private, public, owner, tenant)
- Running costs and investment costs are separated
- Too high investment costs
- Uncertainty about the savings and calculations of saving potential

In 5-6 countries the following was considered to be a barrier:

- Building owners are not allowed to increase rent to pay for energy renovation investments (i.e. the building owner pays for the tenant´s benefits)

Recommendations

The investigations of the six Case Studies and the interviews in ten European countries allow making recommendations for cost effective renovations towards nearly zero energy and emissions in future. In the next paragraphs these recommendations are presented corresponding to their sources (parametric calculations, co-benefits analyses and interviews):

Parametric calculations

A switch to renewable energy sources reduces the carbon emissions more significantly than energy efficiency measures on one or more envelope elements. 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 combined with energy saving 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. This can depend on national standards, prices, weather conditions and other factors.

Energy efficiency measures, when compared with measures associated with the use of renewable energy sources, are the main source of co-benefits at building level.

To maximize the co-benefits associated with energy related building renovation, it is more effective to improve the performance of all the elements of the building envelope than to significantly improve the performance of just one element.

Depending on the original condition of the building, improving the performance of all the elements of the building envelope usually means going beyond cost optimality, but it is still cost-effective when compared to the “anyway renovation”, i.e. a renovation scenario where energy performance is not improved.

The calculation results within the Case Studies have shown that high carbon emissions and Primary Energy reductions are possible, where the corresponding renovation packages are also cost effective, which means that the Life Cycle Costs of the renovation packages 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. Moreover higher values, compared to the reference case, were calculated in some Case Studies. Therefore a detailed look at different possible renovation measures, including the calculation of the Life Cycle Costs and the Life Cycle Assessment are necessary.

It also has to be mentioned that the assumptions made in the Life Cycle Cost calculation and the Life Cycle Assessment are very important and can influence the results a lot. Therefore these assumptions have to be well-considered and if possible a sensitivity analysis of the most important parameters should be carried out. It is advisable to consult an expert with profound knowledge in the field of Life Cycle Cost calculations and Life Cycle Assessments.

<u>Interviews</u>

Missing good examples for successful renovations are often the biggest barriers for renovations towards nearly zero energy and emissions. The investigated Case Studies are such good examples, but more are needed. This means that national initiatives have to be launched to promote these kinds of building renovations. One of these initiatives could be the financial support or funding programs via direct funding or via research projects. Research projects would bring the additional benefit that new, innovative measures could be tested and evaluated, which in turn would increase the technical knowledge of the building professionals and also of the building owners.

Such a campaign could also counter the lack of economic incentives or uncertainty about the incentives. This means that by launching economic incentives building owners will receive support in financing nearly zero energy and emissions buildings. This will give building professionals the opportunity to realize good building renovations without constantly having the investment costs in mind.

A further important step towards cost effective building renovations is the consideration of the whole building life cycle. That means the Life Cycle Costs of the renovation packages should be regarded over the life cycle of the building and the building element. The investment costs should not be taken as main decision criterion.

If the building owner is faced with the problem of not being allowed to increase the rent to pay for energy renovation measures, it is advisable to go for the cost optimal renovation.

<u>Co-benefits</u>

It is 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 scope of cost effective renovation packages of measures. Within the scope of cost effective renovation scenarios, costs and co-benefits should be considered to find the solution that adds more value to the renovated building. 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 ("anyway renovation").

Table of content

Abbreviations

Abbreviations	Meaning
AT	Austria
BITS	Building integrated technical systems
CO_2-eq	Carbon dioxide equivalent
CZ	Czech Republic
DH	District heating
DHW	Domestic hot water
DK	Denmark
Eff	Heat recovery efficiency of the mechanical ventilation system
EPS	Expanded polystyrene insulation
ES	Spain
GHFA	Gross heated floor area
HP	Heat pump
HVAC	Heating, ventilation, air conditioning
kWh	Kilowatt hours
kWp	Kilowatt peak
LCC	Life Cycle Costs
LCA	Life Cycle Assessment
MVHR	Mechanical Ventilation with Heat Recovery
PE	Primary Energy
PT	Portugal
PV	Photovoltaic (cell)
RES	Renewable energy sources
SE	Sweden
SFP	Specific fan power in $kW/(m^3/s)$
U-value	Thermal transmittance of a building element in W/m^2K
WP	Wood pellets
XPS	Extruded polystyrene insulation

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, as described in the Energy Performance of Buildings Directive[5]. However, these standards are mainly focused on new buildings neglecting, most of the time, the existing ones that represent the least efficient, the largest consumers and the largest share of the building stock. These standards do not respond effectively to the numerous technical, functional and economic constraints of the existing buildings stock. Renovations attempting to reach these standards often result in very expensive measures and complex procedures, hardly accepted by any owners or promoters.

The IEA-EBC Annex 56 project «Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation» intends to develop a new methodology for cost-effective renovation of existing buildings, using the right balance between the energy conservation and efficiency measures on one side and the measures and technologies that promote the use of renewable energy on the other side. It aims to provide a calculation basis for future standards, which aims at maximizing effects on reducing carbon emissions and primary energy use in building renovation. The project pays special attention to cost-effective energy related renovation of existing residential buildings and low-tech office buildings (without air conditioning systems). Apart from including operational energy use, also the impact of including embodied energy is investigated in the project.

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 than energy conservation and efficiency measures. In existing buildings, the most cost effective renovation solution is often a combination of energy efficiency measures and measures for utilizing renewable energy. Hence, it is relevant to understand the potential of energy conservation and efficiency measures (initially often less expensive measures) and from which point the use of renewables become more economical considering the local context.

To promote energy efficient buildings, with low energy consumption and energy generation on-site, innovative buildings are needed that act as forerunner and also serve as best practice examples for the expert audience and the general public.

Within this project, the gathering of case studies is one of the activities undertaken to reach the overall project objectives because it is a recognized fact that the process of decision-making has to be strongly supported by successful renovations, where comprehensive energy and

5 Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

environmental measures have been realized, i.e. with experiences and lessons learned from practice.

The assessment of the Case Studies was performed according to the methodology developed within this project[6], including Life Cycle Cost (LCC), Life Cycle Assessment (LCA) and the co-benefits. 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 in building use during the estimated life cycle period. Included is also the embodied energy of the materials added to improve the energy efficiency of the building.

6 Ott, W. et al. (2015): "Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)", see http://www.iea-annex56.org/Groups/GroupItemID6/STA_methods_impacts_report.pdf

2. Scope

The specific mission of the case study activity in this project is to provide significant feedback from practice on a scientific basis. The main objectives of this work are:

- To understand barriers and constraints for high performance renovations by a thorough analysis of case studies and feedback from practice in order to identify and show measures on how to overcome them;
- To test the theoretically developed methodology in this project with practical experiences within realized renovations in order to identify possible inconsistencies and providing feedback to refine the methodology;
- To reach an in-depth understanding of the performance of some selected case studies in order to increase the general understanding of the performance of technologies when applied in practice;
- To support decision-makers and experts with profound, science based information (as a result of thoroughly analyzed case-studies) for their future decisions;
- To show successful renovation projects in order to motivate decision-makers and stimulate the market towards more ambitious renovations.

Within the “Case Studies”, a deeper analysis was performed in order to evaluate the impact and relevance of different renovation measures and strategies within the project objectives and also testing the methodology of this project.

Within the international cooperation seven Case Studies were analyzed deeper. Six of them are presented in this report as well as the major challenges, findings and conclusions of these best practice examples. The seventh Case Study is the demonstration project “Montarroio” in Portugal, which is an ancient building upgrade within an UNESCO World Heritage context from 1845. Due to the rareness of this building and the investigated renovation measures it is hardly comparable to the other six Case Studies. Furthermore the renovation of the building is not finished yet. For these reasons the Case Study “Montarroio” not included in the findings and conclusion in chapter 5. Nevertheless it is also a remarkable renovation project, even though it is still in the planning stage. Therefore this Case Study can be found with the other country papers in the appendix of this report.

The report is separated in several chapters. Chapter 3 shows first of all an overview of the different Case Studies, gathered and analyzed within this project. Chapter 4 includes the framework conditions for the analysis of the six buildings. The description of the defined renovation packages, the reference case in each country and the main results and conclusions can be found in chapter 5. In chapter 6 the identified challenges are explained together with suggested future research and finally chapter 7 presents recommendations for future renovations. The appendix of this report includes each country paper on the Case Studies.

3. Overview of Case Studies

Table 4 on the next page shows an overview of the six analyzed Case Studies in Austria, Czech Republic, Denmark, Portugal, Spain and Sweden. The evaluated buildings are all residential buildings with the exception of the elementary school in Brno, Czech Republic.

The oldest of these buildings dates from 1953, the youngest was constructed in 1987. The gross heated floor area of the buildings varies between 123 m² and more than 9,900 m². These building characteristics, together with the country-specific influencing factors, ensure a quite broad overview and application of the methodology for the investigation of the cost effective energy and carbon emission optimized renovation based on Life Cycle Costs and Life Cycle Assessment.

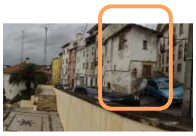
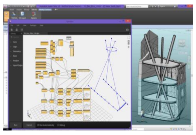
All six Case Studies have been renovated in the past years and the main reasons for the renovations were maintenance, improvement of standard and the energy efficiency of the building. Furthermore this means that the performed calculations and analyses in chapter 5 serve mainly as comparisons between the actual renovation carried out and theoretical renovation packages, which would also have been possible to apply. In this case the investigations in this report do not support the real planning of the building renovations.

A seventh Case Study is undergoing renovation in 2015: located within an UNESCO World Heritage context in Coimbra, Portugal, and thus subjected to very stringent regulations, the final solution is still being negotiated. The Case Study "Montarroio" is a single-family house that aims to demonstrate alternative ways to include ancient buildings as active players in energy efficiency and sustainable practices, with a special focus on the importance of a good initial assessment. Due to the uniqueness of this building and the investigated renovation measures it is hardly comparable to the other six Case Studies and therefore not included in the findings and conclusions in chapter 5. Nevertheless it is also a remarkable renovation project, even though it is still in the planning stage, which should be presented. Therefore this special Case Study can be found with the other country papers in the appendix of this report.

Following Table 4 shows some impressions of the Case Studies before and after the renovation together with some relevant information about the buildings. More information on the Case Studies can be obtained from:

- Individual Case Studies chapters (pages referenced in the first column of Table 4) including a short description of the investigated renovation packages and the reference renovations, the results and the conclusions of the calculations.
- Descriptions of the Case Studies in the country papers in the appendices.

Table 4: Overview of the analyzed Case Studies

Country	Before	After	Site	Building type	Year(s) of construction	Year(s) of renovation	GHFA[7]
Austria (page 37)			Johann-Böhmstraße, Kapfenberg	Multi-family building	1960 – 1961	2012 – 2014	2,845 m^2
Czech Republic (page 81)			Kamínky 5, Brno	Elementary School	1987	2009 – 2010	9,909 m^2
Denmark (page 46)			Traneparken, Hvalsø	Multi-family Building	1969	2011-2012	5,293 m^3
Portugal (page 55)			Neighborhood RDL, Porto	Two-family Building	1953	2012	123 m^2
Portugal (app. 7)			Montarroio, Coimbra	Single family in UNESCO context	14^{th} - 16^{th} century (late medieval)	(2015) ongoing	36 m^2
Spain (page 64)			Lourdes Neighborhood, Tudela	Multi-family Building	1970	2011	1,474 m^2
Sweden (page 73)			Backa röd, Gothenburg	Multi-family Building	1971	2009	1,357 m^2

7 Gross Heated Floor Area (GHFA) after the renovation of the building

4. Evaluation framework

4.1. Objectives of the analysis

For each of the renovation packages and measures the Life Cycle Cost (LCC) calculation and the Life Cycle Assessment (LCA) were performed according to the developed methodology of this project. The detailed analysis of the LCC regarding investment costs and annual costs were included and the Life Cycle Impact of each renovation package was evaluated according to its total final energy use, the total carbon emissions, the Non-Renewable Primary Energy (NRPE) and the total Primary Energy (PE).

In the following chapter the focus is on the presentation of the most important results, further information on the LCC and LCA results can be found in the individual Case Study papers in the appendix.

For each Case Study the goal was to find out:

- Which carbon emissions and total Primary Energy reductions are possible and still cost effective?
- Characterization of the influence of the renovation measures of the building envelope on the carbon emissions, total PE and LCC results.
- Characterization of the influence of the choice of the energy source for heating and domestic hot water production on the carbon emissions, total PE and LCC results.
- Characterization of the influence of the energy generation on-site on the carbon emissions, total PE and LCC results.

Further conclusions were drawn from the calculation results of each Case Study to answer the hypotheses defined in this project. These hypotheses are:

1. **The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements.**
2. **A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements.**
3. **A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level.**
4. **Synergies are achieved when a switch to RES is combined with energy efficiency measures.**
5. **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.**

4.2. Definition of renovation packages and reference case

For the six investigated Case Studies parametric studies were performed to identify the cost effective renovations for the individual real building renovations. The parametric studies were performed based on the methodology developed in this project, including Life Cycle Cost (LCC) and Life Cycle Assessment (LCA)[8]. After, the several renovation packages have also been analyzed considering the co-benefits that potentially result from the combination of the selected renovation measures.

The focus of this project is on residential and non-residential buildings without complex HVAC systems. The main focus areas of the studies are primary energy use and carbon emissions as well as the costs incurred by energy related renovation measures.

For the Case Studies 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 production (fossil fuels and renewables) as well as different ventilation situations (mechanical and natural) in the considerations.

Besides those renovation measures which lead to a reduction of the energy demand of the building also a reference case was defined. This reference represents the starting point on the global cost curve and 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 and that do not improve the energy performance of the building. Therefore this reference case can also be named as “anyway renovation”. Renovation measures in this package could be for example repainting of windows or outside walls or a roof sealing.

In this reference case the replacement of the entire or part of the existing heating system is also included. This replacement has an implicit influence on the energy performance by an improved level of efficiency. The replacement of the heating system is included in the reference case due to a more realistic depiction of the real situation.

The investigated renovation packages are named consecutively “renovation package v1”, “renovation package v2” and “renovation package v3”, where v3 represents the actual renovation carried out for the particular building.

More detailed information about the different renovation measures of each country can be found in the findings and conclusion in following sections and pages. A description of the existing building and additional information to the actual renovation carried out can be found in the individual country papers in the appendix:

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8 More information to the developed methodology can be found on the official IEA EBC Annex 56 website: http://www.iea-annex56.org/
The Methodology report can be downloaded here:
http://www.iea-annex56.org/Groups/GroupItemID6/STA_methods_impacts_report.pdf

Residential buildings

Non-residential building

In these sections the reference case and the investigated renovation packages of each country are presented in a condensed way to give a short overview of the included renovation measures. The presented renovation measures are structured in following way:

- **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
- **BITS (building integrated technical systems)** – measures on technical systems for heating, domestic hot water, cooling, auxiliaries, lighting, ventilation and common appliances
- **Investigated energy sources for heating and domestic hot water production** – energy sources that were investigated in the parametric studies
- **RES (renewable energy sources) generation on-site** – measures for the renewable energy generation on-site, e.g. solar thermal installation, photovoltaic modules, renewable district heating…

4.3. Co-benefits in the Case Studies

In the reviewed literature, several notions are used to refer to the benefits that arise from building renovation with energy efficiency and carbon emissions reduction. In this project, the main focus is on energy, carbon emissions and costs and consequently, the reduction of energy use, carbon emissions and costs are direct benefits. All the benefits that arise from a renovation project besides these direct benefits are included in the notion of co-benefits. Only co-benefits deriving from energy and carbon emissions related renovation measures are considered (e.g. the change of the interior floor of a dwelling from carpet to a wooden floor might be a measure that improves the indoor air quality but has no impact on the operational energy or carbon emissions).

The co-benefits that arise from energy and carbon emissions related building renovation can be independent from energy, carbon emissions and costs (e.g. less exterior noise), or can be a consequence of these (e.g. less risk of exposure to future energy price increases), and the benefits can impact at private level (e.g. increased user comfort) or/and at society level (e.g. impact on climate change or air pollution).

In this context, the notion of co-benefits refers to all benefits (positive or negative) resulting from renovation measures related to energy and carbon emissions optimized building renovation, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction.

The co-benefits resulting from renovation measures related to energy and carbon emissions, besides or as a consequence of energy efficiency increment, carbon emissions reduction or costs reduction is a quite embracing concept, including numerous effects at different levels of economy and society. Therefore, it is useful to identify and classify these co-benefits according to underlying principles helping to better understand their nature.

The first distinction that needs to be made regards the different perspectives of the different target groups. For the policy makers, a societal or macroeconomic perspective is required in order to show how policies that are implemented for the reduction of energy and emissions in the building sector may be used to reach other objectives such as economic and social development, sustainability and equity. From the perspective of building owners and promoters, the economic value of a building and the value added by energy related renovation measures, are the most relevant indicators and, therefore, the co-benefits that can potentially increase the willingness to pay for the building present a private perspective.

The focus in this report is only on the private benefits that arise due to the different energy related renovation measures. Table 5 gives an overview of the identified co-benefits.

Table 5: Typology of private benefits of cost effective energy related renovation measures

Category	Co-benefit	Description
Building quality	**Building physics**	Less condensation, humidity and mould problems
	Ease of use and control by user	Ease of use and control of the renovated building by the users (automatic thermostat controls, easier filter changes, faster hot water delivery, etc.)
	Aesthetics and architectural integration	Aesthetic improvement of the renovated building (often depending on the building identity) as one of the main reasons for building renovation
	Useful building areas	Increase of the useful area (taking advantage of the balconies by glazing or enlarging the existing ones) or decrease of useful area (like the case of applying interior insulation or new BITS)
	Safety (intrusion and accidents)	Replacement of building elements with new elements at the latest standards, providing fewer risks such as accidents, fire or intrusion.
Economic	**Reduced exposure to energy price fluctuations**	Reduced exposure to energy price fluctuations gives the user a feeling of control and increased certainty to be able to keep the needed level of comfort.
User wellbeing	**Thermal comfort**	Higher thermal comfort due to better room temperatures, higher radiant temperature, lesser temperature differences, air drafts and air humidity.
	Natural lighting and contact with the outside	More day lighting, involving visual contact with the outside living environment (improved mood, morale, lower fatigue, reduced eyestrain).
	Indoor Air quality	Better indoor air quality (less gases, particulates, microbial contaminants that can induce adverse health conditions) better health and higher comfort
	Internal and external noise	Higher noise insulation but increased risk of higher annoyance due to internal noise after the reduction of external noise level
	Pride, prestige, reputation	Enhanced pride and prestige, an improved sense of environmental responsibility or enhanced peace of mind due to energy related measures
	Ease of installation and reduced annoyance	Ease of installation can be used as a parameter to find the package of measures that aggregates the maximum of benefits

For each Case Study the co-benefits, derived from energy related renovation measures, are presented together with the calculation results. The co-benefits analysis is based on the parametric calculations following the developed methodology and also, for some of the Case Studies, interviews performed among the residents of the buildings.

The co-benefits were analyzed for selected renovation packages, where positive effects or improvements were marked with a green triangle (▲) and negative effects or impairments with a red triangle (▼). The number of triangles stands for the magnitude of positive or negative effects. If a renovation measure leads to both, positive and negative effects, green and red triangles are used at once.

4.4. PE and carbon emissions conversion factors of the six countries

Table 6 and Table 7 show an overview of the different conversion factors used in each country in the Life Cycle Assessment. In Table 6 the conversion factors to calculate the kgCO_2-eq emissions based on the final energy use of the building and in Table 7 the conversion factors to calculate the total Primary Energy, also based on the final energy demand of the building are presented. The references are indicated in the footnotes. "-" means that this conversion factor was not used in the calculations of the specific country.

Table 6: Carbon emissions conversion factors in kgCO_2-eq/kWh_{final}

Country	Austria[9]	Czech Republic[12]	Denmark[10]	Portugal[11]	Spain[12]	Sweden
Oil	0.302	-	0.331	-	0.294	0.295[12]
Natural gas	0.252	0.238	0.251	0.262	0.237	0.238[12]
Wood / biomass	0.052	-	-	0.045	0.012	-
District heating	0.050	0.087	0.202	-	0.114	0.080[13]
Electricity	0.322	0.924	0.413	0.691	0.594	0.100[12]

Table 7: Total Primary Energy conversion factors kWh_{prim}/kWh_{final}

Country	Austria[9]	Czech Republic[12]	Denmark[14]	Portugal[11]	Spain[12]	Sweden
Oil	1.13	-	1.28	-	1.20	1.21[12]
Natural gas	1.20	1.13	1.19	1.24	1.10	1.13[12]
Wood / biomass	1.19	-	-	1.34	1.14	-
District heating	1.60	1.56	0.69	-	1.64	0.30[13]
Electricity	1.83	3.73	1.78	3.22	3.40	2.96[12]

9 Reference: GEMIS 4.8

10 Reference: Danish Energy Agency - 2015

11 Reference: LCI Ecoinvent v2.2

12 Reference: Eco-bat 4.0

13 Reference: Göteborg Energi 2013

14 Reference: DGNB - DGNB-DK

5. Findings and Conclusions

Residential Buildings

5.1. Case Study “Kapfenberg”, Austria

5.1.1. Investigated renovation packages

	Reference case	Renovation package v1	Renovation package v2	Renovation package v3
Building envelope	Painting of the outside walls	80 mm EPS insulation of the façade	240 mm EPS insulation of the façade	Insulation of the façade with prefabricated timber modules and a total insulation of 240 mm
		200 mm EPS insulation of the roof	300 mm EPS insulation of the roof	300 mm EPS insulation of the roof
	Painting and repair of wooden frame windows	New double-glazed windows with an external shading device	New triple-glazed windows with an external shading device	New triple-glazed windows with an external shading device (already integrated in the prefabricated façade modules)
BITS (Building Integrated Technical Systems)	New central heating and domestic hot water production	New central heating and domestic hot water production	New central heating and domestic hot water production	New central heating and domestic hot water production
			New mechanical ventilation system with heat recovery (SFP = 1.62, Eff.= 65%)	New mechanical ventilation system with heat recovery (SFP = 1.62, Eff.= 65%)
Investigated energy sources for heating and domestic hot water	Oil	Oil	Oil	
		Natural gas	Natural gas	
		Wood	Wood	
		District heating based on renewables	District heating based on renewables	District heating based on renewables
RES (renewable energy generation on-site)	None	None	None	144 m² solar thermal system for heating and DHW production
				92 kWp PV system for electricity generation on-site

Based on these renovation packages different additional combinations of the individual renovation measures were tested to answer the defined hypotheses. Following combinations of renovation measures (marked with M1, M2,...) were tested:

Renovation package	Description
Ref	In the reference case, the wall and the windows are repainted and the pitched roof is refurbished. These measures do not improve the energy performance of the building.
M1	80 EPS mm insulation of the façade
M2	240 mm EPS insulation of the façade
M3	M2 + 200 mm EPS insulation of the roof
M4	M2 + 300 mm EPS insulation of the roof
M5	M4 + solar thermal installation
M6	M5 + new double-glazed windows (U-value 1.4 W/m²K)
M7	M5 + new triple-glazed windows (U-value 1.0 W/m²K)
M8	M7 + mechanical ventilation system with heat recovery
M9	M8 + photovoltaic installation

To test the influence of different energy sources for heating and DHW production (RES and non-RES) on the results the defined renovation measures M1 to M9 were also tested with various energy systems. These were:

- Oil (reference case)
- Natural gas
- District heating
- Wood pellets
- Air-water heat pump
- Geo-thermal heat pump

The results of the several calculations can be found in following chapter 5.1.2.

5.1.2. *Results*

Figure 6 shows the calculation results of the Austrian Case Study “Kapfenberg”. On the left side the comparison of the Life Cycle Costs with the carbon emissions, on the right side the comparison with the total Primary Energy.

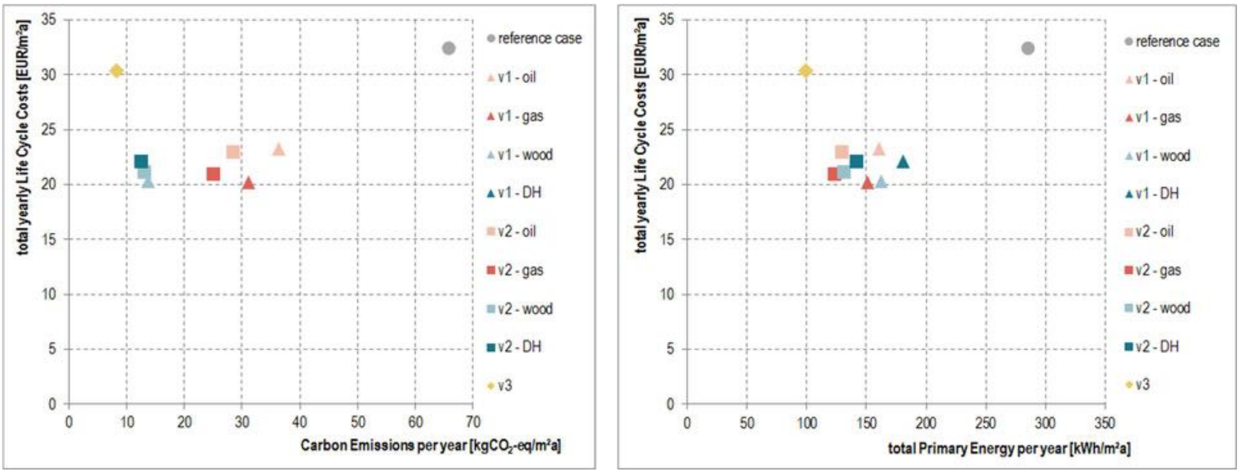


Figure 6: Life Cycle Costs in comparison with carbon emissions (left chart) and total Primary Energy (right chart) of the Case Study “Kapfenberg”, Austria

The results show that all investigated renovation packages are cost effective. This means that the annual specific LCC of each renovation package are lower than the LCC of the reference case.

The lowest carbon emissions are achieved by the executed renovation package v3 with heating and domestic hot water production based on district heating including renewable energy generation on-site by solar thermal and photovoltaic installations. This renovation package has annual carbon emissions of about 8 $kgCO_2$-eq/m²a, which is a reduction of nearly 60 $kgCO_2$-eq/m²a or 85%, compared to the reference case.

The lowest total PE is also achieved by renovation package v3. This renovation package achieves a total Primary Energy of 100 kWh/m²a. This is a reduction of nearly 190 kWh/m²a or 65% compared to the reference case.

The cost optimal solution for the Austrian Case Study would be renovation package v1 with heating and DHW production based on natural gas. The cost optimal solution achieves carbon emissions of 31 $kgCO_2$-eq/m²a, total Primary Energy of 152 kWh/m²a and annual LCC of 20.19 EUR/m²a. But in reality this renovation package was no option. The goal of the renovation was to realize a demonstration building which should achieve 80% reduction of the heating energy demand of the existing building, cover at least 80% of the final energy demand of the renovated building by renewable energy sources and reduce the CO_2 emissions by 80% compared to the existing building. The costs were in fact not the most important criterion.

To have a more detailed understanding of the influence of the different renovation measures on the total results, additional analyses of the different energy related renovation measures were performed. On that account the Life Cycle Costs, the carbon emissions and the total Primary Energy were calculated for the renovation measures M1 to M9 (as described on page 38). The following charts show the comparison of cost effectiveness of energy efficiency renovation measures for the Austrian Case Study for the different heating systems, including also renewable energy generation on-site through solar thermal and photovoltaic installations. The reference shown as a grey dot refers to a situation with renovation measures on the building envelope without improving energy-efficiency levels and the installation of a new oil heating system.

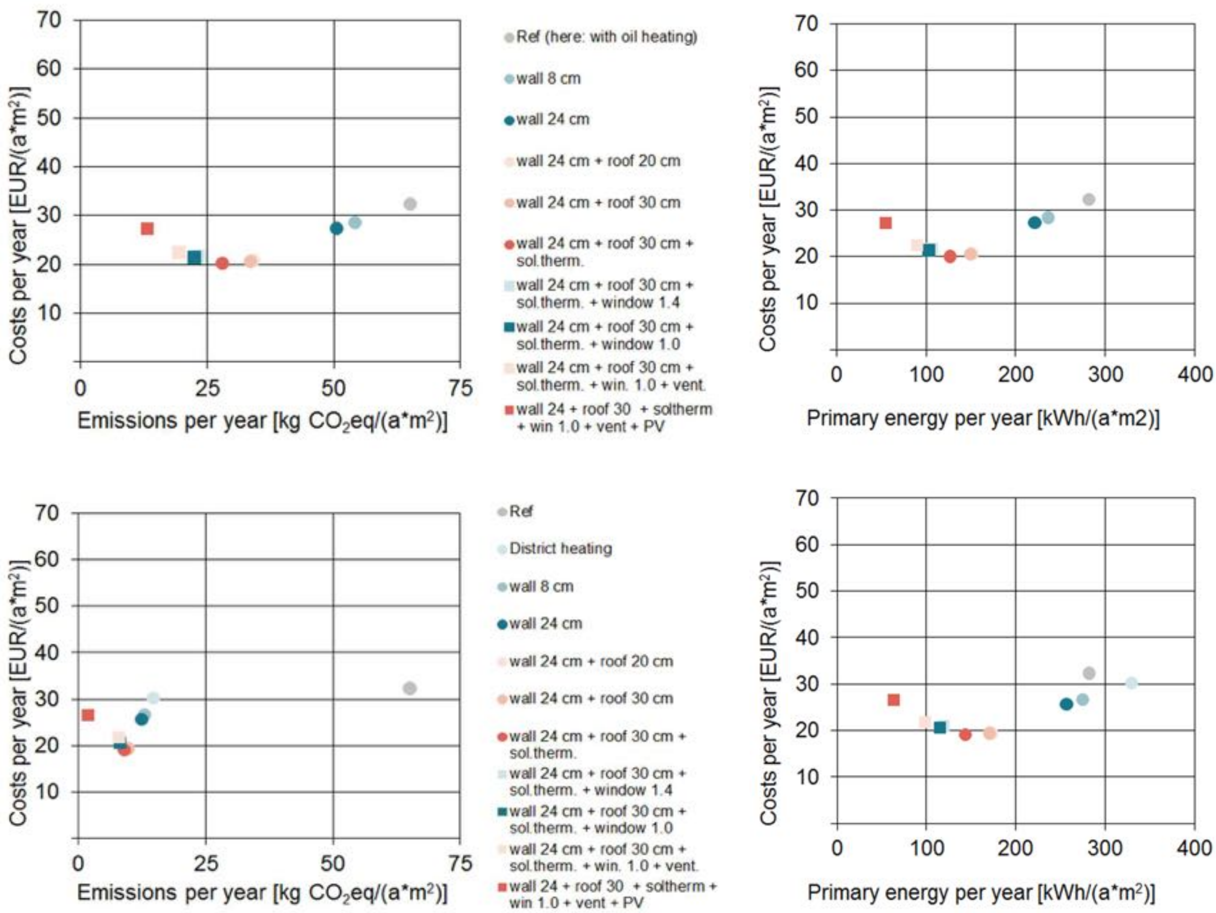


Figure 7: Comparison of cost effectiveness of energy efficiency renovation measures for the Austrian Case Study for the heating systems: oil heating (top) and district heating (bottom), as well as related impacts on carbon emissions and primary energy use

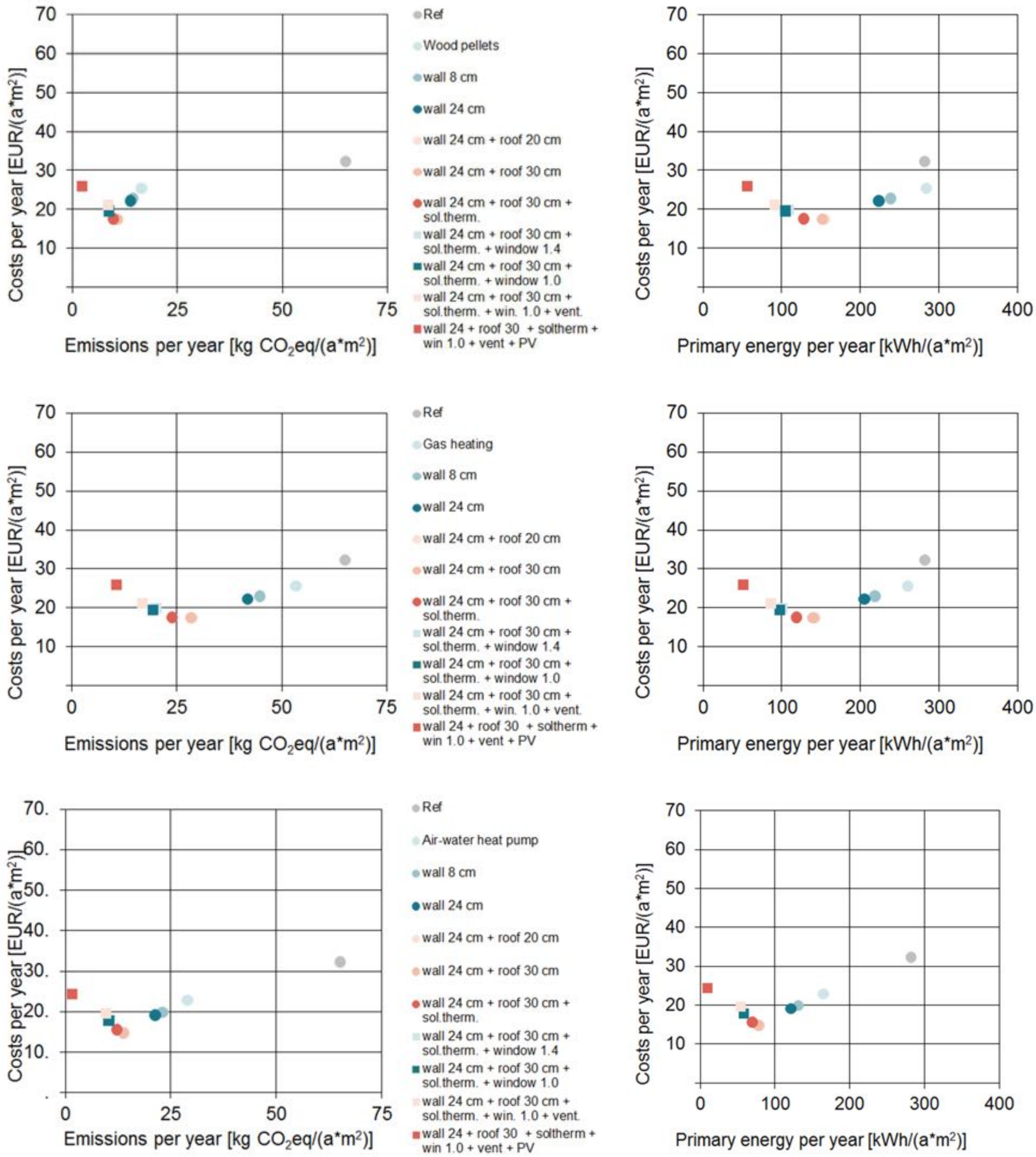


Figure 8: Comparison of cost effectiveness of energy efficiency renovation measures for the Austrian Case Study for the heating systems: wood pellets (top), gas heating (middle) and air-water heat pump (bottom), as well as related impacts on carbon emissions and primary energy use

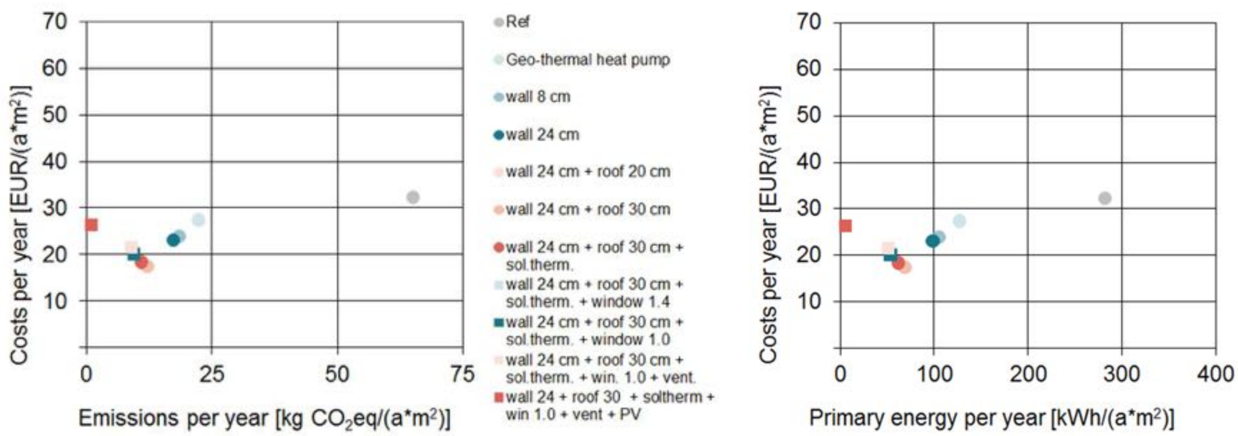


Figure 9: Comparison of cost effectiveness of energy efficiency renovation measures for the Austrian Case Study for a geo-thermal heat pump system, as well as related impacts on carbon emissions and primary energy use

Following graphs summarize the cost curves for different renovation packages on the building envelope with different heating systems. In each of these graphs, three different curves are shown, representing the application of the different renovation packages on the building envelope in combination with the installation of different heating systems. Each dot in the curves represents the application of a particular renovation package. The points with the highest emissions or highest primary energy use for each energy source represent the anyway renovation. As more measures are added to the renovation packages, carbon emissions and primary energy use decrease.

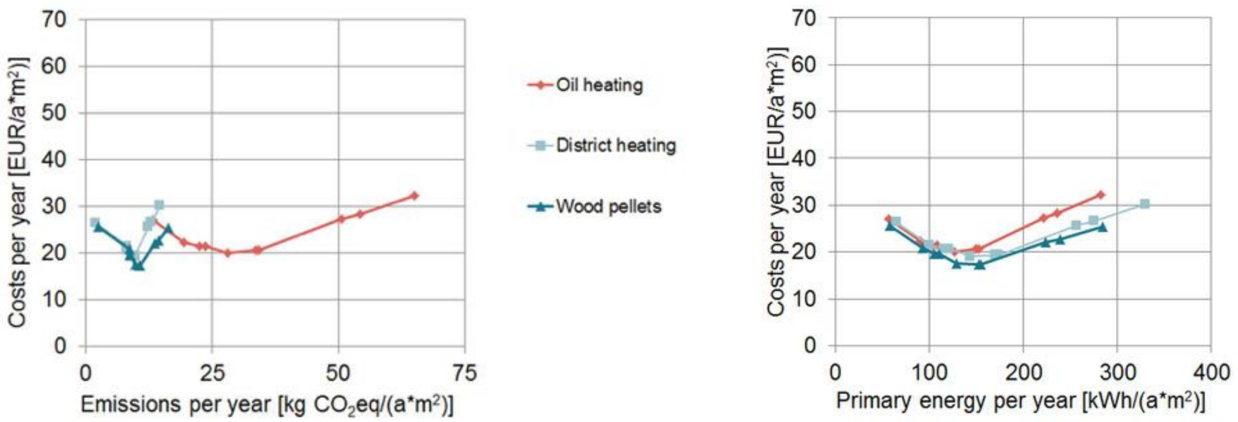


Figure 10: Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on carbon emissions and primary energy use for the Austrian Case Study (part I)

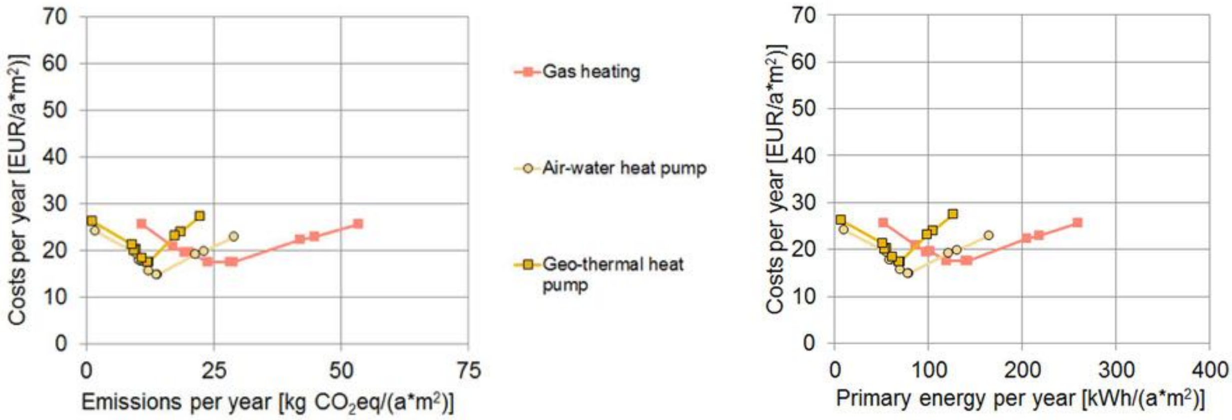


Figure 11: Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on carbon emissions and primary energy use for the Austrian Case Study (part II)

5.1.3. Co-benefits

Some interviews were done with the residents considering the building renovation rather or very important due to the several problems and difficulties felt before the renovation, namely the moist, cold, low fresh air, too small areas and discomfort. All the residents of the building had to leave their dwelling for nearly one year because the building renovation was performed in 2 construction phases and also the dwellings inside the building were renovated and modified. That means people living in a dwelling of the 1st construction phase moved to a dwelling in the 2nd construction phase and after finishing the 1st construction phase they moved back.

After the renovation the residents consider the dwelling convenient, large, dry and warm. Less consistent opinions were collected regarding the noise, natural light and air quality. 1/3 of the respondents considered that the dwelling became noisy. Regarding the natural light, 31% of the respondents considered it dark and regarding the air quality 62% of the respondents considered not having enough fresh air in the dwelling.

Although 85% of the respondents have declared that the expectations with the building renovation have been rather or totally satisfied, about 1/3 have identified some relevant problems, namely disturbance through construction works, less daylight and too low indoor temperature.

Table 8 on the next page presents the co-benefits for some of the investigated renovation packages, namely: the reference case, the cost optimal scenario (M3 + air-water heat pump), the best energy performance scenario which is very close to zero (M9 + geothermal heat pump) and the least cost scenario using the geothermal heat pump (M3 + geothermal heat pump).

When analyzing the packages of measures beyond the cost optimal, it is possible to understand that some of these packages present co-benefits that may justify the extra costs that result from the cost benefit calculations that only considers energy related costs.

Based on Table 8, M9 + Geo HP present more co-benefits than the other renovation packages. The mechanical ventilation with heat recovery improves the air quality and the change of windows allows reducing the disturbance from external noise and the security against intrusions. The geothermal heat pump, due to its high efficiency leads to reduced exposure to energy price fluctuations, but on the other hand its installation is not an easy task. In all of the scenarios, the intervention on the façades affects positively the aesthetics, but this benefit is also present in the reference scenario, so it is not a co-benefit that derives from energy related renovation measures.

The use of renewable energy system such as the solar thermal panels and the photovoltaic system as well as the mechanical ventilation with heat recovery, allows reducing significantly the exposure to energy price fluctuation and also increase the notion of pride and prestige related with the building.

Comparing the cost optimal scenario (M3 + air heat pump), with the scenario with the best energy performance (M9 + geothermal heat pump) yearly costs per m2 increase €11. On the other hand, the air quality is improved, the building becomes more protected from external noise and against intrusions, residents are less exposed to energy price fluctuations and experience an increased sense of pride and prestige related to their renovated building.

Table 8: Identification of co-benefits in several renovation packages in the Austrian Case Study

Building elements	Reference	M3 + Air. HP	M3 + Geo. HP	M9 + Geo HP
Façade	Maintenance	24cm of insulation	24cm of insulation	24 cm insulation
Roof	Maintenance	20 cm of insulation	20 cm of insulation	30cm insulation
Floor	Maintenance	Maintenance	Maintenance	Maintenance
Windows	Maintenance	Maintenance	Maintenance	Windows (U=1)
Ventilation	Natural	Natural	Natural	Mech + heat recov.
Heating system	Oil heating	Air Heat Pump	Geo Heat pump	Geo Heat pump
DHW system	Oil heating	Air Heat pump	Geo Heat pump	Geo Heat pump
RES	None	None	None	Solar thermal + PV
Co-benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲	▲	▲	▲▲
Thermal comfort		▲▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲▲
Ease of installation		▲▲	▲▼	▲▼
Air Quality		▲	▲	▲▲▲
External noise				▲▲▲
Safety				▲▲
Additional costs [EUR/m²a]	16	Cost optimal	2	11

5.1.4. Conclusions

For the analyzed parameters carbon emissions, total Primary Energy and the Life Cycle Costs the following conclusions can be drawn:

- All investigated renovation measures are cost effective, which means that the LCC are lower than the LCC of the reference case.
- The highest carbon emissions are found in the reference case. That means that all renovation measures on the building envelope and the variation of the energy sources for heating and DHW production can reduce the carbon emissions.
- The highest total Primary Energy is achieved by the anyway renovation in combination with district heating. Again all investigated renovation packages on the building envelope lead to a reduction of the total PE.
- In order to reduce carbon emissions and total Primary Energy further it is more efficient to concentrate on several building elements than only on one element.
- For natural gas heating and the heat pump systems it could be investigated that only the change of the heating system, without including any further measures on the building envelope, can reduce the carbon emission and the total Primary Energy.
- Renovation measure M9, which represents the most improved building envelope including also renewable energy generation on-site through solar thermal and photovoltaic systems, achieves the lowest carbon emissions and also the lowest Primary Energy values.
- The renewable energy sources (district heating, heat pump systems and wood pellets) achieve the lowest carbon emissions, the heat pump systems the lowest Primary Energy.

Based on the additional calculation results the hypotheses were tested. Table 9 shows the investigated hypotheses for the Austrian Case Study.

Table 9: Results for the investigated hypotheses for the Case Study “Kapfenberg“ in Austria

Hypothesis	Results from Case Study “Kapfenberg”, Austria
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements	✓
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements	✓
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.	✓

For the Austrian Case Study all five hypotheses could be confirmed.

5.2. Case Study “Traneparken”, Denmark

5.2.1. Investigated renovation packages

	Reference case	Renovation package v1	Renovation package v2	Renovation package v3
Building envelope	Maintenance of the outer skin of the external walls	100 mm insulation of the façade	No insulation of the façade	211 mm insulation of the façade
	New roofing	450 mm insulation of the roof	450 mm insulation of the roof	250 mm insulation of the roof
	Painting and repair of wooden frame windows	New triple-glazed windows (energy glass)	New triple-glazed windows (energy glass)	New triple-glazed windows (energy glass)
BITS (Building Integrated Technical Systems)	Renewal of the heating and domestic hot water system	Renewal of the heating and domestic hot water system	Renewal of the heating and domestic hot water system	Renewal of the heating and domestic hot water system
		New mechanical ventilation system with heat recovery (SFP = 1.2, Eff.= 90%)	New mechanical ventilation system with heat recovery (SFP = 1.2, Eff.= 90%)	New mechanical ventilation system with heat recovery (SFP = 1.4, Eff.= 80%)
Investigated energy sources for heating and domestic hot water		Oil	Oil	
		Natural gas	Natural gas	
	District heating based renewables with a share of 53%	District heating based renewables with a share of 53%	District heating based renewables with a share of 53%	District heating based renewables with a share of 53%
RES (renewable energy generation on-site)	None	33 kWp photovoltaic system for the electricity generation on-site	132 kWp photovoltaic system for the electricity generation on-site	33 kWp photovoltaic system for the electricity generation on-site

Note: The heating energy supply of Traneparken is district heating, so in practical terms it is not a real alternative to change this supply to anything else. However, for the purpose of the LCC and LCA the calculations were carried out also for a changed heating supply system, i.e. gas and oil boilers.

The on-site generated electricity counts for the same level as energy savings, with a weighting factor of 0.413 kgCO_2-eq/kWh$_{final}$ respectively 1.78 kWh$_{prim}$/kWh$_{final}$ (see also Table 6 and Table 7 in chapter 4.4 on page 36).

Based on these renovation packages, again different additional combinations of the individual renovation measures were tested to answer the defined hypotheses.

Following combinations of renovation measures (marked with M1, M2,...) were tested:

Renovation package	Description
Ref	In the reference case, the outer skin of the external walls was maintained and the wooden frame windows were painted and repaired. New roofing was also included but none of these measures improves the energy performance of the building.
M1	150 mm insulation of the roof
M2	300 mm insulation of the roof
M3	M2 + 100 mm insulation of the façade
M4	M2 + 200 mm insulation of the façade
M5	M4 + new triple-glazed windows
M6	M5 + mechanical ventilation SFP 1.4, Eff=80%
M7	M5 + mechanical ventilation SFP 1.2, Eff=90%

In addition to the different renovation measures on the building envelope and the ventilation system again different energy sources for heating and DHW production were tested, including also photovoltaic energy generation on-site. The investigated energy systems were:

- Oil heating
- Heat pump
- District heating (53% renewable)
- District heating (53% renewable) + 32 kWp photovoltaic system
- District heating (53% renewable) + 132 kWp photovoltaic system

For each of these renovation measures and packages Life Cycle Costs, carbon emissions and Primary Energy were calculated. The results are presented in chapter 5.2.2.

5.2.2. Results

Figure 12 shows the calculation results of the Case Study “Traneparken” in Denmark. On the left side the Life Cycle Costs are plotted in comparison with the carbon emissions and on the right side with the total Primary Energy of the building.

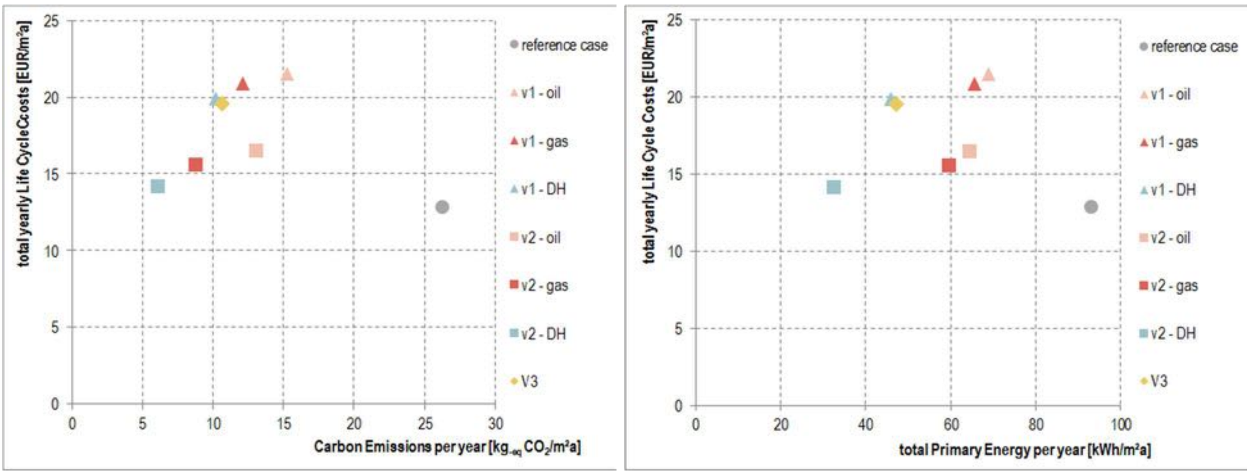


Figure 12: Life Cycle Costs in comparison with carbon emissions (left chart) and total Primary Energy (right chart) of the Case Study “Traneparken”, Denmark

The results show that none of the defined and investigated renovation packages is cost effective. In other words, the annual LCC of each renovation package are higher than the LCC of the reference case, which means that the reference case is the cost optimum renovation. A possible reason for that might be that the existing building is already insulated and the additional insulation measures can reduce the carbon emissions and the total Primary Energy but increase the annual Life Cycle Costs.

The lowest carbon emissions are achieved by renovation package v2 with heating and domestic hot water production based on district heating and additionally adding a large PV system. This renovation package achieves carbon emissions of 6.2 $kgCO_2$-eq/m²a. The reference case achieves carbon emissions of 26.4 $kgCO_2$-eq/m²a. Renovation package v2 can therefore save up to 20.2 $kgCO_2$-eq/m²a or 77% of the carbon emissions compared to the reference case.

Renovation package v2 with heating and domestic hot water production based on district heating also achieves the lowest total Primary Energy, with a value of about 33 kWh/m²a. This is, compared to the reference case, a reduction of 61 kWh/m²a or 65%.

The actual renovation carried out (renovation package v3) achieves carbon emissions of 10.7 $kgCO_2$-eq/m²a, a total Primary Energy of 47 kWh/m²a and annual Life Cycle Costs of 19.54 EUR/m²a. Compared to the reference case this is a reduction of 15.7 $kgCO_2$-eq/m²a respectively 60% (carbon emission) and of 46 kWh/m²a respectively 50% (total Primary Energy).

This particular renovation package was chosen, despite it is not the cost optimal solution, due to following reasons: the goal was to renovate the buildings because they were worn down and the external concrete walls were weakened by deterioration. At the same time external balconies were added to improve the flats. The overall intention was to:

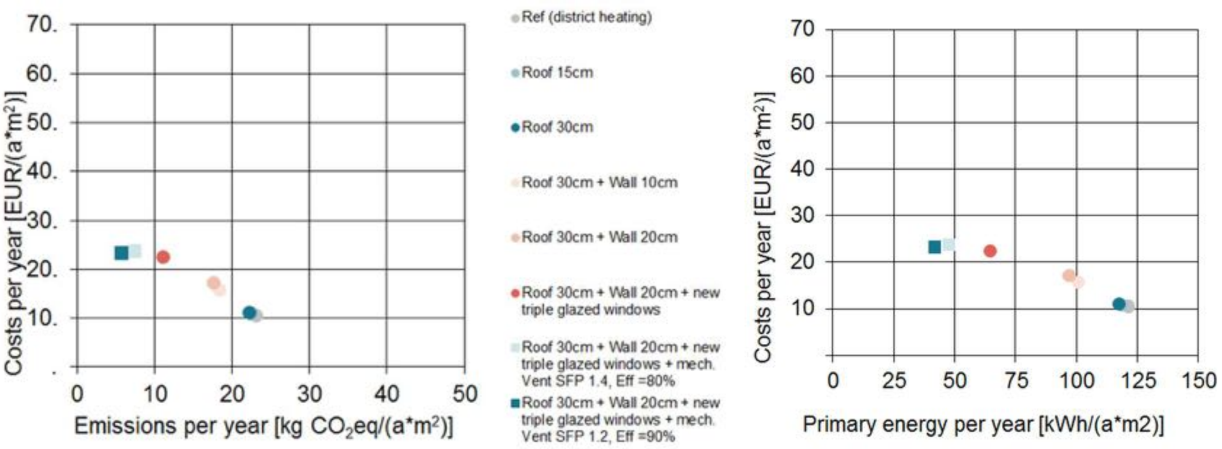
- Renovate worn down parts of the buildings
- Improve the indoor climate
- Improve flats with external balconies
- Improve outdoor areas
- Reduce energy consumption (insulation of constructions, new windows/doors, mechanical ventilation with heat recovery)

The apparent needs - necessary repair of external walls and replacement of windows - were used as an opportunity to drastically improve the insulation of the walls and to choose triple-glazed low energy windows. Thereby a far more sustainable solution was achieved.

Looking at the results it is obvious that not installing any external wall insulation in v2 results in lower Life Cycle Costs than in renovation package v1 and v3. Even when in v2 a much larger PV system is installed, the LCC are still lower. It is interesting to see that installation of a larger photovoltaic system seems to be able to out-balance the expensive exterior wall insulation, especially if the generated energy from the photovoltaic system can be allocated to the building and in this way reduce the annual energy consumption. Nevertheless it has to be mentioned that the insulation of the exterior walls was not an option but a must. The walls were worn down and the comfort in the building was suffering severely due to their state.

The comparison of cost effectiveness of energy efficiency renovation measures for the Danish Case Study for different heating systems (oil heating, district heating and heat pump) and related impacts on carbon emissions and primary energy use is shown in Figure 13 and Figure 14 show.

Figure 15 shows the influence of the different heating systems, including also different photovoltaic energy generation on-site, on the reference case with no additional energy related renovation measures.



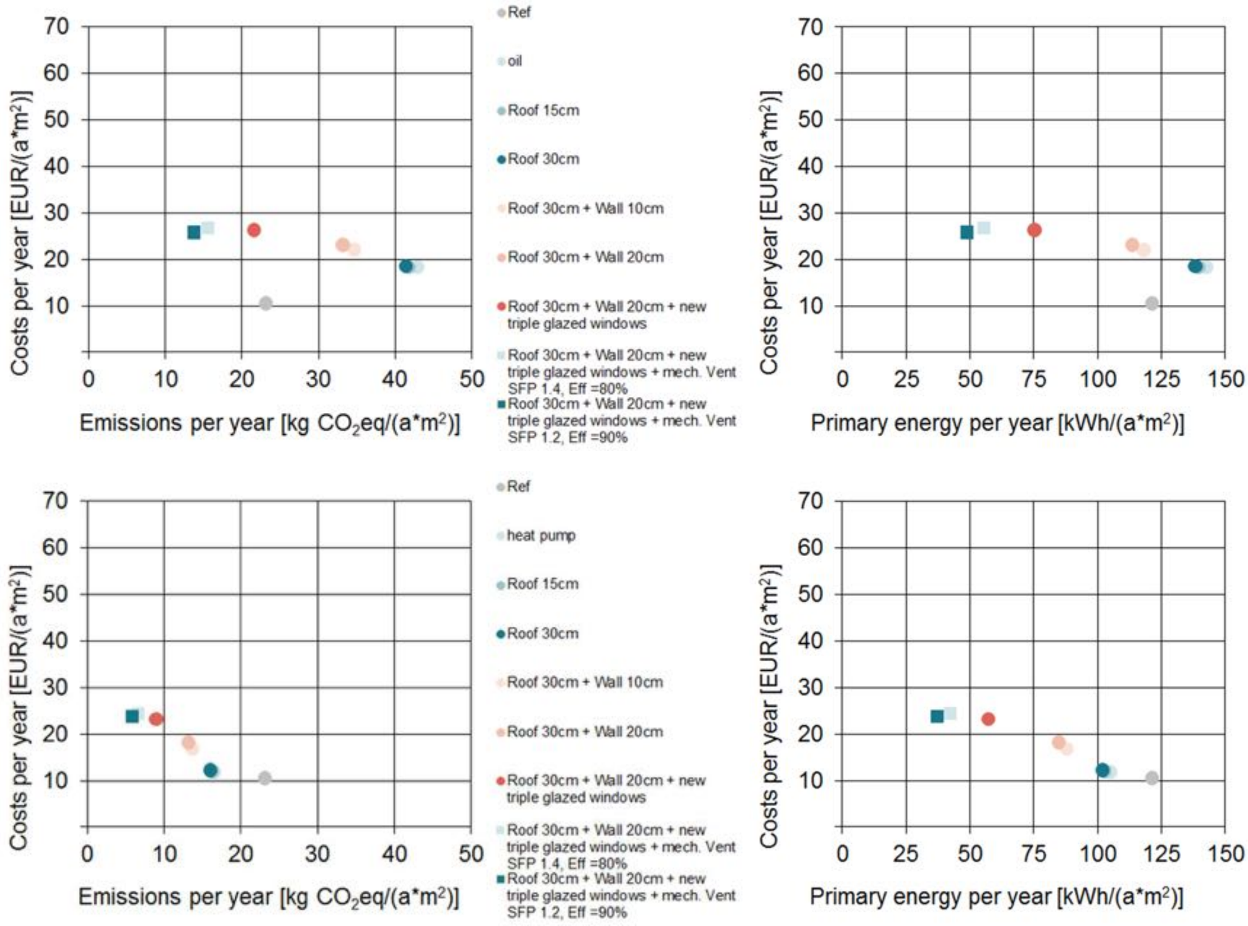


Figure 13: Comparison of cost effectiveness of energy efficiency renovation measures for the Danish Case Study for district heating (top), oil heating (middle) and heat pump (bottom), as well as related impacts on carbon emissions and primary energy use

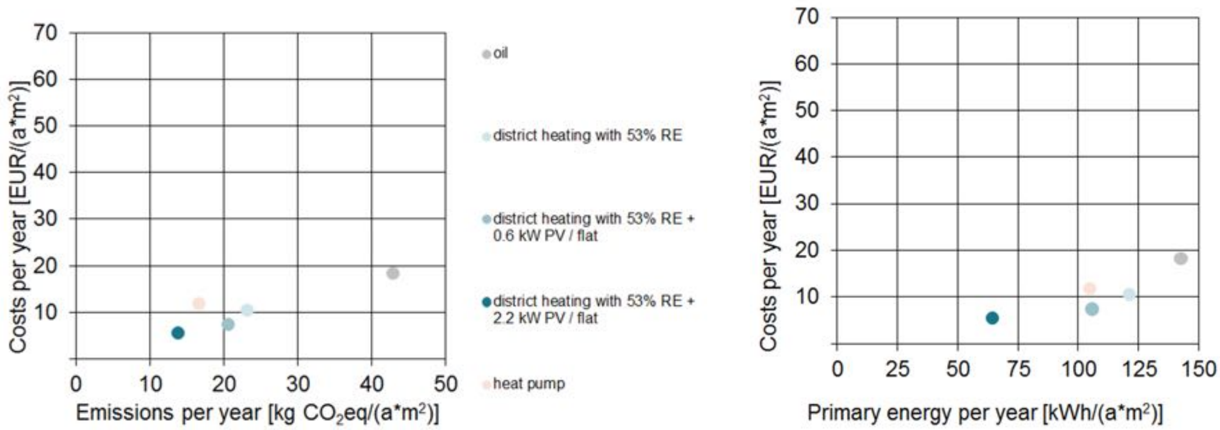


Figure 14: Comparison of cost effectiveness of energy efficiency renovation measures for the Danish Case Study for the different heating systems, including renewable energy generation on-site by the photovoltaic installation, only reference case

Figure 15 summarizes the cost curves for different renovation packages on the building envelope with different heating systems. In the graph, three different curves are shown, representing the application of the different renovation packages on the building envelope in combination with the installation of different heating systems. Each dot in the curves represents the application of a particular renovation package.

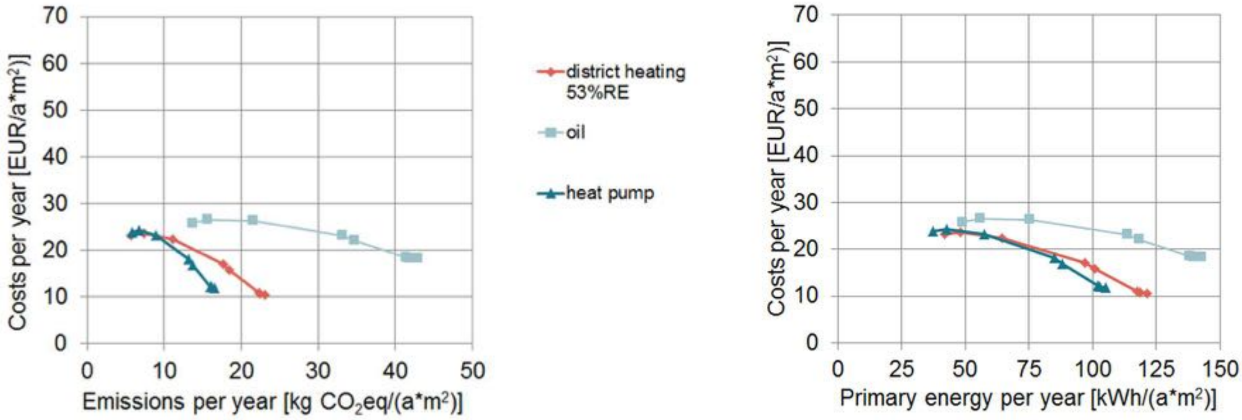


Figure 15: Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on carbon emissions and primary energy use for the Danish Case Study

5.2.3. *Co-benefits*

Before renovation, the buildings seemed rather grey and boring and had problems with façades, windows and roofs. The indoor climate was unacceptable and the energy consumption was very high.

Table 10 shows the co-benefits of four renovation packages: the cost optimal solution, a renovation package using a heat pump instead of district heating, renovation package M4 which improves the energy performance of the façade and the roof, and the scenario that leads to the best energy performance (M7 + Heat Pump).

Table 10: Identification of co-benefits in several renovation packages in the Danish Case Study

Building elements	Reference	Reference + HP	M4 + DH	M7 + HP
Façade	Maintenance	Maintenance	20 cm insulation	20 cm insulation
Roof	Maintenance	Maintenance	30cm insulation	30cm insulation
Floor	Maintenance	Maintenance	Maintenance	Maintenance
Windows	Maintenance	Maintenance	Maintenance	Triple Glazed
Ventilation	Maintenance	Maintenance	Maintenance	Mech + heat recov.
Heating system	District heating	Heat pump	District heating	Heat pump
DHW system	District heating	Heat pump	District heating	Heat pump
RES	53% RES	None	None	None
Co-benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort			▲▲▲	▲▲▲
Building physics			▲▲	▲▲
Internal noise			▼	▼
Price fluctuation		▲	▲	▲▲▲
Air Quality				▲
External noise				▲▲
Safety				▲
Additional costs [EUR/m²a]	Cost optimal	1	7	13

Looking at the table, the last two renovation packages which improve the buildings envelope, present some advantages that can play an important role in the final decision. From an economical perspective the difference in the global cost to the cost optimal solution is definitely given but the improvements in the thermal comfort and reduction in the problems related to the building physics are interesting additional benefits. There is a negative co-benefit related to the increase of the insulation on the buildings envelope which is the internal noise from adjacent dwellings that becomes noticeable when the external noise is reduced.

The exposure to the energy price fluctuation decreases significantly in the last renovation package, which also presents the co-benefits of further reducing the external noise and improve safety against intrusions, related with the replacement of windows.

5.2.4. *Conclusions*

The analysis of the Danish Case Study "Traneparken" allows following conclusions:

- The lowest Life Cycle Costs are achieved by the reference case. That means that none of the investigated renovation measures is cost effective. A reason for this might be the already included façade insulation of the existing building.
- The lowest carbon emissions are achieved by renovation measure M7, which includes the most improved thermal envelope and very efficient mechanical ventilation with heat recovery, together with district heating and similar also with heat pump.
- The lowest Primary Energy is achieved by renovation measure M7 together with the heat pump system.
- If only measures on the wall and the roof are included, together with an oil heating system, the carbon emissions increase. All other investigated renovation measures can reduce the carbon emissions compared to the reference case.
- All investigated renovation measures can reduce the Primary Energy, compared to the reference case. The exception is, if an oil heating is used and only the roof is insulated. This combination increases the total Primary Energy.
- It´s more efficient to concentrate on several building elements than only on one element to reduce the carbon emissions and the total Primary Energy.
- The on-site energy generation by the photovoltaic system reduces carbon emissions, total PE and also LCC compared to the reference case but also compared to the option without the PV installation.

Based on these conclusions the hypotheses for the Danish Case Study were tested (Table 11).

Table 11: Results for the investigated hypotheses for the Case Study "Traneparken" in Denmark. ✓ thereby means that the hypothesis is confirmed, ✗ indicates a not-confirmed hypothesis. (✓) means that the hypothesis is confirmed, but with restrictions

Hypothesis	Results from Case Study "Traneparken", Denmark
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements	✓
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements	✓
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.	✓**

* In this particular case the reference case is the cost optimum renovation. All investigated energy related renovation measures lead to an increase of the annual Life Cycle Costs.

** If the initial situation includes oil heating and the switch to district heating or heat pump is performed.

For the Danish Case Study four of the five hypotheses could be confirmed. Not confirmed is the hypothesis *"Synergies are achieved when a switch to RES is combined with energy efficiency measures"*. This could be explained as follows: starting with anyway renovation and an oil heating system it is more cost efficient to change only the heating system, to district heating or heat pump, and not carrying out further energy related renovation measures on the building envelope. The reduction of carbon emissions and Primary Energy due to the improved building envelope is quite small compared to the change of the energy source. Additionally the LCC increase due to these energy related renovation measures on the building envelope and therefore it is not efficient to combine the switch to RES with the energy efficiency measures on the building envelope.

5.3. Case Study “Rainha Dona Leonor neighborhood “, Portugal

5.3.1. Investigated renovation packages

	Reference case	Renovation package v1	Renovation package v2	Renovation package v3
Building envelope	Maintenance of the outside walls	100 mm EPS insulation of the façade	80 mm cork board insulation of the façade	60 mm EPS insulation of the façade
	Maintenance of the roof	140 mm rock wool insulation of the roof	80 mm cork board insulation of the roof	50 mm XPS insulation of the roof
		80 mm rock wool insulation of the floor	80 mm cork board insulation of the floor	No insulation of the floor
	Maintenance of the existing windows	Maintenance of the existing windows	New double-glazed windows	New double-glazed windows
BITS (Building Integrated Technical Systems)	Renewal of the existing electrical heating and domestic hot water systems HVAC system for cooling	Replacement of the heating and domestic hot water system	Replacement of the heating and domestic hot water system	Replacement of the heating and domestic hot water system
Investigated energy sources for heating and domestic hot water	Electricity (electric heater)	HVAC (multi-split air conditioned for heating and cooling and solar thermal panels backed up by electric heater for DHW) Natural gas Heap pump + PV Biomass	HVAC (multi-split air conditioned for heating and cooling and solar thermal panels backed up by electric heater for DHW) Natural gas Heap pump + PV Biomass	HVAC (multi-split air conditioned for heating and cooling and solar thermal panels backed up by electric heater for DHW)
RES (renewable energy generation on-site)	None	3.8 m² solar thermal panels for DHW 3.7 kWp photovoltaic panels to support the heat pump	3.8 m² solar thermal panels for DHW 3.7 kWp photovoltaic panels to support the heat pump	3.8 m² solar thermal panels for DHW

The chosen renovation scenario (renovation package v3) presents the most current renovation praxis in Portugal, with significant limitation on the investment costs and no major concerns with Life Cycle Costs, especially in cases such as this where the investor is not the one who pays the future energy bills.

Based on these renovation packages v1, v2 and v3 different additional combinations of the individual renovation measures were tested to confirm the defined hypotheses:

Renovation package	Description
Ref	In the reference case, the walls, the roof and the windows are maintained. These measures do not improve the energy performance of the building.
M1	80 mm rock wool insulation of the roof
M2	80 mm cork board insulation of the roof
M3	140 mm rock wool insulation of the roof
M4	M3 + 60 mm EPS insulation of the façade
M5	M3 + 80 mm cork board insulation of the façade
M6	M3 + 100 mm EPS insulation of the façade
M7	M6 + 80 mm rock wool insulation of the floor
M8	M6 + 80 mm cork board insulation of the floor
M9	M8 + new double-glazed windows

The renovation measures M1 to M9 were tested with following combinations of building integrated technical systems for heating, cooling and DHW:

- Electric heater
- Natural gas
- HVAC + electric heater
- HVAC + electric heater + solar thermal
- Heat pump + PV
- Biomass

The results of these investigations are presented in following chapter 5.3.2.

5.3.2. Results

The calculation results in Figure 16 show on the left side the comparison of the Life Cycle Costs with the carbon emissions and on the right side the comparison of the LCC with the total Primary Energy.

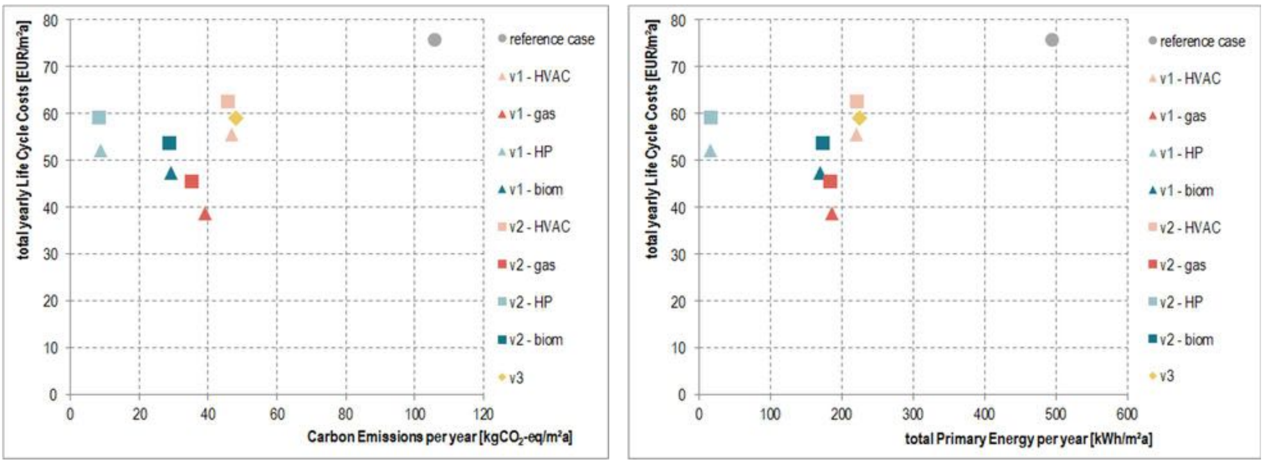


Figure 16: Life Cycle Costs in comparison with carbon emissions (left chart) and total Primary Energy (right chart) of the Case Study "Rainha Dona Leonor neighborhood", Portugal

The charts show that all investigated renovation packages are cost effective. That means the annual specific LCC of each renovation package are lower than the LCC of the reference case.

The lowest carbon emissions are achieved by renovation package v2 with heating (the energy efficiency measures on the building envelope allowed to avoid the need of a cooling system) and domestic hot water production based on a heat pump, which is supported with a photovoltaic system. The carbon emissions of this system are 8.5 $kgCO_2$-eq/m²a. This is a reduction of more than 97 $kgCO_2$-eq/m² or 92% compared to the reference case, which achieves carbon emissions of 106 $kgCO_2$-eq/m²a.

The lowest total PE is achieved by renovation package v1 with heating and domestic hot water based on a heat pump. With a value of 16 kWh/m²a this renovation package can reduce the total PE, compared to the reference case, by 479 kWh/m²a or 97%. The difference between the renovation package achieving the lowest carbon emissions (renovation package v2) and the one achieving the lowest PE (renovation package v1) is due to the insulation material used in renovation package v2 (cork), which has lower carbon emissions but a significant PE from the biomass used in the fabrication process.

The cost optimal solution for the Portuguese Case Study is renovation package v1 with heating and domestic hot water production based on natural gas. This cost optimal solution achieves carbon emissions of 39.4 $kgCO_2$-eq/m²a, a total PE of 186 kWh/m²a and LCC of 38.78 EUR/m²a.

In relation to the most ambitious, the gap to the cost optimal solution is:

- Carbon Emissions: with additional annual LCC of 20.07 EUR/m²a the carbon emissions could be reduced from 39.37 kgCO_2-eq/m²a (cost optimal solution) to 8.50 kgCO_2-eq/m²a (lowest carbon emissions). That means with 52% higher LCC the carbon emissions could be reduced by 78%.
- PE: with additional annual LCC of 13.34 EUR/m²a the total PE could be reduced from 186 kWh/m²a (cost optimal solution) to 16 kWh/m²a (lowest total PE). 26% higher LCC would therefore result in a 91% lower total PE.

To have a more detailed understanding of the influence of the different renovation measures on the calculation results of the Portuguese Case Study, the influence of improving the thermal quality of the building envelope, the modification of the energy source for heating and domestic hot water and the use of renewable energy generated on-site was analyzed and is presented on the following pages.

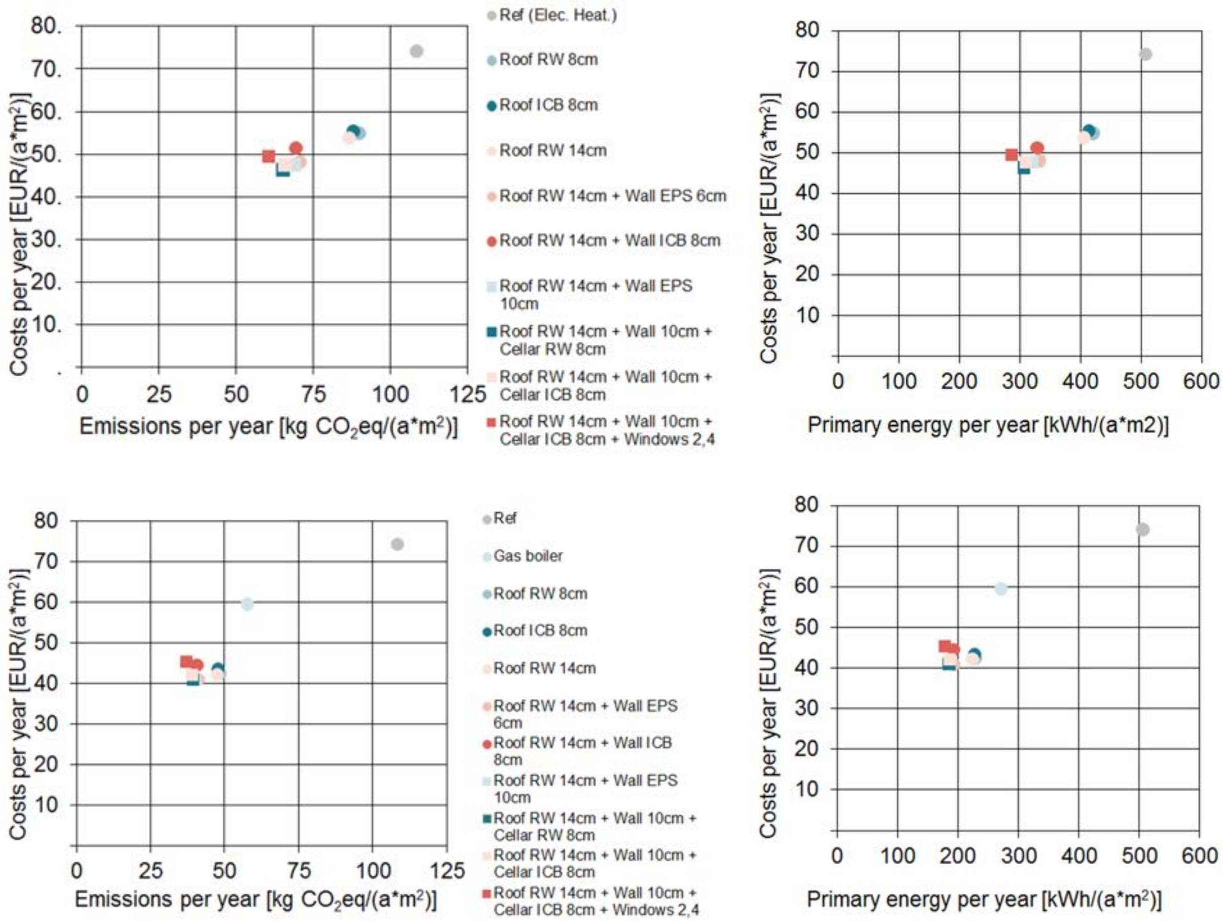


Figure 17: Comparison of cost effectiveness of energy efficiency renovation measures for the Portuguese Case Study for the BITS: electric heater (top) and gas boiler (bottom), as well as related impacts on carbon emissions and primary energy use

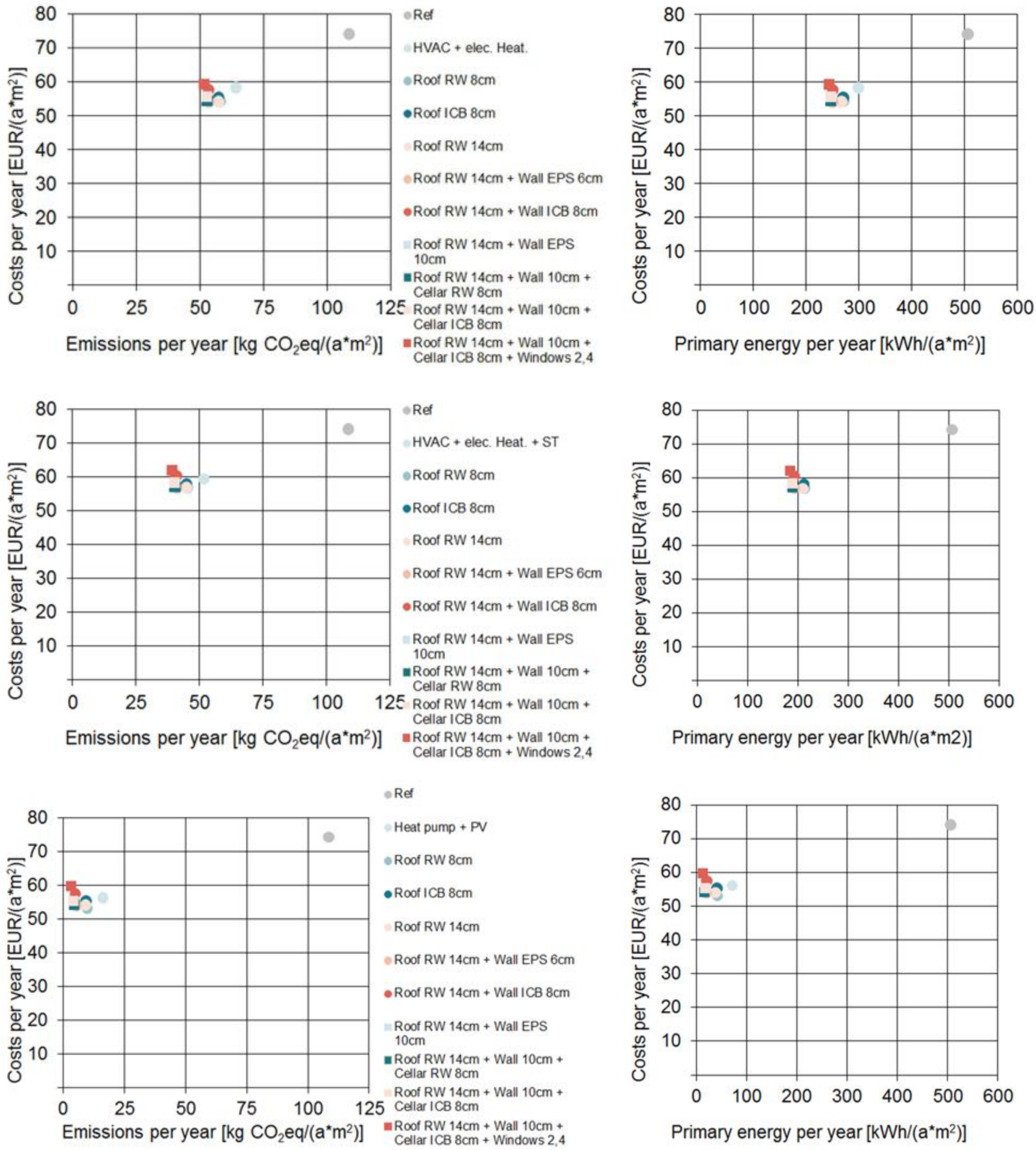


Figure 18: Comparison of cost effectiveness of energy efficiency renovation measures for the Portuguese Case Study for the BITS: HVAC + electric heater (top), HVAC + electric heater + solar thermal (middle) and heat pump + photovoltaic (bottom), as well as related impacts on carbon emissions and primary energy use

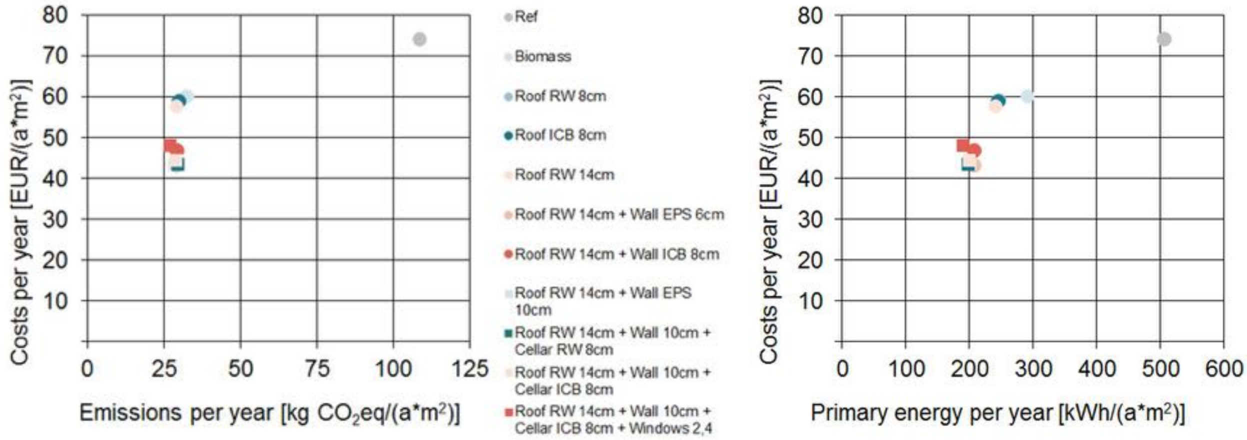


Figure 19: Comparison of cost effectiveness of energy efficiency renovation measures for the Portuguese Case Study for a biomass system, as well as related impacts on carbon emissions and primary energy use

Following Figure 20 summarizes the cost curves for different renovation packages on the building envelope with different BITS.

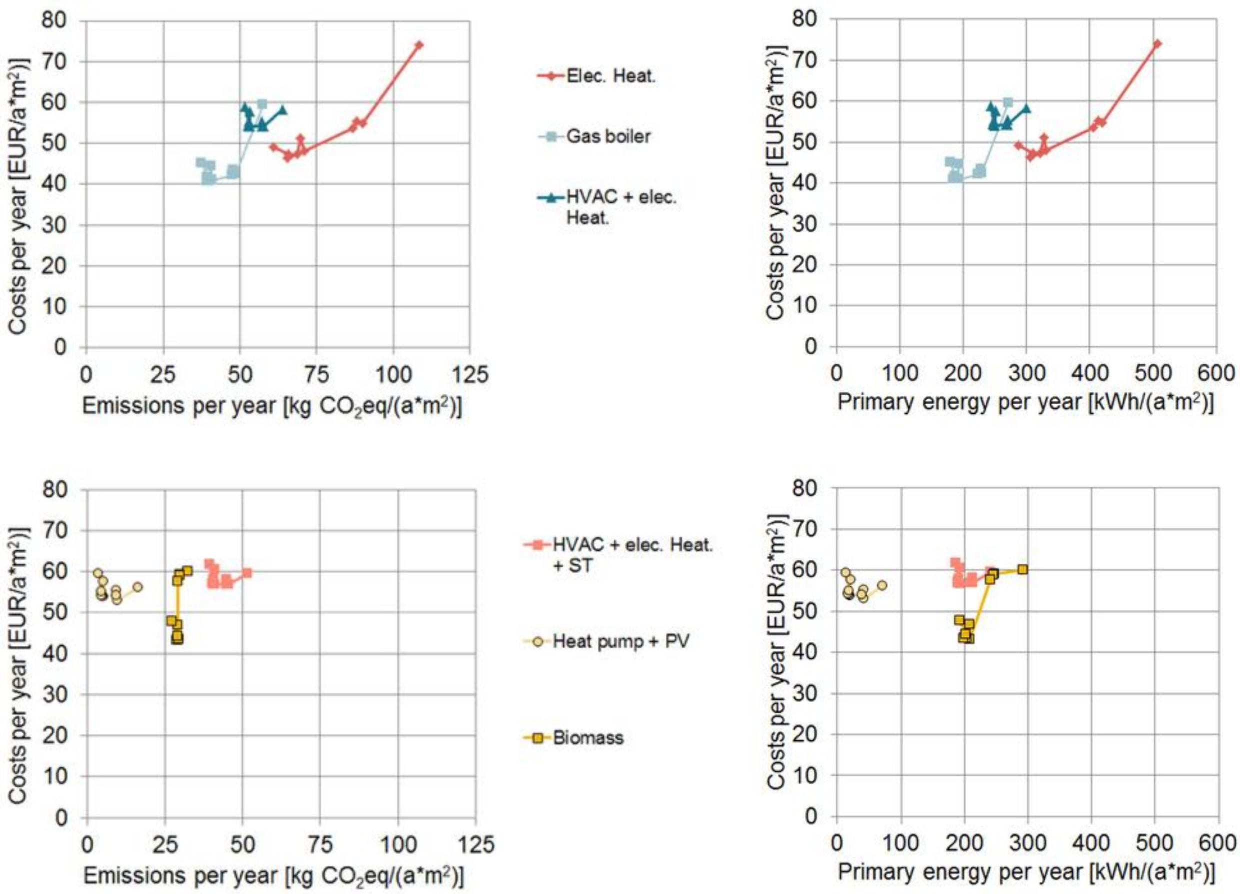


Figure 20: Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different BITS and related impacts on carbon emissions and primary energy use for the Portuguese Case Study

5.3.3. Co-benefits

To synthetize the co-benefits analysis, 3 different renovation packages were compared to the cost optimal solution, namely the reference case, the chosen renovation and the best energy performance solution (M9 wit heat pump and photovoltaic panels). The results are presented in Table 12.

Table 12: Identification of co-benefits in several renovation packages in the Portuguese Case Study

Building elements	Reference	Chosen R.	M7 + GB	M9 + HP + PV
Façade	Maintenance	6 cm of RW	10 cm of EPS	10 cm of EPS
Roof	Maintenance	8 cm of RW	14 cm of RW	14 cm of RW
Floor	Maintenance	5 cm of RW	Maintenance	8 cm ICB
Windows	Maintenance	New windows U 2.4	Maintenance	New windows U 2.4
Heating system	Electric heater	Electric heater	Gas boiler	Heat pump + PV
DHW system	Gas boiler	Electric heater + ST	Gas boiler	Heat pump + PV
Co-benefits				
Aesthetics	▲	▲	▲	▲ ▼
Pride/prestige	▲ ▲	▲ ▲	▲ ▲	▲ ▲
Thermal comfort		▲ ▲ ▲	▲ ▲ ▲	▲ ▲ ▲
Building physics		▲ ▲	▲ ▲	▲ ▲
Internal noise		▼	▼	▼
Price fluctuation		▲ ▲	▲ ▲	▲ ▲ ▲
Air Quality		▲	▲	▲
External noise		▲		▲
Safety		▲		▲
Additional costs [EUR/m^2a]	33	12	Cost optimal	13

Regarding the aesthetics/architectural integration, the positive co-benefit is also present in the reference case, so it cannot be accounted as a co-benefit deriving from energy related measures. In fact, in the best energy performance package, the existence of photovoltaic panels may be a problem due to the required dimensions and the characteristics of the buildings.

In the implemented renovation package, the introduction of new frames with double glazing present the co-benefit of safety and also of reduced external noise. However, in the interviews performed among the residents, these positive co-benefits have never been mentioned. In fact, once the neighbourhood is located in a very quiet area, nor noise or safety were an issue before the renovation. So the potential co-benefits from the improved window were not felt. Therefore, the relevance of these co-benefits is reduced when compared with the same measure in other case studies.

In the reduction of the exposure to the energy price fluctuation, the best energy performance package is the most independent one, due to the renewable energy production.

The analysis of the interviews to the respondents have also made visible that wrong design might have a huge influence in residents perception. In this case, internal shading and larger windows had negative impact in thermal comfort, natural lighting, building physics, and in the case of internal shading also creating problems with functionality and useful living areas.

5.3.4. Conclusions

For the analyzed parameters carbon emissions, total Primary Energy and Life Cycle Costs following conclusions can be drawn:

- The reference case achieves the highest carbon emissions, the highest Primary Energy values and also the highest LCC for the particular heating systems.
- The lowest carbon emissions and also the lowest Primary Energy values are achieved by the heat pump + PV combination.
- The change of the energy source reduces carbon emissions and total Primary Energy more significantly than the renovation measures on the building envelope.
- The influence of the renovation measures on the building envelope on the carbon emissions and the total Primary Energy reductions is depending on the BITS.
- The cost optimal package of energy efficiency measures does not change significantly with the different BITS combinations. On the other hand, with the use of the most efficient BITS, namely the HVAC and the heat pump, some energy efficiency measures, if compared with the use of those BITS without energy efficiency measures, are not cost effective.

Following Table 13 shows the investigated hypotheses for the Portuguese Case Study.

Table 13: Results for the investigated hypotheses for the Case Study “Rainha Dona Leonor neighborhood“ in Portugal. ✓ means that the hypothesis is confirmed. Symbols in parenthesis indicate that the hypotheses are only partly confirmed.

Hypothesis	Results from Case Study “Rainha Dona Leonor neighborhood”, Portugal
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements	(✓)*
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements	✓
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.	(✓)**

* This hypothesis can be confirmed for the renovation measures roof and wall but not for the remaining measures, due to the small number of variants tested for those remaining measures.

** This hypothesis cannot clearly be answered. For the majority of the measures in this case study this is true. Only measures with a gas heating system is a contender.

For the Portuguese Case Study three hypotheses can absolutely be confirmed. The confirmation of the remaining hypotheses is more difficult and not completely possible. So for example the hypothesis: *"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements"* can only be confirmed for the renovation measures roof and wall. This means that it is more efficient to renovate the roof and the wall instead of concentrating only on the roof. Improving also the floor and changing the windows in this case doesn´t lead to major reductions in carbon emissions and Primary Energy. Instead these measures lead to an increase of the annual Life Cycle Costs compared to the situation where only insulation on the roof and the walls is considered.

5.4. Case Study "Lourdes Neighborhood", Spain

5.4.1. Investigated renovation packages

	Reference case	Renovation package v1	Renovation package v2	Renovation package v3
Building envelope	Maintenance of the existing façade	40 mm EPS insulation of the façade	220 mm EPS insulation of the façade	60 mm EPS insulation of the façade
	Maintenance of the existing roof	40 mm XPS insulation of the roof	240 mm XPS insulation of the roof	60 mm XPS insulation of the roof
	No renovation measure regarding the floor	40 mm mineral wool insulation of the floor	240 mm mineral wool insulation of the floor	100 mm mineral wool insulation of the floor
	Maintenance of the old single-glazed windows	New double-glazed windows	New double-glazed windows	New double-glazed windows in addition to the existing single-glazed and sliding aluminum frame
BITS (Building Integrated Technical Systems)	New central heating system for heating and domestic hot water production	New central heating system for heating and domestic hot water production	New central heating system for heating and domestic hot water production	Renewal of the district heating system
			New mechanical ventilation system with heat recovery which can be also used to pre-cool the air (SFP = 1.5, Eff.= 75%)	
Investigated energy sources for heating and domestic hot water	Oil	Oil	Oil	
		Natural gas	Natural gas	
		Air-water heat pump	Air-water heat pump	
		District heating based on renewables (75%) and on natural gas (25%).	District heating based on renewables (75%) and on natural gas (25%).	District heating based on renewables (75%) and on natural gas (25%).
RES (renewable energy generation on-site)	None	None	26 m² solar thermal system for DHW production	
				11 kWp photovoltaic system for the electricity generation on-site

Note: For the scenario comparison, in renovation package v3 prefabrication and on-site photovoltaic system, that covers 50% of the electricity demand of the building, were included but not performed in reality.

Also for the Spanish Case Studies additional combinations of the individual renovation measures were defined and calculated. Again these additional measures were based on the previously described renovation packages v1, v2 and v3. In this case following combinations of renovation measures (marked with M1, M2,...) were tested:

Renovation package	Description
Ref	The reference case includes the maintenance of the existing façade, the existing roof and the old single-glazed windows.
M1	40 mm insulation of the façade
M2	60 mm insulation of the façade
M3	220 mm insulation of the façade
M4	M3 + 40 mm insulation of the roof
M5	M3 + 60 mm insulation of the roof
M6	M3 + 240 mm insulation of the roof
M7	M6 + 40 mm insulation of the floor
M8	M6 + 100 mm insulation of the floor
M9	M6 + 240 mm insulation of the floor
M10	M9 + new double-glazed windows

Also different heating systems were tested. Thereby renewable and non-renewable energy sources were calculated, including also renewable energy generation on-site by solar thermal and photovoltaic installations:

- Oil
- Natural gas
- Natural gas + solar thermal (26 m²)
- Electricity
- District heating (75% biomass)
- District heating (75% biomass) + solar thermal (26 m²)
- District heating (75% biomass) + solar thermal (26 m²) + photovoltaic (11 kWp)
- Heat pump
- Biomass

5.4.2. Results

The calculation results of the Spanish Case Study “Lourdes Neighborhood” can be seen in Figure 21. The chart shows on the left side the comparison of the Life Cycle Costs with the carbon emissions and on the right side the comparison of the LCC with the total Primary Energy.

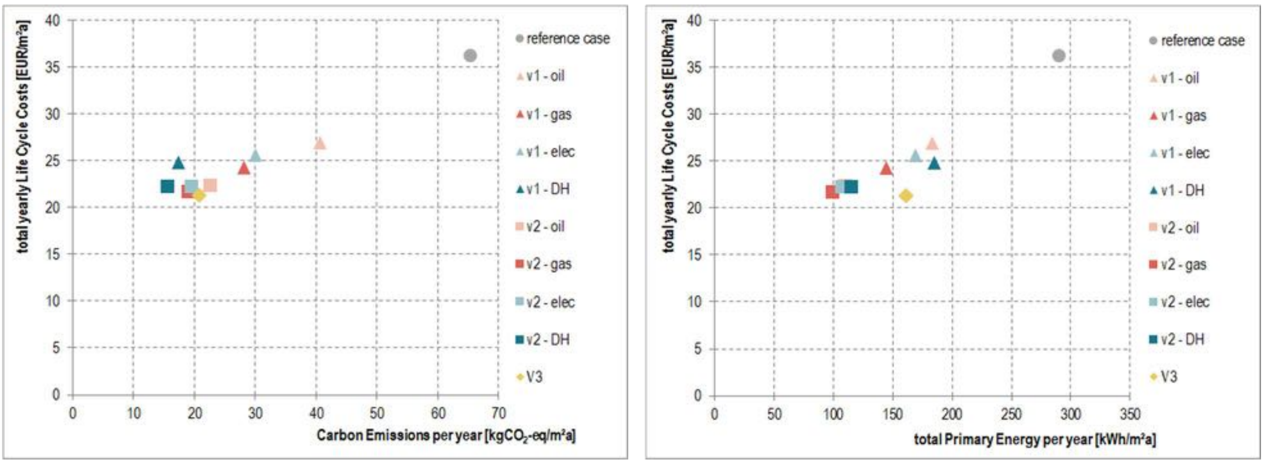


Figure 21: Life Cycle Costs in comparison with carbon emissions (left chart) and total Primary Energy (right chart) of the Case Study “Lourdes Neighborhood”, Spain

As visible in Figure 21 all investigated renovation packages are cost effective. That means the annual specific LCC of each renovation package are lower than the LCC of the reference case.

The lowest carbon emissions are achieved by renovation package v2 with district heating as main energy source for heating and domestic hot water production. For the DHW production also a solar thermal installation was considered. The carbon emissions of this renovation package are 15.7 kgCO_2-eq/m²a. The reference case achieves carbon emissions of 65.5 kgCO_2-eq/m²a. This means renovation package v2 with district heating and solar thermal installation can reduce the annual carbon emissions by 49.8 kgCO_2-eq/m²a respectively 76%.

The lowest total PE is achieved by renovation package v2 with natural gas as main energy source for heating and domestic hot water production. Again a solar thermal installation is considered in this case to support the DHW production. The total PE of this renovation package is 100 kWh/m²a. This is a reduction compared to the reference case of 190 kWh/m²a or 66%.

The cost optimal solution for the Case Study “Lourdes Neigborhood” in Spain is the actual renovation carried out (renovation package v3) considering that DHW is also supplied by the district heating and an additional PV installation is added. The cost optimal solution achieves carbon emissions of 20.9 kgCO_2-eq/m²a, a total PE of 162 kWh/m²a and annual LCC of 21.26 EUR/m²a.

The comparison of the cost optimal solution with the most ambitious renovation shows:

- Carbon Emissions: with additional annual LCC of 0.88 EUR/m^2a the carbon emissions could be reduced from 20.9 $kgCO_2$-eq/m^2a (cost optimal solution) to 15.7 $kgCO_2$-eq/m^2a (lowest carbon emissions). That means an increase of the LCC by 4%, which is higher than the LCC of the cost optimal solution, the carbon emissions could be reduced by 25%.
- PE: with additional annual LCC of 0.26 EUR/m^2a the total PE could be reduced from 162 kWh/m^2a (cost optimal solution) to 100 kWh/m^2a (lowest total PE). 1% higher annual LCC compared with the cost optimal solution would reduce the total PE by 38%.

To test the separate influence of the different renovation measures on the building envelope and the different heating systems, the cost effectiveness of the energy efficiency measures is analyzed for the Spanish Case Study in Figure 22, Figure 23 and Figure 24.

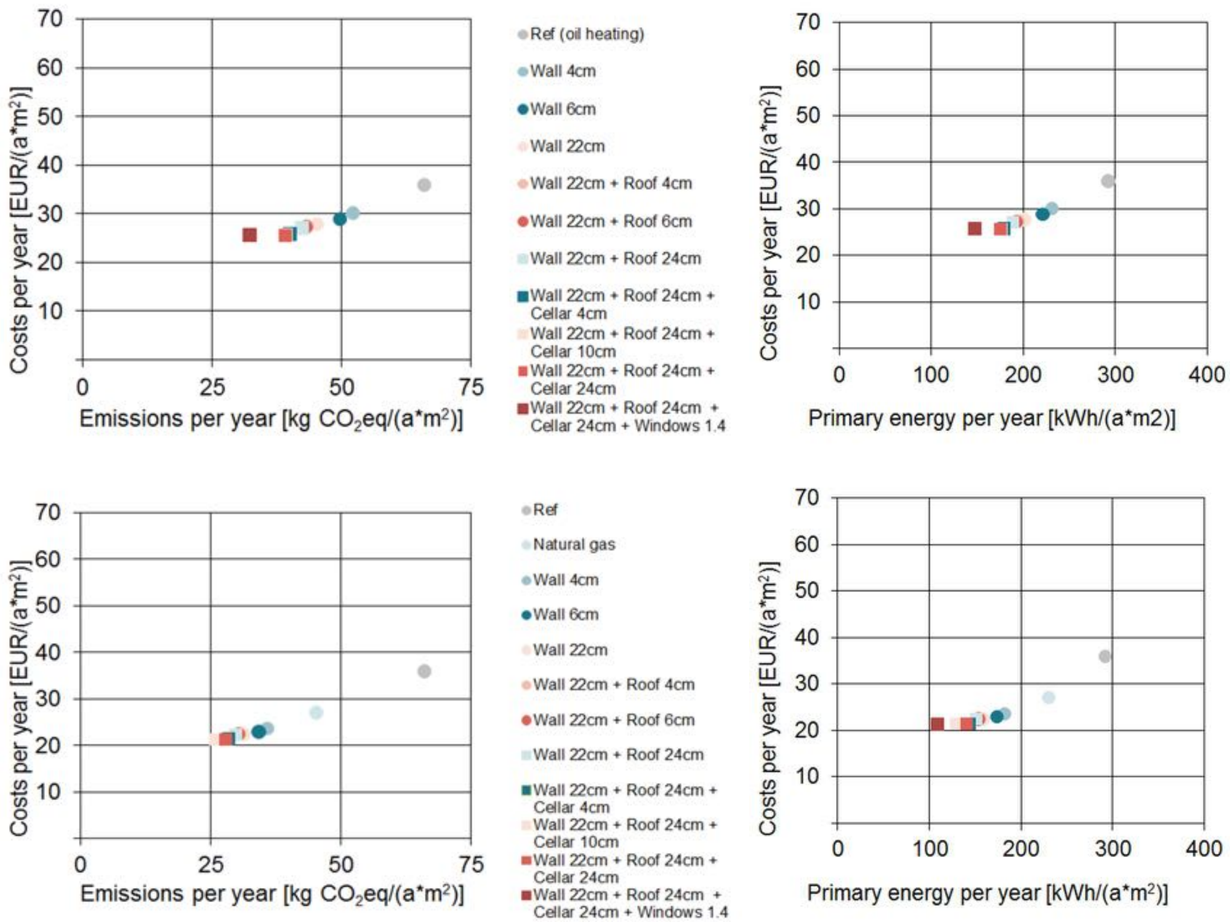


Figure 22: Comparison of cost effectiveness of energy efficiency renovation measures for the Spanish Case Study for the heating systems: oil heating (top) and natural gas (bottom), as well as related impacts on carbon emissions and primary energy use

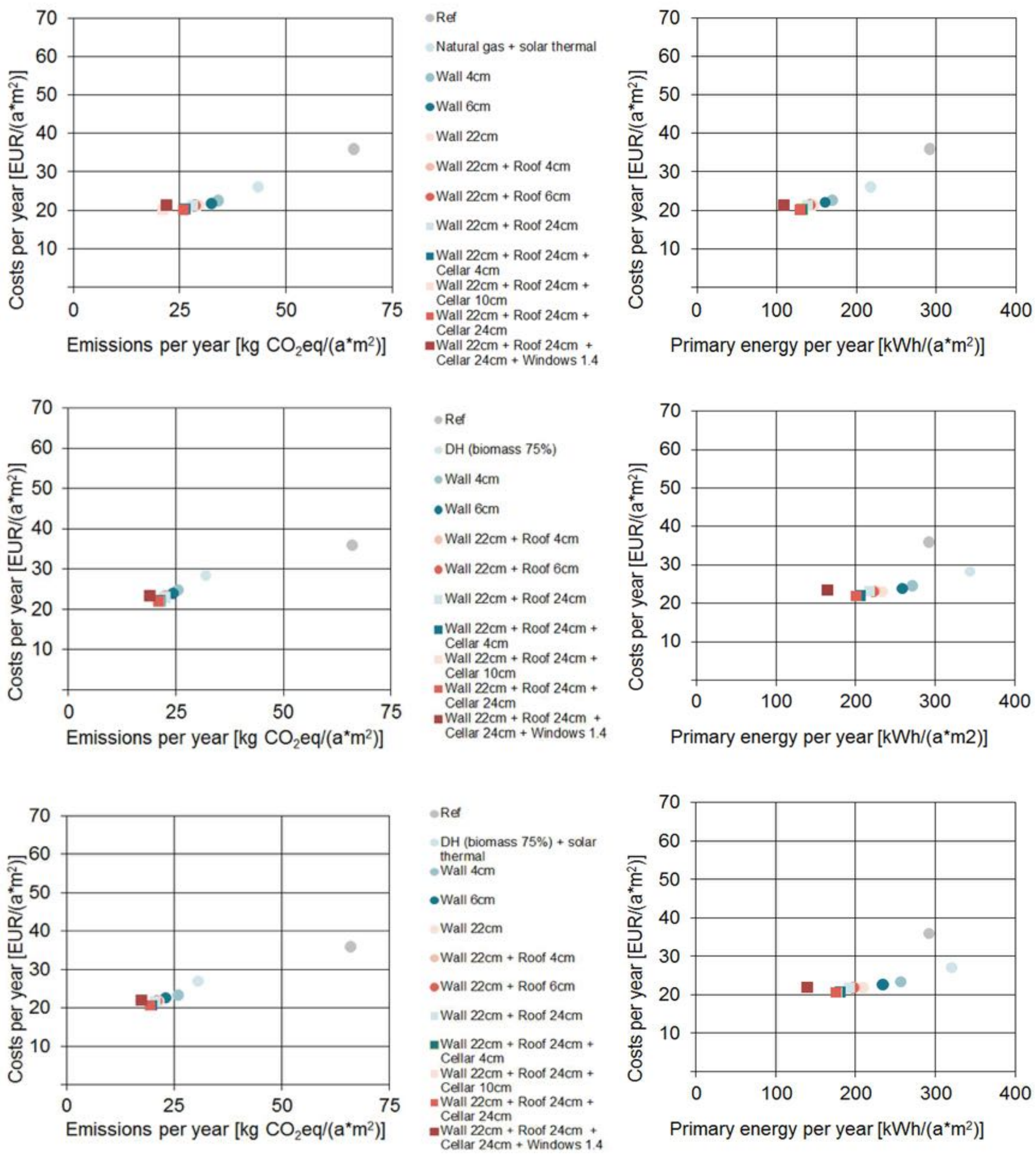


Figure 23: Comparison of cost effectiveness of energy efficiency renovation measures for the Spanish Case Study for the heating systems: natural gas + solar thermal (top), district heating (middle) and district heating + solar thermal (bottom), as well as related impacts on carbon emissions and primary energy use

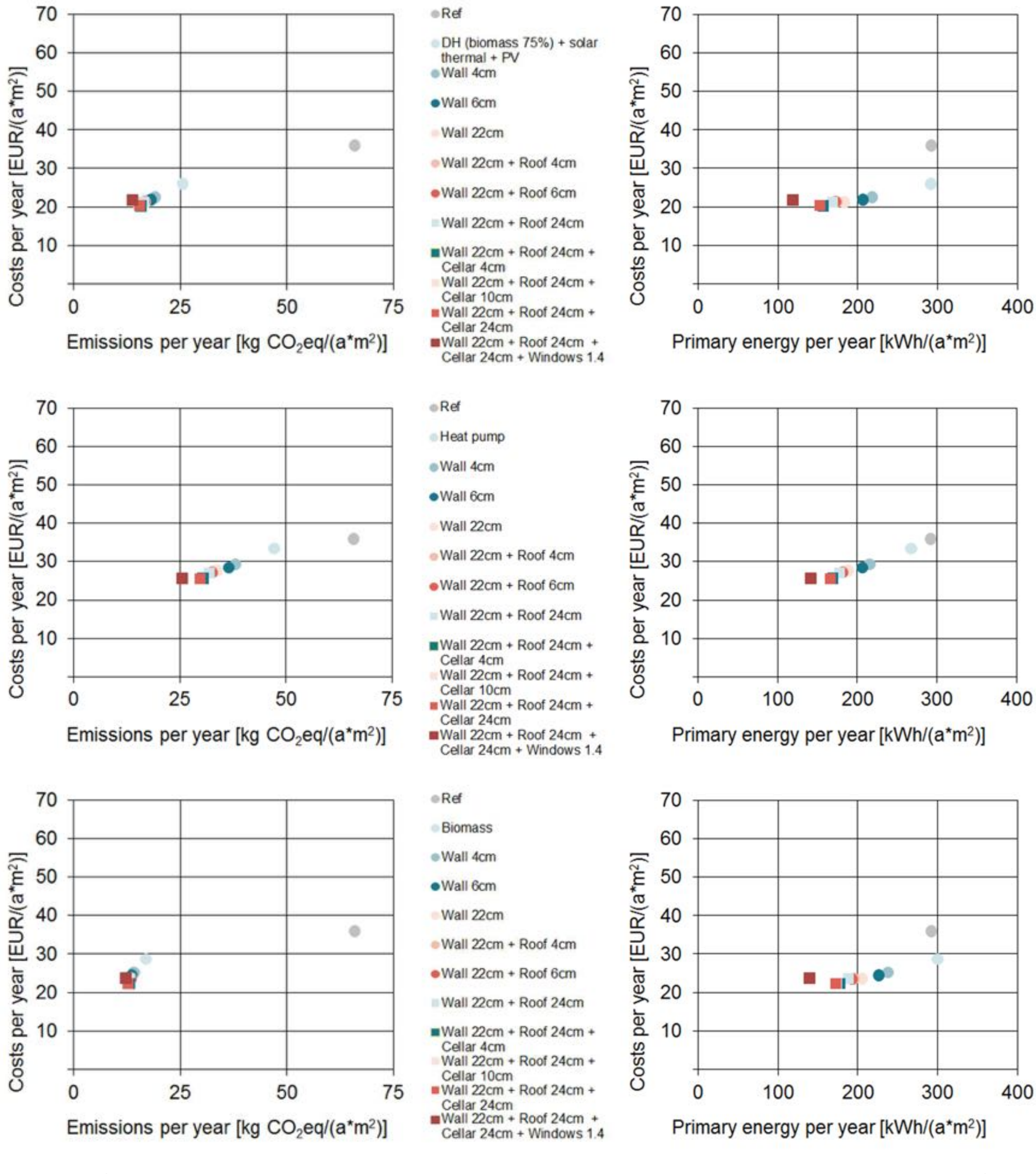


Figure 24: Comparison of cost effectiveness of energy efficiency renovation measures for the Spanish Case Study for the heating systems: district heating + solar thermal + photovoltaic (top), heat pump (middle) and biomass (bottom), as well as related impacts on carbon emissions and primary energy use

The cost curves for the different renovation packages on the building envelope with different heating systems are summarized in Figure 25. In each of these graphs, four different curves are shown, representing the application of the different renovation packages on the building envelope in combination with the installation of different heating systems. Each dot in the curves represents the application of a particular renovation package.

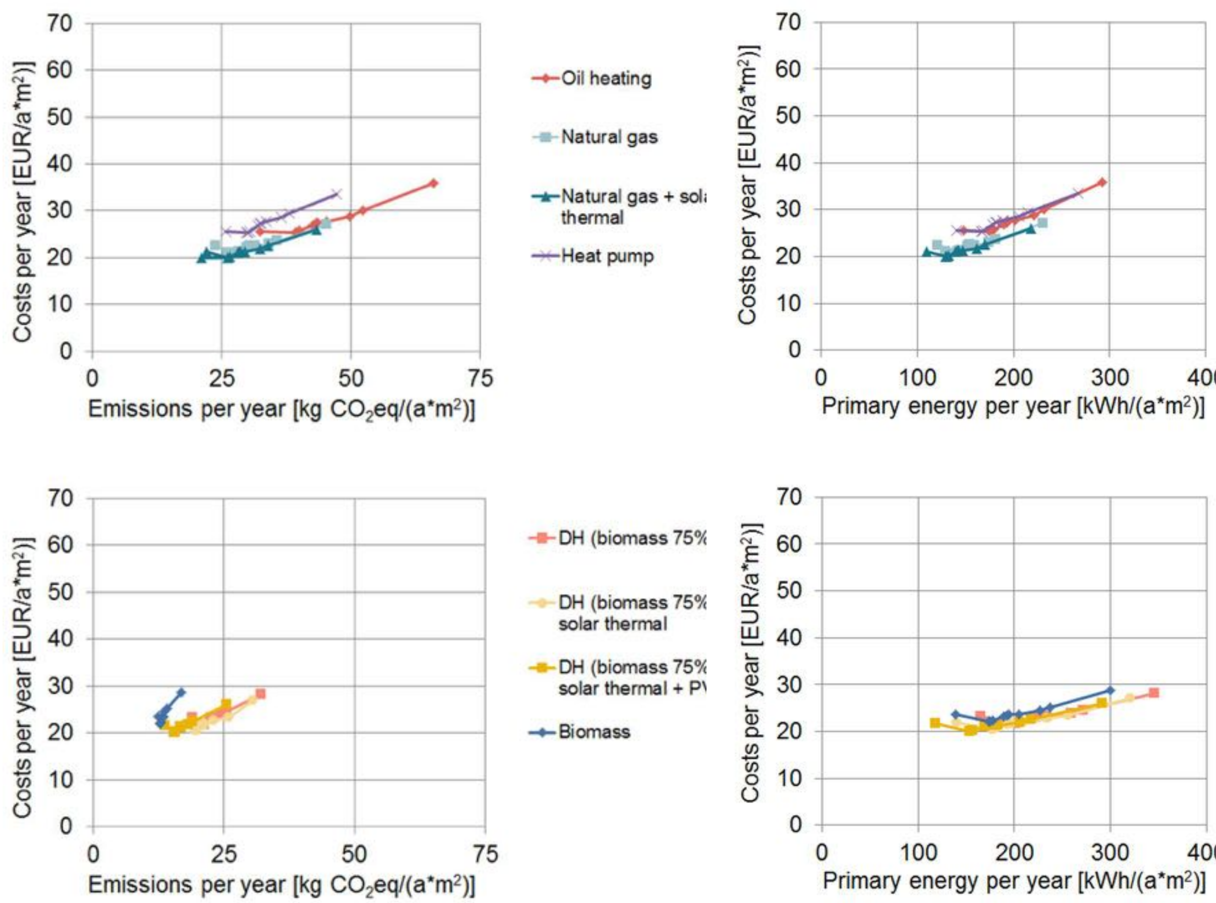


Figure 25: Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on carbon emissions and primary energy use for the Spanish Case Study

5.4.3. Co-benefits

Table 14 presents the co-benefits for some of the renovation packages, namely the reference case, the cost optimal solution (M9 with gas boiler backed by solar thermal), the solution with the best energy performance (M10 with gas boiler backed by solar thermal) and the chosen renovation package.

Despite presenting higher global costs and worse energy performance than the other two packages improving the energy performance, the chosen renovation package presents more positive co-benefits than the cost optimal and similar benefits to the scenario with the best energy performance. This evaluation derives from the fact that the cost optimal scenario doesn't include the change of the windows while the chosen renovation and the scenario with the best energy performance include improvements in all the building envelope elements.

Table 14: Identification of co-benefits in several renovation packages in the Spanish Case Study

Building elements	Reference	Chosen Renov.	M9 + GB + ST	M10 + GB + ST
Façade	Maintenance	6 cm of XPS	22 cm of XPS	22 cm of XPS
Roof	Maintenance	6 cm of XPS	24 cm of XPS	24 cm of XPS
Floor	Maintenance	10 cm of RW	24 cm of RW	24 cm of RW
Windows	Maintenance	New windows U 1.8	Maintenance	New windows U 1.4
Heating system	Collec. Oil boiler	DH biomass + gas	Gas boiler	Gas boiler
DHW system	Collec. Oil boiler	Gas boiler	Gas boiler	Gas boiler
Renewables	None	None	Solar thermal	Solar thermal
Co-benefits				
Aesthetics	▲	▲	▲	▲
Pride/prestige	▲▲	▲▲	▲▲	▲▲
Thermal comfort		▲▲	▲▲▲	▲▲▲
Building physics		▲▲	▲▲	▲▲
Internal noise		▼	▼	▼
Price fluctuation		▲▲	▲▲	▲▲
Air Quality		▲	▲	▲
External noise		▲▲		▲▲
Safety		▲▲		▲▲
Additional costs [EUR/m²a]	16	1.4	Cost optimal	1.2

5.4.4. Conclusions

For the analyzed parameters carbon emissions, total Primary Energy and Life Cycle Costs the following conclusions can be drawn:

- The reference case achieves the highest Life Cycle Costs and highest carbon emissions.
- The highest Primary Energy is achieved, when only the heating system is changed to district heating based on 75% biomass and no further energy related measures are carried out.
- The lowest carbon emissions are achieved by renovation measure M10, which represents the most improved building envelope, together with a biomass heating system.
- The lowest total Primary Energy is also achieved by renovation measure M10 but in this case a natural gas heating system together with a solar thermal installation leads to these low total PE values.
- The calculation results show that it is more effective to reduce the carbon emissions if several building elements are renovated instead of concentrating only on one element. The exception is if the renovation measures on the building envelope are combined with a biomass heating systems. In this case the investigated efficiency measures on the envelope don´t have a big influence on the carbon emissions. The impact of switching from oil to biomass is much larger.
- Only changing the heating system (without improving the thermal properties of the building envelope) reduces the carbon emissions but not automatically the Primary Energy. In the case of district heating, district heating + solar thermal and biomass this measure leads to an increase of the total Primary Energy.

- Carbon emission and total Primary Energy reductions in consequence of renewable energy generation on-site by the solar thermal and photovoltaic installations are given but are quite small. Nevertheless the on-site generation leads also to a reduction of the Life Cycle Costs compared to the system without generation on-site.

Following Table 15 shows the investigated hypotheses for the Spanish Case Study.

Table 15: Results for the investigated hypotheses for the Case Study "Lourdes Neighborhood" in Spain. ✓ means that the hypothesis is confirmed, ✗ means that the hypothesis is not confirmed. Symbols in parenthesis or separated by a slash indicate that the hypothesis is only partly confirmed / not confirmed.

Hypothesis	Results from Case Study "Lourdes Neighborhood", Spain
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements	✗
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements	(✓)*
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.	✓/✗*

* Confirmation for district heating with 75% biomass of for biomass heating system possible, yet not for heat pump.

For the Spanish Case Study two of the five hypotheses can be completely confirmed. The hypothesis *"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements"* is disproved, as for example the 22 cm wall insulation achieves similar good results as the same measure plus adding insulation on the roof. That means carrying out additional measures doesn´t lead to major carbon emissions and total Primary Energy reductions.

The hypotheses *"A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements"* and *"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."* cannot completely be confirmed. The hypotheses are true for biomass based heating systems but not for heat pump.

5.5. Case Study "Backa röd", Sweden

5.5.1. Investigated renovation packages

	Reference case	Renovation package v1	Renovation package v2	Renovation package v3
Building envelope	Maintenance of the façade	100 mm additional insulation of the façade	195 mm additional insulation of the façade	195 mm additional insulation of the façade
		100 mm additional insulation of the roof	300 mm additional insulation of the roof	300 mm additional insulation of the roof
		100 mm additional insulation of the base wall and 100 mm expanded clay added in the crawl space	195 mm additional insulation of the base wall and 500 mm expanded clay added in the crawl space	195 mm additional insulation of the base wall and 500 mm expanded clay added in the crawl space
		New triple-glazed windows (U-value 1.7 W/m²K)	New triple-glazed windows (U-value 0.9 W/m²K)	New triple-glazed windows (U-value 0.9 W/m²K)
BITS (Building Integrated Technical Systems)	New district heating substation, for heating and new recirculation for domestic hot water installed	New radiators New individual metering and invoicing of domestic hot water	New radiators New individual metering and invoicing of domestic hot water	New radiators New individual metering and invoicing of domestic hot water
		New balanced mechanical ventilation system with heat recovery (Eff.= 50%)		New balanced mechanical ventilation system with rotary heat exchangers (Eff.= 75%)
		New building automation system		New building automation system
			New low-energy lighting	New low-energy lighting
Investigated energy sources for heating and domestic hot water		Oil	Oil	
		Natural gas	Natural gas	
		Electricity	Electricity	
	District heating partly (81%) based on renewables	District heating partly based on renewables	District heating partly based on renewables	District heating partly (81%) based on renewables
RES (renewable energy generation on-site)	None	None	None	None

Following combinations of renovation measures (marked with M1, M2,...) were defined and tested to answer the defined hypotheses in detail. In addition to the investigated renovation measures in the renovation packages v1, v2 and v3 in M11 a photovoltaic installation was included to test also the influence of a renewable energy generation on-site on the total results.

Renovation package	Description
Ref	In the reference case, the existing façade is maintained. No further energy related renovation measures are considered.
M1	100 mm insulation of façade
M2	195 mm insulation of façade
M3	M2 + 100 mm insulation of the roof
M4	M2 + 300 mm insulation of the roof
M5	M4 + 100 mm insulation of the floor
M6	M4 + 195 mm insulation of the floor
M7	M6 + new windows (U-value 1.7 W/m²K)
M8	M6 + new windows (U-value 0.9 W/m²K)
fasc	M8 + mechanical ventilation with heat recovery
M10	M9 + building automation and low-energy lighting
M11	M10 + photovoltaic installation

The renovation measures M1 to M11 were also tested with different heating systems:

- Oil
- Pellets
- District heating partly (81%) based on renewables
- District heating based on 100 % RES

Again, carbon emissions, total Primary Energy and Life Cycle Costs of the different combinations of renovation measures on the building envelope and of the Building Integrated Technical Systems were tested. The results of the Swedish Case Study “Backa röd” are presented in following chapter 5.5.2.

5.5.2. *Results*

Figure 26 shows the calculation results. On the left side the comparison of the Life Cycle Costs with the carbon emissions, on the right side the comparison with the total Primary Energy.

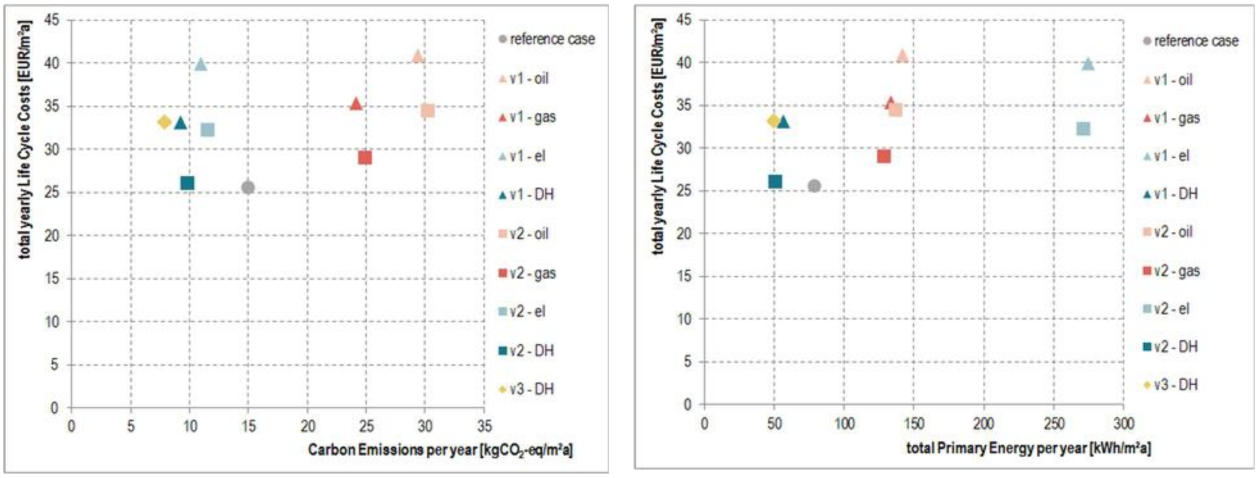


Figure 26: Life Cycle Costs in comparison with carbon emissions (left chart) and total Primary Energy (right chart) of the Case Study “Backa röd”, Sweden

The results show that if the carbon emissions are the main parameter, the renovation packages v2 with heating and domestic hot water production based on electricity, the renovation packages v1 and v2 based on district heating and the actual renovation carried out, renovation package v3, achieve carbon emissions reductions, but are not cost effective. However, the annual costs of renovation package v2 based on district heating are almost the same as for the reference case.

The renovation packages v1 and v2 with heating and DHW production based on natural gas and based on oil achieve higher carbon emissions than the reference case.

The increased carbon emissions can be explained by the higher conversion factor of oil compared to the conversion factor of the partly renewable district heating. The district heating is to 81 % based on renewable energy and 19 % fossil fuels according to Göteborg Energy, which explains the low carbon emission and the low primary energy.

Nevertheless it has to be mentioned that all investigated renovation packages have higher LCC than the reference case. This means that although carbon emissions reduction could be achieved, carrying out these renovation measures would not be cost effective.

If the total PE is regarded as the main parameter the renovation packages v1 and v2 with district heating and the actual renovation carried out (renovation package v3) achieve a reduction of the total PE. The total PE of all other renovation packages is higher than the reference case.

The lowest carbon emissions are achieved by the executed renovation package v3 with a value of 8 kgCO_2-eq/m²a. This is a reduction compared to the reference case by 7 kgCO_2-eq/m²a respectively 47%. In comparison with the highest carbon emissions, which are achieved by renovation package v2 with an oil based heating and domestic hot water production, this is a reduction of 74%.

The lowest total PE is achieved by renovation package v3 with heating and domestic hot water based on district heating. The total PE of this renovation package is 50 kWh/m²a and therefore 30 kWh/m²a or 37% lower than the total PE of the reference case. Compared to the highest total PE, which is achieved by the renovation package v1 with heating and DHW production based on electricity, it is a reduction of 225 kWh/m²a or 82%.

The cost optimal solution is, as mentioned before, the reference case with annual LCC of about 26 EUR/m²a.

The following charts in Figure 27 and Figure 28 show the comparison of the different energy efficiency renovation measures for the Swedish Case Study for conventional district heating, which is partly based on renewables, district heating completely based on renewable energy sources, oil heating and pellets burner (top down), and related impacts on carbon emissions and primary energy use. The reference shown as a grey dot refers to a situation with district heating partly based on renewables.

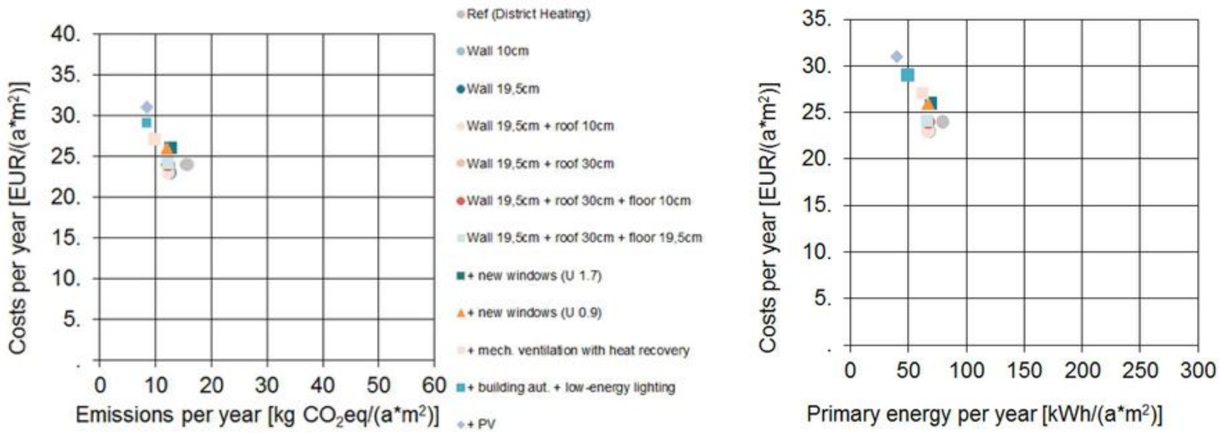


Figure 27: Comparison of cost effectiveness of energy efficiency renovation measures for the Swedish Case Study for district heating (partly based on renewable energy sources), as well as related impacts on carbon emissions and primary energy use.

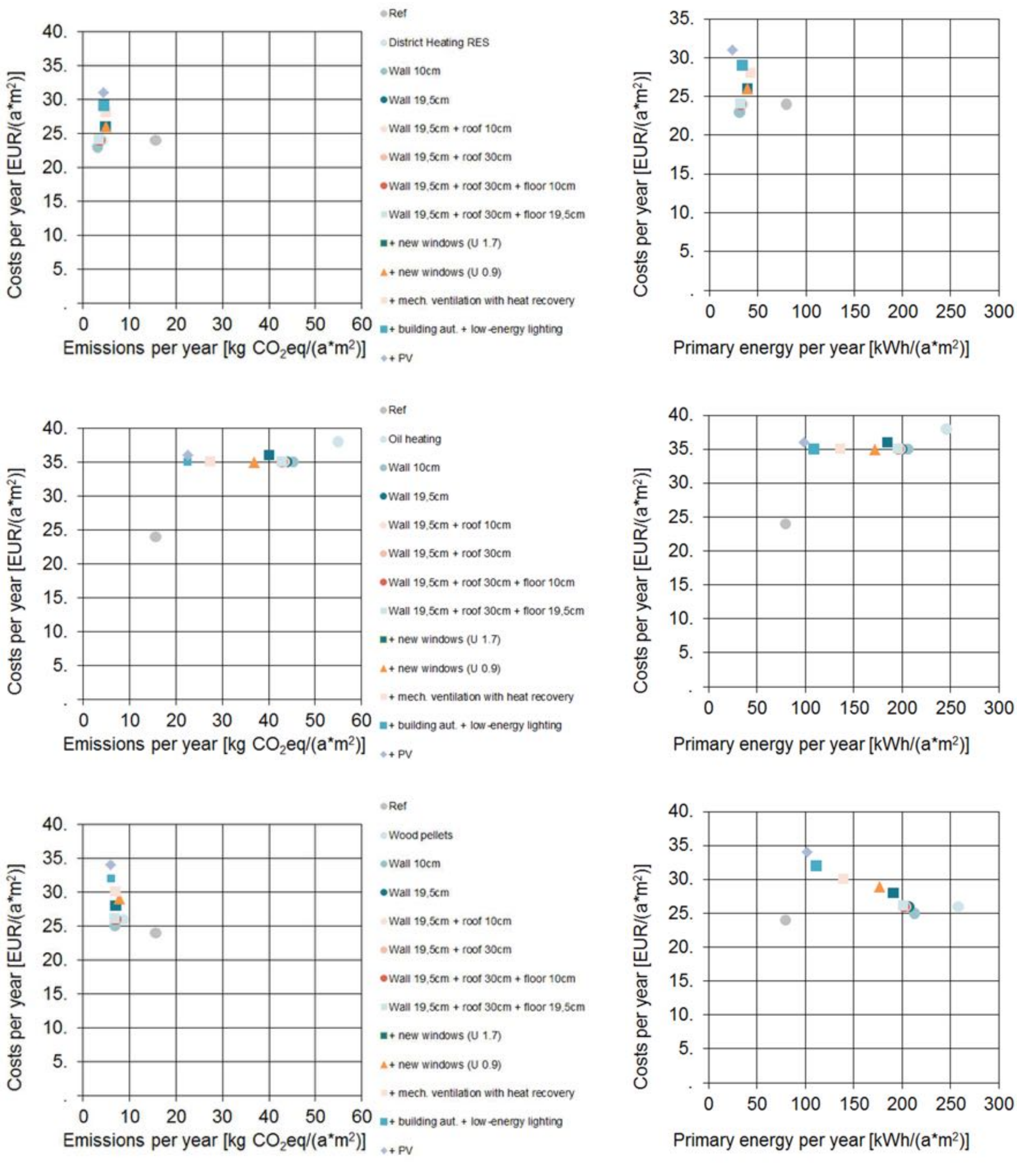


Figure 28: Comparison of cost effectiveness of energy efficiency renovation measures for the Swedish Case Study for district heating based on renewable energy sources (top), oil heating (middle) and pellets burner (bottom), as well as related impacts on carbon emissions and primary energy use

Figure 29 summarizes the cost curves for the different renovation measures on the building envelope with different heating systems. The four different curves represent the application of the different renovation measures on the building envelope in combination with the installation of different heating systems. Each dot in the curves represents the application of a particular renovation package. The point with the highest emissions or highest primary energy use for each energy source represents the anyway renovation. As more measures are added to the renovation packages, carbon emissions and primary energy use decrease.

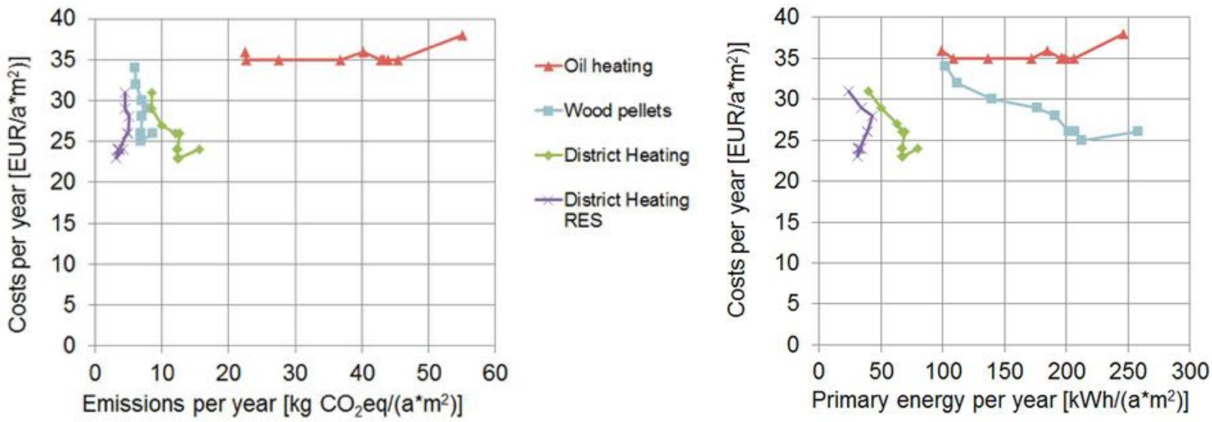


Figure 29: Aggregated comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on carbon emissions and primary energy use for the Swedish Case Study

5.5.3. Co-benefits

The façades were damaged by carbonation and were in need of renovation. The building was leaky, through the façade and between the apartments. Draught occurred from the infill walls at the balcony and cold floors were caused by thermal bridges from the balconies.

For the co-benefits analysis the cost optimal solution (renovation package M1 + district heating for heating and domestic hot water production) was compared to the solution that leads to best energy performance (renovation package M11 + district heating + photovoltaic installation on-site) and also with M11 combined with wood pellets. The identified co-benefits are visible in Table 16.

Analyzing Table 16 it is noticeable that the packages of measures improving significantly the building envelope present several co-benefits related with the building quality such as improved thermal comfort, reduced problems related to building physics, reduced external noise and improved safety against intrusion. However, this come with increased global cost when compared to the cost optimal package, an increase of 8 to 11 €/m²a. On the other hand, the use of district heating, particularly if mainly based on renewables, is the main origin of financial benefits and economic co-benefits, namely the reduction of the exposure to energy price fluctuations.

Table 16: Identification of co-benefits in several renovation packages in the Swedish Case Study

Building elements	Reference	M1 + DH	M11 + WP + PV	M11 + DH (RES) + PV
Façade	Maintenance	19.5 cm of RW	19.5 cm of RW	19.5 cm of RW
Roof	Maintenance	Maintenance	50 cm of RW	50 cm of RW
Floor	Maintenance	Maintenance	19.5 cm of RW	19.5 cm of RW
Windows	Maintenance	Maintenance	3x glazing U=0.9	3x glazing U=0.9
Ventilation	Natural	Natural	Mech. + heat recov	Mech. + heat recov
Heating system	District heating	District Heating	Wood pellets	RES District heating
DHW system	District heating	District Heating	Wood pellets	RES District heating
RES	None	None	PV	PV
Co-benefits				
Aesthetics	▲	▲	▲ ▼	▲ ▼
Pride/prestige	▲	▲	▲ ▲	▲ ▲
Thermal comfort		▲ ▲	▲ ▲ ▲	▲ ▲ ▲
Building physics		▲	▲ ▲	▲ ▲
Internal noise			▼	▼
Price fluctuation		▲	▼	▲ ▲
Air Quality			▲	▲
External noise			▲ ▲	▲ ▲
Safety			▲ ▲	▲ ▲
Additional costs [EUR/m²a]	1	Cost optimal	11	8

5.5.4. Conclusions

Summarized the following conclusions can be drawn for the analyzed parameters:

- Only changing the heating system from conventional district heating to district heating based on renewables, without improving the building envelope, is not a cost effective measure but reduces carbon emissions and total Primary Energy.
- The oil heating achieves higher (and also highest) carbon emissions and total Primary Energy values. Furthermore none of the investigated renovation measures are cost effective, when combined with oil heating or wood pellets.
- The lowest carbon emissions are achieved by the renovation measure which includes the photovoltaic installation, independent of the chosen energy source for heating and DHW. But it has to be mentioned that the influence of the photovoltaic system on the carbon emissions is quite small, as the photovoltaic system only contributes to the operation of fans and pumps. Besides this measure, the lowest carbon emissions are achieved by the renewable district heating combined with the complete renovation package.
- The lowest total Primary Energy is also achieved by the renovation measure which includes the photovoltaic installation, again independent of the chosen energy source for heating and DHW. Compared to the carbon emissions the influence of the photovoltaic system on the total PE is bigger. If the photovoltaic installation is not taken into account, the lowest total Primary Energy is also achieved by the renewable district heating in combination with the entire investigated renovation measures.

Following Table 17 shows the investigated hypotheses for the Swedish Case Study.

Table 17: Results for the investigated hypotheses for the Case Study "Backa röd" in Sweden. ✓ means that the hypothesis is confirmed, ✗ means that the hypothesis is not confirmed. Symbols in parenthesis or separated by a slash indicate that the hypothesis is only partly confirmed / not confirmed.

Hypothesis	Results from Case Study "Backa röd", Sweden
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements	✗
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements	✓
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.	✓

For the Swedish Case Study two of the five hypotheses can absolutely be confirmed. Disproved is the hypothesis *"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements"*, where the calculations show that performing additional renovation measures on the building envelope does not result in reduced carbon emissions, total Primary Energy values and Life Cycle Costs. The hypotheses *"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level"* and *"Synergies are achieved when a switch to RES is combined with energy efficiency measures"* cannot completely be confirmed. The hypothesis mentioned second for example is true for insulation of the exterior wall in combination with the change to district heating based on RES but not confirmed for all remaining renovation measures in combination with district heating based on RES and also for all combinations with a pellets heating system.

Non-Residential Building

5.6. Case Study “Kamínky 5”, Czech Republic

5.6.1. Investigated renovation packages

	Reference case	Renovation package v1	Renovation package v2	Renovation package v3
Building envelope		Addition of 60 to 90 mm EPS, XPS and mineral wool insulation on the façade	Addition of 60 to 290 mm EPS, XPS and mineral wool insulation on the façade	Addition of 60 to 160 mm EPS, XPS and mineral wool insulation on the façade
		Addition of 90 mm EPS insulation on the roof	Addition of 300 mm EPS insulation on the roof	Addition of 180 mm EPS insulation on the roof
		Addition of up to 130 mm EPS and mineral wool insulation to the ceiling under the first floor	Addition of up to 380 mm EPS and mineral wool insulation to the ceiling under the first floor	Addition of up to 240 mm mineral wool insulation to the ceiling under the first floor
	New double- and triple glazed windows	New double- and triple-glazed windows	New triple-glazed windows	New double- and triple-glazed windows
BITS (Building Integrated Technical Systems)	New mechanical ventilation system with heat recovery in the kitchen, storage rooms, toilets and showers	New mechanical ventilation system with heat recovery in the kitchen, storage rooms, toilets and showers	New mechanical ventilation system with heat recovery in the kitchen, storage rooms, toilets and showers	New mechanical ventilation system with heat recovery in the kitchen, storage rooms, toilets and showers
	Renovation of the heat exchanger connected to the district heating	New heating system including new storage tank for DHW	New heating system including new storage tank for DHW	New heating system including new storage tank for DHW
Investigated energy sources for heating and domestic hot water	District heating based on natural gas	District heating based on natural gas Natural gas Electricity	District heating based on natural gas Natural gas Electricity	District heating based on natural gas Natural gas Electricity
RES (renewable energy generation on-site)	None	Installation of a 66.42 kWp photovoltaic system for the electricity generation on-site	Installation of a 66.42 kWp photovoltaic system for the electricity generation on-site	Installation of a 66.42 kWp photovoltaic system for the electricity generation on-site

A photovoltaic power plant was installed on the school`s roof during the renovation. Due to the lack of funding it was installed by a private investor who pays a rent for the necessary space. The electricity is supplied to public grid. This “indirect” incorporation of photovoltaic is included in all variants of renovation package v1, renovation packages v2-DH, v2-gas and v2-elec as well as in all variants of v3.

Remaining variants of renovation package v2 (v2-DH+PV, v2-gas+PV and v2-elec+PV) model “direct” incorporation of the photovoltaic – generated electricity covers 50 % of DHW energy consumption and the rest is used for lighting, common appliances, etc.

5.6.2. Results

The calculation results of the Czech Case Study “Kamínky 5” are shown in Figure 30. The chart on the left side shows the comparison of the Life Cycle Costs with the carbon emissions, the right side shows the comparison of the Life Cycle Costs with the total Primary Energy.

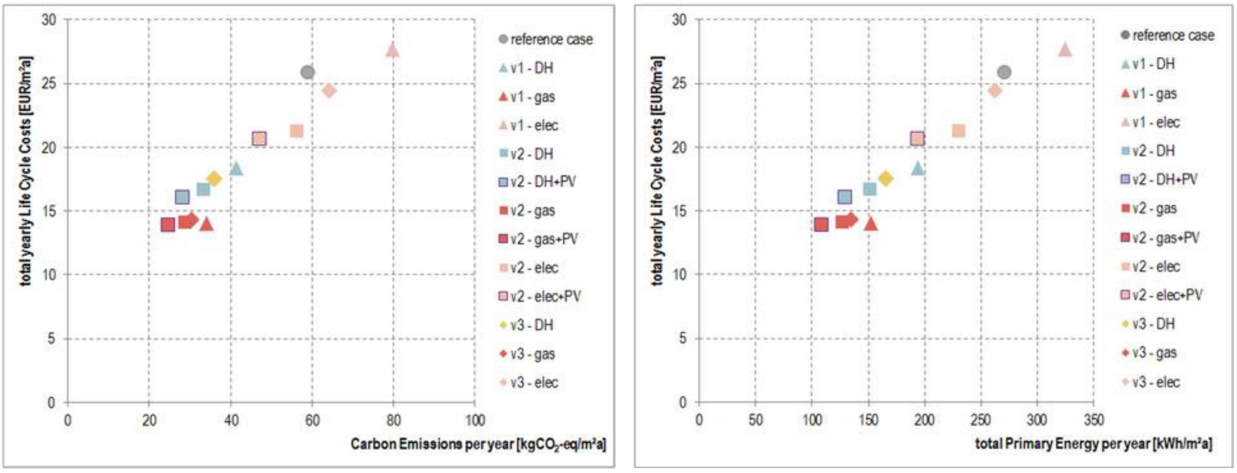


Figure 30: Life Cycle Costs in comparison with carbon emissions (left chart) and total Primary Energy (right chart) of the Case Study “Kamínky 5”, Czech Republic

The results in Figure 30 show that almost all renovation packages v1, v2 and v3 are cost effective. Only the renovation package v1 with heating and DHW production based on electricity achieves higher Life Cycle Costs than the reference case.

The lowest carbon emissions are achieved by renovation package v2, with heating and DHW production based on natural gas, including also the photovoltaic installation owned by the school[15]. This renovation package achieves annual carbon emissions of 25 $kgCO_2$-eq/m²a, which is a reduction of more than 34 $kgCO_2$-eq/m²a or 58% compared to the reference case.

15 In this case the generated electricity is used to cover the electricity demand of the school building.

The executed renovation package v3 with district heating achieves annual carbon emissions of 36 kgCO_2-eq/m²a. This is a reduction of almost 23 kgCO2-eq/m²a or 39% compared to the reference case.

The lowest total PE is also achieved by renovation package v2 with natural gas based heating and DHW production, including again the photovoltaic installation for on-site energy generation. This package achieves a total PE of 109 kWh/m²a, which is a reduction of 162 kWh/m²a or 60% compared to the reference case.

The executed renovation achieves a total PE value of 166 kWh/m²a. This is a reduction, compared to the reference case, of 105 kWh/m² or 39%.

The cost optimal solution of all investigated renovation packages is also renovation package v2 based on natural gas for heating and DHW supported by a photovoltaic installation for the energy generation on-site. The annual LCC of this renovation package are 13.89 EUR/m²a. This is a reduction of 12 EUR/m²a or 46% compared to the reference case.

The executed renovation achieves annual Life Cycle Costs of 17.48 EUR/m²a. This value represents a reduction of 8.41 EUR/m²a, which is a reduction of 32% compared to the reference case.

The executed renovation met the expectations, even though the ex-post assessment presented above shows that there were more cost-efficient ways of improving the school's energy consumption and environmental impacts. Other variants were dismissed due to increased costs or time requirements during the design process.

Especially time was the limiting factor for the renovation. It was not possible to provide alternative spaces for the school. Thus most of the indoor construction works had to be done during summer holiday, when the school was closed. This meant approximately two months of working time. For example the cost optimum renovation package presented in this assessment uses gas heating. The installation of the gas boiler would have required modifications of the whole heating system. These modifications would have required modifications of floor covers, floors structures and also of other structures of the building. This scale of work would have either required much more time than available two months or increase the unnecessarily increase the construction costs.

Influence of improving the energy performance of the building envelope:

To test the influence of the energy performance of the building envelope on the total results the reference case is compared to the renovation packages v1, v2 and v3, in each case equipped with district heating and the same BITS. In this case only the influence of improving the thermal envelope can be investigated.

Figure 31 shows the comparison of the four different renovation scenarios for district heating, and related impacts on carbon emissions and Primary energy use.

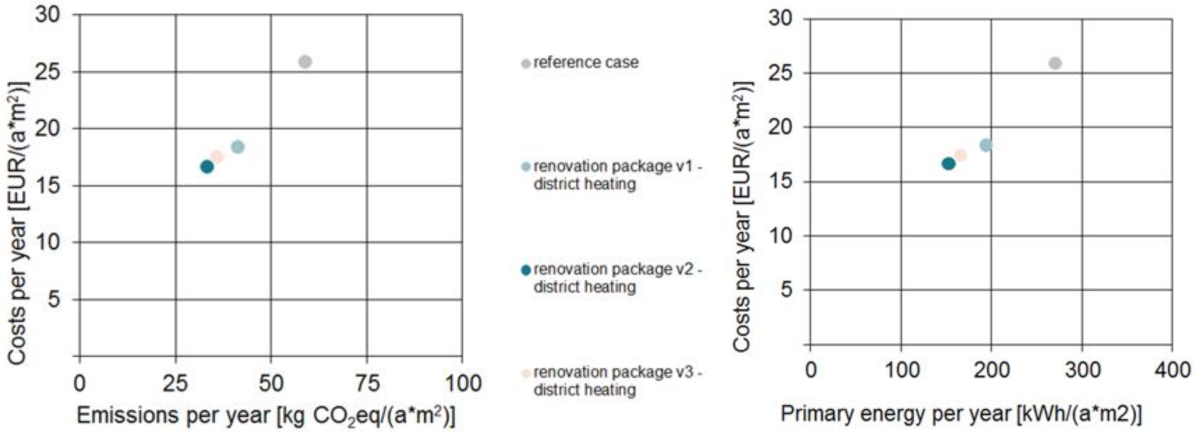


Figure 31: Comparison of four different renovation scenarios, all equipped with district heating, for the Czech Case Study, to investigate the influence of the thermal quality of the building envelope on the annual Life Cycle Costs, carbon emissions and Primary Energy

Influence of modifying the energy source for heating and domestic hot water

For each of the three thermal standards (renovation package v1, v2 and v3) district heating, natural gas and electricity were tested to investigate the influence of the choice of the heating system on the total results of Life Cycle Costs, carbon emissions and total Primary Energy.

The results of this investigation are visible in Figure 32 and Figure 33.

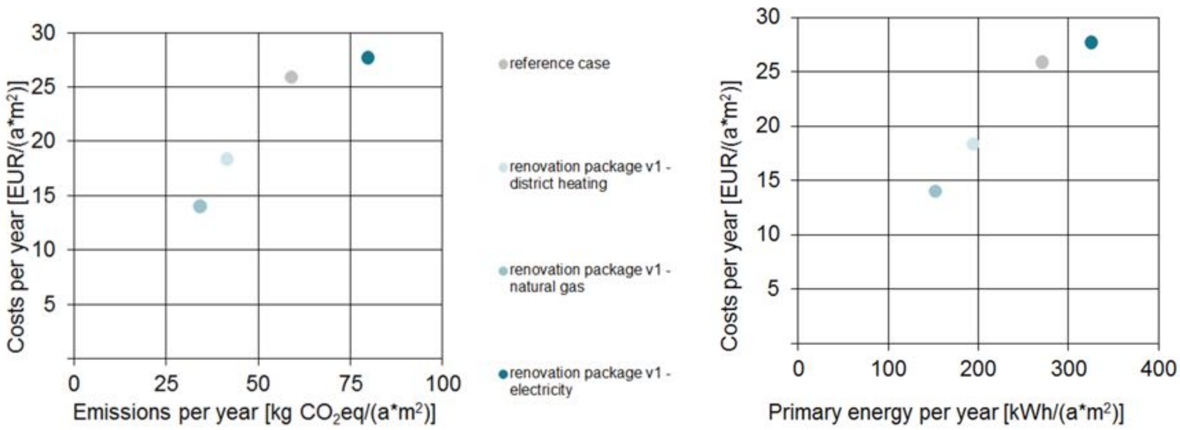


Figure 32: Comparison of district heating, natural gas and electricity for the renovation package v1 of the Czech Case Study to investigate their influence on the annual Cycle Costs, carbon emissions and total Primary Energy

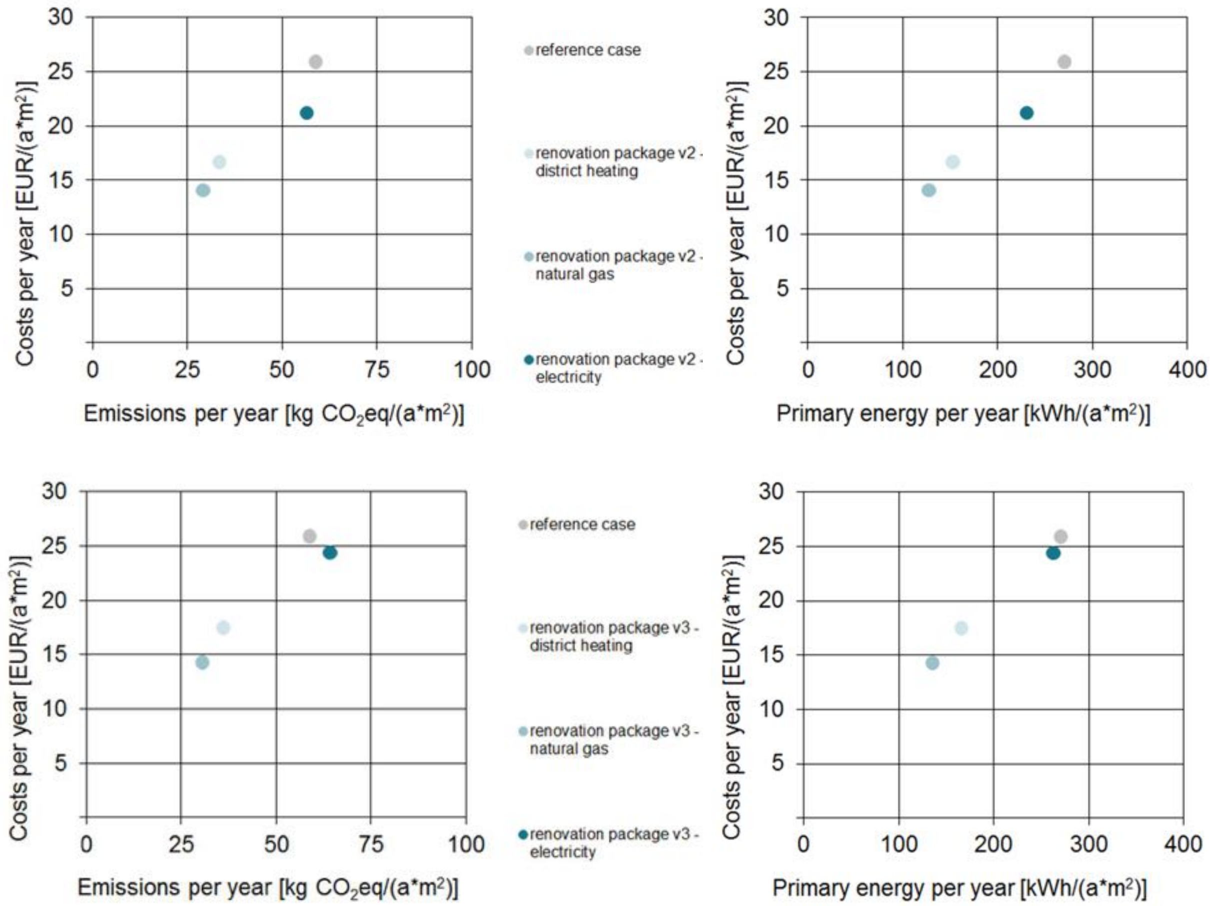


Figure 33: Comparison of district heating, natural gas and electricity for the renovation packages v2 (top) and v3 (bottom) of the Czech Case Study to investigate their influence on the annual Cycle Costs, carbon emissions and total Primary Energy

Influence of renewable energy generation on-site

In the Czech Case Study a photovoltaic installation is considered to generate renewable energy on-site. To investigate the influence of this PV system on the total results, the renovation package v2 was tested with three different energy sources, district heating, natural gas and electricity, both with and without the additional energy generation by the photovoltaic installation. Figure 34 shows the results of these calculations.

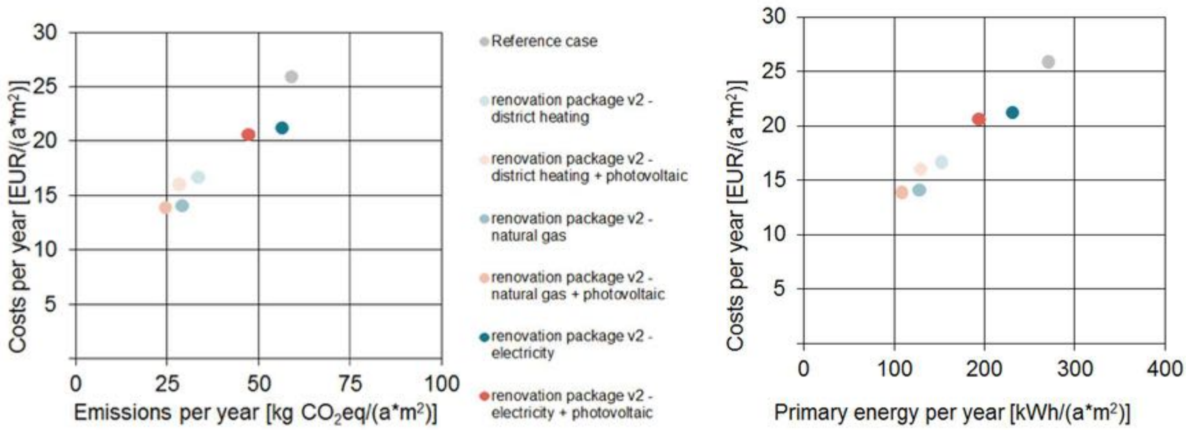


Figure 34: Influence of the photovoltaic energy generation on-site, tested with three different energy sources for heating and DHW (district heating, natural gas and electricity) for the renovation package v2

5.6.3. Conclusions

For the analyzed parameters carbon emissions, total Primary Energy and Life Cycle Costs following conclusions can be drawn:

- Improving the thermal quality of the building envelope reduces the annual carbon emissions, total Primary Energy and Life Cycle Costs. The lowest values are achieved by the renovation package v2, which represents the most improved thermal envelope.
- The highest carbon emissions, total PE and LCC are achieved by the electric heating systems. A modification of the energy source for heating and domestic hot water can reduce the values. Higher reductions are possible if the change is to natural gas heating compared to district heating. The reductions are higher the lower the thermal quality of the building envelope is. That means renovation package v1 achieves the highest reductions and renovation package v2 the lowest.
- The renewable energy generation on-site can reduce carbon emissions and total Primary Energy by about 15%, independent of the used energy source for heating and domestic hot water production. The reduction of the LCC is quite small (within a range of 1-4%) but existing.

For the Czech school building the hypotheses could not be answered based on the existing data and are therefore not shown at this point. The small number of renovation packages that was available didn’t allow the test of the hypotheses.

5.7. Overall Results

This chapter includes some overall results to the investigations of each Case Study in the previous chapters. In chapter 5.7.1 the focus is on the carbon emissions results. For each Case Study the calculated carbon emissions are presented and the reduction potentials are shown. Chapter 0 includes the results for the total Primary Energy and chapter 5.7.3 includes a summary of the Life Cycle Costs of each Case Study. In the last part the investigated hypotheses are summarized (see chapter 5.7.4).

5.7.1. Carbon emissions

Figure 35 shows the calculated annual carbon emissions of the six Case Studies. The carbon emissions of the reference cases (light green columns) are compared to the lowest carbon emissions of investigated renovation packages v1, v2 and v3 (dark green columns). The range between the lowest and the highest carbon emissions among all analyzed renovation packages is also highlighted by the arrow.

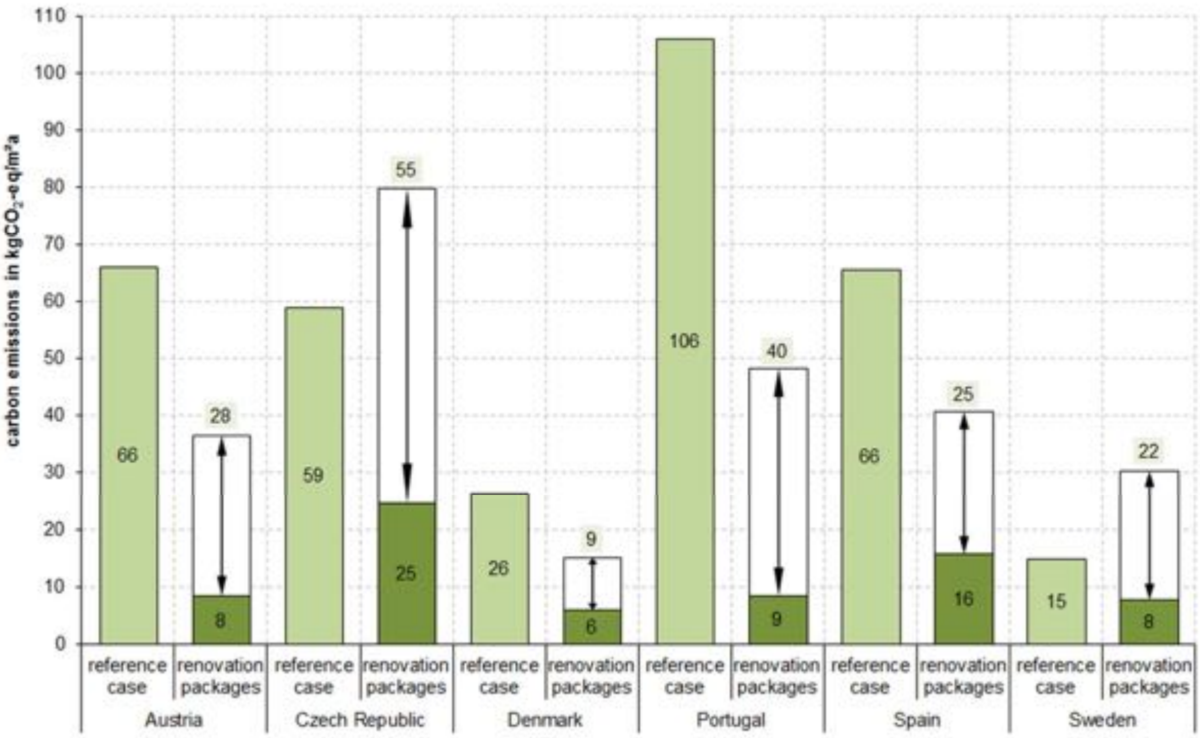


Figure 35: Carbon emissions of the six Case Studies. The carbon emissions of the reference cases are compared to the carbon emissions of the investigated renovation packages, shown as lowest value and as range between the lowest and the highest carbon emissions.

The calculation results show that the Portuguese Case Study achieves the highest carbon emissions in the reference case with 106 $kgCO_2$-eq/m²a. The lowest carbon emissions in the reference case are achieved in the Swedish Case Study with 15 $kgCO_2$-eq/m²a. The reasons for these low carbon emissions of the reference case might be the energy source for heating and domestic hot water, which is district heating based on 81% renewable energy sources. This situation is very common in Sweden.

The lowest carbon emissions of the investigated renovation packages are achieved in the Danish Case Study with 6 $kgCO_2$-eq/m²a. The main reasons for this low value are the chosen energy source for heating and domestic hot water (district heating) and the large photovoltaic installation which is included in this specific renovation package.

The results showed that in four of the six buildings carbon emissions reductions are always given, independently of the chosen measures. This can be seen by the comparison of the highest value of the renovation packages with the reference cases. For the Czech Case Study and the Swedish Case Study this statement is not true. In the Czech Republic the reference case uses district heating based on natural gas for heating and domestic hot water supply. If the energy source is changed to electricity, the carbon emissions increase, although renovation measures on the building envelope are included too (see results for renovation package v3 in Figure 33). Therefore the measures on the envelope cannot compensate the worse conversion factor of electricity compared to district heating.

The same situation is given in the Swedish Case Study. As mentioned before the reference case uses district heating, which is largely, 81%, based on renewables. If the energy source is changed to oil or natural gas the carbon emissions increase, again although energy related renovation measures on the building envelope are included.

Figure 36 shows the carbon emissions reduction potentials of the six Case Studies. The reduction potentials are shown as absolute values (yellow columns) and as relative reduction potentials (orange columns). Again the range between the lowest and the highest reduction potential is highlighted.

The chart shows that the Portuguese Case Study achieves the highest minimum reduction of all investigated buildings with a value of 58 $kgCO_2$-eq/m²a and also the highest possible savings with 98 kgCO2-eq/m²a, which is a reduction of 92% compared to the reference case. 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 production is necessary.

The Danish Case Study shows the smallest absolute reduction potential with values between 11 $kgCO_2$-eq/m²a and 20 $kgCO_2$-eq/m²a. The reason for that low absolute reduction is the quite low carbon emissions of the reference case (see also Figure 35), which is similarly true also in Sweden. 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.

In the Spanish Case Study similar results are achieved as in 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. In both cases the high carbon emissions of the reference cases lead to those high reductions of the investigated renovation packages.

For the Swedish and the Czech Case Studies no minimum reduction is given (see description of Figure 35). That means the reduction potentials range between 0 $kgCO_2$-eq/m²a and 34 $kgCO_2$-eq/m²a (Czech Republic) respectively 7 $kgCO_2$-eq/m²a (Sweden). Compared to the reference cases these are reductions of up to 58% in the Czech case and up to 47% in the Swedish case.

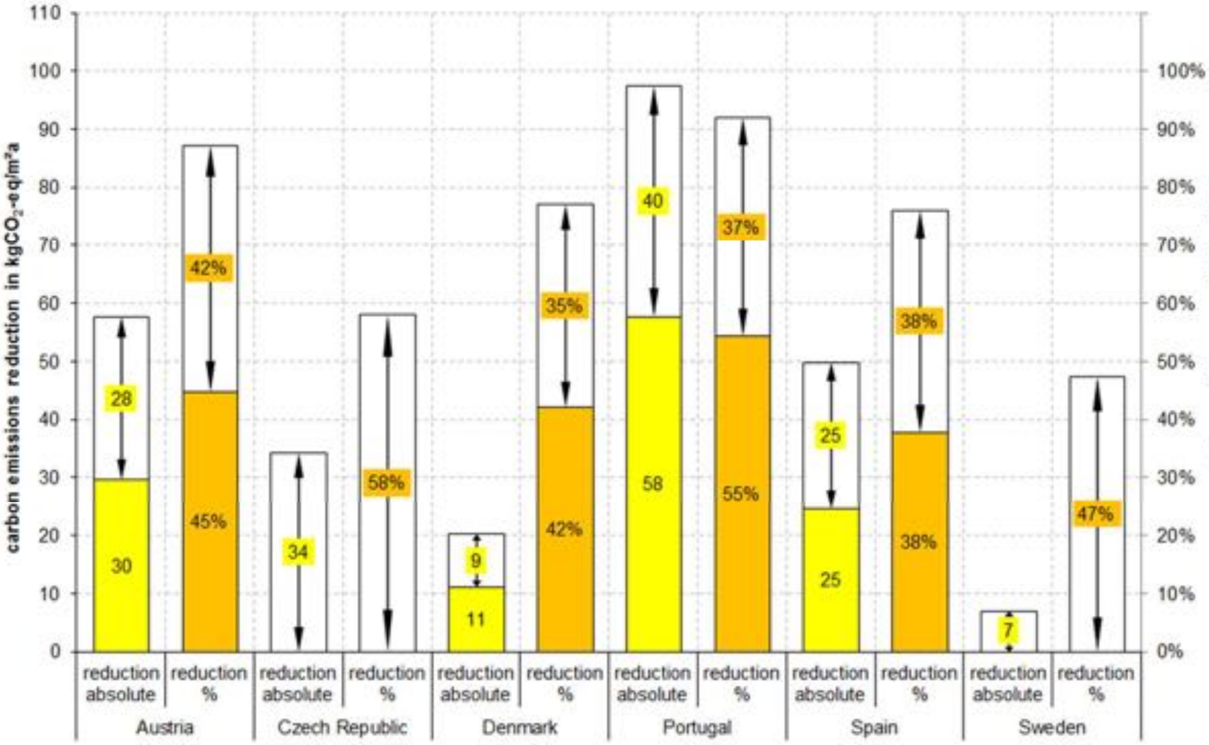


Figure 36: Carbon emissions reduction potential of the six Case Studies. The absolute (yellow columns) and the relative reduction potentials (orange columns) are presented as minimum reduction and also as range between the minimum and maximum reduction.

A comparison of the Life Cycle Costs of the reference cases (light red columns) and those renovation packages which achieve the lowest carbon emissions (dark red columns) are shown in Figure 37. The chart shows that almost all renovation packages, which achieve the lowest carbon emissions, are also cost effective. That means that the LCC of these renovation packages are lower than the LCC of the reference cases. The exceptions are the Danish and the Swedish Case Study, where all investigated renovation packages lead to an increase of the annual LCC (see descriptions in chapter 5.2 (Denmark) and chapter 5.5 (Sweden)).

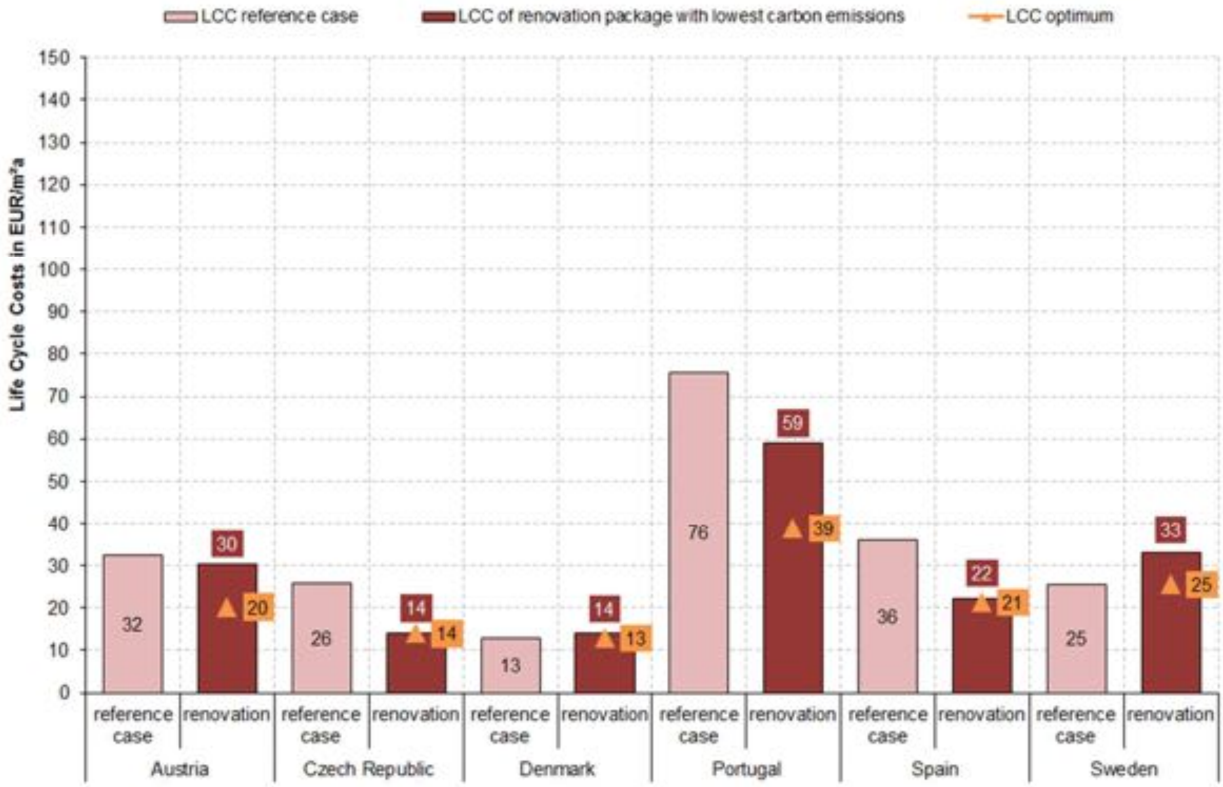


Figure 37: Life Cycle Costs of the six Case Studies. The LCC of the reference cases are compared to the LCC of those renovation packages, which achieve the lowest carbon emissions. Additionally the LCC optimum for each Case Study was marked.

A further analysis of the Life Cycle Costs is shown in Figure 38. The chart demonstrates the possible Life Cycle Cost reductions, when bringing the carbon emissions to the lowest value. That means for each 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 EUR/m²a in the Austrian Case Study up to 17 EUR/m²a in the Portuguese Case Study (in the Danish and Swedish Case Studies no reduction of the LCC is given, therefore no value is shown for these two countries in Figure 38). In relative value these are reductions of 6% in Austria to 22% in Portugal. 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 package v3, which achieves the lowest carbon emissions, due to the prefabricated façade and the large photovoltaic and solar thermal installations. Therefore the LCC are higher than they would be without the prefabrication and the on-site energy generation.

In Czech Republic and Spain the relative reductions are even higher than in Portugal. In the Czech Case Study the relative reduction is 46% and in the Spanish Case Study 39%, always compared to the reference cases.

The conclusion of the evaluation of the carbon emissions and the corresponding Life Cycle Costs is that high carbon emissions reductions are possible which are cost effective and lead to a high reduction of the Life Cycle Costs. However these case studies, one per country, on which the conclusion is based, might not always be completely representative for the individual country.

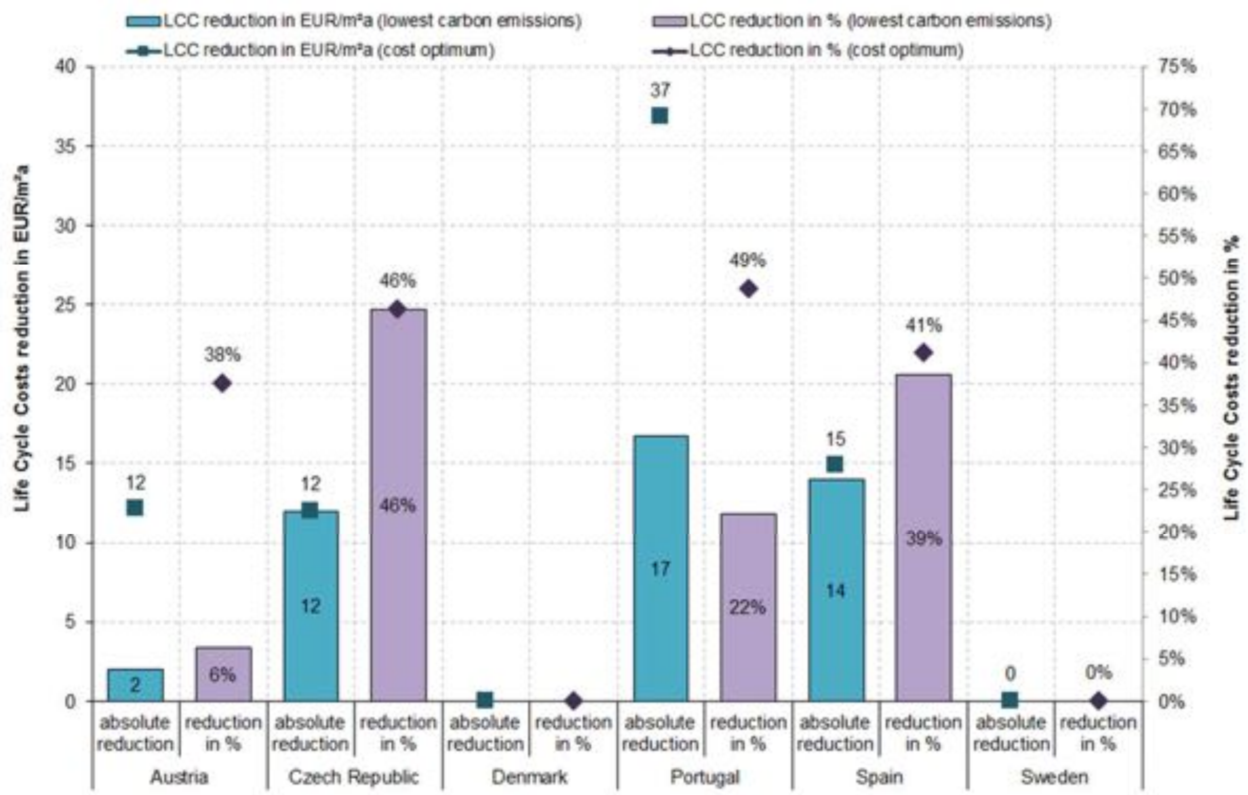


Figure 38: Life Cycle Costs reduction potentials of the six Case Studies. The absolute reduction potential (blue column) and the relative reduction potential (purple column) are presented as values between the reference case and the renovation package which achieves the lowest carbon emissions. Additionally the reduction potentials of the LCC optimum, compared to the reference cases, were marked.

5.7.2. Total Primary Energy

Figure 39 shows the calculated total Primary Energy of the six Case Studies. The total Primary Energy of the reference cases (light blue columns) are compared to the lowest total PE of the investigated renovation packages (dark blue columns). The range between the lowest and the highest Primary Energy is highlighted and estimated.

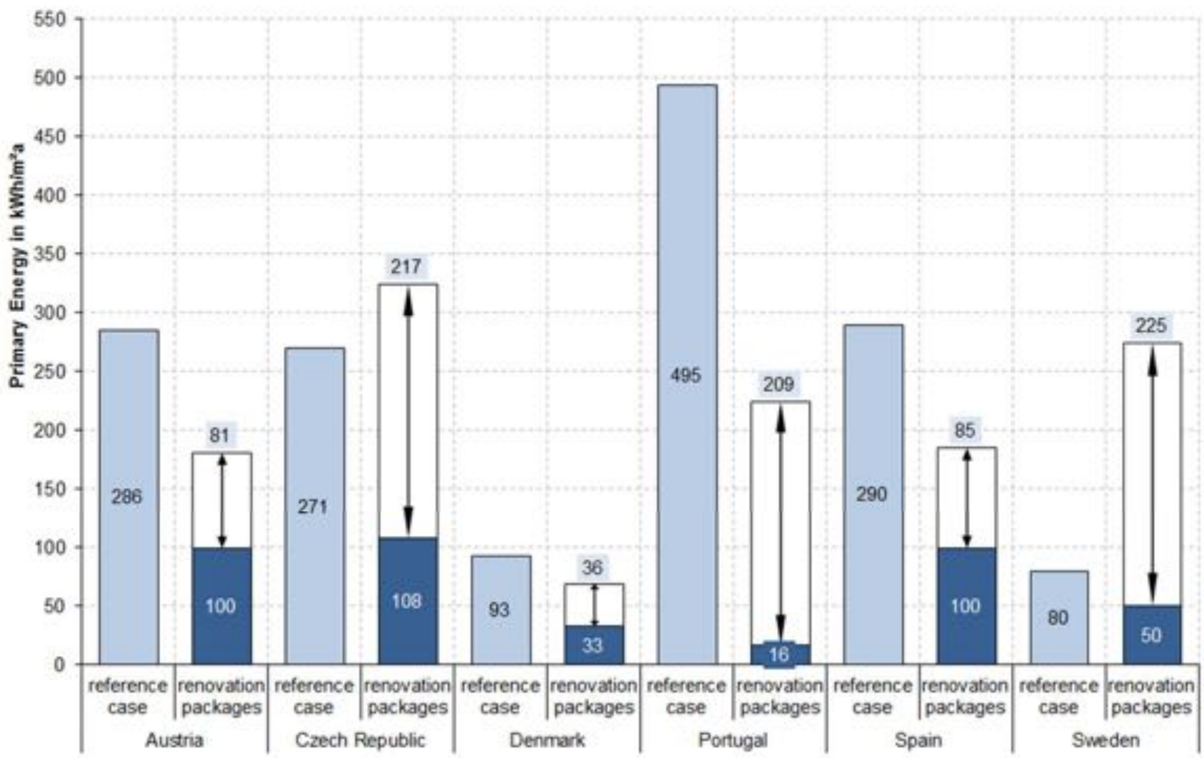


Figure 39: Total Primary Energy of the six Case Studies. The total Primary Energy values of the reference cases are compared to the total Primary Energy values of the investigated renovation packages, shown as lowest value and as range between the lowest and the highest value.

The calculation results show that the Portuguese Case Study achieves the highest total Primary Energy in the reference case with 495 kWh/m²a. The lowest total Primary Energy of all reference cases is achieved in the Swedish Case Study with 80 kWh/m²a. This value is more than six times lower than the total PE of the Portuguese reference case. The main reason for this low value is the high share of renewable energy sources in the considered district heating.

The lowest total Primary Energy after renovation is achieved in the Portuguese Case Study with a value of 16 kWh/m²a. The main reason for this low value is the switch to heat pump, which is supported by a photovoltaic installation on-site (similar to carbon emissions reduction in chapter 5.7.1).

The investigation of the energy related renovation measures in the six Case Studies showed that, similar to the carbon emissions, in four of the six buildings total Primary Energy reductions are always given, independent of the chosen measures. For the Czech Case Study and the Swedish

Case Study this statement is not true. In the Czech case the reference case uses district heating based on natural gas for heating and domestic hot water supply of the building. If the energy source is changed to electricity the total Primary energy values increase, although renovation measures on the building envelope are included (see also description of Figure 35).

The same situation is given in the Swedish Case Study. As mentioned before the reference case uses district heating, which is (largely) based on renewables. If the energy source is changed to oil, natural gas or electricity the total Primary Energy increases, again although energy related renovation measures on the building envelope are included.

Figure 40 shows the total Primary Energy reduction potentials of the six investigated Case Studies, the absolute values (yellow columns) and also the relative (orange columns).

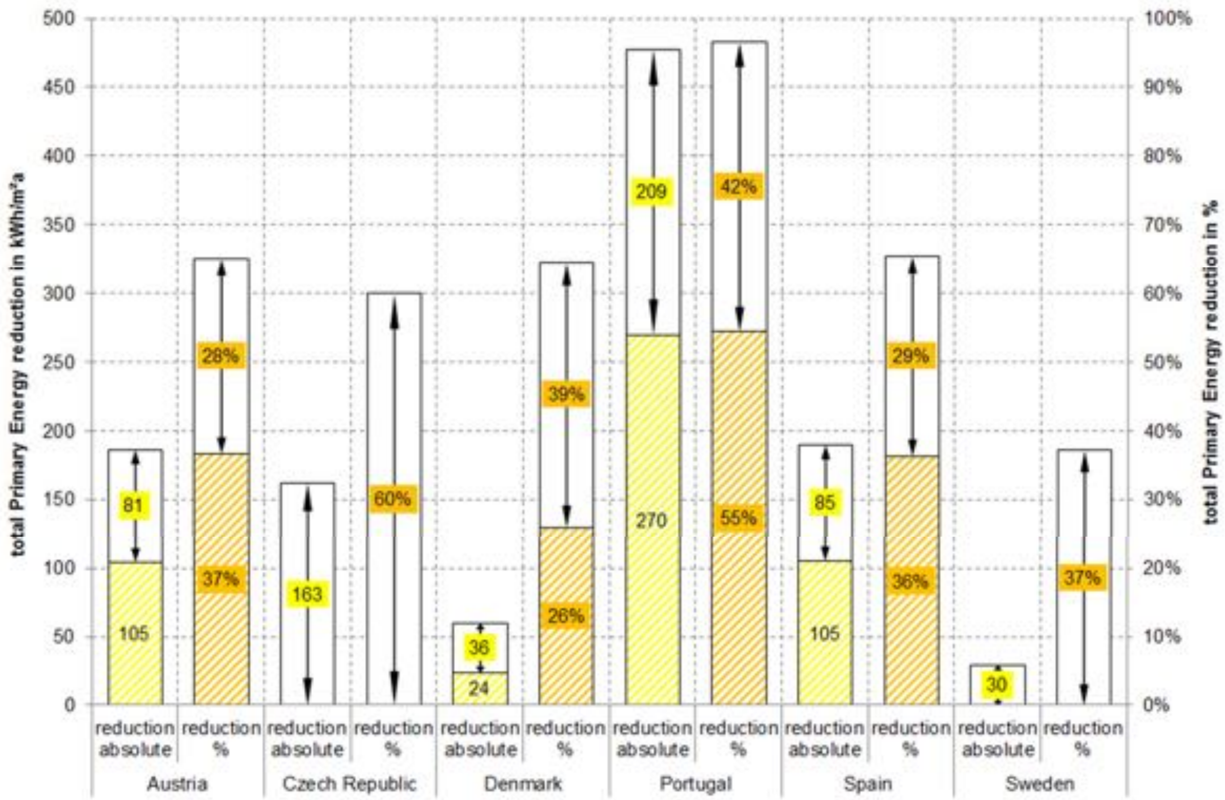


Figure 40: Total Primary Energy reduction potential of the six Case Studies. The absolute (yellow columns) and the relative reduction potentials (orange columns) are presented as minimum reduction and also as range between the minimum and maximum reduction.

The chart shows that the Portuguese Case Study achieves the highest reduction potentials (of all investigated buildings) with the minimum of 270 kWh/m²a and up to 479 kWh/m²a. In relative numbers this represents reductions between 55% and 97%, compared to the Portuguese reference case. The reasons for this high 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 a multi-split air conditioned heating and cooling system. 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 Case Study, even if the absolute reductions are smaller (between 24 kWh/m²a and 60 kWh/m²a) due to the lower total Primary Energy demand of the Danish reference case.

For the Swedish and the Czech Case Studies no minimum reduction is given (similar to carbon emissions in previous chapter). That means the reduction potentials range between 0 kWh/m²a and 163 kWh/m²a (Czech Republic) respectively 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 case high relative reductions of the total Primary Energy are possible but the investigated renovation measures can also lead to an increase of the total Primary Energy (see figures in sections 5.5.2 and 5.6.2).

Figure 41 shows similar to Figure 37 the comparison of the Life Cycle Costs of the reference cases (light red columns) and of those renovation packages which achieve the lowest total Primary Energy (dark red columns). The chart shows that almost all renovation packages, which achieve the lowest total Primary Energy in each particular Case Study, are also cost effective. That means that the LCC of these renovation packages are lower than the LCC of the reference cases. The exceptions are again the Danish Case Study and the Swedish Case Study, where all investigated renovation packages lead to an increase of the annual LCC (see section 5.2.2 (Denmark) and section 5.5.2 (Sweden)).

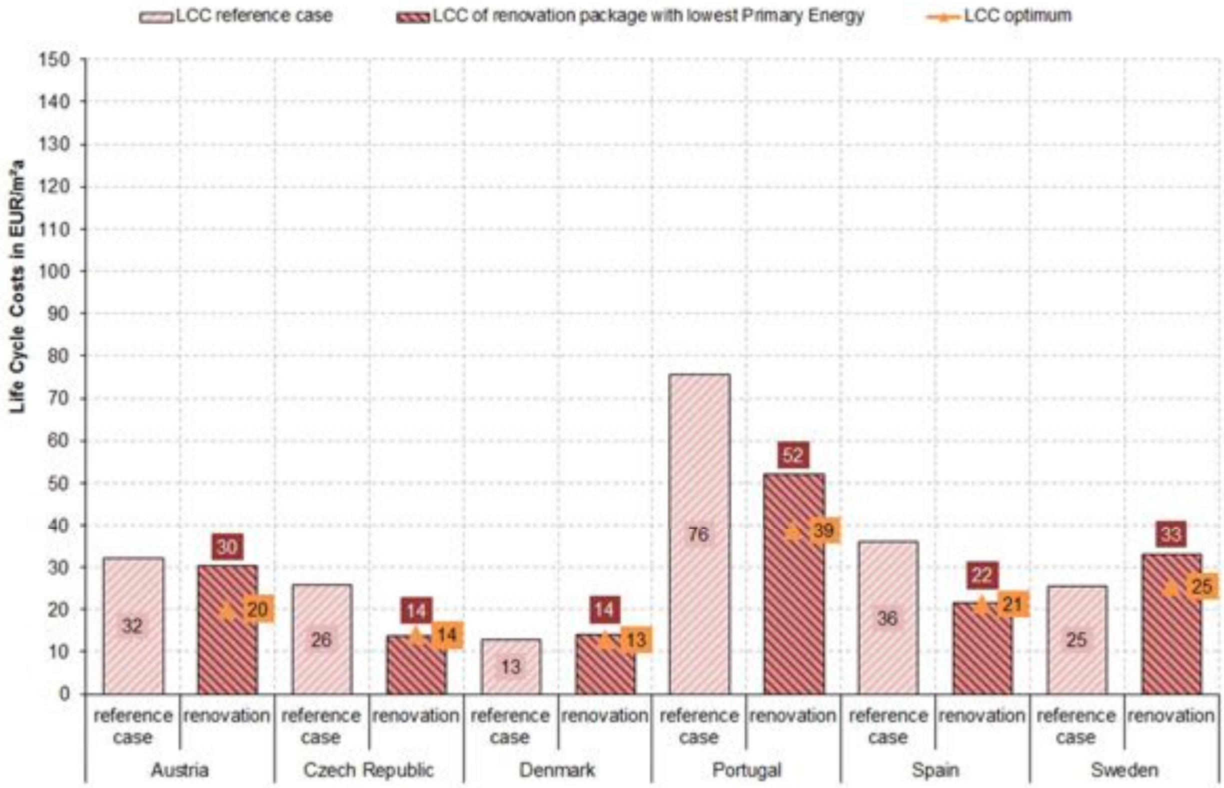


Figure 41: Life Cycle Costs of the six Case Studies. The LCC of the reference cases are compared to the LCC of the renovation packages, which achieve the lowest total Primary Energy. Additionally the LCC optimum for each Case Study was marked.

Figure 42 shows the LCC reduction potentials when reducing the total Primary Energy to the minimum. For each 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 EUR/m²a and also in relative reductions (in %).

The analysis shows that the LCC can be reduced from 2 EUR/m²a in the Austrian Case Study up to 23 EUR/m²a in the Portuguese Case Study (again no values for the Danish and the Swedish Case Studies because for these two buildings no reductions of the LCC were given). In relative value these are reductions of 6% in Austria to 31% in Portugal. 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 package v3, which achieves the lowest total Primary Energy, due to the prefabricated façade and the photovoltaic and solar thermal installations.

Reducing the total Primary Energy in the Czech Case Study to the lowest possible level also reduces the Life Cycle Costs considerably. The absolute reduction is quite small at a first glance, with a value of 12 EUR/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 production based on natural gas achieve similar LCC results and savings. The photovoltaic installation could further reduce the Life Cycle Costs.

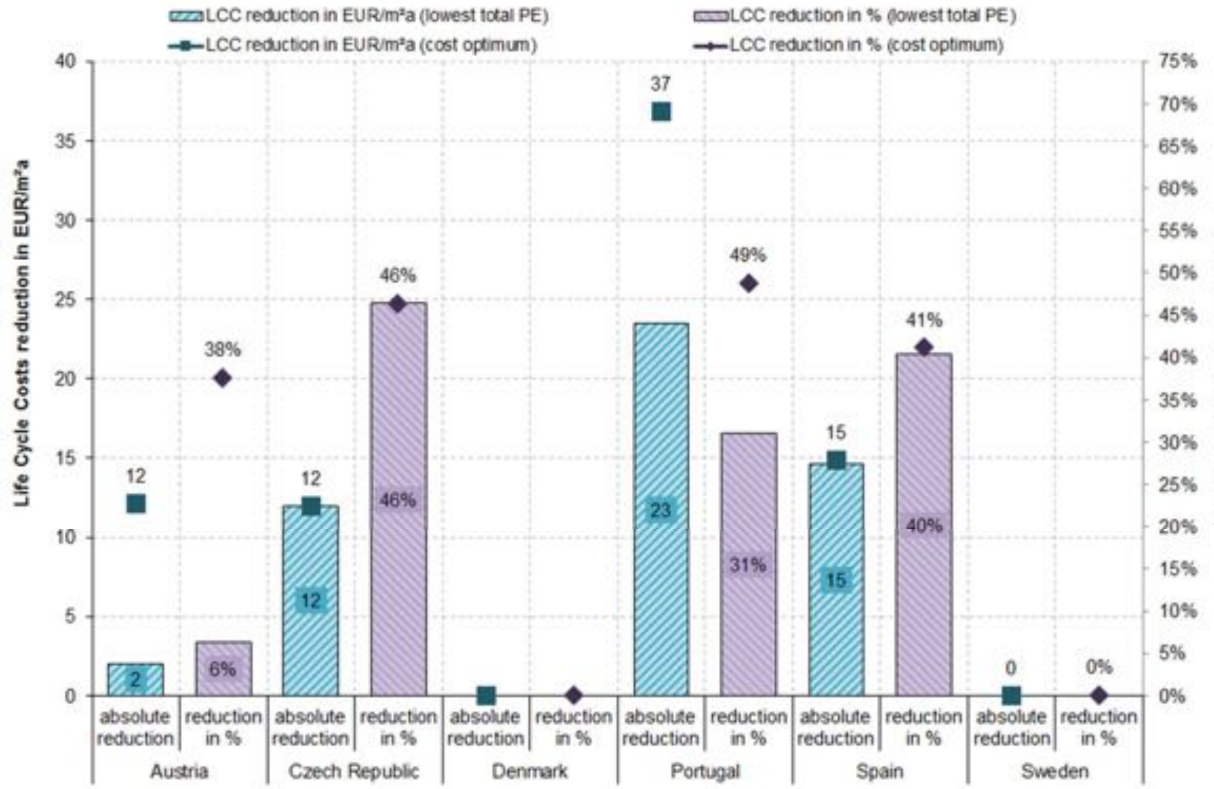


Figure 42: Life Cycle Costs reduction potentials of the six Case Studies. The absolute reduction potentials (blue columns) and the relative reduction potentials (purple columns) are presented as values between the reference case and the renovation package which achieves the lowest total Primary Energy. Additionally the reduction potentials of the LCC optimum, compared to the reference cases, were marked.

5.7.3. Life Cycle Costs vs. Carbon emission and Primary Energy

This chapter focuses only on the Life Cycle Costs and the comparison of the cost curves of each country. Interestingly the measures in the studied cases seem to group together so that each case dominates different parts of the graphs. However, it is not known if this is due to country specific conditions or case specific conditions. This becomes apparent in Figure 43, which shows the comparison of the annual Life Cycle Costs with the carbon emissions of all countries on the left side and with the total Primary Energy of all countries on the right side. Each country is marked in a separate color without identifying the individual renovation packages.

Each mark represents one of the investigated renovation packages (reference case, v1, v2, v3) including also different energy sources for heating and DHW.

The analysis of the data in Figure 43 shows that the Portuguese Case Study achieves the highest annual costs of all countries. The LCC range between 39 EUR/m²a (cost optimum) and almost 76 EUR/m²a. Even the cost optimal renovation package has higher LCC than almost all defined renovation packages of the other countries. The investigated renovation packages in Austria, Czech Republic, Denmark and Spain achieve similar LCC, which range between 15 EUR/m²a and 30 EUR/m²a. The LCC range therefore is quite small. The absolute lowest LCC were achieved in the reference case of the Danish Case Study with a value of 12.79 EUR/m²a.

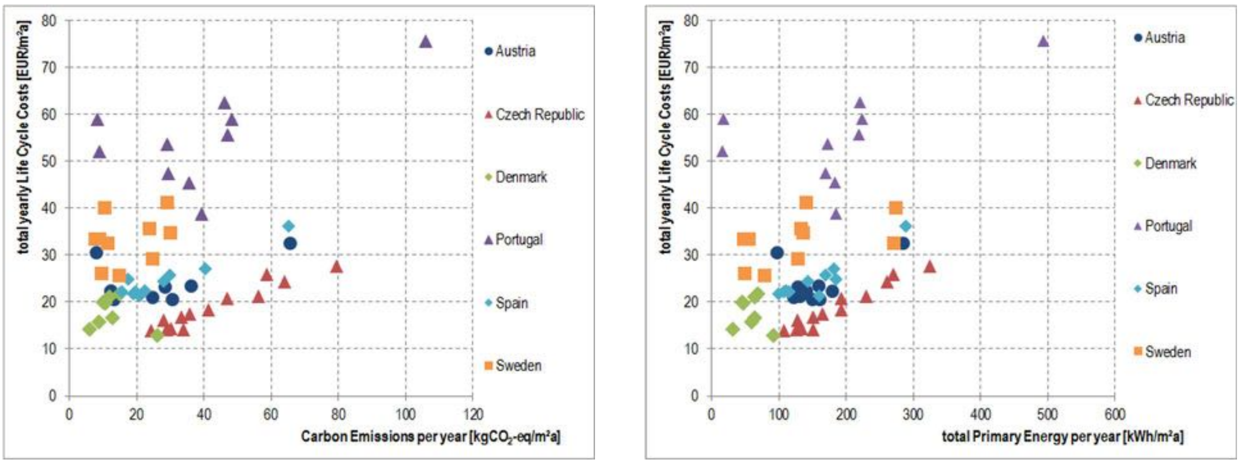


Figure 43: Comparison of Life Cycle Costs, carbon emissions (left side) and total Primary Energy (right side) of all investigated Case Studies

The conclusion of this analysis is that the values can differ from country to country and therefore it is not possible to compare the six Case Studies directly. The differences can be explained for example by differences in building costs, energy costs, climates, building and HVAC technology. Furthermore these factors can also differ from project to project within a country. Especially if the fact is considered that the investigated buildings represent pretty much unique building renovations and therefore are hardly comparable to most other buildings in the six countries.

More information to the differences between the countries and the comparison of the Case Studies with generic buildings can be found in the report "Investigation based on calculations with generic buildings and case studies" (Bolliger and Ott, 2015), which can be downloaded from the IEA EBC Annex 56 website (see: http://www.iea-annex56.org/index.aspx)

5.7.4. *Overview of investigated hypothesis for the five residential Case Studies*

The five investigated hypotheses were tested for each residential building of the Case Studies and presented in the previous chapters. For the Case Study from the Czech Republic, the small number of renovation packages that was available didn't allow the test of the hypotheses. Therefore the analysis in this chapter includes only the five residential Case Studies.

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 RES as well as their combinations.

At this point the confirmation of the hypotheses is summarized and shown in following Table 18.

Table 18: Results for the investigated hypotheses for the five residential buildings of the Case Studies. ✓ means that the hypothesis is confirmed, ✗ means that the hypothesis is not confirmed. Symbols in parenthesis or separated by a slash indicate that the hypothesis is only partly confirmed / not confirmed.

Hypothesis	Austria	Denmark	Portugal	Spain	Sweden
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements.	✓	✓	(✓)	✗	✗
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements.	✓	✓	✓	(✓)	✓
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.	✓	✓	(✓)	✓/✗	✓

The hypothesis ***"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements."*** could be completely confirmed for Austria and Denmark and partially for Portugal. In Portugal this hypothesis was only confirmed for the renovation measures roof and wall but not for the remaining measures on the building envelope. For the Spanish and the Swedish Case Study this hypothesis was not confirmed.

The hypothesis ***"A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements."*** was confirmed in all five countries, with limitations in the Spanish Case Study where the hypothesis was confirmed for the switch to district heating with 75% biomass or to a biomass heating system, yet not for a switch to heat pump.

The hypothesis ***"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level."*** is completely confirmed for the Austrian, the Portuguese and the Spanish Case Study and confirmed with limitations in Denmark and Sweden. In the Danish Case Study for example the reference case or simply a switch to a different heating system, without energy efficiency measures, is the cost optimum renovation. All investigated energy related renovation measures lead to an increase of the annual Life Cycle Costs. In the Swedish case, the cost-optimum was not changed by a combination of energy efficiency measures with RES measures. However, it can to be noted that in the case of an oil heating system, renovation measures beyond the cost optimum are similarly cost-effective as the cost optimum, whereas for district heating and the RES based heating systems investigated, additional renovation measures on the building envelope beyond the cost optimum make the renovation significantly less cost-effective.

The hypothesis ***"Synergies are achieved when a switch to RES is combined with energy efficiency measures."*** is confirmed in Austria, Portugal and Spain. In Denmark this hypothesis is disproved. The results showed that it is more cost efficient to use district heating or heat pump and not carrying out further energy related renovation measures on the building envelope. In Sweden the hypothesis can be partly confirmed for the insulation of the exterior wall in combination with the change to district heating based on RES. The hypothesis however is disproved for all remaining renovation measures in combination with district heating based on RES and also for all combinations with a pellets heating system.

The hypothesis ***"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."*** is completely confirmed in Austria, Denmark and Sweden. In Portugal and Spain limitations exist. The Spanish Case Study shows a confirmation for the district heating system with 75% biomass and the biomass heating system, yet not for a heat pump. In Portugal it is in general difficult to answer this hypothesis. In fact it cannot clearly be answered. It is more likely to be confirmed but a hundred per cent confirmation is not possible.

5.7.5. *Comparison of the results with the generic parametric calculations*[16]

In all investigated generic buildings investigated there is a cost optimum, with lower costs than those of an «anyway renovation». Costs are rising for measures going beyond the cost optimum, but many or sometimes all of the measures considered in the assessment are still cost-effective, i.e. lower than the cost of the anyway renovation.

With respect to the energy performance of energy related building renovation measures and the balance between renewable energy deployment and energy efficiency measures, the five main hypotheses have also been investigated. Within this context, some tentative conclusions are made referring to renewable energy sources (RES) in general. However, it is important to note that only specific RES systems were taken into account in the generic calculations. For example the role of solar thermal or small wind turbines has not been investigated and not all types of renewable energy systems were investigated for all reference buildings. In the case of the countries Austria, Denmark, Spain and Sweden, geothermal heat pumps and wood pellet heating systems have been investigated as RES systems; in the case of Portugal an air-water heat pump and its combination with PV were investigated as RES systems. The related findings obtained from the parametric calculations with the investigated generic buildings are summarized in the following Table 19.

Table 19: Results for the investigated hypotheses for the generic multi-family buildings

Hypothesis	Austria	Denmark	Portugal	Spain	Sweden
The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements.	✓	✓	✓	✓	✗
A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements.	✓	✓	✓	✓	✓
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.	✓	✓	✓	✓	✓

16 Taken from the report: ""Investigation based on calculations with generic buildings and case studies" (Bolliger and Ott, 2015)

The comparison of the results of the Case Studies (Table 18) with the results of the generic buildings (Table 19) shows good correlation.

Small deviations could be found:

- in Austria for the hypothesis **"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level"**
- in Portugal for the hypotheses **"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements."** and **"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."**
- in Spain for the hypotheses **"A switch to RES reduces emissions more significantly than energy efficiency measures on one or more envelope elements."** and **"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."**
- in Sweden for the hypothesis **"Synergies are achieved when a switch to RES is combined with energy efficiency measures."**

In the mentioned cases the named hypotheses could be fully confirmed in the generic buildings but only confirmed with limitations in the real Case Studies (exception: in Austria it´s vice versa).

For some hypotheses however, no correlation between the Case Studies and the generic buildings is given:

- in Denmark the hypothesis **"Synergies are achieved when a switch to RES is combined with energy efficiency measures."** was confirmed in the generic building but not confirmed in the Case Study
- in Spain the hypothesis **"The energy performance of the building depends more on how many building elements are renovated than on the energy efficiency level of individual building elements."** was confirmed in the generic building but not in the Case Study
- in Sweden the hypothesis **"A combination of energy efficiency measures with RES measures does not change significantly the cost optimal efficiency level."** was partly confirmed in the Case Study but not in the generic building.

6. Challenges to reach nearly zero energy and nearly zero emissions

Besides the technical solutions, which are necessary to reach cost effective nearly zero energy buildings after renovation, including high reductions of carbon emissions and total Primary Energy, it is important to know the challenges that occur when trying to reach this goal and also the measures that can be taken to overcome them.

Therefore participants from the six countries that have provided a Case Study have been asked 13 general questions to this topic, which were not directly related to the Case Studies. Beyond these six countries, representatives from four more countries have been asked to extend the survey and the results. This means representatives from following countries have been interviewed: Austria, Denmark, Czech Republic, Portugal, Spain, Sweden, Finland, The Netherlands, Norway and Switzerland.

The questions asked in the interviews were divided into four main categories:

- **information issues** (information asymmetry, information from Energy Declaration of Buildings, lack of requirements, lack of knowledge, lack of examples,…)
- **technical issues** (lack of well proven systems, total solutions and information)
- **ownership issues** (structure of ownership, rent increase, running costs vs. investment costs)
- **economic issues** (lack economic knowledge, uncertainties about saving potentials, high investment costs, lack of economic incentives)

Each partner was asked to answer questions to above-named issues with yes (Y), if the barrier is relevant in their country, or with no (N), if there is no relevance of the barrier in the specific country.

The investigated questions in each of these four categories and the evaluation results to each of the categories and questions are presented below.

A) Information Issues:

- *Information asymmetry – differing opinions expressed by professionals*
- *Incomplete information from the Energy Declaration of Buildings*
- *Lack of clear requirements*
- *Lack of knowledge about possibilities, potential benefits and added values*
- *Lack of examples and inspiration*

Table 20: Evaluation results of the INFORMATION issues in the 13 countries

A) Information issues	AT	CZ	DK	PT	ES	SE	CH	FI	NE	NO	Total yes	Total no
Information asymmetry – differing opinions expressed by professionals - is this a relevant barrier in your country?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	0
Incomplete information from the Energy Declaration of Buildings - Is this a relevant barrier in your country?	Y	Y	Y	Y	Y	Y	-	N	N	Y	7	2
Lack of clear requirements – is that a relevant barrier?	N	N	N/Y	Y	Y	Y	N	Y	Y	Y	7	4
Lack of knowledge about possibilities, potential benefits and added values	Y	Y	N/Y	Y	N	Y	Y	Y	N	Y	8	3
Lack of examples and inspiration	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9	1

The results show that all ten countries have experienced differing opinions given by professionals, for instance dealing with extra insulation. This information asymmetry between investors and professionals often leads to suboptimal solutions, especially if the professional person is a craftsman without a general approach and corresponding know-how regarding building renovation.

7 of the countries have answered that inadequate information from the Energy Declaration of Buildings is a barrier, often the buildings don´t even have an Energy Declaration at all.

7 of the countries consider the lack of requirements as a barrier, whereas 2 countries do not consider it as a barrier (Denmark has answered as well yes as no). In Portugal for example, there are no requirements imposed to the building if the total value of the renovation works is less than 25% of the value of the building. If it exceeds this value, compliance with rules for new buildings is needed. There is no strong control over this frontier. In Spain, the situation is also quite similar. When the use of the building changes or 25% of the envelope is modified the building has to comply with some limits in energy demand; in other cases, only the components that are modified

have to comply with the requisites for new buildings. And there are always some criteria that avoid implementing the rules.

7 countries consider the lack of knowledge about possibilities, potential benefits and added values as a barrier, whereas 2 countries do not consider it a problem (Denmark has answered as well as yes as no). In Norway for example, the public building owner wants to realize a renovation project on passive house level but does not know that he has to find qualified planners. The planners are chosen based on a competition on price and availability. Special qualifications are not demanded.

The lack of examples and inspiration is relevant in all countries except for Finland. This means that very often good examples of advanced building renovations do not exist, and if they exist they are often not fully and impartially evaluated.

B) Technical Issues:

- *Lack of well proven systems, total solutions & information about these*

Table 21: Evaluation results of the TECHNICAL issues in the 13 countries

B) Technical issues	AT	CZ	DK	PT	ES	SE	CH	FI	NE	NO	Total yes	Total no
Lack of well proven systems, total solutions & information about these	Y	Y	Y	Y	Y	Y	N	N	N	Y	7	3

The lack of well proven systems, total solutions and information about these is relevant for 70% of the countries.

In Portugal for example, systems and solutions to renovate Portuguese buildings to high energy performance are known and available, but they aren´t generally used in integrated solutions. In Austria and the Czech Republic the missing or inadequate national climatic data and the lack of independent technical and pricing control of project for public building are the biggest obstacles in this point.

In Switzerland there are quite many well established solutions for building renovations available. The problem is much more lacking overall analyses and strategic planning of renovation activities for the next 10-20 years, slow know-how diffusion into the renovation practice and craftsmen who favor traditional solutions.

C) Ownership Issues:

- *The structure of ownership, (private, public, owner, tenants)*
- *Building owners not allowed to increase rent to pay for energy renovation investments (building owners pay, tenants benefits)*
- *Running costs and investment costs are two different "boxes"*

Table 22: Evaluation results of the OWNERSHIP issues in the 13 countries

C) Ownership issues	AT	CZ	DK	PT	ES	SE	CH	FI	NE	NO	Total yes	Total no
The structure of ownership, (private, public, owner, tenants)	Y	Y	Y	Y	Y	Y	Y	N	Y	-	8	1
Building owners not allowed to increase rent to pay for energy renovation investments (building owners pay, tenants benefits)	N	N	Y	Y	Y	Y	Y	N	N	N	5	5
Running costs and investment costs are two different "boxes"	Y	Y	Y	Y	N	Y	Y	N	Y	Y	8	2

Eight countries consider ownership issues a problem, one does not and one has neither answered yes nor no. The owner/tenant problem, for example, is very relevant in Switzerland with >60% tenants and with a tenancy law which is basically cost based and requires in the case of renovation that only the share of renovation costs which improves the basic quality of the building may give reasons for an increase of rents. A further problem in Switzerland is the age of the private owners of tenements. About 60% of private owners of tenements are older than 60 years, potentially risk averse and less inclined to large investments.

On the other hand in half of the countries it is a problem that building owners are not allowed to increase rent to pay for energy renovation investments. In Sweden for example, a rent increase in an apartment building usually has to be negotiated with the Swedish Union of Tenants and usually the rent cannot be increased as a result of energy efficiency measures only.

In 8 out of 10 countries it is a problem that running costs and investment costs are two different "boxes".

D) Economic Issues:

- *Lack of economic knowledge*
- *Uncertainty about the savings and calculations of saving potential*
- *Investment costs too high*
- *Lack of economic incentives or uncertainty about the incentives*

Table 23: Evaluation results of the ECONOMIC issues in the 13 countries

D) Economic issues	AT	CZ	DK	PT	ES	SE	CH	FI	NE	NO	Total yes	Total no
Lack of economic knowledge	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9	1
Uncertainty about the savings and calculations of saving potential	N	Y	Y	Y	Y	Y	N	Y	N	Y	7	3
Investment costs too high	Y	N	Y	Y	Y	Y	Y	Y	N	Y	8	2
Lack of economic incentives or uncertainty about the incentives	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9	1

The lack of economic knowledge is a barrier in 90% of the countries. In Norway, for example, the economic knowledge would have to be integrated with building knowledge and used in a more holistic way. In Sweden, there is partly lacking know-how. Even professional investors calculate with a surprisingly short payback period. One reason is lacking know-how of renovation measures and performance of renovation measures. A second reason is the attempt to reduce risks because of risk aversion or because of the difficulty to predict longer future time periods. This would typically be necessary for renovation investments having life cycles of 15-40 years.

The uncertainty about the savings and calculations of savings potentials is also a barrier in 7 of the 10 countries as well as the too high investment costs which are a barrier in 80% of the countries. In Norway for example, the investment costs are high with relative low energy prices. Also the planning costs and the maintenance costs for building equipment are high.

The lack of economic incentives or uncertainty about the initiatives is a barrier in 9 countries. Only Finland does not consider this as a problem, in Switzerland on the other hand this is a severe problem.

Conclusions

The evaluation of the barriers to reach nearly zero energy buildings can be summarized as, in average 7 out of 10 of the countries consider the mentioned barriers as relevant.

One barrier is relevant for all countries, which is the information asymmetry of differing opinions expressed by professionals.

In 9 out of ten countries it was considered to be a barrier that there is a:

- Lack of examples and inspiration
- Lack of economic incentives or uncertainty about the incentives
- Lack of economic knowledge

In 7-8 countries the following were considered to be barriers:

- Incomplete information from the Energy Performance Certificate of Buildings
- Lack of knowledge about possibilities, potential benefits and added values
- Lack of well proven systems, total solutions and information about these
- Lack of clear requirements
- The structure of ownership (private, public, owner, tenant)
- Running costs and investment costs are two different “boxes”
- Investment costs too high
- Uncertainty about the savings and calculations of saving potential

In 5-6 countries the following was considered to be a barrier:

- Building owners are not allowed to increase rent to pay for energy renovation investments (i.e. the building owner pays for the tenant´s benefits)

7. Conclusions and recommendations

The investigations of the six Case Studies and the interviews in ten European countries allow making recommendations for cost effective renovations towards nearly zero energy and emissions in future. In the next paragraphs these recommendations are presented corresponding to their sources (parametrical analyses of LCC and LCA, co-benefits analyses and interviews):

Parametric calculations

A switch to renewable energy sources reduces the carbon emissions more significantly than energy efficiency measures on one or more envelope elements. 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 combined with energy saving 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. This can depend on national standards, prices, weather conditions and other factors.

Energy efficiency measures, when compared with measures associated with the use of renewable energy sources, are the main source of co-benefits at building level.

To maximize the co-benefits associated with energy related building renovation, it is more effective to improve the performance of all the elements of the building envelope than to significantly improve the performance of just one element.

Depending on the original condition of the building, improving the performance of all the elements of the building envelope usually means going beyond cost optimality, but it is still cost-effective when compared to the “anyway renovation”, i.e. a renovation scenario where energy performance is not improved.

The calculation results within the Case Studies have shown that high carbon emissions and Primary Energy reductions are possible, where the corresponding renovation packages are also cost effective, which means that the Life Cycle Costs of the renovation packages 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. Moreover higher values, compared to the reference case, were calculated in some Case Studies. Therefore a detailed look at different possible renovation measures, including the calculation of the Life Cycle Costs and the Life Cycle Assessment are necessary.

It also has to be mentioned that the assumptions made in the Life Cycle Cost calculation and the Life Cycle Assessment are very important and can influence the results a lot. Therefore these assumptions have to be well-considered and if possible a sensitivity analysis of the most important parameters should be carried out. It is advisable to consult an expert with profound knowledge in the field of Life Cycle Cost calculations and Life Cycle Assessments.

Interviews

Missing good examples for successful renovations are often the biggest barriers for renovations towards nearly zero energy and emissions. The investigated Case Studies are such good examples, but more are needed. This means that national initiatives have to be launched to promote these kinds of building renovations. One of these initiatives could be the financial support or funding programs via direct funding or via research projects. Research projects would bring the additional benefit that new, innovative measures could be tested and evaluated, which in turn would increase the technical knowledge of the building professionals and also of the building owners.

Such a campaign could also counter the lack of economic incentives or uncertainty about the incentives. This means that by launching economic incentives building owners will receive support in financing nearly zero energy and emissions buildings. This will give building professionals the opportunity to realize good building renovations without constantly having the investment costs in mind.

A further important step towards cost effective building renovations is the consideration of the whole building life cycle. That means the Life Cycle Costs of the renovation packages should be regarded over the life cycle of the building and the building element. The investment costs should not be taken as main decision criterion.

If the building owner is faced with the problem of not being allowed to increase the rent to pay for energy renovation measures, it is advisable to go for the cost optimal renovation.

Co-benefits

It is 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 scope of cost effective renovation packages of measures. Within the scope of cost effective renovation scenarios, costs and co-benefits should be considered to find the solution that adds more value to the renovated building. 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 (“anyway renovation”).

Appendices

Appendix 1: Case Study “Kapfenberg”, Austria

Appendix 2: Case Study “Kamínky 5”, Czech Republic

Appendix 3: Case Study “Traneparken”, Denmark

Appendix 4: Case Study “Rainha Dona Leonor neighbourhood”, Portugal

Appendix 5: Case Study “Lourdes Neighborhood”, Spain

Appendix 6: Case Study “Backa röd”, Sweden

Appendix 7: Case Study “Montarroio”, Portugal

Appendix 1

Demonstration project Kapfenberg

A renovation to “plus energy standard”

Owner: ennstal SG

Architect: Nussmüller Architekten ZT GmbH

Energy concept: AEE INTEC

Report: AEE INTEC

Location: Kapfenberg, AT

Date: November 2014

Key technologies

- **Prefabricated active and passive façade elements**
- **Prefabricated elements for the building services**
- **Renewable energy production on-site via photovoltaic and solar thermal panels**
- **Using existing heat and electricity grids to achieve plus-energy**

View of existing (small picture) and the renovated building (large picture) (west elevation)

Background

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

Figure 1: View of the existing building (west elevation)

The existing building was a typical building from the 1960's made of prefabricated sandwich concrete elements without an additional insulation.

The basement ceiling was insulated with approx. 60 mm polystyrene. The old roof was a pitched roof with no insulation. The ceiling to the unheated attic was insulated with 50 mm wood wool panels.

The existing windows were double glazed windows with an U-value of 2.5 W/m²K.

In the existing building a variety of different heating systems was installed: a central gas heating, electric furnaces, electric night storage heaters, oil heaters, wood-burning stoves and coal furnaces.

The ventilation of the existing building was accomplished by opening the windows; no mechanical ventilation system was installed.

The enormous energy demand caused very high heating and operating costs. A high quality refurbishment of the building with a change in the layout of the apartments should make the building more attractive to new residents and young families.

Project data of building before renovation

Altitude	502 m
Heating degree days	3794 Kd
Cooling degree days	- Kd
Year of construction	1960- 1961
Gross heated floor area	2845 m²
Specific heating energy need excl. hot water	105,5 kWh/(m²a)
Specific cooling energy need	0 kWh/(m²·a)
Specific hot water energy need	12,78 kWh/(m²·a)
Type of energy carrier for heating	mixed (gas, oil, wood,…)
Type of energy carrier for hot water	mixed
Specific heating energy consumption (excl. hot water)	150,97 kWh/(m²·a)
Specific hot water energy consumption	16,83 kWh/(m²·a)
Installed heating capacity	136 kW
Specific electricity consumption (excl. hot water and heating)	27,69 kWh/(m²·a)
Energy costs	28851 €/a

Figure 2: Typical floor plan of the residential building

Renovation concept

Figure 3: View of renovated building (west elevation)

Design data for renovated building

Year of renovation	2012 - 2014
Gross heated floor area	2845 m²
Specific heating energy need excl. hot water	16,90 kWh/(m²a)
Specific cooling energy need	0 kWh/(m² a)
Specific hot water energy need	12,78 kWh/(m² a)
Type of energy carrier for heating and hot water	district heating, solar thermal
Specific heating energy consumption (excl. hot water)	to be measured
Specific hot water energy consumption	to be measured
Installed heating capacity	63 kW
Specific electricity need (excl. hot water and heating)	16,43 kWh/(m² a)
Energy costs	14810 €/a
Other additional costs	-

Figure 4: prefabricated façade element

The specific renovation objectives were:

Realization of the developed active and passive façade modules and of the modules for the building services.

Optimization of the building through an innovative energy supply and disposal concept:

80% reduction of the energy demand of the existing building

80% reduction of the CO2 emissions of the existing building

80% use of renewable energy (based on the total energy consumption of the renovated building)

Optimization of the energy concept by using the existing heat and electricity grids to achieve plus-energy.

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.

Figure 5: Floor plan changes of renovated building

Renovation design details

Facade Solutions

Instead of conventional insulation systems the façade in this project is covered with large-sized active and passive façade elements.

Similar façade elements were developed and tested in previous projects. For this demonstration building the developed façade elements should comprise following alterations:

- The elements should be cheaper and
- allow more prefabrication.
- There should be less effort at the building site.
- The building services should be visible and also easy accessible (for service an maintenance)

With these face elements it should be possible to reach an energy reduction and a reduction of the CO_2 emissions of 80%, as defined in the renovation objectives.

The idea was also to create a prefabricated façade element which allows the use of different surfaces with the same substructure.

The surface materials can vary between e.g. wood, stone or fiber cement boards. Also active components like solar thermal or photovoltaic panels can be integrated in the façade element.

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

These separate elements are also prefabricated and the building owner has the possibility to decide which ducts should be included (heating, domestic hot water, ventilation, electricity, waste water etc.)

Figure 9: building services in a prefabricated equipment in the façade

Figure 10: Prefabricated façade elements with integrated active energy production (photovoltaic and solar thermal panels)

Figure 7: assembling of the prefabricated façade elements

Figure 6: assembling of the prefabricated façade modules

Figure 8: prefabricated façade element

Roof solution

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: first of all was the old truss not able to carry the charges of the photovoltaic power plant, secondly the orientation of the old pitched roof was not ideal for the active energy production.

The new flat roof is highly insulated with approximately 35-40 cm.

On the new roof the photovoltaic panels were installed and it now accommodates also the mechanical ventilation units.

Figure 11: renovated flat roof with scaffold for the mounting of the photovoltaic panels

Ground floor solution

Due to the low ceiling height no more than 6 cm insulation was possible even though a higher insulation would have been desirable for energetically reasons.

The existing building has already been insulated with 6 cm insulation. This thermal insulation was renewed during the renovation but the energy performance of this component was not improved.

The u-value of the ground floor therefore is still 0.39 W/m²K.

Figure 12: construction detail of the cellar ceiling and the exterior wall

Window solution

The old existing windows are replaced by new triple glazed windows with following characteristic values:

U_{glass} = 0,70 W/m²K

U_{frame} = 1,17 W/m²K

U_{window} = 0,97 W/m²K

g-value = 0,60

The new windows are already integrated in the prefabricated façade modules and are of high thermal quality.

An external shading device is also installed and already integrated in the façade module too. This external shading device helps to reduce the solar gains and therefore to avoid overheating of the rooms in the warm periods of the year.

The integration of the external shading device in the prefabricated façade element had to be as thermal bridge-free as possible. So this point had to be considered in the planning stage.

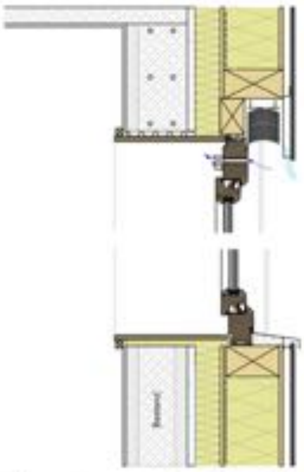


Figure 14: construction detail of the window incl. shading device

Figure 13: rendering with renovation concept for the roof (solar panels)

Heating

The basic heat supply of the renovated building is accomplished by the local district heating.

The district heating grid of the city of Kapfenberg is largely supplied with waste heat (heat losses) of the local steel manufacturer (Böhler-Uddeholm).

Additionally to the district heating a solar thermal system with a collector surface of 144 m² is installed. For this purpose a scaffold on the south façade was mounted to increase the area for the solar thermal panels and also to optimize the inclination of those (inclination of the solar thermal panels = 72°).

An annual heat production from the solar thermal system of 39.5 MWh/a was calculated.

Figure 15: Solar thermal and pv panels on the south facade

Both, district heating and solar thermal system, store the produced heat in a 7500 liter buffer storage which is located right below the solar thermal panels.

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.

Domestic hot water

The boiler for the domestic hot water has a storage volume of 120 liter and gets supplied with the necessary heat from the buffer storage via the 2-pipe-system. Every apartment is equipped with one boiler.

The small boiler is loaded twice a day from 06:00 a.m. to 07:00 a.m. and from 07:00 p.m. to 08:00 p.m.

In this way the temperatures and therefore the heat losses of the 2-pipe-system can be reduced because of the lower flow temperature of the heating system compared to the flow temperature for the domestic hot water preparation.

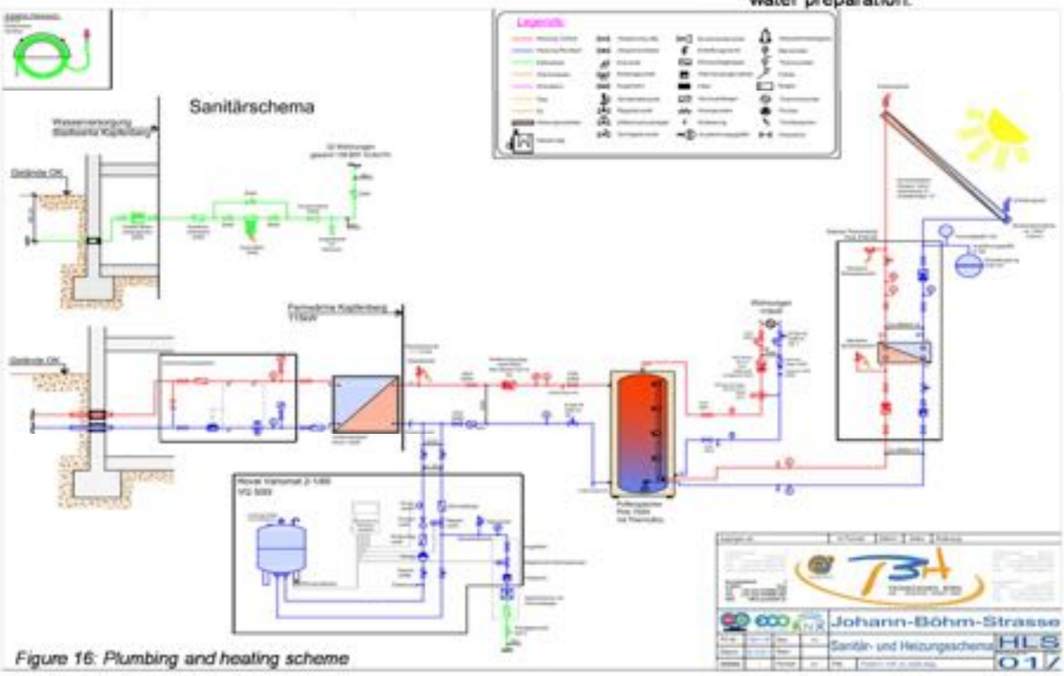


Figure 16: Plumbing and heating scheme

Ventilation

A new mechanical ventilation system with heat recovery is installed (heat recover efficiency =65% / SFP= 0.45 Wh/m³).

The ventilation unit is positioned on the flat roof and the existing shafts of the building are used for the ventilation ducts.

An additional benefit of using these existing shafts are the short ventilation ducts which result thereof.

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 switch individually.

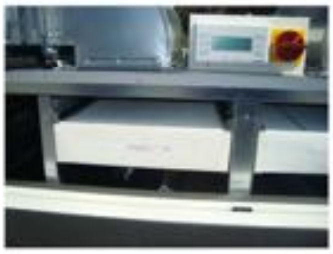


Figure 17: view into the mechanical ventilation unit

Photovoltaic

Photovoltaic panels with a size of 550 m² (80 kWp) are installed on the roof on an extra mounted scaffold which has the form of a wing.

Additionally 80 m² (12 kWp) photovoltaic panels are installed on the south façade next to the solar thermal panels.

total, the calculated annual energy production of the 630 m² (92 kWp) photovoltaic panels is about 80 MWh/a.

Figure 18: mounting of the photovoltaic panels on the roof

Cooling

A cooling system is not necessary in this region and therefore not considered.

Residential buildings in Austria in general should be designed in a way that no active cooling is required.

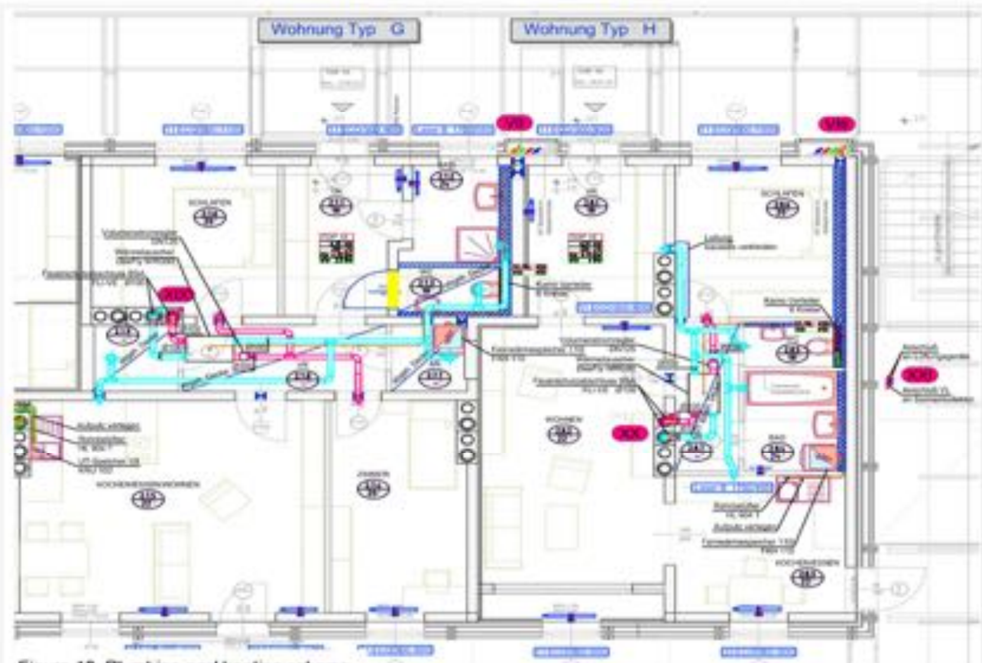


Figure 19: Plumbing and heating scheme

Integrated Building Performance

Ecological/Environmental sustainability

The environmental impacts of the different materials of the prefabricated module were calculated and the parameters "Total Primary Energy (CED)" in MJ/m²a, the "Non-renewable Primary Energy (NRE)" in MJ/m²a and the "Global Warming Potential (GWP)" in $kgCO_{2\text{-}Eq}/m^2a$ were analysed. The result of this analysis is shown in Figure 20.

The wood-metal frame of the windows which are already integrated in the prefabricated façade modules has the biggest influence on the environment. In all three parameters this window frame has the largest share among all.

Other important influencing materials are the 3-layer timber board (CED), the expanses polystyrene (NRE), the Rockwool (NRE) and the Fibre-cement slab (GWP).

Improvements of the total environmental impact would be most likely possible modifying these materials.

Economical sustainability

A first assessment of LCC showed that the costs of the facade modules over the life cycle in comparison to thermal insulation composite systems are significantly higher. With a sensitivity analyses it was tried to analyse the effects and interactions of the chosen systems variables on the LCC over the period under consideration.

Five scenarios have been evaluated and following aspects have been modified:

- increase of energy prices
- power of the PV module
- decrease of construction costs
- combination of the mentioned aspects

Sociocultural sustain-ability

- Thermal comfort in winter and summer: higher supply air temperatures due to the mech. ventilation system; high surface temperatures because of low u-values of the roof, façade and windows
- Indoor hygiene: CO_2 concentration is kept low, mech. ventilation system ensures the required air change rate
  → improved indoor climate
- acoustical comfort: new and better windows result in a better sound insulation to the outside
  → noise sensitivity within the building changes
- Visual improvements: new technologies and materials are used
  → residents feel certain pride
- Barrier-free access to the building is now possible due to the elevator and the pergola
- Efficient usage of the existing area: e.g. ducts of the building services installed in the façade
  → creates more space inside

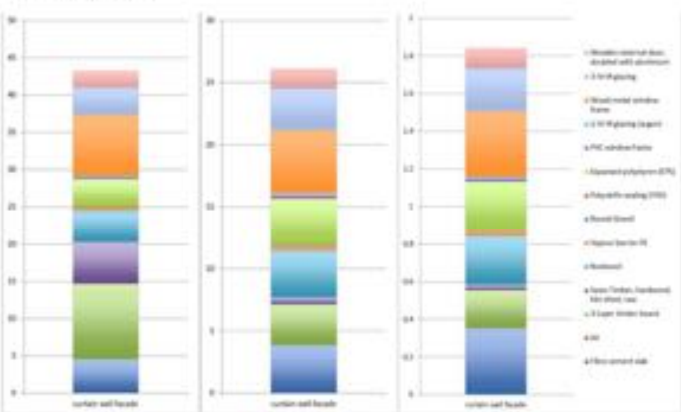


Figure 20: environmental impact of the different materials of the prefabricated façade module

Ecological/Environmental Sustainability

Global Warming Potential [kg $CO_{2\text{-}eq}/m^2a$] 1.84

Total Primary Energy [MJ/m²a] 43.23

Non-renewable Energy [MJ/m²a] 26.11

8

Integrated Building Performance - Construction sustainability

Construction process

Because of detachable joining technologies the façade elements are easy to remove both for maintenance and demolition. Some floor constructions show inseparable connections because of the occurrence of certain components. As example the floor screed and the glued hardwood floor can be mentioned. Because of the indissoluble joining technique a dismantling of the hardwood floor is not possible without destroying the device layer beneath.

These aspects reflect discredit on the technical sustainability regarding separability between elements.

Building material

Regarding the basic requirement 7 of the Construction Products Regulation which became effective on July 1st, 2013 the basic façade element and the exterior wall are analysed due to their recyclability. Every single device layer was evaluated to its possibility to be returned to the cycle of material.

The construction for the façade elements is primarily made of wood, mineral wool acts as insulation in between. Both can be recycled, the wood probably even reused, if the separation was varietal. The sealing (including wind sealing) are PE-foils and thermally recyclable just as the OSB boards. The fibre cement boards can be seen as a weak point, because their recyclability is not state of the art at the moment. All the other materials, such as the concrete, the interior and exterior plaster can be recycled as well. The plasterboards can be seen as weak point because it has to be landfilled.

All of these assumptions are based on a variety separation of the individual component layers.

Special aspects of sustainability in the construction

The replacement of more short-living component layers without destroying the more long-living components is an aspect that has to be considered. During the construction or renovation phase it is possible to integrate predetermined breaking points.

The construction façade shows a special aspect of sustainability regarding separability and dismantling. The new insulation elements were fixed on the existing building where the old exterior plaster hasn't been removed. This plaster can now be seen as a predetermined breaking point between the wall and the insulation. While removing the insulation the wall cannot be destroyed because the exterior plaster acts as a protective layer.

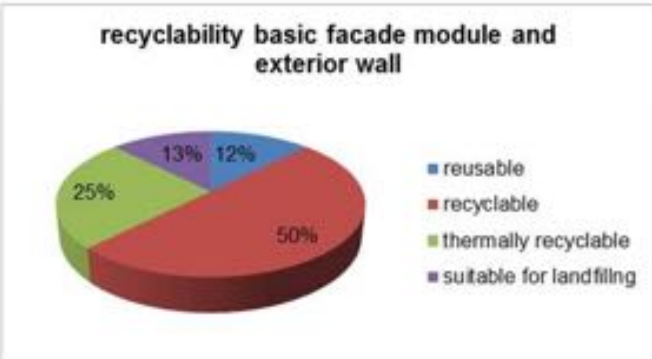


Figure 21: recyclability of device layers in the basic façade module and wall

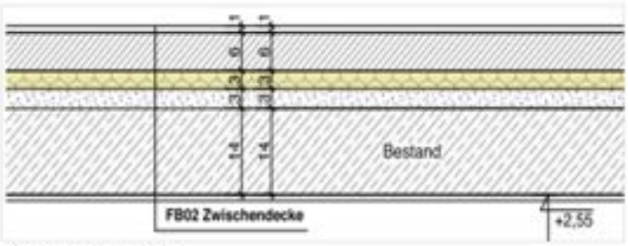


Figure 22: detail ceiling

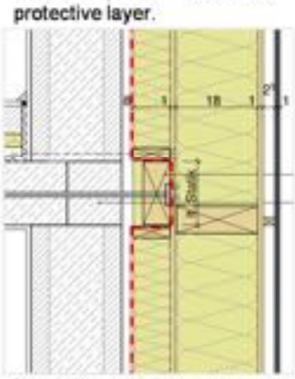


Figure 23: construction detail wall

Performance Data

Monitoring system

The monitoring system at the Austrian demonstration project in Kapfenberg includes following parameters:

- Total energy consumption of the building (heat and electricity)
- Delivered energy from the district heating
- Delivered energy from the solar thermal system
- Detailed monitoring of the system statuses of the heating and mechanical ventilation system:
  - Temperatures of the solar thermal system
  - Heat storage temperatures
  - Temperature, humidity and CO_2 concentration of the exhaust air and the supply air
  - Air velocity of the exhaust air and the supply air
- Comfort parameters: room air temperature, relative humidity and CO_2 concentration in the apartments

The display of the electrical energy consumption is separated into following areas:

- Total electricity consumption
- Separated monitoring of:
  - Mechanical ventilation system
  - Heat pump
  - Building services
  - Common areas (e.g. lighting)
  - Elevator
  - Domestic electricity
- Energy production by PV-modules

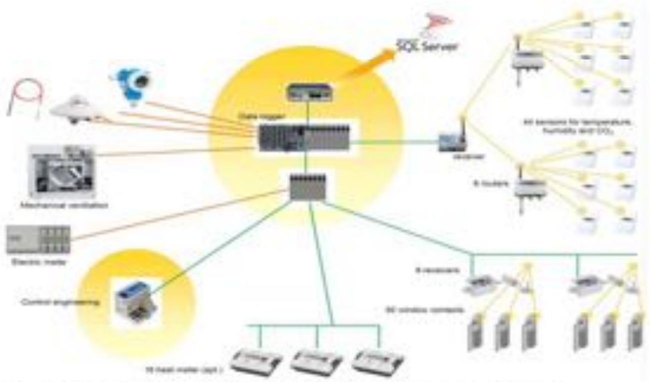


Figure 24: Measuring system at the residential building in Kapfenberg

In one apartment detailed measurements of the domestic electricity consumption are carried out to analyze the potentials for savings in this area. Thereby the electricity consumption of the lighting in the living room/bedroom, the sector EDP/consumer electronics, the electricity consumption of the washing machine and the electricity consumption in the kitchen, such as dishwasher (white goods), are monitored separately.

Additionally climate data like global radiation, ambient temperature and ambient humidity are also measured.

Energy consumption

The detailed monitoring of the building was started in September 2013.

Figure 25 shows the measured thermal energy consumption for heating and domestic hot water preparation.

The analysis of the results shows i.a. that the average thermal energy consumption for domestic hot water in Dec. and Jan. is nearly as high as the thermal energy consumption for heating. The domestic hot water preparation is therefore an energy consumer which can´t be neglected in high performance buildings.

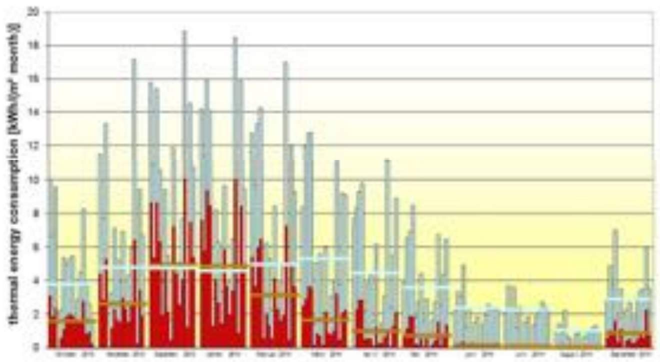


Figure 25: Measured thermal energy consumption for heating and domestic hot water preparation

Improvements & Co-benefits

Besides the reduction of the energy demand and the CO2 emissions, the renovation of the building implicates further improvements and co-benefits:

- The renovation of the building increases the pride/prestige and the reputation of the building and of the residents by integrating all renovation measures in an overall architectural design process.
- The thermal insulation of the building envelope and the new windows with an external shading device bring following benefits:
  - Higher inner-surface temperatures in winter are possible which increase the thermal living comfort for the residents.
  - The new and airtight windows improve the thermal comfort on the one hand and the noise protection to the outside on the other hand.
  - Reduced solar inputs the warm periods of the year as a result of the installation of an external shading device increase also the living comfort in the apartments.
- The installation of the mechanical ventilation system with heat recovery (MVHR) brings following improvements and benefits:
  - The heat recovery reduces the infiltration heat losses and therefore the energy demand of the building.
  - 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 the MVHR system reduces the condensation and mold formation
- The renewal of the heating system and of the hot water preparation results in following improvements:
  - Improved operational comfort by centralized and automatically controlled heating and hot water systems.
  - Reduction of the CO_2-emissions and of the primary energy demand by using district heating (largely supplied with waste heat) and heat from the solar thermal system.
- The renewable energy generation on-site 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 the overall architectural design of the renovation.
  - New functional area for the residents is available.
  - Improved thermal quality of the building envelope by reducing the 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.

Package	CO-BENEFITS	Thermal Comfort	Natural Lighting	Air Quality	Building Physics	Internal Noise	External Noise	Ease of Use / Control by User	Reduced Exposure to Energy Price Fluctuations	Aesthetics	Useful Living Area	Pride / Prestige	Ease of Installation / Reduced Annoyance	Feeling of easyness to sell or rent
Refer. Package	Replacement of heating system	P						P					N	
	Solar thermal systems													
	Photovoltaic systems													
Renovation Package 1	Windows replacement	P				N	P							
	Insulation of entire building envelope	P			P				P	P		P		
	External shading	P												
	Replacement of heating system	P						P					N	
	Solar thermal systems													
	Photovoltaic systems													
Renovation Package 2	Windows replacement	P				N	P							
	Insulation of entire building envelope	P			P				P	P		P		
	External shading	P												
	Replacement of heating system	P						P					N	
	MVHR systems	P		P	P								N	
	Solar thermal systems													
	Photovoltaic systems													
Renovation Package 3	Windows replacement	P				N	P							
	Insulation of entire building envelope	P			P				P	P		P		
	External shading	P												
	Balconies & loggias	P			P					P	P	P		
	Replacement of heating system	P						P					P	
	MVHR systems	P		P	P								P	
	Solar thermal systems								P	P		P		
	Photovoltaic systems								P	P		P		

Legend: P - Positive Effect; N - Negative Effect

11

Methodology

In the frame of the Detailed Case Studies three different renovation packages are described, analyzed and assessed. Those three renovation packages range from the minimum required renovation measures to the high thermal insulation of the building envelope right up to the high performance renovation of the building, including renewable energy production on-site.

Renovation package 1

The objective of renovation package 1 is to fulfill only the minimum requirements of the Austrian OIB guideline 6 .

This minimum requirements concern the u-values of the components, the heating energy demand and the final energy demand.

In this renovation package 1 neither a mechanical ventilation nor a solar thermal system nor a photovoltaic system are included. Renovation measures include 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 to a centralized supply by the district heating.

Renovation package 2

In renovation package 2 the building has the same u-values as the real renovated building in renovation package 3.

The difference between those renovation packages is that in renovation package 2 the u-values are achieved by a conventional composite heat insulation system instead of a prefabricated façade system.

Additionally in renovation package 2 no mechanical ventilation system is installed. Furthermore no solar thermal system and no photovoltaic system are included. This means that renovation package 2 does not have active energy production from renewable energy sources on-site.

As in renovation package 1 the renovation measures only include the thermal insulation of the roof and the façade, new windows with an external shading system and the renewal of the heating and domestic hot water system.

Renovation package 3

Renovation package 3 represents the actually executed renovation of the demonstration building and hence the mentioned high performance renovation with renewable energy production on-site.

The executed renovation of the building includes the thermal insulation of the façade by prefabricated wood modules, the thermal insulation of the roof, the mounting of new triple-glazed windows (with an external shading device) which are already integrated in the prefabricated façade modules, the installation of a new mechanical ventilation system with heat recovery, the renewal of the heating and domestic hot water system as well as the installation of a solar thermal system for the heating and domestic hot water preparation and a photovoltaic system for the electricity production on-site.

		reference case	alternative scenario I	alternative scenario II	chosen renovation
justification and statement	strengths, co-benefits	- replacement of the heating systems improves the ease of use for the residents	- replacement of the heating systems improves the ease of use for the residents - improvement of thermal comfort; - reduction of energy demand of the building	- improvement of ease of use for the residents - improvement of thermal comfort; - reduction of energy demand of the building - improvement of air quality by MVHR	- improvement of ease of use for the residents - improvement of thermal comfort; - reduction of energy demand of the building - improvement of air quality by MVHR; - renewable energy generation on site - improved living quality (no layouts, barrier-free access, ...)
	weaknesses, additional costs	- no reduction of the energy demand of the building; - no improvement of the thermal comfort inside the apartments; - no improvement of the living quality (no change of layouts, barrier-free access, ...) - "conventional" installation of heating system	- no improvement of the living quality (no change of layouts, barrier-free access, ...) - "conventional" installation of heating system	- no improvement of the living quality (no change of layouts, barrier-free access, ...) - "conventional" installation of heating system and mechanical ventilation system	- additional capital costs for the prefabricated facade system - additional capital costs for the energy generation on-site
Conclusions	**Conclusions of comparison; why was final solution chosen, how does it relate to refrence case and alternative scenarios?**	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 final solution achieves miscellaneous co-benefits and positive side evvects which represent an important added value compared to the reference case and to the other renovation packages.			

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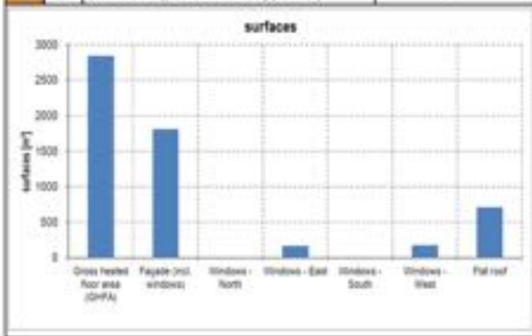
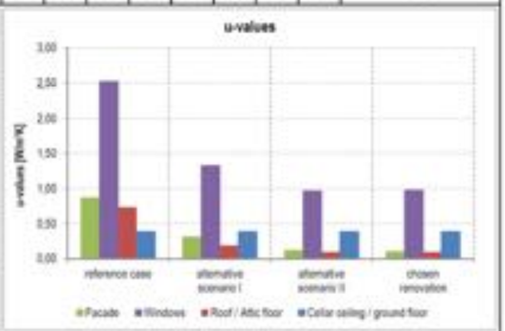
Comparison of renovation measures

			reference case	alternative scenario I				alternative scenario II				chosen renovation
renovation measures	Building envelope	roof	-	20 cm EPS				38 cm EPS				30 cm EPS
		facade	-	8 cm EPS				28 cm EPS				prefabricated wooden facade modules with total insulation of 24 cm
		glazing/frame	-	new double-glazed thermally insulated windows with external shading device				new triple-glazed thermally insulated windows with external shading device				new triple-glazed thermally insulated windows with external shading device
		floor	-	-				-				-
	BTS	Heating	new oil heating system	new centralized heating system				new centralized heating system				new centralized heating system based on district heating and solar thermal on-site
		DHW	new oil heating system	with centralized domestic hot water preparation combined with heating				with centralized domestic hot water preparation combined with heating				with centralized domestic hot water preparation combined with heating
		Cooling	-	-	-	-	-	-	-	-	-	-
		Auxiliaries	-	-	-	-	-	-	-	-	-	-
		Lighting	-	-	-	-	-	-	-	-	-	-
		Ventilation	-	-	-	-	-	new mechanical ventilation system with heat recovery				new mechanical ventilation system with heat recovery
		(Common appliances)	-	-	-	-	-	-	-	-	-	one appartement equipped with energy efficient equipment
characteristic values	heating	Calculated energy demand for heating [kWh/m²a]	150,97	58,89				33,45				33,45
		Energy carrier of heating system	oil	oil	natural gas	biomass	district heating	oil	natural gas	biomass	district heating	district heating
		Conversion efficiency of heating system	91%	91%	91%	85%	95%	91%	91%	85%	95%	95%
		2nd energy carrier of heating system	-	-	-	-	-	-	-	-	-	solar thermal
		2nd conversion efficiency of heating system	-	-	-	-	-	-	-	-	-	23%
		Share of 2nd energy carrier on heating energy demand	-	-	-	-	-	-	-	-	-	32%
	DHW	Calculated energy demand for DHW [kWh/m²a]	16,83	22,06				22,06				22,06
		Energy carrier of hot water system	oil	oil	natural gas	biomass	district heating	oil	natural gas	biomass	district heating	solar thermal
		Conversion efficiency of hot water system	91%	95%	95%	95%	95%	95%	95%	95%	95%	23%
		2nd energy carrier of hot water system	-	-	-	-	-	-	-	-	-	district heating
		2nd conversion efficiency of hot water system	-	-	-	-	-	-	-	-	-	88%
		Share of 2nd energy carrier on hot water energy demand	-	-	-	-	-	-	-	-	-	38%
	cool.	Calculated energy demand for cooling [kWh/m²a]	-	-	-	-	-	-	-	-	-	-





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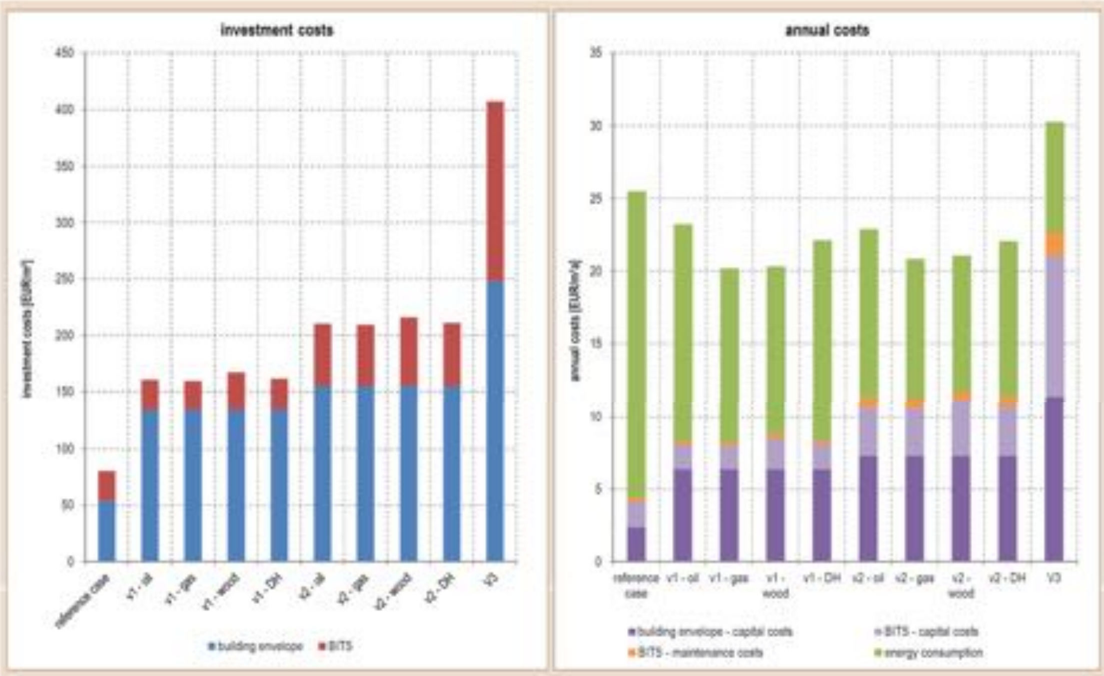
Comparison of renovation measures - LCC



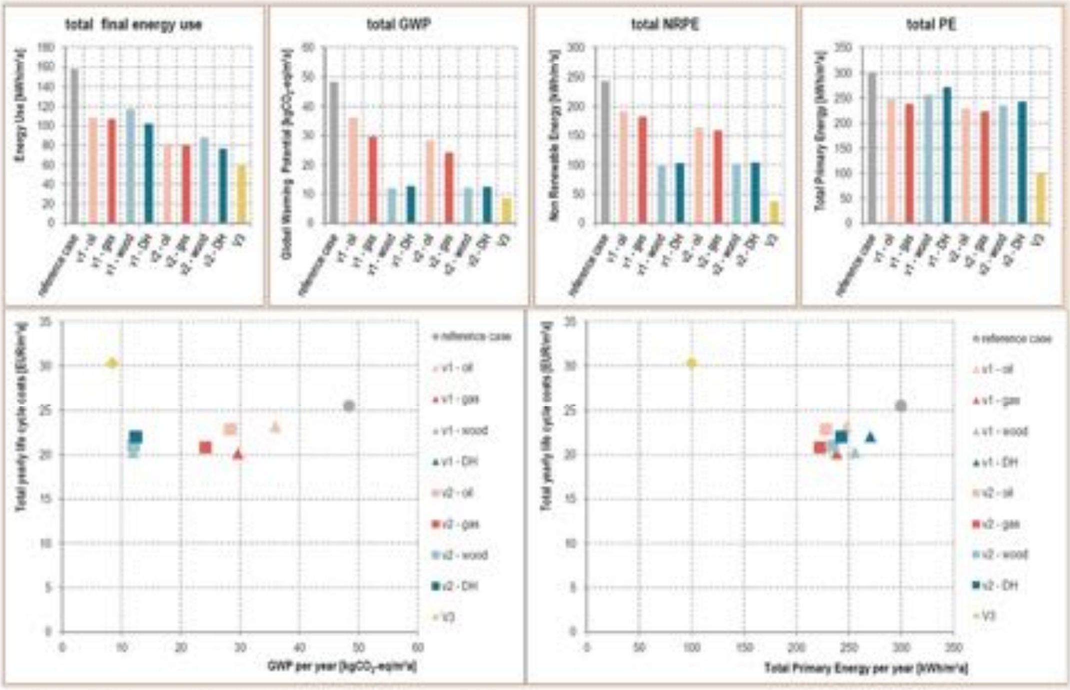
Description and analysis of the LCC results

The reference case shows the lowest investment costs, with a value of about 80 €/m². This is due to the fact that no renovation measures regarding the building envelope are included and only the existing heating system has been replaced by a new centralized oil heating system.
The total investment costs of renovation package v1 are about 150 €/m². The results show that the influence of the energy source for heating and domestic hot water is very small.
The results of renovation package v2 show that the additional insulation of the building envelope (compared to renovation package v1) only increases the investment costs slightly, the additional mechanical ventilation system however almost doubles the investment costs for the BITS.
Renovation package v3 achieves the highest investment costs for the building envelope due to the new developed prefabricated façade elements but also the highest investment costs for BITS due to the mechanical ventilation system and the energy generation on-site (solar thermal and photovoltaic installation).

Looking at the annual costs it´s obvious that the reference case achieves the lowest capital costs, low maintenance costs but by far the highest costs due to the energy consumption of the building.
The total annual costs of renovation packages v1 and v2 are quite similar. It becomes apparent that the influence of the energy supply for heating and domestic hot water is higher than the thermal quality of the building envelope. Renovation package v2 shows higher maintenance costs compared to renovation package v1 but in relation to the capital costs and the costs due to the energy consumption of the building these costs are almost negligible.

Renovation package v3 has the highest investment costs due to the implemented innovations and also the highest annual costs. These high annual costs are a result of high capital costs of the prefabricated façade system, the energy generation on-site and also the heating system (solar thermal system).

Comparison of renovation measures - LCIA



Description and analysis of the LCIA results

Looking at the results it is obvious that the reference case has the highest Global Warming Potential with a value of about 48 $kgCO_2$-Eq/m²a. 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 11-13 $kgCO_2$-Eq/m²a. 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 significantly lower than of all the other renovation packages with a value of about 8 $kgCO_2$-Eq/m²a.

The detailed analysis of the calculation results shows that the total Primary Energy Demand of the reference case is the highest with a value of about 300 kWh/m²a. The PED of the renovation packages v1 and v2 ranges between 220 kWh/m²a and 270 kWh/m²a. The best result regarding the PED is achieved by renovation package v3. The Primary Energy Demand of the realized renovation is about 100 kWh/m²a. This is a reduction compared to the reference case of nearly 70% and compared to the other renovation packages of about 55-65%.

Considering only the non renewable part of the Primary Energy Demand leads to quite similar results as it is observable at the Global Warming Potential. The reference case has the highest value, the renovation package v3 achieves the best result and the renewable (biomass and district heating) based variants of renovation packages v1 and v2 achieve better results than those renovation packages where the heating and domestic hot water supply is based on fossil fuels (oil and natural gas). The values range between about 240 kWh/m²a (reference case) and about 38 kWh/m²a (renovation package v3), which is reduction of nearly 85%.

Summary and conclusion

Before the renovation the building was exemplary for the residential buildings of the 1960´s: high energy consumption and therefore also high energy costs as well as low thermal comfort characterized the existing building.

Additionally the apartments were too small for today´s requirements and needs, the access to the building was not barrier-free possible and the building was in general run down.

A high performance renovation of the building, including the improvement of the energy efficiency, the change of the design and the adaption to the modern way of living was absolutely necessary.

Furthermore a plus-energy building, which produces more energy than it needs in the same period, should be achieved by integrating solar thermal and photovoltaic systems in the energy renovation concept.

Even though there are no complete monitoring results to prove the targeted plus energy goal, the realized renovation of the building definitely was a success.

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

Especially the renovation of the building with prefabricated façade elements was certainly the right decision. In this way the construction time at the construction site could be reduced and the renovation works could be accomplished independently of the weather conditions.

The first feedback of the tenants was also quite good: The expectations of the tenants to the retrofit were generally answered. 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 preparation.

Practical experience

The financing of the renovation was kind of a barrier because due to governmental regulations it was not possible to increase the rental prices for the apartments excessively. So other funding and financing solutions were necessary to realize the renovation.

Additionally, the renovation works inside the building such as the change of the layout made a resettlement of the residents necessary. Due to the fact that no apartments were available in Kapfenberg at this time, the renovation of the building in two construction phases was the only possibility to guarantee the residents an apartment during the renovation period. (This was only possible because not all apartments of the existing building were rented at that time.)

References

[all AEE INTEC]

Figure 26: Renovated building (north-east elevation)

Appendix 2

Elementary School Kamínky 5, Brno

Owner: Statutory city of Brno

Architect: MENHIR projekt s.r.o.

Energy concept: Borough Office Brno - Nový Lískovec and MENHIR project s.r.o.

Report: BUT – Faculty of Civil Engineering and Borough Office Brno – Nový Lískovec

Location: Brno, CZE

Date: November 2014

Key technologies
- ETICS
- District heating
- Photovoltaics

View of existing (small picture) and the renovated building (large picture)

1

Background

Figure 1: School's main block viewed from the street. [1]

Buildings of Elementary School Kamínky 5 were constructed in 1987. The school consist of 3 blocks connected via multi-storey corridors. The main block (Block A) where the classrooms and offices are located, kitchen and cafeteria block (Block B) and gymnasium (Block C).

The maximum capacity of the school is approx. 380 students and 44 staff members. Net heated area of school buildings is 7296 m².

Superstructure of the buildings is made of prefabricated reinforced concrete frame MS-OB with basic length module 6.0 m. Walls are made mostly of 300 mm thick ceramic panels. Part of the walls is built using aerated concrete blocks. Mean average U-value of W/m²K. All buildings have flat roof. Superstructure of the roof is made of timber and steel trusses and reinforced concrete panels. The roof was insulated by 50 mm of EPS on a sloping layer of gravel. Bituminous sheets with mineral granules granules (and Ti-Zn flashing) were used as a covering and waterproofing layer of the roof. U-value of the roof before renovation was 0.66 W/m²K.

Doors and windows were wooden, steel or aluminum, using single or double glazing. Mean average U-value of walls before renovation was 2.35 W/m²K.

Main goals of the renovation during 2009 and 2010 were increasing the quality of the indoor environment (and adaptation to modern requirements and teaching methods), and reducing the overall energy consumption of the school by renovating the school according to low-energy standards.

Figure 2: Ground plan of the main block's second floor. Red – classrooms and offices; blue – toilets; green – corridors and staircases.

Figure 3: Atrium in the centre of the main block. [1]

Project data of building before renovation

Altitude	312.6 m
Heating degree days	3712 Kd
Cooling degree days	0 Kd
Year of construction	1987
Gross heated floor area	9711 m²
Specific heating energy need excl. hot water	129.06 kWh/(m²a)
Specific cooling energy need	0 kWh/(m²·a)
Specific hot water energy need	8.49 kWh/(m²·a)
Type of energy carrier for heating hot water – district heating network	
Type of energy carrier for hot water hot water – district heating network	
Specific heating energy consumption (excl. hot water)	107.23 kWh/(m²·a)
Specific hot water energy consumption	14.76 kWh/(m²·a)
Installed heating capacity	0 kW
Specific electricity consumption (excl. hot water and heating)	11.26 kWh/(m²·a)
Energy costs	2485826 CZK/a

2

Renovation concept

Figure 4: Present panoramic view of the renovated main block.

Design data for renovated building

Year of renovation 2009 - 2010

Gross heated floor area 9909 m²

Specific heating energy need excl. hot water 376.67 kWh/(m²a)

Specific cooling energy need 0 kWh/(m²·a)

Specific hot water energy need 8.49 kWh/(m²·a)

Type of energy carrier for heating hot water – district heating network

Type of energy carrier for hot water hot water – district heating network

Specific heating energy consumption (excl. hot water) 35.37 kWh/(m²·a)

Specific hot water energy consumption 13.95 kWh/(m²·a)

Installed heating capacity 0 kW

Specific electricity consumption (excl. hot water and heating) 11.42 kWh/(m²·a)

Energy costs 1238189 €/a

Other additional costs - €/a

The main goal of the renovation was significantly reducing the energy consumption of the school. Therefore the Borough Office in Brno – Nový Lískovec asked design company (MENHIR project s. r. o.) to prepare designs for low-energy renovation. The superstructure of the buildings was in good condition therefore the renovation consisted mostly of reducing the energy losses through the building envelope and improving the efficiency of used equipment:

Additional thermal insulation (ETICS) made of expanded (EPS) or extruded (XPS) polystyrene or mineral wool was installed on the walls and roof. Also new waterproofing was installed on the roof. New U-values of the building's envelope vary between ≤ 0.16 W/m²K

Figure 5: Façade of Block B right after the renovation. [2]

(roof) and ≤ 0.20 W/m²K (walls).

Most of the doors and windows in the building's envelope were replaced. New doors and windows have plastic or aluminum frames with double and triple glazing, with U-value ≤ 1.70 W/m²K. Also a new exterior shading system was installed on clasrooms' windows to improve the user's (students and staff) comfort during sunny weather.

Figure 6: Exterior sunblinds installed on the windows of all classrooms. [2]

A small photovoltaic power plant installed on the roof was considered in one variant of the designs, thanks to government subsidies for ecological power generation. It is owned by private investor who has rented the school's roof for this purpose. It consits of 324 photovoltaic panels with installed output 66.42 kWp was approved. It should produce approx 72.5 MWh annually.

Renovation design details

Facade Solutions

To comply with low-energy requirements, external walls are insulated using contact thermal insulation (ETICS) covered by a thin-layer acrylic plaster. Insulation panels are anchored using plastic anchors with steel screw.

Two insulation materials are used on the walls – Orsil EPS 70 F and mineral wool Orsil TF – due to the fire safety requirements. The thickness of added thermal insulation layer is the same for both materials – 160 mm.

The plinth is insulated using 60 mm thick panels of XPS. These panels reach at least 300 mm below ground level all over the school buildings.

The walls adjacent to ground or non-heated areas are insulated by 100 mm thick panels of EPS.

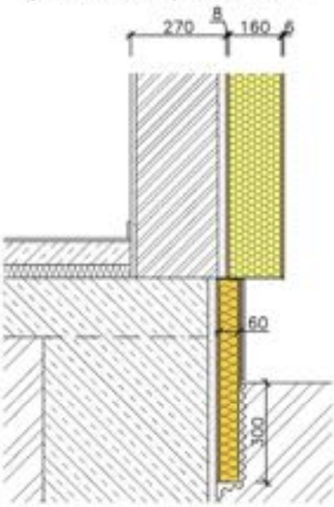


Figure 7: Base of the exterior wall after renovation. Added EPS thermal insulation (beige) is covered by acrylic plaster. The plinth is insulated by XPS (orange), covered by ceramic tiles.

Roof Solutions

Based on the probes into the existing flat roofs the designers decided to leave all the installed materials in place. On top of the existing roof were added two layers of EPS (100 mm and 80 m thick) and a new waterproofing/covering layer made of SBS modified bituminous sheets with mineral granules to improve their durability.

The photovoltaic power plant is built on the part of Block A's roof. Its 324 panels are oriented to the south (under 30° incline). Each panel has maximum output of 205 Wp.

Figure 8: Aerial view of the main block's roof with installed PV panels. [3]

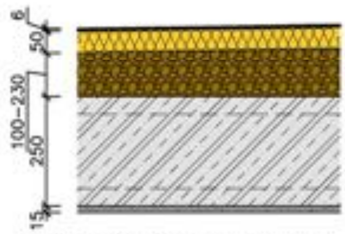


Figure 9: Original roof's composition. Reinforced concrete panels (grey) covered by gravel sloping layer (brown) and EPS thermal insulation (beige). Waterproofing and covering layer was made of bituminous sheets (black) with mineral granules.

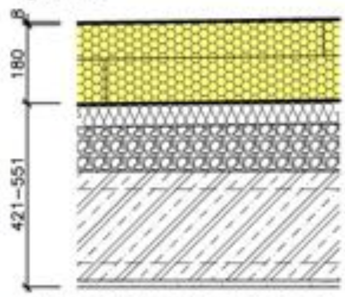


Figure 10: Renovation of the roof. Additional EPS thermal insulation (beige) and modified (SBS) bituminous sheets (black) with mineral granules.

Figure 11: Photovoltaic power plant on the roof of the school's main block. [3]

Ground floor solution

Due to the financial issues the floor in contact with the ground was not renovated. Instead the ceiling above the ground floor was insulated using 80 mm thick panels of EPS 70 F.

Window solution

New windows have plastic 6-chamber frame and double or triple glazing. New shading system is installed in front of the windows to improve the inner conditions during sunny weather.

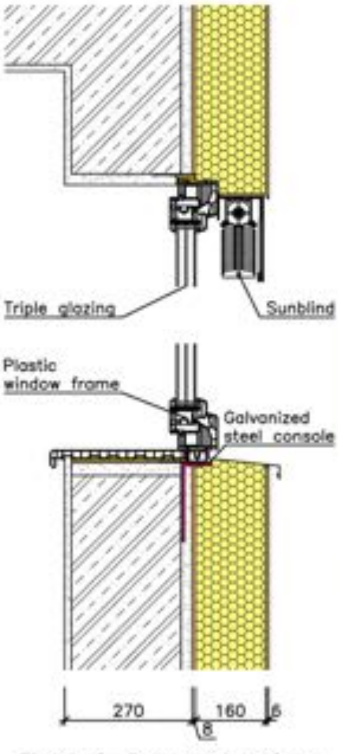


Figure 12: Cross section of the exterior wall and window. Window frame installed on galvanized steel consoles (red) protruding to new EPS thermal insulation layer (beige).

It is made of metal exterior sun blinds remotely controlled from individual classrooms or offices.

Plastic panels with EPS thermal insulation are used to fill-in the place where the interior walls(or columns) are connected to the façade to visually unify the look of the rows of the windows. Due to the unevenness of the original exterior wall part of the windows had to be installed on steel consoles protruding to the new thermal insulation layer.

Figure 13: Original state: Row of windows separated by particle-board panels where interior walls connect to the façade. [2]

Figure 14: Row of windows (2nd floor) after renovation separated by colored plastic panels.

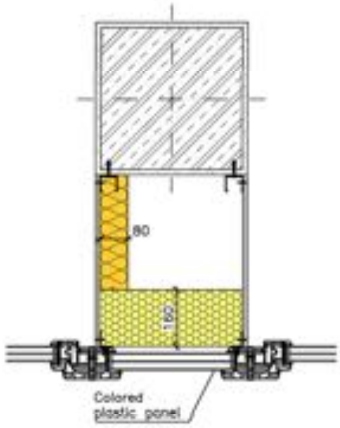


Figure 15: Detail of installation of plastic panel in front of the load/bearing reinforced concrete column. EPS thermal insulation (beige) is installed from the interior side. Acoustic insulation made of mineral wool (orange) is also visible.

New entrance doors have aluminum frames and triple glazing.

Figure 16: Original main entrance of the school. [2]

Figure 17: Main entrance of the school after renovation. Addition of (not heated) anteroom reduced heat losses through the entrance doors.

Heating

The school is heated by district heating from a nearby (gas burning) heating plant. The heating medium (water) is supplied by 4-pipe distribution system, which also supplies nearby apartment buildings.

New compact heat exchanger station is located on the ground floor of Block A. Steel heating pipes lead from the exchanger to the distributor. There they split into 4 separate branches with equithermal regulation. During the renovation most of the heating pipes were deemed to be in good condition. Therefore they were just cleansed of scale using chemical cleaning agents and left in place. Due to the changes in the overall design, new heating pipes had to be installed too. To minimize the heat losses, the heating pipes are insulated by 20 mm of MIRELON foam (pipes with inside diameter less than 40 mm) or 40 mm of mineral wool with aluminum foil cover (larger pipes). All original fittings and valves were replaced by new (adjustable) ones.

Originally the school was heated using 118 cast-iron and 170 other (mostly steel) radiators. Most of the cast-iron radiators were deemed to be in good condition, cleansed, repaired and reinstalled. On the other hand other (steel) radiators were found to be at the end of their service life, malfunctioning or damaged. They were removed and replaced by new cast-iron radiators (and steel-stone heating desks in the changing rooms). Currently the building is heated using 276 (112 original) cast-iron radiators and 8 heating desks. The temperature gradient in the heating system is 75/55° C. The radiators are fitted with thermostatic valves and heads. Heating system's efficiency is 95 %.

Hot water installations

DHW is also prepared centrally in the heat exchanger station.

The pipes are made of steel. During the renovation, only part of the pipes was replaced. They are insulated the same way as the heating pipes. New circulation circuit was added during the renovation to optimize distribution of DHW and minimize the heat losses.

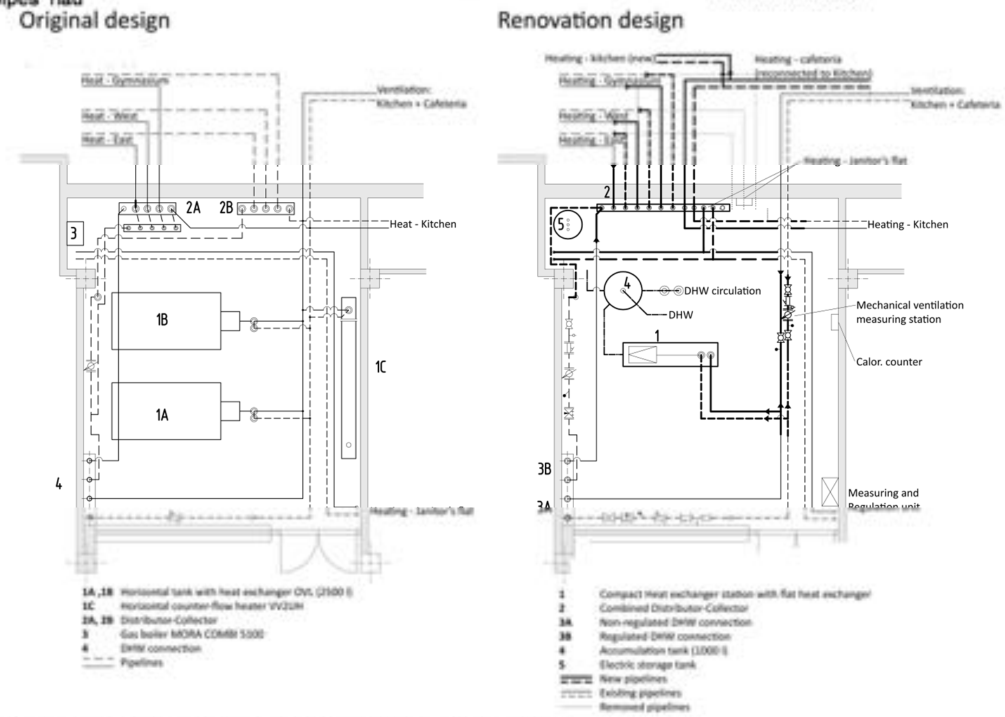


Figure 18: Schema of the boiler room before and after the renovation [1]

Heating system problems

Since 2011 a problem with original steel heating pipes appeared – spreading corrosion. It is most visible around the new fittings and valves. It is probable that it will cause leaks of hot water. It was decided that the heating pipes will be renovated as soon as the funding is ensured.

Ventilation

Air exchange in most of the school (all classrooms, offices and gymnasium) is natural, using windows. The indoor air quality is directly regulated by the users (teachers and staff) according to immediate needs.

Kitchen and cafeteria are mechanically ventilated. The ventilation unit is located in the basement of Block B. During renovation the original system was removed and replaced by new one. New system creates a slight suction to help removing the fumes and vapors. The ventilation unit's maximum output is 15000 m^3 of fresh air per hour – 9000 m^3 for kitchen and 6000 m^3 for cafeteria (60 m^3 per person). This means almost 20-fold air exchange. The maximum output is used only during peaks approx. between 9 am and 13 am, when the meals are prepared and distributed. During the rest of the day (approx. between 6 am to 9 am and 13 am to 15 am) the output is reduced to 50 %. The system is disabled at night. The system is regulated automatically based on timers and thermal sensors. Manual control is also possible from the office of the Head of Operations.

Ventilation of storage rooms in the basement of Block B requires small ventilation unit with maximum output (suction) 500 m^3 per hour. This unit is regulated by thermal and humidity sensors.

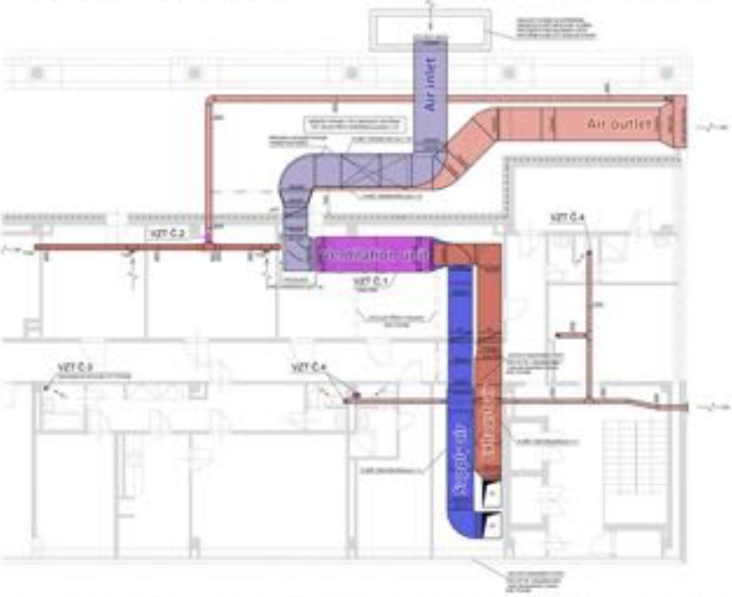


Figure 19: part of the ground plan of the mechanical ventilation in the basement of kitchen and cafeteria block. The ducts are highlighted by colors for better understanding.

Toilets and bathrooms are ventilated by new suction ventilators. These ventilators are operated manually with timers for switching off.

The boiler room is ventilated by an overpressure system consisting of intake and outtake ventilators. The maximum output of the system is 500 m^3 per hour. The system is regulated by thermal sensors. Natural ventilation (using windows) is also possible.

Supplementary ventilators are installed in storage rooms in the school. They are operated manually only when necessary, otherwise the ventilation of these rooms is natural.

All ducts are made of galvanized steel with plastic and steel inlets and outlets. The ducts have rubber silencers to reduce the noise volumes. Maximum noise volume does not exceed 50 dB.

Cooling

There are no cooling systems installed in the school. Only a shading system (external sunblinds) is used to improve the inner climate during hot weather.

Future development

Natural ventilation of classes and gymnasium is sufficient during most of the year. But during hot summer days, when there is only little or no wind, the indoor conditions can deteriorate quickly. Especially in classrooms that are exposed to direct sunlight, because using the sunblinds hampers the airflow. Mechanical ventilation system is planned to solve this issue as soon as enough funding is ensured.

Integrated Building Performance

Ecological/Environmental sustainability

From the environmental point of view the most important phase of building's life cycle is the operation phase. Therefore significant improvements in energy consumption and other activities are of great importance for any renovation.

Environmental impacts of all 3 assessed renovation scenarios were calculated in 4 impact categories: Total Primary Energy (TPE) in MJ/m²a, Non-renewable Primary Energy (NRE) in MJ/m²a, Global Warming Potential (GWP) in kg CO_2 equivalent/m²a and Energy Use in MJ/m²a. The overall results can be seen in page 15. Figure 20 shows detailed environmental impacts for the renovation scenarios in one of the assessed impact categories – GWP. It confirms that the greatest share of environmental impacts is caused by the energy consumption. In case of the first scenario energy required for heating is responsible for more than 65 % of overall environmental impacts. With implementation of energy-saving renovation measures this share decreases, but it is still significant – approx. 36 % of overall environmental impacts in the second and third scenario.

Economical sustainability

The renovation of the ageing school was necessary. After a debate the Borough Office ordered the design of renovation to low-energy standards. Priority was given to improvements of energy efficiency.

The LCC analysis that is part of this case study confirmed the benefits this renovation brought. Comparison of the annual operating costs of the school shows 52 % savings between the state before and after renovation.

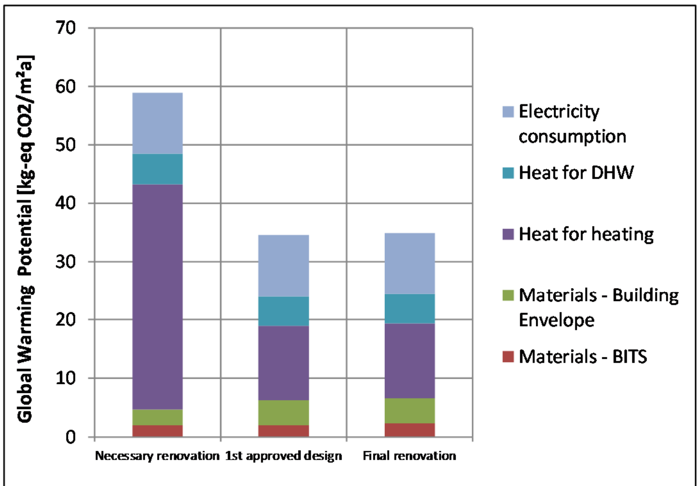


Figure 20: Environmental impacts of the renovation scenarios in GWP category

Socio-cultural sustainability

following contents should be considered:

- Thermal comfort in winter and summer: The insulation of the school's envelope and replacement of windows had positive effect on thermal stability and comfort, especially in winter.
- Indoor hygiene: The indoor hygiene improved slightly thanks to installation of new equipment (e.g. new mechanical ventilation in the cafeteria).
- acoustical comfort: Acoustical comfort improved due to replacement of windows, which reduced the external noise.
- visual comfort: New equipment and façade improved visual perception of the school by staff, pupils and public.
- area efficiency: New technical equipment requires less space which lead to slight increase of free space, especially in facility areas. This makes this equipment more easy to use and maintain.

Ecological/Environmental Sustainability

Global Warming Potential [kg$CO_{2\text{-eq}}$/m²a] 34.9

Total Primary Energy [MJ/m²a] 245.2

Non-renewable Energy [MJ/m²a] 572.0

Integrated Building Performance - Construction sustainability

Construction process

As (even temporary) relocation of the school was impossible, it was crucial to prepare the schedule of the renovation works according to the course of the school year.

The renovation started in June 2009, near the end of the school year. Summer vacation in Czech Republic are 2 months long. In this time the renovation of the technical equipment and replacement of windows had to be finished to allow the regular start of school year on 1st September. During the fall and winter 2009 the rest of the school's envelope was renovated. Thermal insulation (ETICS) was added to all accessible surfaces to reduce the heat losses. Whole renovation was finished by the end of 2010 with renovation of new outdoor sport facilities – playgrounds, running track, etc.

Several changes to the original design occurred during the renovation:

First was the decision to install new windows on the steel consoles protruding into the ETICS. This decision had two reasons. Main reason was unevenness of the original surfaces. Because of this problem some of the windows would have to be placed (at least partially) on the consoles nonetheless. Placing all windows on the consoles unified and simplified their installation. Another reason for installing the windows on the steel consoles was better thermal performance of the building – installation of the windows in the plane of thermal insulation minimizes thermal bridges around the window. Installation of the windows on the steel consoles also has an advantage for future renovations or deconstruction. The consoles can be seen as a "breaking point". Replacing or removing the windows would have almost no impact on the original structure.

Figure 21: Installation of new windows. [1]

Another feature that was implemented during the renovation was an external shading system. Installation of external shading was considered since the beginning of the design works. When additional funds were found during the renovation, it was decided to use them for the external shading.

Photovoltaic power plant is the last system which was not part of the approved design before the start of the construction works. During the construction a private company offered that it will use the school's roof for a photovoltaic installation. As it would be impossible for the municipality to fund the power plant by themselves, they instead agreed to rent the roof to the company for a yearly fee. The power plant is not directly connected to the school – it supplies electricity to the public network. The income from the rent is reinvested in the school.

The changes and additions to the original design almost didn't slow the renovation process. According to the school's director the construction company cooperated very well and every time swiftly adapted the schedule to the current situation.

Building materials

Only common building materials and components (EPS, plastic windows with double or triple glazing, etc.) were used during the renovation. As most of the savings (energy or environmental) are achieved during the use of the building it was decided to use cheaper materials which would ensure higher savings during the use of the renovated school.

Figure 22: To ensure the best possible improvements and overall performance of the school's envelope thermal insulation was installed even on the commonly inaccessible ceiling below ground floor. [1]

No special attention was given to the possible future renovations or deconstruction of added materials and structures, but thanks to the durability of the original reinforced concrete load-bearing structure it is probable that such works would have minimum negative impact on the life span of the whole building. Also all used materials are at least partially recyclable, therefore it would be possible to subsequently use them as secondary raw materials.

Performance Data

Monitoring system

The school is equipped with monitoring systems required by Czech standards and laws. These include:

Measuring of energy (heat) used for heating and DHW.

Measuring of overall water consumption.

Measuring of overall electricity consumption.

Measuring of gas consumption (used only for cooking).

Thermometers for measuring of indoor and outdoor air, which are used mainly for the regulation of the heating system. After renovation the heating system was also equipped with thermostatic valves to improve the regulation of individual radiators.

Measuring and regulation equipment for the heating system. This includes measuring of temperature of water in the system, water flow, etc.

Measuring and regulation equipment for the ventilation system – air flow measuring, thermometers, etc.

All these systems were modernized (mostly replaced) during the renovation.

Energy consumption

The information about energy consumption and costs were taken from direct measurements in school and issued bills. Average values (energy consumption and prices including VAT) were calculated to represent energy consumption before and after the renovation. Periods 2006 to 2008 (state before the renovation) and 2011 to 2013 (state after the renovation) were chosen to calculate these average values.

As can be seen in Figure 23, the most significant improvement in energy consumption is related to heating. Thermal insulation of the school's envelope reduced heating energy consumption by more than 67.0 % - from approx 107.2 kWh/(m²a) to approx 35.3 kWh/(m²a).

DHW consumption was only slightly (5.5 %) reduced by the renovation. This is due to the fact that during the renovation the previously malfunctioning DHW circulation circuit was repaired. This caused increase of DHW consumption and minimized the savings caused by the renovation of the whole system.

Electricity is the only energy whose consumption has risen after the renovation. This is an expectable change, because the electricity consumption of the new equipment is higher – there are new computer measuring and regulatory systems, etc.

Overall the energy consumption after the renovation is 54.4 % lower than before the renovation.

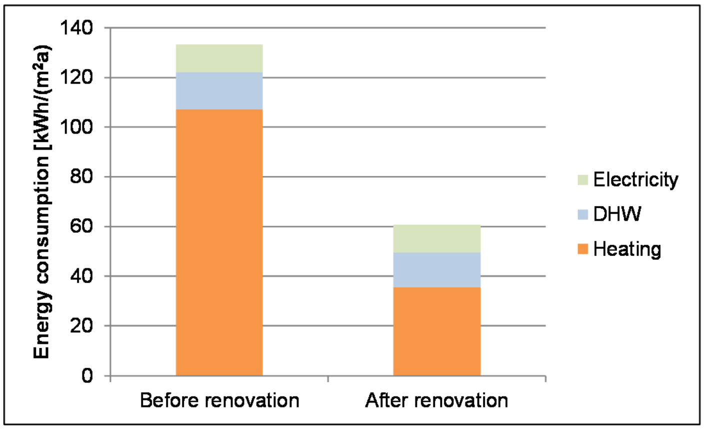


Figure 23: Differences in energy consumption before and after renovation.

Improvements & Co-benefits

Stage	CO-BENEFITS	Thermal Comfort	Natural Lighting	Air Quality	Building Physics	Internal Noise	External Noise	Ease of Use / Control by User	Reduced Exposure to Energy Price Fluctuations	Aesthetics	Useful Living Area	Pride / Prestige	Ease of Installation / Reduced Annoyance	Feeling of easyness to sell or rent
Necessary renovation	Windows replacement	P	P	P	P	P	P	P	P	P		P		P
	Renovation of heating system	P			P			P	P			P	P	P
	Renovation of DHW system	P			P			P	P	P	P	P	P	P
	Renovation of MVHR	P		P	P			P	P	P		P	P	P
1st approved renovation	Windows replacement	P	P	P	P	P	P	P	P	P		P		P
	Insulation of entire building envelope	P		N	P	P	P		P	P	P	P		P
	Renovation of heating system	P			P			P	P			P	P	P
	Renovation of DHW system	P			P			P	P	P	P	P	P	P
	Renovation of MVHR	P		P	P			P	P	P		P	P	P
Finished renovation	Windows replacement	P	P	P	P	P	P	P	P	P		P		P
	Insulation of entire building envelope	P		N	P	P	P		P	P	P	P		P
	External shading	P		N	P		P	P	P	P		P	P	P
	Renovation of heating system	P			P			P	P			P	P	P
	Renovation of DHW system	P			P			P	P	P	P	P	P	P
	Renovation of MVHR	P		P	P			P	P	P		P	P	P
	Photovoltaic systems	P			P				P	N	N	P		P

Legend: P - Positive Effect; N - Negative Effect

Interviewed sample

Out of current 340 students and 40 permanent staff members a sample of 10 people was asked about their opinion on the changes caused by the renovation. This sample consisted of:

Director (male)

Head cook (female, employed at the end of the renovation)

Janitor (male, employed after the renovation)

Clerk – accountant (female)

2 teachers of secondary school (female)

2 teachers of primary school (female, both employed after the renovation)

2 9th grade students (male and female)

Positive co-benefits

All interviewed agreed that the renovation improved the conditions in the building and lead to significant energy savings. The visual perception of the renovated school also improved and interviewed are proud to be (work or study) in the school.

In the eyes of the interviewed the most important part of the renovation was addition of thermal insulation to the school's envelope and replacement of old windows. These renovation measures significantly improved thermal comfort inside the school, especially in winter.

Renovated technical systems (e.g. heating or DHW) and equipment (e.g. external shading - sunblinds) of the school are also easier to use and maintain.

Negative co-benefits

According to some of the interviewed the renovation caused several problems too. These are related mostly with the air quality and natural lighting in the classrooms after replacement of windows and installation of the external shading.

Female teachers complained that new windows are much heavier than previous ones and that their opening/closing is very strenuous.

All classrooms with windows facing east are overheating during summer. This problem should have been solved by installation of sunblinds during the renovation. According to the teachers the new external shading system improved the overheating at a price of reducing the fresh air supply. When fully detached the individual plates of the sunblinds fit too tightly to each other. Allegedly, in summer when the air is hot and there is no wind this causes that the air cannot flow freely into the classrooms. Mechanical ventilation of classrooms would solve this problem.

Key notes – improvement

Thermal comfort

Reduced exposure to energy price fluctuations

Ease of use

Pride / Prestige

Methodology

Three scenarios of the renovation are accessed in this case study:

Necessary renovation

The necessary renovation of the school does not take into account the energy efficiency or comfort of the users. It is only meant as a reference scenario that would extend the service life of the school.

Replacement of old windows and renovation of heating and DHW systems, including the measurement and regulatory equipment, are taken into account. The renovation of heating and DHW includes renovation of the heat source – heat exchanger connected to the district heating network. All other equipment and structures remain in the original state.

1st approved design

This scenario represents the design that was approved and given to the construction company. Its goal was renovation of the school into a low-energy standard to create an example of energy efficient renovation of a public building in Brno. Its design also prepares stage for future installation of a mechanical ventilation system in the classrooms.

The most important part of this scenario is replacement of doors and windows and thermal insulation of the school's envelope. This significantly improves the energy consumption. It also improves the comfort of the users.

Another feature of this scenario was renovation of heating and DHW system (similar to previous scenario) and replacement of the old mechanical ventilation in the kitchen, cafeteria, etc. The heating and DHW systems were also insulated to minimize the heat losses through the pipes.

Final renovation

This scenario is an evolution of the previous scenario. During the construction process it was decided to further improve the renovation designs:

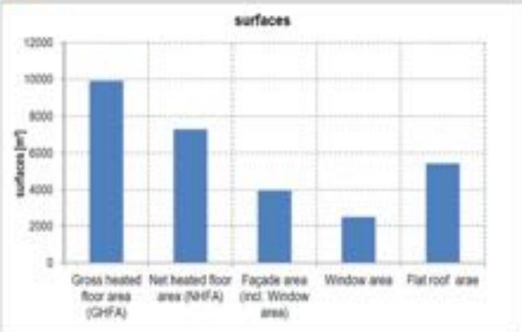
It was decided that an external shading system (sunblinds) will be installed to improve the indoor climate during sunny days. Originally there were only indoor sunblinds installed in the school These were prone to malfunction and due to their position they proved ineffective in improving the thermal comfort of the users (especially in summer).

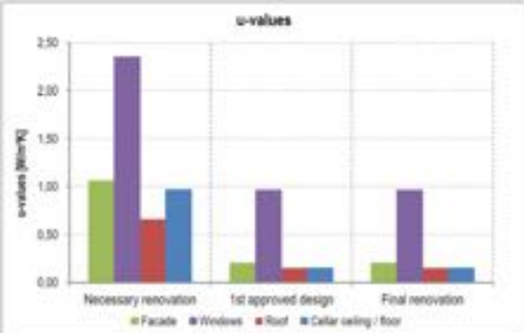
Important part of this scenario is addition of renewable energy source to the building. Because of lack of funding it was impossible to add any renewable sources to the school itself. But a private investor shown interest in renting the school's flat roof for an installation of a photovoltaic power plant. This power plant is not directly connected to the school - it supplies the electricity to public network. But the Borough office (owner of the school) receives the rent which is re-invested in the school. This power plant has also high educational value. It promotes possible use of renewable energy sources in cities not only to the pupils, but everyone who lives in the surroundings.

		Necessary renovation	1st approved design	Final renovation
Justification and statement	strengths, co-benefits	Necessary renovation of the heating and DHW systems, replacement of ageing windows.	Renovation of the BITS to improve their efficiency and user comfort. Renovation (including additional thermal insulation) of the envelope to improve the thermal comfort and reduce the energy consumption of the school building. Improvement of the aesthetic value of the building.	Renovation of the BITS to improve their efficiency and user comfort. Renovation (including additional thermal insulation) of the envelope and installation of external shading to improve the thermal comfort. Significant reduction of the energy consumption of the school building. Improvement of the aesthetic value of the building. Provision of unused roof space for installation of PV power plant.
	weaknesses, additional costs	No reduction of energy consumption. Only minimum improvement of thermal comfort and user comfort.	No use of renewable energy sources. Inadequate improvement of thermal comfort in summer.	Additional costs for the external shading system. Photovoltaic power plant is on directly connected to the shool - it does not directly help to reduce the environmental impacts of the school's use.
Conclusions	Conclusions of comparison; why was final solution chosen, how does it relate to refrence case and alternative scenarios?	Chosen renovation has the best effect on the thermal comfort of the users. The installation of the external shading is important to the thermal comfort and when this will be combined with new mechanical ventilation of classrooms in the future it will have the best possible effect on the quality of indoor environment. Chosen renovation has the energy consumption in accordance with the targets set during the design. It also incorporated renewable energy sources to the building - the photovoltaic power plant. This does not supply the electricity to the school directly, but income it produces to the owner of the school is re-invested in the school.		

Comparison of renovation measures

			Necessary renovation	1st approved design	Final renovation
renovation measures	Building envelope	roof	-	Addition of 180 mm EPS and new bitumenous/plastic covering layer	Addition of 180 mm EPS and new bitumenous/plastic covering layer
		facade	-	Addition of thermal insulation layer - 60 to 160 mm EPS, XPS or mineral wool	Addition of thermal insulation layer - 60 to 160 mm EPS, XPS or mineral wool
		glazing/frame	New plastic or aluminum frames with double and triple glazing	New plastic or aluminum frames with double and triple glazing	New plastic or aluminum frames with double and triple glazing and external shading system (sunblinds)
		floor	-	Addition of up to 240 mm of mineral wool or EPS thermal insulation to the ceiling under the first floor	Addition of up to 240 mm of mineral wool thermal insulation to the ceiling under the first floor
	BTS	Heating	New heat exchanger, valves and fittings	New heat exchanger, valves and fittings	New heat exchanger, valves and fittings
		DHW	New storage tank and restoration of circulation circuit	New storage tank and restoration of circulation circuit	New storage tank and restoration of circulation circuit
		Cooling	-	-	-
		Auxiliaries	New measuring and regulation equipment	New measuring and regulation equipment	New measuring and regulation equipment. Rental of the roof space for installation of a PV power plant.
		Lighting	-	-	-
		Ventilation	-	New mechanical ventilation (with heat recovery) in the kitchen, storage rooms, toilets and showers	New mechanical ventilation (with heat recovery) in the kitchen, storage rooms, toilets and showers
		(Common appliances)	-	-	-
characteristic values	heating	Energy carrier of heating system	district heating	district heating	district heating
		Conversion efficiency of heating system	85,70	85,70	85,70
		2nd energy carrier of heating system	-	-	-
		2nd conversion efficiency of heating system	-	-	-
		Share of 2nd energy carrier on heating energy need	-	-	-
	DHW	Energy carrier of hot water system	district heating	district heating	district heating
		Conversion efficiency of hot water system	85,70	85,70	85,70
		2nd energy carrier of hot water system	-	-	-
		2nd conversion efficiency of hot water system	-	-	-
		Share of 2nd energy carrier on hot water energy need	-	-	-





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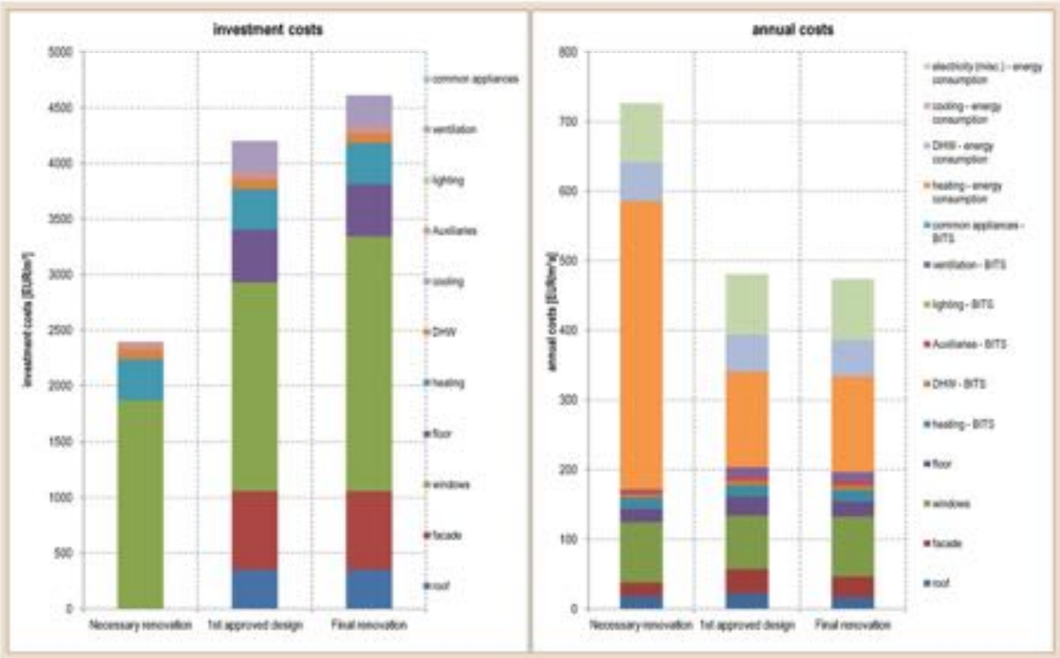
Comparison of renovation measures - LCC



All 3 renovation scenarios are calculated using the interest rate of 3 % and inflation (price increase) of 2 %.

Necessary renovation

First renovation scenario has the lowest investment costs . This is caused by the fact that only renovated parts of the building are windows, heating and DHW systems (including the measuring and regulatory equipment).

In contrast this renovation scenario has the highest annual costs, mostly due to the high heating energy consumption.

Investment costs:
2395 CZK/m²

Annual operating costs:
640 CZK/(m²a)

Total yearly life cycle costs:
729 CZK/(m²a)

1st approved renovation

Investments in this scenario are almost twice as high as in first scenario. The cause is more extensive renovation – thermal insulation of the whole envelope, more extensive BITS renovation, etc.

Annual costs are significantly reduced, mostly thanks to the reduced heating energy consumption. Increase in the maintenance costs is caused by addition of new materials and installation of more complex systems.

Investment costs:
4202 CZK/m²

Annual operating costs:
329 CZK/(m²a)

Total yearly life cycle costs:
481 CZK/(m²a)

Final renovation

Further increase of investment costs in comparison with second scenario is caused by the installation of external shading system.

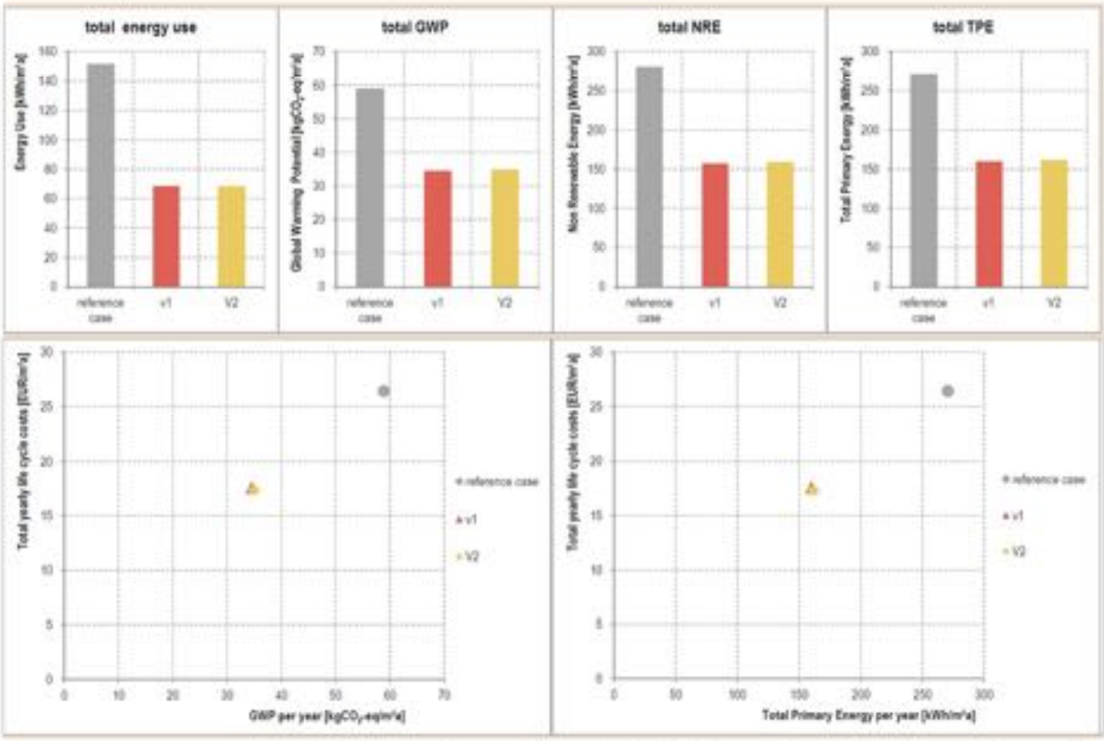
Small annual cost reduction }in comparison with the second scenario) is caused by the income (rent) from the owner of the photovoltaic power plant - in this calculation it was incorporated to the maintenance costs, which were therefore slightly reduced. Overall this scenario reduced the total life cycle costs by 35 %.

Investment costs:
4613 CZK/m²

Annual operating costs:
307 CZK/(m²a)

Total yearly life cycle costs:
473 CZK/(m²a)

Comparison of renovation measures - LCIA



Description and analysis of the LCIA results

As can be seen in the charts above the first scenario has the worst environmental impacts. Two assessed renovation scenarios have environmental impacts reduced by approximately ½. For example in the GWP category the first scenario produces 58.9 $kgCO_{2}$-eq/(m²a), while the second scenario produces 34.5 $kgCO_{2}$-eq/(m²a) and the third 34.9 $kgCO_{2}$-eq/(m²a). This is caused mainly by improving the energy consumption of the building and it confirms that the use of the building has major share of its overall environmental impacts.

If closely compared a small difference between environmental impacts of the last two scenarios in GWP, NRE and TPE categories. It is caused by addition of environmental impacts of the external shading system and the photovoltaic power plant installed on the roof. After the installation this power plant became a part of the school building and therefore it should be added when calculating overall environmental impacts of. On the other hand, as the power plant supplies the produced electricity directly to the public network and not to the school itself, the environmental impacts of the electricity generation (which are positive, as it is a renewable energy) are not included in this assessment. If they were included the overall environmental impacts of the final renovation scenario would be further reduced (approx. by 35 %). The difference between results of second and third scenario caused by addition of the shading system and photovoltaic power plant is less than 2 %.

Summary and conclusion

Kaminky 5 elementary school is a typical representative of the buildings built in Czech Republic in the 80s of 20th century. It was built using prefabricated reinforced concrete and ceramic elements with only minimum attention to thermal bridges, energy efficiency, etc.

Before the renovation the technical state of the school was questionable. The superstructure was in good condition but there were problems with the air tightness of the school's envelope. There were strong drafts in the classrooms and sometimes the windows were even letting rainwater or snow inside. The technical equipment was functional, but ageing and inefficient. An extensive renovation was necessary.

As (at that time) there were many buildings in the vicinity with similar problems the Borough office (owner of the school) decided to use this renovation as an opportunity to show an example of energy efficient and environmentally-friendly approach towards the existing building stock.

The renovation met the expectations. The energy consumption was significantly reduced. Also the perception of the school improved greatly - the new appearance is a matter of pride among the staff, students and public.

After 4 years of use several problems related to the renovation are identified and plans are made to solve them. The most pressing problem is that the designed renovation of the heating and DHW system was insufficient. The parts of the original systems that were left in place are at the end of their expected service life and will have to be replaced in a few years.

Another issue is that new airtight envelope successfully prevents infiltration of fresh air from the exterior. To maintain adequate quality of indoor air it is necessary to regularly open the windows and ventilate, which causes problems with overheating of rooms during hot days. Planned mechanical ventilation system would solve this but currently there is a lack of funds which hampers its installation.

Figure 24: View of the outdoor sport facilities that are part of the renovated school. Main school building with the photovoltaic power plant on the roof can be seen in the background.

Practical experience

From the perspective of the users the renovation was mostly a success. Remaining problems were already mentioned before.

This renovation also has also shown the importance of pre-design phase and preparation of a detailed tender documentation. The subsequent selection of the construction company and close cooperation with its employees resulted in exemplary running of the construction works. Even the additional changes of the design during the construction were implemented without delays to the original schedule.

References

[1] Borough office Brno – Nový Lískovec

[2] MENHIR projekt, s. r. o.

[3] J. Kučera, Pronájem střechy školy na fotovoltaickou elektrárnu (Renting the school's roof for photovoltaic power plant), Stavitel, Prague, 2009

Appendix 3

Traneparken, Hvalsø, Denmark

Deep renovation of three apartment blocks with focus on energy

Owner: Hvalsø Boligselskab
Location:
Traneparken 2 – 20
4330 Hvalsø, Denmark
Architects: ARKIPLUS 1969

Energy concept:
Comprehensive energy retrofitting

Start of renovation:
November 2011
End of the renovation:
October 2012
Report:
Cenergia, SBi/AAU, DTI
Date: November 2014

Key technologies
- Additional insulation of walls, basement and roof
- New low-energy windows
- Photovoltaic system
- Demand-controlled mechanical ventilation system with heat recovery

View of existing (small picture) and the renovated building (large picture)

1

Background

Traneparken consists of 3 multi-story blocks of flats. Each block has 3 storeys with in all 66 flats.

Building envelope

The buildings are typical of the 1960s and made of prefabricated re-enforced sandwich concrete elements with approx. 50 mm insulation material.

Panel walls between windows are insulated with approx. 45 mm. Floor above basement has approx. 45 mm insulation material. The roof is insulated with approx. 190 mm. Windows are double-glazed with a U-value of 1.8 W/m²K.

Heating, ventilation, cooling and lighting systems

The buildings are heated by district heating delivered through the basement of one of the blocks to a 200 kW plate heat exchanger.

From there it is distributed to the 3 blocks.

There are pre-insulated domestic hot water (DHW) tanks in each block. There are eight 300 l tanks in total, corresponding to one for each stairway.

Figure 1: The 3 multi-storey blocks, ref.: Google maps

Figure 2: External wall before retrofitting

Originally, the flats were ventilated by a mechanical exhaust system which extracted air from bathroom, toilets and kitchens.

There are energy-saving light bulbs in all indoor lamps on the stairways. The stairway lighting is equipped with automatic switch-off controls based on presence sensors. Outdoor lighting has automatic daylight switch-off.

Before renovation, the buildings seemed rather grey and boring and had problems with facades, windows, roofs, etc. The indoor climate was unacceptable and the energy consumption was far too high.

Table 1: U-values before and after renovation

Element (only block A)	Area, m²	U-value before renovation, W/m²K	U-value after renovation, W/m²K
Exterior walls	486	0.66	0.15
Floor over basement	361	0.66	0.66
Panel walls	106	0.70	0.11
Windows/doors	205	2.40	0.80
Roof	333	0.20	0.09

Project data of the three buildings before renovation

Altitude	47 m
Heating degree days	2,906 Kd
Cooling degree days	0 Kd
Year of construction	1969
Gross heated floor area	5,293 m²
Specific heating energy demand incl. DHW	137 kWh/(m²a) *)
Specific cooling energy demand	0 kWh/(m²·a)
Type of energy carrier for heating	District heating
Type of energy carrier for DHW	District heating
Specific heating energy consumption incl. DHW	139 kWh/(m²a) *)
Installed power for heating	200 kW
Energy costs	66,700 €/a

*) The two values are almost identical due to the very small losses from the district heat exchanger located in the basement of one of the blocks.

Renovation concept

Figure 3: Retrofitting of exterior walls

Design data for the renovated buildings

Year of renovation	2011-2012
Gross heated floor area	5,293 m²
Specific heating energy demand incl. DHW	95 kWh/(m²a) *)
Specific cooling energy demand	0 kWh/(m²a)
Type of energy carrier for heating	District heating
Type of energy carrier for DHW	District heating
Specific heating energy consumption (incl. DHW)	95.6 kWh/(m²a) *)
Installed power for heating	200 kW
Energy costs	45,500 €/a/m²

*) The two values are almost identical due to the very small losses from the district heat exchanger located in the basement of one of the blocks.

Figure 4: Insulation work on the basement walls

Figure 5: Scaffolding for facade

Energy-saving concept

The goal was to renovate the buildings because they were worn down and the external concrete walls were weakened by deterioration. At the same time external balconies were added to improve the flats.

The overall intention was to:

- Renovate worn down parts of the buildings
- Improve the indoor climate
- Improve flats with external balconies
- Improve outdoor areas
- Reduce energy consumption (insulation of constructions, new windows/doors, mechanical ventilation with heat recovery)

Building

- Exterior walls were renovated: Supplementary thermal insulation was added to the outside of the exterior walls. The external insulation was continued to the base of the building to reduce/avoid thermal bridges.
- Roofs were renovated and insulated.
- Windows and doors were replaced by triple-glazed low-energy windows/doors.

Ventilation:

- Flats are now ventilated by a demand-controlled balanced mechanical ventilation system with heat recovery. Exhaust air from bathroom, toilets and kitchens and supply air to the living rooms.

Renewable energy systems:

- 33 kW_p PV system were installed on the roof of one of the blocks.

Renovation design details

Three existing apartment blocks were retrofitted with new facades with extra insulation, additional insulation for the roof, new windows, mechanical demand-controlled ventilation with heat recovery and a PV installation on the roof.

Facade solutions

Exterior walls were renovated: Thermal insulation was added to the outside of the exterior walls. 190 mm new insulation material plus exterior solid standard bricks. Now the walls are insulated by 240 mm insulation material in total.

Panel walls (between windows): 285 mm new insulation material plus exterior solid standard bricks. Now: 330 mm insulation material in total.

Cost: € 1.67 million (incl. VAT).

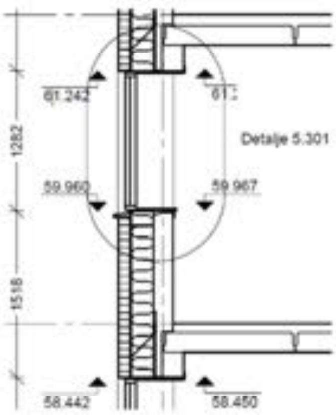


Figure 6 : Wall section: 190 mm new insulation material plus exterior solid standard bricks. Windows – plastic, triple-glazed energy glass.

Figure 7: New insulation and new bricks near the roof

Figure 8: The new insulation and new windows almost in place

Figure 9 : New 190 mm insulation plus exterior solid standard bricks in the construction phase - shown with scaffolding

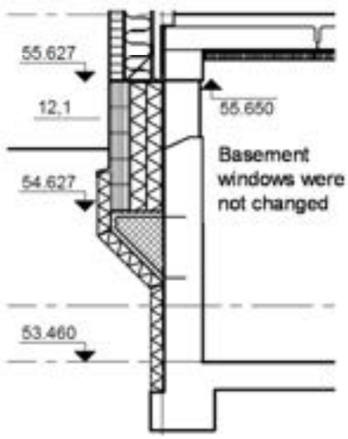


Figure 10: The external insulation is continued to the base of the building to reduce/avoid thermal bridges

Figure 11: The external insulation (EPS) of the basement walls

Figure 12: The external insulation of the basement covered by Leca bricks

Window solution

Windows were replaced by low-energy windows with plastic frames and triple-glazing with low-E coating.

Cost: € 113,000 (incl. VAT, excl. installation).

Figure 13: New balcony doors – plastic with energy-efficient glazing

Roof solution

The roofs were renovated and insulated:

250 mm insulation material was added.

The new roof is insulated with a total of 435 mm mineral wool.

Cost: € 0.56 million (incl. VAT)

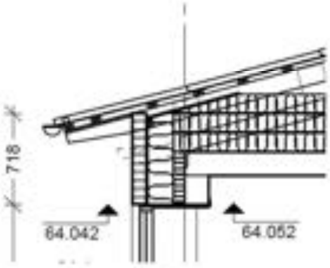


Figure 15: Section showing added roof insulation – new total: 435 mm

Ventilation solution

Flats are now ventilated by a centrally balanced mechanical ventilation system with 80% heat recovery and a SFP factor of 1.4. Exhaust air is extracted from toilets, bathrooms and kitchens and supply air is led to the living rooms.

Figure 16: A new ceiling in the corridor is used to hide the inlet ventilation ducts

Figure 17: LeanVent damper in place on an air inlet duct to reduce energy consumption

Figure 18: LeanVent damper in open position – schematic

Figure 14: Lower corner of a plastic triple-glazed low energy window

Figure 19: LeanVent damper in closed position - schematic

Renewable energy system solution

A photovoltaic (PV) system (see photo below) was installed for electricity production mainly to be used in the common laundry. Tilt: 15° and orientation: 10° from south towards west. When extra electricity is produced, it will be used for common lighting.

The PV system was expected to produce 30,000 kWh/a, but from September 1, 2012 to September 1, 2013 the production was 38,159 kWh. The summer of 2013 had 19% more sunshine hours than a normal year.

Demand-controlled ventilation

To minimize the energy consumption due to ventilation, a simple demand control of the ventilation system was installed. The users can increase ventilation when they are cooking in the kitchen and a presence sensor activates forced ventilation when someone is in the bathroom/toilet. Thereby the standard ventilation can be kept at a minimum level reducing both the heating loss from ventilation and the electricity consumption of the fans.

To further reduce the electricity load of the fans, a new type of damper was used in the inlet air ducts. It is a so-called drop-damper produced by the company LeanVent. This damper reduces energy consumption in the ventilation system and it ensures lower noise generation due to the lower pressure drop over the dampers. See figures 17-19.

Economic sustainability

The increased running costs for the ventilation system is 13,300 €/year, and the expected PV electricity production is 30,000 kWh corresponding to savings of approx. 8,000 €/year.

The expense for district heating is approx. 45,500 €/year. The savings in district heating due to energy retrofit correspond to approx. 20,500 €/year.

For the tenants, the overall results of the energy retrofit is an annual increase in rent of 11.8 €/m² and a decrease in energy costs of 4.2 €/m².

For the net increase of 7.6 €/m² they get:

- Improved thermal comfort
- Improved indoor air quality
- Increased living space within the flats due to warmer outer walls and windows.
- New balconies
- Aesthetically far more attractive buildings which improve the general quality of the area.

Figure 20: The 33 kW_p south-facing PV system and the coverings for the new mechanical ventilation systems located above each stairway

Ecological/environmental sustainability

The renovation has reduced the global warming potential, total primary energy consumption and non-renewable energy use as follows:

Global warming potential reduction: 9.3 [$kgCO_{2-eq}/m^2a$]

Total primary energy 71.9 [MJ/m^2a]

Non-renewable energy 47.4 [MJ/m^2a]

Integrated Building Performance - Construction sustainability

Special aspects of sustainability of the construction

The apparent needs - necessary repair of external walls and replacement of windows - were used as an opportunity to drastically improve the insulation of the walls and to choose triple-glazed low energy windows. Thereby a far more sustainable solution was achieved.

The use of scaffolding is often a very expensive element of the renovation and in this case the scaffolding was used both for the repair of the walls and installation of additional insulation. The roof had additional insulation installed at the same time.

For the installation of the new demand-controlled balanced mechanical ventilation system with heat recovery, the existing exhaust air ducts were used – thereby minimising costs and material use. Available space was identified and utilised for the supply air system.

Building materials

For the insulation of the external walls and the roof, an insulation product most often used in Denmark was chosen: Mineral wool. Mineral wool is produced at high temperatures with some energy consumption, but when compared with the energy saved by its use, this is close to negligible. It has a very high durability and will last for the rest of the lifetime of the building.

Plastic windows have been the object of some debate over the years. However, today the quality of plastic windows has greatly improved so their lifetime is comparable with that of other types of windows. Unlike wooden windows, they need no protective treatment every 5 - 7 years. The windows can be completely taken apart and materials recycled after end service life. Thereby the plastic can be recycled for new plastic products – for example plastic windows.

Figure 22: The low-energy plastic windows and doors at the building site

Sociocultural sustainability

In social housing projects in Denmark, a majority of the tenants must agree on decisions. This calls for a lot of information, many meetings etc.

Tenants are satisfied with the improved indoor climate. For example: The benefits of the ventilation system: "now we don't have to open windows to change the air" - and the cost of heating has been significantly reduced, while the thermal comfort in the dwellings has improved considerably.

It is expected that the earlier problems with mould growth will not re-occur due to the improved ventilation.

Figure 21: Insulation material waiting to be installed at the foot of the scaffolding

Performance Data

Monitoring system

The three buildings are supplied by a district heating system.

The heating energy consumed is measured by a standard heating energy meter supplied by the district heating company. This means that the heating energy consumption before and after can be compared directly. Also, the total electricity consumption is monitored by a standard meter as well as the electricity production of the PV installation.

Energy consumption

Calculated and measured energy consumption for heating and DHW is shown in Table 2. There is good agreement between calculated and measured values.

The renovation of the building envelope, i.e. new windows and insulation of the exterior wall and roof accounts for 120 MWh/year while the reduction in the ventilation heat loss, i.e. increased air tightness and mechanical ventilation with heat recovery accounts for 106 MWh/year.

Reduced running costs

In the future the running costs for district heating will be approx. 45,510 €/year. The savings due to the renovation correspond to approx. 20,490 €/year.

The increased running costs for electricity for the ventilation systems will be approx. 13,300 €/year. The expected PV electricity production is 30,000 kWh, which corresponds to savings of approx. 8,000 €/year.

The distribution of the heating energy costs on each tenant is based on electronic heat cost allocators located on each radiator in the flats, see the photo below. When the size and type of the radiator is known, the share of the total energy bill for space heating for each flat can be calculated.

Table 2: Calculated and measured energy consumption before and after

Energy consumption for heating and DHW before and after renovation:			
Calculated energy consumption:			
Before renovation:		728	MWh/year
After renovation:		502	MWh/year
Calculated savings:		226	MWh/year
Measured energy consumption:			
Before renovation:	2011 – 2012	736	MWh/year
After renovation:	2012 – 2013	506	MWh/year
Measured savings:		230	MWh/year

Figure 23: Tenant representative in front of a renovated block

Figure 24: The electronic heat cost allocator

Improvements & Co-benefits

Package	CO-BENEFITS	Thermal Comfort	Natural Lighting	Air Quality	Building Physics	Internal Noise	External Noise	Ease of Use / Control by User	Reduced Exposure to Energy Price Fluctuations	Aesthetic	Useful Living Area	Pride / Prestige	Safety (intrusion and accidents)	Ease of Installation / Reduced Annoyance	Feeling of Easiness to Sell or Rent	Independence from Energy Sources
Renovation Package 1	Replacement of windows	P			P		P		P		P				P	P
	Insulation of external walls	P			P				P	P	P				P	P
	Insulation of roof	P			P				P						P	P
	MVHR system	P		P	P	N		P	P						P	P
	Photovoltaic systems								P	P		P			P	P
Renovation Package 2	Replacement of windows	P			P		P		P		P				P	P
	Insulation of roof	P			P				P						P	P
	MVHR systems	P		P	P	N		P	P						P	P
	Photovoltaic systems								P	P		P			P	P
Renovation Package 3	Windows replacement	P			P		P		P		P				P	P
	Insulation of external walls	P			P				P	P	P				P	P
	Insulation of roof	P			P				P						P	P
	MVHR system	P		P	P	N		P	P						P	P
	Photovoltaic systems								P	P		P			P	P

Legend: P - Positive Effect; N - Negative Effect

Co-benefits.

The deep renovation with focus on energy of Traneparken not only reduces energy costs, it also introduces a number of co-benefits. The financial value of the co-benefits is hard to establish, but they are often more appreciated by the tenants than the energy savings. The table above provides an overview of the co-benefits of 3 different energy renovation concepts/-packages – described on page 10. Package 3 is the actually implemented renovation and 1 & 2 are examples of how it might also have been done.

The table uses two legends: "P" for a positive effect and "N" for a negative effect. It appears from the table that the three energy renovation packages show much the same pattern of co-benefits. The only difference that can be observed is that Package 2 does not include added insulation of the exterior walls. So, the positive effects of this measure are missing for this package, for example: Improved thermal comfort and additional useful living area. When comparing the alternatives, there is a risk that this is forgotten as there are no costs or savings connected with these co-benefits.

Actual co-benefits

The co-benefit table provides an overview of the different renovation packages, but they do not present all the actual co-benefits experienced by the tenants. For the implemented re-novation package these are:

- New balconies
- New green surroundings
- Improved indoor climate (from the Mechanical Ventilation and Heat Recovery (MVHR) system).
- Improved thermal comfort (from less heat loss and draught through walls, windows and doors)
- It is expected that earlier problems with mould growth will not occur anymore due to improved ventilation.

User satisfaction survey

A questionnaire survey of occupant satisfaction with living in Traneparken before and after the renovation is carried out in November 2014 after 2 years of post-renovation occupancy. The purpose is to study occupant satisfaction after renovation and get views on energy consumption, perceived indoor climate and the new ventilation system. Furthermore, the survey intends to investigate which co-benefits the occupants have achieved.

Indoor climate measurements

Measurements of the indoor climate are performed in order to verify that the indoor climate meets expectations. Measurements comprise continuous registration of relative humidity, indoor air temperature and CO_2-concentration. Ventilation rates are measured using passive tracer gas technique.

Methodology

Three different energy renovation packages were analysed by Life Cycle Cost (LCC) and Life Cycle Impact Assessment (LCIA) calculations and their strengths and weaknesses compared. The results of these analyses, and comparisons are shown in the following.

The three alternatives are numbered v1, v2 and v3, where number v3 is the actually implementted renovation package. The heating energy supply of Traneparken is district heating, so in practical terms it is not a real alternative to change this supply to anything else. However, for the purpose of the LCC and LCIA analyses the calculations were carried out also for a changed heating supply system, i.e. gas and oil boilers. Thus v1 – oil refers to the situation where an oil boiler is used instead of v1 – DH – the district heating case.

The actually implemented renovation package

Consisted of the following:

- 211 mm additional (average) external wall insulation
- 250 mm additional roof insulation
- New triple-glazed low-energy windows
- New mechanical ventilation system with heat recovery – MVHR system
- 33 kW_p PV system.

Alternative scenario 1

For this scenario 200 mm insulation was further added to the roof insulation, but the additional wall insulation was reduced to 100 mm – to simulate a situation where it was not possible to add 211 mm to the wall. To reach the same energy conservation level as v3, the MVHR used was given a higher heat recovery efficiency – 90% instead of 80% and a lower SFP factor of 1.2 instead of 1.4.

The size of the PV system was identical to the one used in v3 and the new windows as well.

Alternative scenario 2

For this scenario the basic idea was to illustrate a situation where it was not possible or realistically cost-efficient to add insulation to the exterior wall. To compensate for this, additional roof insulation and an improved MVHR system like in scenario 1 was chosen. To further compensate for the lack of savings, a larger PV system of 132 kW_p was tested.

Strengths and weaknesses

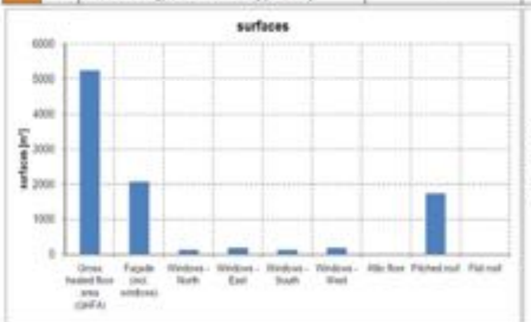
An overview of the strengths and weaknesses is presented in the table below. Not to renovate was not an option considered by the building owner (Building Association Zealand) since the exterior walls were worn down and in need of refurbishment. Based on this and the fact that there was a practical possibility of adding 211 mm external wall insulation at the same time as the walls were refurbished the chosen renovation package seems to be the most cost-efficient choice.

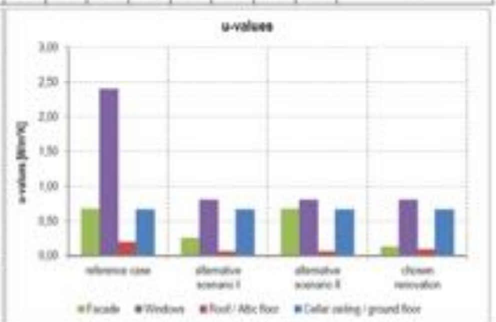
In the following the results of the LCC and the LCIA calculations and comparisons are presented and discussed.

		reference case	alternative scenario I	alternative scenario II	chosen renovation
justification and statement	**strengths, co-benefits**	no investment costs involved	-makes use of the situation where the external wall had to be renovated anyway -the external wall becomes warm on the inside	-this alternative shows what could have been done if the wall didn't need a renovation -thus this package would results in the same energy savings at a much lower cost	-makes use of the situation where the external wall had to be renovated anyway -the external wall becomes warm on the inside
	weaknesses, additional costs	-external wall in critical need of repair - without it would have to be demolished within a few years -energy costs too high	-external insulation of external walls is very costly, if there is no "anyway" measure in the form of a wall in need of renovation	-the thermal indoor climate will not be improved due to higher inside wall surface temperatures -as the installation of new windows requires a scaffold this package does not take advantage og that	-external insulation of external walls is very costly, if there is no "anyway" measure in the form of a wall in need of renovation
Conclusions	**Conclusions of comparison; why was final solution chosen, how does it relate to refrence case and alternative scenarios?**	The solution chosen appears to be the most cost-efficient as it makes optimal use of the fact that the external wall had to be renovated anyway. The other measures have been chosen also with a cost optimisation in mind.			

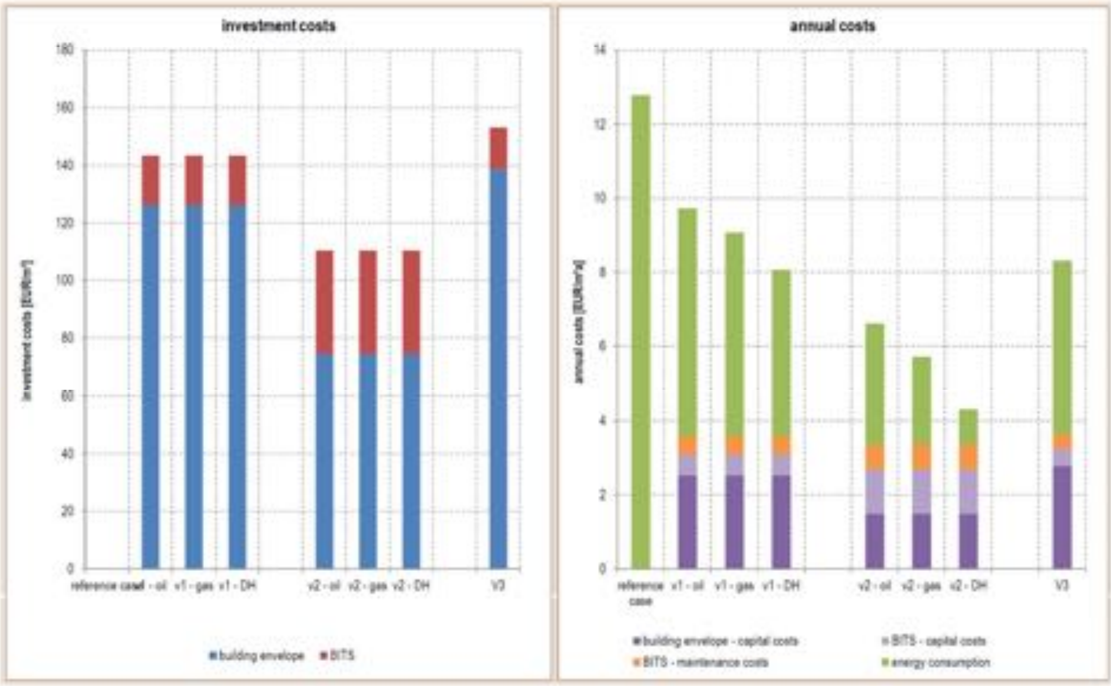
Comparison of renovation measures

			reference case	alternative scenario I				alternative scenario II				chosen renovation
renovation measures	Building envelope	roof	185 mm iso	chosen+200mm + reference +ca 450mm iso				chosen+200mm + reference +ca 450mm iso				reference + ca 250mm iso
		facade	50 mm iso	reference + 100mm iso				no insulation				reference + ca 211mm iso
		glazing/frame	2 layer old windows	3 layer energy glass				3 layer energy glass				3 layer energy glass
		floor	-	-				-				-
	BTS	Heating	District (DH)	oil	gas	DH	wood	oil	gas	DH	wood	DH
		DHW	District	oil	gas	DH	wood	oil	gas	DH	wood	DH
		Cooling	None	-				-				-
		Auxiliaries	None	-				-				-
		Lighting	Fluorescent tubes	-				-				-
		Ventilation	Exhaust ventilation	Mechanical with Heat Recovery SEL=1,2 Eff = 90%				Mechanical with Heat Recovery SEL=1,2 Eff = 90%				Mechanical with Heat Recovery SEL=1,4 Eff = 80%
		(Common appliances) / PV	None	33 kWpeak				132 kWpeak				33 kWpeak
characteristic values	heating	Calculated energy demand for heating [kWh/m²a]	31,20	25,08	25,08	25,08		40,09	40,09	40,09		26,07
		Energy carrier of heating system	District (DH)	oil	gas	DH	wood	oil	gas	DH	wood	DH
		Conversion efficiency of heating system	1,00	0,92	1,00	1,00		0,92	1,00	1,00		1,00
		2nd energy carrier of heating system	-	-	-	-	-	-	-	-	-	-
		2nd conversion efficiency of heating system	-	-	-	-	-	-	-	-	-	-
		Share of 2nd energy carrier on heating energy demand	-	-	-	-	-	-	-	-	-	-
	DHW	Calculated energy demand for DHW [kWh/m²a]	13,90	13,93	13,93	13,93		13,93	13,93	13,93		13,93
		Energy carrier of hot water system	District (DH)	oil	gas	DH	wood	oil	gas	DH	wood	DH
		Conversion efficiency of hot water system	1,00	0,92	1,00	1,00		0,92	1,00	1,00		1,00
		2nd energy carrier of hot water system	-	-	-	-	-	-	-	-	-	-
		2nd conversion efficiency of hot water system	-	-	-	-	-	-	-	-	-	-
		Share of 2nd energy carrier on hot water energy demand	-	-	-	-	-	-	-	-	-	-
	cool.	Calculated energy demand for cooling [kWh/m²a]	-	-	-	-	-	-	-	-	-	-





Comparison of energy efficiency measures – LCC



Description and analysis of the Life Cycle Costs (LCC) results

The histograms above show the investment costs and the annual costs of the three alternative scenarios for energy retrofit and for v1 and v2 also for three different heat sources (oil, gas and district heating).

On the investment histogram, blue refers to the cost of retrofitting the building envelope and red to improving the building installation technologies systems (BITS). It is obvious that not installing any external wall insulation in v2 results in much lower investment costs than the other two alternatives. Even when in v2 a much larger PV system is installed, the investment costs are still the lowest for v2.

The histogram to the right shows the annual costs of the various alternatives. It is obvious that for the reference situation, the high energy consumption results in the highest annual costs.

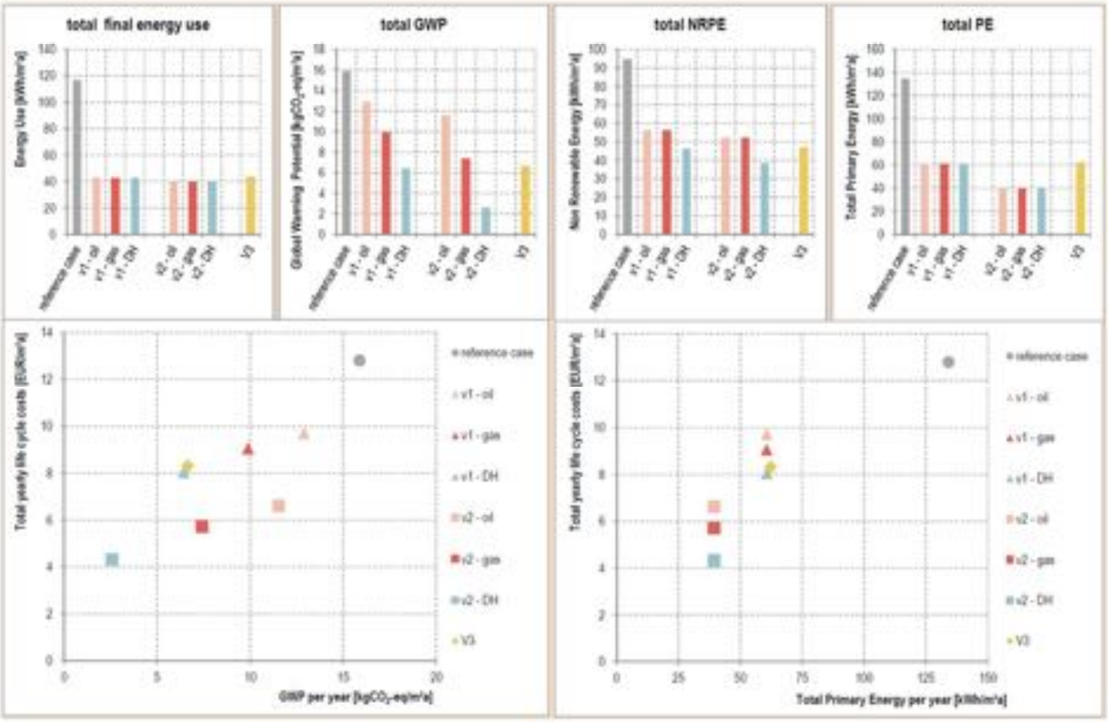
Annual costs for "v1 – DH" and the actual implemented retrofit – v3 are very close to being the same, whereas all the scenarios for v2 show lower annual costs. This is due to the higher cost of the electricity produced by the PV system. It should be noted, though, that in this calculation it is assumed that all the electricity produced can be used at the site/by the buildings for common electricity consumption with the same price for the electricity as that paid to the electricity company. If some of the PV-produced electricity needs to be sold to the grid, a much lower price must be used for the calculation in which case the annual costs for v2 will be considerable higher.

It is interesting to note that installation of a larger PV system seems to be able to out-balance the expensive exterior wall insulation.

As the price of PV systems continues to decrease, the tendency is likely to be stronger in the future.

The histogram also clearly shows that district heating is more cost-efficient than oil and gas heating, and gas heating being clearly better than oil heating.

Comparison of energy efficiency measures – LCIA



Description and analysis of the Life Cycle Impact Assessment (LCIA) results

The different scenarios were analyzed by a LCIA calculation resulting in the four top histograms on this page: for respectively: total final energy consumption, total Global Warming Potential – GWP, total Non Renewable Primary Energy - NRPE and total Primary Energy – PE. On the two figures below, the total yearly life cycle costs were plotted against the GWP/year and the total primary energy consumption per year. It should be noted that the primary energy factors required by the Danish Building Regulations were used for the PE and NRPE calculations. These are: 2.5 for electricity and 1.0 for gas, oil and district heating.

The top four histograms show that all three renovation alternatives result in almost the same total final energy consumption – the second alternative being the lowest. For all scenarios, the savings are close to 1/3 of those for the reference case. However, from the histogram showing GWP, the differences between the alternatives are quite large – mainly due to the different factors for CO_2 emissions assigned to gas, oil, district heating and electricity. The large PV installation of alternative 2 results in lower GWP because of the high CO_2 emissions of electricity production. The total primary energy consumption is almost identical for the gas, oil and district heating alternatives due to identical primary energy factors as previously explained. The plot of NRPE consumption shows that the district heating alternatives come out the lowest – but all close to 50% lower than the starting point.

The two lower figures show how the different alternatives can reduce the total annual life cycle cost, GWP/year and total primary energy per year from the "upper right corner" to less than half the cost and less than one fifth of GWP and one third of the primary energy consumption. This is obtained by alternative 2 with district heating. Alternative 1 with district heating and the actual implemented energy retrofit shows almost the same results – primary energy and GWP more than halved and the total annual life cycle costs reduced from about 13 to 8 €/m²year.

Summary and conclusion

Before renovation, the three blocks with in all 66 flats were typical examples of Danish buildings from the 1960s with prefabricated sandwich concrete elements with only little insulation.

The buildings were worn down and looked grey and rather dull. There were problems with facades, windows, roofs etc. The energy demand was high and the indoor climate unsatisfactory. The buildings were in need of a in-depth make-over.

The housing company decided, supported by the tenants, not only to fix the problems, but also to upgrade the buildings to match new buildings with respect to energy demand, indoor climate, architecture and quality of life.

The exterior walls were insulated externally including the walls of the basement. Additional insulation was added to the roof, the old double-glazed windows were replaced by triple-glazed windows.

The old mechanical exhaust ventilation system was replaced by an efficient demand-controlled mechanical ventilation system with efficient heat recovery.

The added insulation and new ventilation systems improved the thermal comfort and air quality in the flats. The warmer walls and windows make it easier and more comfortable to utilize all m² of the apartments. All flats now have a balcony overlooking the also refurbished green areas of the courtyard surrounded by the blocks of flats.

A PV system on the roof of one of the blocks helps reducing the energy consumption of the common laundry facility.

The overall energy demand and energy bill for heating is reduced by 31%.

The electricity demand for ventilation has gone up, but the electricity production from the PV system covers around 60% of this increase.

Figure 25: Apartment block during renovation and another block before renovation

Practical experience

It takes longer to plan and carry out renovation than new construction, especially if the flats are inhabited during the process. It is important that the tenants get what they expect, so from the beginning it is necessary to spend a great deal of effort in making sure that the expectations are aligned with what can be achieved in practice. The tenants need to be included in the decision process (tenant democracy is mandatory in Denmark). The time schedule is important – the tenants need to know when something is going to take place in their dwelling. It is cumbersome to carry out work in flats, where people live – the individual craftsmen need to be considerate.

Security on the building site has to be the very best – it has to consider the tenants and especially children living on the building site. The consultants and the contractor succeeded in this in the Traneparken project.

Conclusion

Needed building renovation like repairs of walls and replacement of windows are sometimes referred to as "anyway measures". In this case, these anyway measures made a comprehendsive – deep-energy retrofit possible – resulting in considerably reduced energy consumption, improved indoor climate and additional useful space for the tenants.

References

[1] Building Association Zealand

[2] Cenergia Energy Consultants

[3] SBi/AAU

[2] DTI.

Appendix 4

Rainha Dona Leonor neighborhood

Social housing renovation

Owner: Domus Social

Architect: Inês Lobo Arquitectos, Lda.

Report: Marco Ferreira / Ana Rodrigues

Location: Oporto, Portugal

Date: November 2014

Key technologies
- Insulation of the building envelope
- Windows renovation with introduction of double glazing
- Efficient heating systems
- Solar Thermal to support DHW production

View of existing (small picture) and the renovated building (large picture)

Background

The building is part of a social housing neighbourhood built in 1953 with several two floor buildings with variations in the area and the number of bedrooms. It also has 3 apartment blocks, but the renovation program that is taking place includes only the two floor multifamily buildings.

The neighborhood consisted of 150 dwellings, but after the complete renovation they will be only 90 due to the aggregation of very small apartments. The architectural and urban original characteristics are kept and restored by keeping the buildings boundaries, volumes, main facades elements and accesses.

The dwellings had very small areas which led the users to build external additions to increase the living areas. The age and lack of maintenance took the neighbourhood to a significant state of degradation.

Since all the neighbourhood had never been submitted to significant renovation, none of the buildings had thermal insulation or installed heating or cooling systems and the windows were the original wooden framed with single glazing. The domestic hot water was provided by an electric heater with a storage tank.

The main goals of the intervention were to improve the livability of the dwellings and common areas and simultaneously restore consistency and homogeneity of the group of buildings, by subtracting the added forms, restoring the design and shape of the original volumes.

The present analysis refer to one of these buildings with two dwellings, one per floor.

Figure 1a and 1b. General buildings' conditions before renovation

Table 1: Building elements basic dimensions and thermal performance

Element	Area (m²)	U – Value (before renovation)
Exterior walls	141	1,38/1.69
Windows	16,9	3,40
Roof	73,7	2,62

Figure 2: Urban context

Project data of building before renovation

Altitude 76 m
Heating degree days 1649
Cooling degree days –
Year of construction 1953

Gross heated floor area 123 m²

Specific heating energy need excl. hot water: 119,70 kWh/(m²a)

Specific cooling energy need: 6,49 kWh/(m² a)

Specific hot water energy need: 37,09 kWh/(m² a)

Type of energy carrier for heating: Electricity

Type of energy carrier for DHW: Electricity

Specific heating energy consumption (excl. hot water) 119,70 kWh/(m² a)

Specific hot water energy consumption 43,63 kWh/(m² a)

Installed heating capacity 8,0 kW

Specific electricity consumption (excl. hot water and heating) 32,33 kWh/(m² a)

Energy costs 4948 €/a

Renovation concept


Figure 3: Renovated building vs building under renovation

The neighbourhood was in need of deep renovation, not only because of degradation of the physical elements but also because the dwellings were not adjusted to today minimal living standards. The living areas were increased and the indoor comfort has been improved.

The comfort was achieved by introducing insulation on the walls and roof. Double glazed windows were introduced and interior sun blinds were installed for solar protection. For heating and cooling an HVAC systems has been introduced and for the DHW solar thermal panels were installed and the electric water heater with a storage tank is now only used as back up.

Design data for renovated building

Year of renovation 2012

Gross heated floor area 123 m²

Specific heating energy need excl. hot water: 68,55 kWh/(m²a)

Specific cooling energy need: 7,86 kWh/(m² a)

Specific hot water energy need: 27,13 kWh/(m² a)

Type of energy carrier for heating: Electricity

Type of energy carrier for DHW: Electricity

Specific heating energy consumption: (excl. hot water) 19,34 kWh/(m² a)

Specific hot water energy consumption 31,92 kWh/(m² a)

Installed heating capacity: 10 kW

Specific electricity consumption (excl. hot water and heating): 32,33 kWh/(m² a)

Energy costs: 1491 €/a


Figure 4: Facades renovation

Table 1: Building elements basic dimensions and thermal performance after renovation

Element	Area (m²)	U – Value (after renovation)
Exterior walls	141	0,45/0.48
Windows	16,9	2.90
Roof	73,8	0.64


Figure 5: Renovation plans (in yellow demolitions and in red new elements)

Renovation design details

The renovation concept focused primarily on the redefinition of the living areas once one of the main limitations was the lack of space inside the dwellings. The four original dwellings with two bedrooms were transformed into two dwellings with two bedrooms each.

It was also necessary to renovate the facade of the building and repair several exterior degraded elements thus, improving the building envelope. Intervention on walls, roof and windows was necessary, even if no improvement in energy performance was particularly desired. Given the relevant intervention in the building envelope, the opportunity to significantly improve its energy performance was explored.

Before renovation there were no building integrated heating or cooling systems as happens in most of the old buildings in Portugal. There are no cooling system and heating is provided by portable electric equipment. DHW was provided by an electric water heater. In the case of these systems the opportunity was taken to allow the users to control the indoor temperature without relevant energy costs installing efficient equipment and renewables harvesting was introduced to reduce the energy use with DHW.

Although none of the used measures are out of the current market practice in Portugal, their combination allowed to achieve the rank B- in the Portuguese energy certification scheme, which means that the primary energy use for heating, cooling and DHW is below the maximum allowed for new buildings.

Facade Solutions

The external walls were single brick walls 20cm thick in the lower floor and thinner walls with 15cm in the upper floor without any insulation. The adopted renovation solution consisted in the application of ETICS system on the external side of the wall with a 6cm thick layer of EPS.

The addiction of internal insulation would reduce the inside areas, which was already a problem, and reduce the building thermal inertia. So, external insulation was the option for increasing the thermal performance and also for aesthetical reasons.

The U-value of the external walls have been improved from the original 1,69 and 1,38W/m²K to 0,48 and 0,45W/m²K respectively in the upper and lower floors.

Also regarding the design of the façade openings there's been some changes with larger glazed areas on the living room. The original glazed areas were rather small with the new windows allowing more natural lighting and visual contact with the exterior.

The windows external protection was removed and inside sun blinds were adopted for aesthetical reasons. This option led to some problems with the control of natural lighting during summer (to control the heat gains during summer, no natural light and external views are possible) and also with the space that internal doors use to open and close.

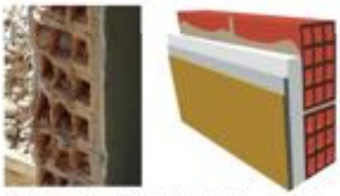


Figure 7: External walls before renovation and the adopted solution

Figure 6: Main façade changes in the openings

Figure 8: Roof renovation solution

Ground floor solution

The ground floor did not received insulation. The intervention was mainly to replace the water pipes and sewer tubes and affected only the surface layers of the floor. The low-ceiling height didn't allowed to raise the ground floor in order to place insulation on it. To do so, it would be necessary to dig deeper in the floor and rebuilt the hole floor, increasing significantly the construction waste.

Roof Solutions

The roof has fibre cement plates resting on a wooden structure. Between the cover and the inside area, there was a lightweight slab.

After the renovation the lightweight slab has been removed and instead of it, it was placed a suspended ceiling. Between this ceiling and the fibber cement plates, 5 cm thick XPS panels have been placed.

This solution reduces the heat losses during winter by the reduction of the thermal transmittance of the element, reduces the volume of internal air to be heated during cold season due to the reduction of the height of space to be heated and leaving the space between the insulation and the external roof slightly ventilated which allows the removal of the significant heat gains during hot season to be naturally removed by ventilation.

The U-value of the roof has been improved from the original 2,62W/m²K to 0,64W/m²K, contributing not only to the improvement of the energy performance of the upper dwelling but also to the comfort of the occupants.

Window solution

The existing windows had wooden frames and single glasses (g=0.88). The U–value was high (3.4W/m².ºC), which combined with significant air leakage due to the lack of adequate maintenance and wood degradation makes them very energy inefficient and uncomfortable.

The windows were protected by external blinds with external blind boxes which were now removed.

The renovation solution was to replace the windows by new ones also with wood frames but with double glass and adequate air tightness.

The new windows have a U-value of 2.9 W/m². ºC and a solar factor of 0.78.

To allow the existence of an air renewal rate that assures the indoor air quality, the windows are equipped with air intake devices that passively allow the natural ventilation of the main spaces of the dwelling.

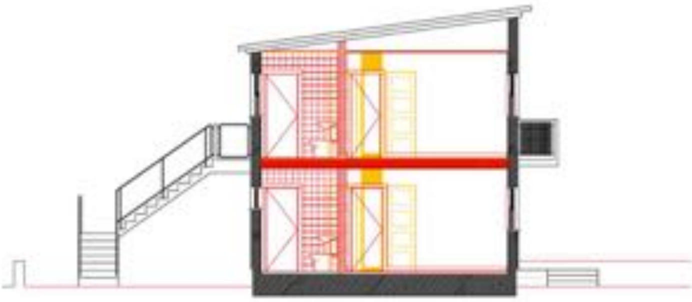


Figure 9: Building section

Figure 10: Building with new windows and blackouts

Heating and cooling

An HVAC system for heating and cooling has been installed. It is a multi-split system, with a COP 4,1 EER 3,50. It has an external machine and three internal splits, on each dwelling. The life time for these equipment is fifteen years.

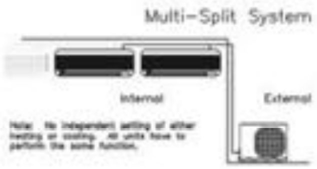


Figure 11: Heating and cooling system technical scheme.

The installed system allows the occupants to adjust the internal temperature of the dwellings whit, in cold season, approximately four times the efficiency of the former system. The installed system can also be used during summer to deal with the over heating moments, although calculations indicate that normally cooling will not be necessary once the thermal inertia of the building, the control of the heat gains and the crossed natural ventilation will probably be enough to keep a comfortable condition inside the dwellings.

The current thermal regulation in Portugal considers the cooling energy needs, depending on the value of the gains utilization factor. When it is lower than the reference value, the energy needs for cooling are despised.

In the case of this renovation, the inclusion of insulation on the roof is the major responsible for the change on the gains utilization factor.

Hot water installations

The system for the preparation of hot water is a solar thermal collector linked to a storage tank with an electrical resistance.

The distribution system is really simple and supplies directly the hot water taps and repeats the existing solution. Although, the new storage tank has 5 cm of insulation reducing significantly the thermal losses and increasing the systems efficiency.

Ventilation

The ventilation is made by natural means, using crossed air circulation by opening the windows.

The new windows and doors increased significantly the air tightness of the dwellings, but adequate air renewal rates are assured by air admission incorporated in windows.

Natural ventilation is also used to remove the heat gains of the unheated space under the roof.

Figure 12: Schematic of the solar water heating system.

Figure 13: Ventilation grids (casa vivaobras,2014)

Figure 14: Renovated buildings.

Integrated Building Performance

Ecological/Environmental sustainability

Comparing the reference scenario, which corresponds to the renovation of the building without improving its energy performance, with the chosen renovation, the global warming potential suffers a reduction from 17,2 $kgCO_{2\text{-}eq}/m^2.a$ to 15,8 $kgCO_{2\text{-}eq}/m^2.a$.

Comparing the same renovation scenarios, the total primary energy reduction is around 26 $kWh/m^2.y$, considering the energy use and also the energy embodied in materials and integrated technical systems installed in the building.

Regarding the energy performance level according to the national certification scheme, the initial energy level for the ground floor was C and for the first floor was D. The building renovation allowed the dwellings to reach the level B- which is the minimum level for the new buildings (Figure 15).

Figure 15: Buildings aspect after the renovation

Economical sustainability

As this case is a social neighbourhood, it was important to use solutions with low cost which allowed to reach significant energy savings and long term low maintenance costs.

The renovation solution, when compared to renovation without energy improvement, does not have major impact in the costs during the buildings life cycle. The extra investment costs in the insulation materials is easily recovered through the energy savings after the buildings renovation.

Sociocultural sustainability

The renovation process allowed to improve the living conditions through the reduction of the heat losses through the envelope, reduction of the thermal bridges and reduction of the probability of condensation problems. It also improved the buildings energy performance which leads to the reduction of the energy consumption and energy costs. It allows to have better indoor temperature and humidity conditions, improving the health conditions.

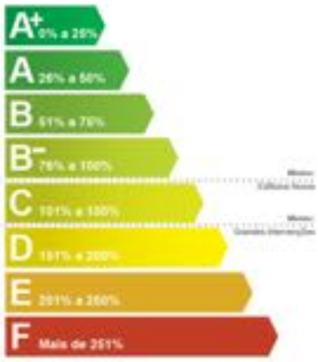


Figure 16: Energy performance levels in national certification scheme

Ecological/Environmental Sustainability

Global Warming Potential	$[kgCO_{2\text{-}eq}/m^2a]$	15,80
Total Primary Energy	$[MJ/m^2a]$	926,30
Non-renewable Energy	$[MJ/m^2a]$	782

Improvements & Co-benefits

Table 2: Evaluation of co-benefits of different renovation scenarios

	CO-BENEFITS	Thermal Comfort	Natural Lighting	Air Quality	Building Physics	Internal Noise	External Noise	Ease of Use / Control by User	Reduced Exposure to Energy Price Fluctuations	Aesthetics	Useful Living Area	Pride / Prestige	Ease of Installation / Reduced Annoyance
Ref. Pack.	Replacement of heating system												
	Replacement of DHW system												
Renovation Package 1	Insulation of entire building envelope	P			P				P	P		P	
	Internal shading	P	N					N			N		
	Replacement of heating system	P						P	P				
	Replacement of DHW system								P				
Renovation Package 2	Windows replacement	P											
	Insulation of entire building envelope	P			P				P	P		P	
	Internal shading	P	N					N			N		
	Replacement of heating system	P						P					
	Replacement of DHW system								P				
Chosen Renovation	Windows replacement	P											
	Insulation of roof	P			P				P				
	Insulation of facades	P			P				P	P		P	
	Internal shading	P	N					N			N		
	Replacement of heating system	P						P					
	Replacement of DHW system								P				

Legend: P - Positive Effect; N - Negative Effect

The improvement of the energy performance of the building, besides reducing life cycle costs, the total primary energy use and the carbon emissions, induces several other benefits:

The thermal insulation on the building envelope bring the following co-benefits:

- Reduced problems with humidity and mold which were a relevant problem due to the age of the buildings and its state of degradation;
- The temperature of the inner surfaces naturally increased during cold season increasing the comfort for occupants;
- The insulation of the roof also increased the comfort during summer reducing the risk of over heating;

The new windows with double glazing and adequate air tightness also have contributed to better indoor comfort due to the increased temperature of the inner surface, but mainly because of the reduction of air drafts.

Their increased size could contribute to better use of natural lighting. Nevertheless, it was noticed on the other hand that these larger windows can be a source of overheating during summer.

It was also expected that the introduction of new windows with double glazing could have the co-benefit of reducing the external noise for the building occupants. However, due to the fact that the neighborhood is located in a very quiet area, the inhabitants felt no change related to acoustic comfort.

The introduction of internal shutters on these windows, presents negative co-benefits by imposing the close of the shutters for sun protection which represent a reduction of the natural lighting and visual relation with external environment.

These internal shutters, in their rotation movement to open and close, create useless areas inside the rooms which is also a negative co-benefit regarding the useful living area.

The replacement of the heating system allowed to improve the operational comfort by better and easier control of indoor temperatures.

In a more general perspective, the intervention contributed to increase the pride of the occupants on their neighborhood and restored the aesthetical value of the urban settlement.

All the measures improving the energy performance of the building contribute to a reduced exposure to energy price fluctuations.

Methodology

The methodology developed in Annex 56 for cost effective energy and carbon emission building renovation was applied to evaluate and compare different building renovation scenarios.

A total of six combinations of building integrated technical systems (BITS) was tested, namely:

- Gas boiler for heating and DHW preparation;
- Heat pump for heating and DHW preparation;
- Heat pump for heating and DHW preparation combined with solar photovoltaic panels;
- Biomass boiler for heating and DHW preparation;
- Multi-split air conditioned for heating and cooling and electric heater for DHW preparation;
- Electric heater for heating and solar thermal backed up by an electric heater for DHW preparation;

With the use of each of these combinations of BITS, different packages of measures to improve the energy performance of the building envelope have been tested, including intervention on the roof, façade, windows and floor.

Packages of measures can include the improvement of all the elements of the building envelope, with different performance levels, or the intervention on only some of the elements.

Besides the testing of packages of measures with different energy performance levels, also the insulation materials have been changed. For each of the initial renovation packages, the insulation has been changed to Cork Boards (ICB) in order to evaluate the impact of using insulation materials with lower embodied energy.

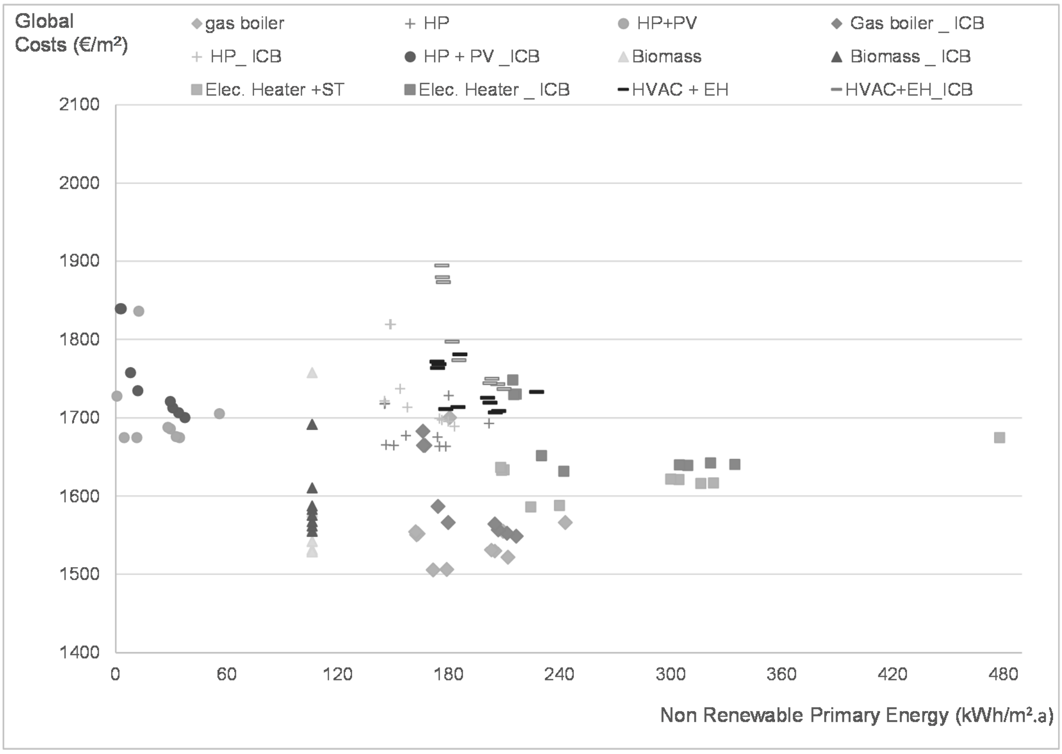


Figure 16: Ecological/Environmental sustainability results

Methodology

Figure 16 presents the results for the non-renewable primary energy costs and global costs for each of the evaluated package of measures.

The non-renewable primary energy value includes the energy use for heating, cooling (when needed), DHW and lighting .

The global costs are calculated from a private perspective (including all taxes and subsidies) with a discount rate of 6% and include investment costs, energy costs, maintenance costs and replacement costs.

From all the evaluated scenarios, for were chosen for a more detailed analysis:

- **Reference case scenario**: In this scenario, the building is renovated without improving its energy performance. Measures to restore the building functionality are applied on the elements of the building envelope and standard BITS of the same type of the used ones are installed once the lifetime of the existing has expired.
- **Chosen renovation scenario**: In this scenario, the measures that have been applied in the field have been evaluated. The chosen renovation scenario presents the most current renovation praxis in Portugal, with significant limitation on the investment costs and no major concerns with life cycle costs, specially in cases such as this where the investor is not the one who pays the future energy bills.
- **Alternative scenario I**: This scenario refers to the one with lower global costs from the analysis presented in Figure 16, including intervention on the roof, the floor and walls. Only windows are not changed because this measures doesn't lead to a reduction of the global costs. Besides the combination of BITS from the cost optimal scenario, also other three combinations of BITS have been evaluated.
- **Alternative scenario II**: In this last scenario, the same four combinations of BITS that were tested in "alternative scenario I" have been evaluated (gas boiler for heating and DHW; multi-split HVAC for heating and solar thermal electrically backed up for DHW; biomass boiler for heating and DHW; heat pump for heating and DHW with photovoltaic panels). Regarding the measures on the building envelope, the best energy performance was searched with all the building elements being improved and the insulation material is always the insulation cork boards to evaluate the impact of its lower embodied energy.

Next pages describe the results of the evaluation of each of these renovation scenarios regarding costs, energy and environmental impact.

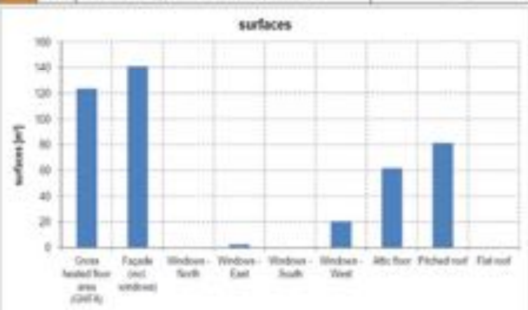
Previously, on Table 2, the other benefits have been explored.

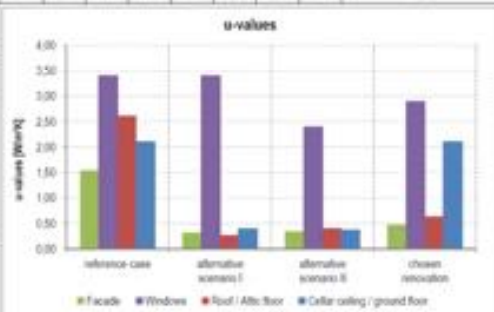
Table 3: Comparison of different renovation scenarios

		reference case	alternative scenario I	alternative scenario II	chosen renovation
justification and statement	**strengths, co-benefits**	This solution has low investment costs and improves the buildings image and living conditions by increasing the living area.	This scenario is the cost optimal solution for the buildings envelope. It improves the energy performance, the comfort and the living conditions. It has the best balance between costs and energy performance during the buildings life cycle.	This scenario is the one with lower primary energy consumption. It improves the energy performance, the comfort and the living conditions. It uses cork which is a green product.	This scenario improves the buildings energy performance, by reducing the energy needs. It also improves the comfort and living conditions.
	weaknesses, additional costs	It does not improve the buildings energy performance and it has high energy costs during the building life cycle. It does not have any environmental cares.	It is not the best solution in terms of primary energy consumption. It does not have any environmental cares.	This scenario requires a bigger investment than all the others, specialy on the buildings envelope.	When compared to the alternative scenarios it has worse energy performance and higher costs during the buildings life cycle. It does not have any environmental cares.
Conclusions	**Conclusions of comparison; why was final solution chosen, how does it relate to refrence case and alternative scenarios?**	Concerning the costs, the chosen solution is between the reference solution and the cost optimal solution. The investment costs for this scenario are among the ones with lower costs.			

Comparison of renovation measures

			reference case	alternative scenario I				alternative scenario II				chosen renovation
renovation measures	Building envelope	roof	Maintenance	Maintenance and inclusion of Rockwool with 14cm				Maintenance and inclusion of Insulation Cork Boards with 8cm				Maintenance and inclusion of XPS with 5cm
		facade	Maintenance	ETICS with EPS with 10cm				ETICS with Insulation Cork Boards with 8cm				ETICS with EPS with 6cm
		glazing/frame	Maintenance	Maintenance				New wood frames with double glazing				New wood frames with double glazing
		floor	No intervention	Rockwool with 8 cm				Insulation Cork Boards with 8 cm				No intervention
	BITS	Heating	Eletric heater	HVAC	Gas boiler	Heat pump + PV	Bio boiler	HVAC	Gas boiler	Heat pump + PV	Bio boiler	HVAC
		DHW	Electric heater with storage tank	Electric heater	Gas boiler	Heat pump + PV	Bio boiler	Electric heater	Gas boiler	Heat pump + PV	Bio boiler	Electric heater with storage tank
		Cooling	HVAC	-				-				-
		Auxiliaries	-	-				-				-
		Lighting	-	-				-				-
		Ventilation	Natural	Natural				Natural				Natural
		(Common appliances)	-	-				-				-
characteristic values	heating	Calculated energy demand for heating [kWh/m²a]	84.92	25.64	25.64	25.64	25.64	20.97	20.97	20.97	20.97	33.00
		Energy carrier of heating system	Electricity	Electric	Gas	Electric	Biom.	Electric	Gas	Electric	Biom.	Electricity
		Conversion efficiency of heating system	1.00	4.10	0.93	3.33	0.92	4.10	0.93	3.33	0.92	4.10
		2nd energy carrier of heating system	-	-	-	-	-	-	-	-	-	-
		2nd conversion efficiency of heating system	-	-	-	-	-	-	-	-	-	-
		Share of 2nd energy carrier on heating energy demand	-	-	-	-	-	-	-	-	-	-
	DHW	Calculated energy demand for DHW [kWh/m²a]	28.85	28.85	28.85	28.85	28.85	28.85	28.85	28.85	28.85	28.85
		Energy carrier of hot water system	Electricity	Electric	Gas	Electric	Biom.	Electric	Gas	Electric	Biom.	Electricity
		Conversion efficiency of hot water system	0.80	0.80	0.93	3.33	0.92	0.80	0.93	3.33	0.92	0.80
		2nd energy carrier of hot water system	-	-	-	-	-	-	-	-	-	-
		2nd conversion efficiency of hot water system	-	-	-	-	-	-	-	-	-	-
		Share of 2nd energy carrier on hot water energy demand	-	-	-	-	-	-	-	-	-	-
	cool.	Calculated energy demand for cooling [kWh/m²a]	16.52	8.14	8.14	8.14	8.14	8.59	8.59	8.59	8.59	7.86





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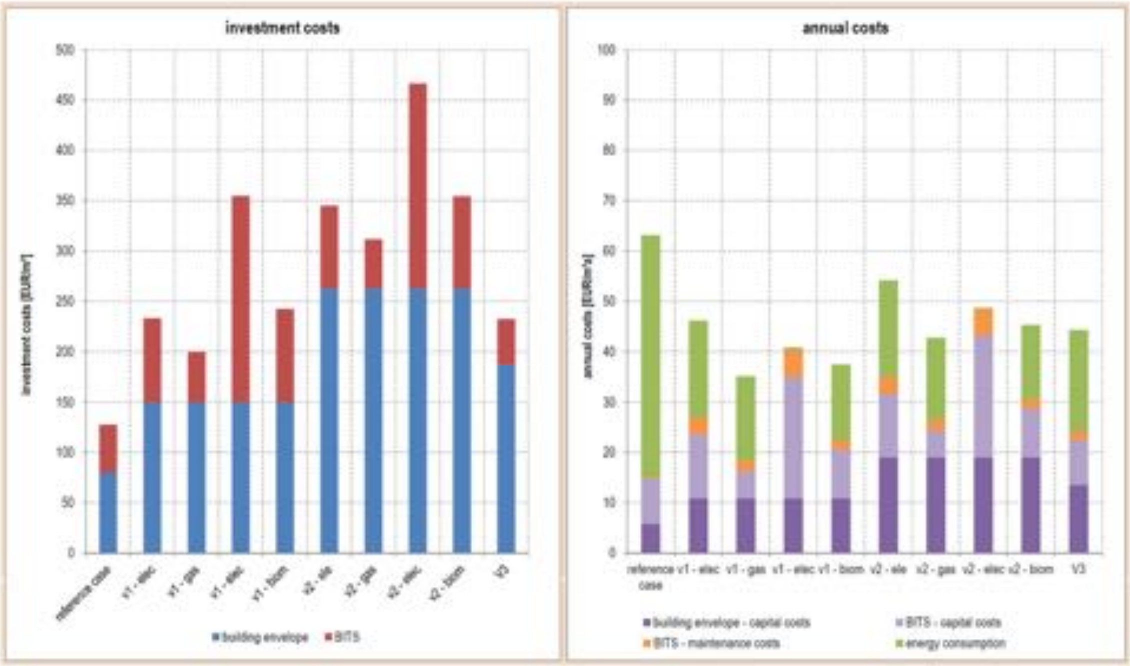
Comparison of renovation measures - LCC



Description and analysis of the LCC results

Analysing the investment costs it is possible to conclude that the solution with lower costs is the reference case, followed by the alternative scenario I with the gas boiler for heating and DHW and then by chosen renovation solution.

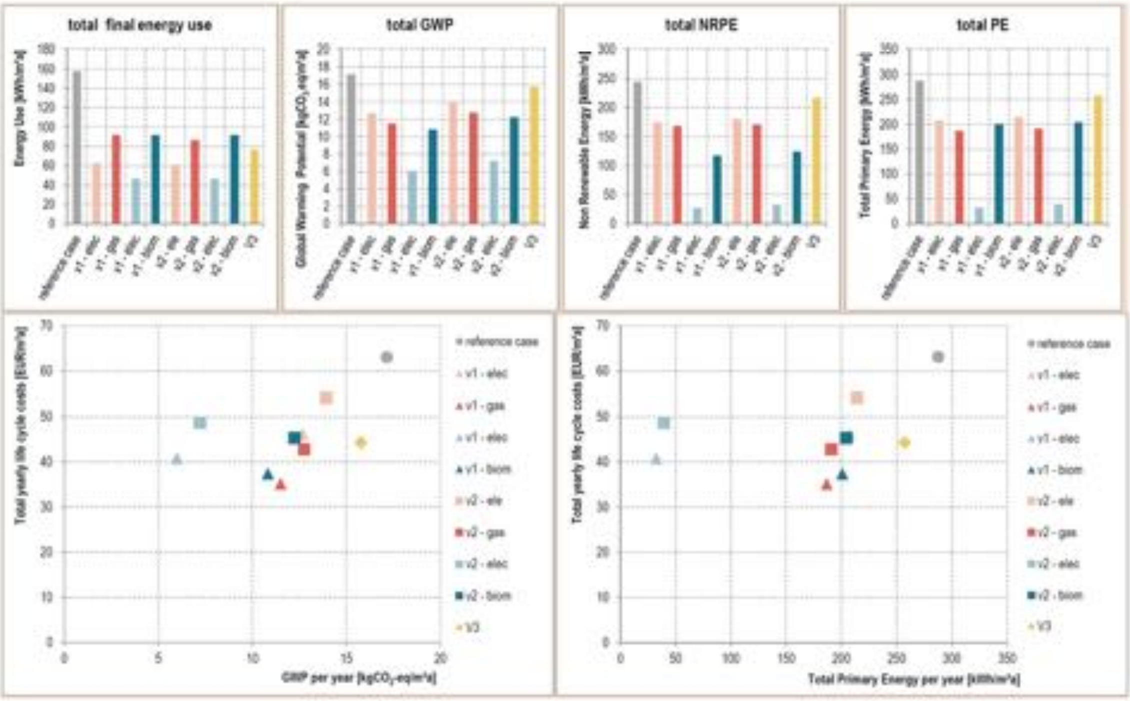
Considering the annual costs the scenarios with lower costs are found among the alternative solutions I and II, more precisely in the ones which account with the gas boiler and biomass boiler. The chosen renovation is one of solutions with higher annual costs. The difference between scenarios are mainly driven by the energy costs and BITS capital costs.

When comparing the cost optimal renovation scenario (v1 with gas) with the chosen renovation scenario (v3) it is interesting to understand that although the chosen renovation presents higher investment costs, the results on life cycle global costs, energy and environmental impact are significantly better on scenario v1. This is mainly due to the fact that the investments on the building envelope were driven for the elements with more impact on the energy performance of the building (façade, roof and floor) and to optimal widths of insulation.

When comparing the alternative scenarios I and II, it is possible to understand that the further improvement of the building envelope beyond the cost optimal level increases the global costs, nevertheless, only with the use of one of the BITS combinations the alternative scenario II is not cost effective when compared with the reference case .

The analysis globally shows a strong relevance of the choice of the combination of BITS on global costs and the fact that, although the intervention on certain elements of the building envelope is not recovered by the energy savings, the combined improvement of all the envelope elements to a cost optimal level leads systematically to cost effective solutions when compared with a building renovation without improving its energy performance.

Comparison of renovation measures - LCIA



Description and analysis of the LCIA results

The LCA analysis was developed using the software Sima Pro.

The database used was LCI Ecoinvent V2.2.

Concerning the energy use, the variant with higher total energy use is naturally the reference case. The ones who have less total energy use are V1 and V2 with the heat pump backed by the photovoltaic panels.

The global warming potential results show that also V1 and V2 with the Heat pump backed by the photovoltaic have the lowest GWP. Between both, the scenario the V1 has the lowest environmental impact and total primary energy use.

For the non renewable primary energy the solutions with lower energy are also V1 and V2 considering the heat pump backed by photovoltaic panels. In all the analysed parameters, there is a very strong correlation with the combination of BITS that are used. Results between scenarios v1 and v2 using the same combinations of BITS present very similar results.

Referring to the total primary energy the solution with the lowest value is scenario V1, with the heat pump and photovoltaic panels for electricity generation. Highest values are achieved by the renovation scenarios using electricity without the photovoltaic panels, including the reference case, the chosen renovation and alternative scenarios V1 and V2 using HVAC and electric heating and also electric DHW preparation (even if only backing up solar thermal panels).

Globally, best results regarding the environmental impact are achieved by alternative scenarios V1 and V2 using the heat pump for heating and DHW preparation backed by the photovoltaic panels. Scenarios using electricity without PV generally present the higher environmental impact.

Comparing the GWP and the total primary energy analysis, it is clear that the hierarchy between the alternative scenarios is kept, with the exception of the cases which include the biomass boiler.

Summary and conclusion

Considering the developed analysis, several conclusions can be drawn from the comparison between the reference case, the chosen renovation and the proposed alternative scenarios.

The reference case naturally presents the worst results regarding the energy use, but it also presents the highest environmental impacts and even regarding costs, almost all tested scenarios are cost effective when compared with this reference case.

The chosen renovation, although presenting better results regarding energy and costs, it becomes clear from the analysis that it possible to make a better use of the invested money, namely choosing the most cost effective combination of building integrated technical systems and also investing on the elements of the building envelope in which higher reductions of the energy needs are achieved. Still regarding the intervention on the building envelope, from which several co-benefits for the occupants are identified, it is clear that an intervention including all of its elements is cost effective, even if including some measures for which the investments costs are not recovered by the reduction of the energy costs.

Regarding the environmental impact it was noticed that the use of the heat pump backed by photovoltaic panels has the best results among the analysed BITS.

A significant aspect related with local climatic context, is the fact that only for the reference case (building without improvement of the energy performance), calculations indicate the need of an active system to deal with cooling needs. All the renovation scenarios improving the building envelope lead to a reduction of the risk of summer overheating to a level that is negligible.

This is an important issue for Portugal, where cooling needs are a problem for inefficient and wrongly designed buildings.

Practical experience

With the renovation of these buildings, the city hall achieved two main goals: return the confidence to the neighborhood and improve the living conditions of the local population.

Additionally, the potential reduction of the non renewable primary energy consumptions for heating, cooling and DHW preparation is about 70%.

The overall improvement of the neighborhood allowed to transform it into the best social neighborhood of Porto city according to the evaluation of the municipality, with comfort and livability conditions much better than other recently built neighborhoods.

Results from a set of interviews with building occupants refer mainly to benefits besides energy and environmental impact. In fact, the most important changes from the occupants perspective were the aesthetical improvement and the recovered dignity and identity of the neighborhood at the global scale and ate the building level the increase of space, the elimination of building pathologies such as humidity and mold and the improved thermal comfort conditions.

Appendix 5

Lourdes Neighborhood, Tudela

Caparroso Paños 11

Owner: Private ownership

Architect: MARQUITECTOS

Energy concept: MARQUITECTOS

Report: University of Navarra

Location: Tudela, Spain

Date: November 2014

Key technologies

- Improved thermal envelope
- Upgrade of existing district heating network and energy production by renewable sources.

View of the renovated building within the lineal block to which it belongs (left picture) and detail of the renovated facade beside another one that has not been renovated (right picture).

Background

This residential building was built in 1970 and is a part of a big social neighborhood with low quality construction. It is a five story building with a northwest – southeast axis. Main façade is 20 meters long with a depth of 21 meters. It has 4 dwellings per floor of approximately 80 m² of gross space (70 m² of net area). The staircase is located in the middle of the building and a new elevator was installed some years ago. Private and commercial locals at street level are nowadays unused.

Building envelope

The building lacks of any insulation. The existing facade was made of a single hollow brick with 25 cm of width. The floor of the first floor (in contact with unheated spaces) is made of a concrete beam slab with ceramic hollow fillers. The old pitched roof has an unheated space under it and is covered by ceramic tiles. The original wooden windows were nearly all replaced by owners at different times during the last years so their thermal performance is variable.

Figure 1: Urban context, in color the buildings whose heating is supplied by the same district heating system.

Facilities

The building was connected to an inefficient district heating grid with gas boilers (originally oil boilers with the burner changed to use gas). The distribution network had huge thermal losses. There were any kind of individual regulation and any energy meters. The heating was paid according to dwelling's area. Individual electrical boilers for domestic hot water are installed in different times by occupants. There are only a few individual air conditioning units and no energy saving system for lighting or common appliances.

Project data of building before renovation

Altitude 264 m
Heating degree days $1534_{(15/15)}$ Kd
Cooling degree days $486_{(18/18)}$ Kd
Year of construction 1970

Gross heated floor area 1453 m²

Specific heating energy need excl. hot water 120 kWh/(m²a)

Specific cooling energy need 5,8 kWh/(m²·a)

Specific hot water energy need 25,4 kWh/(m² a)

Type of energy carrier for heating Natural gas

Type of energy carrier for hot water Natural gas / electricity

Specific heating energy consumption (excl. hot water) 171,4 kWh/(m² a)

Specific hot water energy consumption 29,9 kWh/(m² a)

Installed heating capacity 5235 kW for 40.448m² (District heating)
Specific electricity consumption (excl. hot water and heating) 25,2 Wh/(m² a)

Energy costs 22647 €/a

Figure 2: Floor plan of the building (left picture) and of a dwelling (right picture).

Renovation concept

Figure 3: Main facade of the building once it has been renovated.

Design data for renovated building

Year of renovation	2011
Gross heated floor area	1474 m²
Specific heating energy need excl. hot water	45,3 kWh/(m²a)
Specific cooling energy need	0 kWh/(m² a)
Specific hot water energy need	25,4 kWh/(m² a)
Type of energy carrier for heating	Biomass / Gas
Type of energy carrier for hot water	Natural gas / electricity
Specific heating energy consumption (excl. hot water)	45,3 kWh/(m² a)
Specific hot water energy consumption	29,9 kWh/(m² a)
Installed heating capacity	3435 kW for 40.448m²
Specific electricity consumption (excl. hot water and heating)	48,3 kWh/(m² a)
Energy costs	10017,9 €/a

Figure 4: Installation of exterior insulation.

The retrofit concept is based on energy efficiency measures focused on the envelope (exterior insulation and improved window performance), a high ratio of renewable energy for heating (biomass) with a high efficiency in its generation and distribution.

The main targets were:

- Renovate the buildings due to its deep degradation state.
- Renovate the envelope in order to improve indoor comfort and decrease thermal losses.
- Improve efficiency of district heating and reduce its CO_2 emissions.
- Improve supply lines: electricity, gas distribution, telecommunications, lines.

Heating:

Biomass and gas district heating system for 486 dwellings and a total of 40.448m2 heated. Total installed power of 3.435 kW.

Cooling, DHW, Ventilation, Lighting:

No improvements performed.

Figure 5: Building before and after the renovation.

Renovation design details

Figure 6: Section, thermal envelope

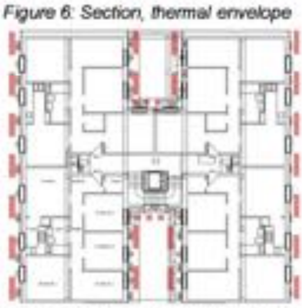


Figure 7: Floor plan, new thermal envelope.

Given the limited budget available the main objectives of this retrofit were three: improve the thermal performance, improve aesthetical appearance of the building and reorganize the facilities lines arranged in the main facade.

Roof Solution

The original pitched roof was renovated. 6 cm of extruded polystyrene was added to the titled slab and a water proofing membrane, tiles were replaced by new ones (See Figure 9).

New telecommunication systems were updated and individual antennas were relocated from the façade to the roof.

Figure 9: Roof under construction.

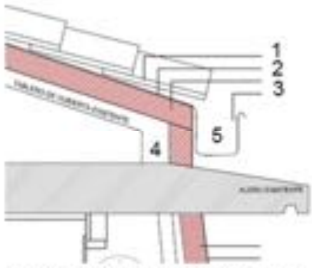


Figure 10: Construction detail D1. Roof detail

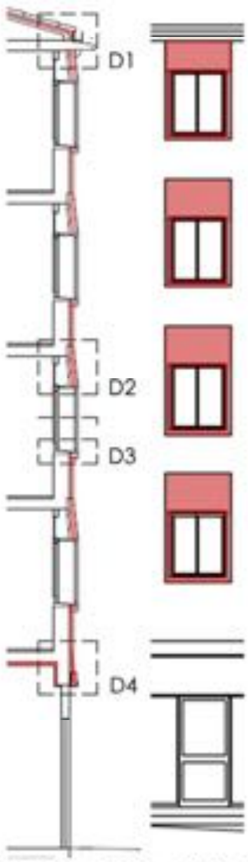


Figure 12: Façade section and elevation.

Figure 8: Preservation state of the facade in the courtyard .

Figure 11: Preservation state of the back facade.

Figure 13: Courtyard after the renovation.

Facade Solution

First of all, it was needed to remove old facilities, fix and open new holes for existing and future exhaust pipes from gas boilers for DHW. A single layer of 6 cm of expanded polystyrene was installed covered by and acrylic elastic mortar.

To ensure thermal uniformity along the façade, interrupted by existing concrete prefabricated panels around the windows, insulated aluminium modules were installed (see Figure 14 & 15).

Windows Solution

Additional sliding aluminium windows were adapted to this frame (Number 10 in Figure 14 & 15), improving the overall performance and aesthetical appearance of the building.

Description of construction details

1. Ceramic tile
2. Water proofing membrane
3. 6cm extruded polystyrene
4. Original ceramic panels
5. Rain water gutter
6. Folding aluminium piece
7. 6cm expanded polystyrene
8. Existing precast concrete piece
9. Holding System structure
10. Additional sliding aluminium window LowE 6.16.6 glass
11. Existing window
12. Existing façade
13. Hidden distribution lines
14. 10cm mineral wool
15. 3cm cellular glass

On the drawings, marked in red, it can be seen where the thermal envelope of the building has been improved.

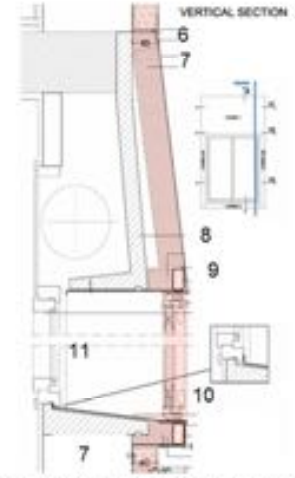


Figure 14: Construction detail D2 & D3. Vertical window section.

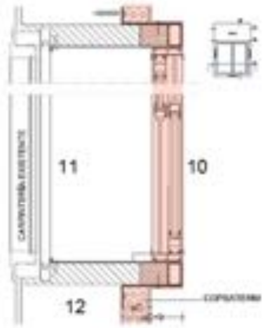


Figure 15: Construction detail D2 & D3. Horizontal window section.

First floor solution

First floor slab in contact with unheated locals was insulated with 10 cm of mineral wool, installed on the ceiling in the entrance of the building or in a hanging ceiling over the unheated locals.

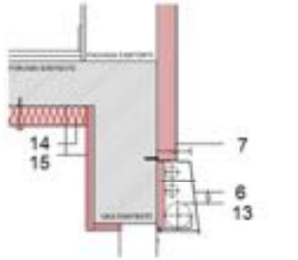


Figure 17: Construction detail D4 Entrance detail. Insulation under the first floor slab (on the ceiling of ground floor) in contact with unconditioned space.

Figure 18: Installation of the insulation on the ceiling of the ground, space that is unconditioned.

Figure 16: Installation of facade insulation, 6cm extruded polystyrene.

Heating

Figure 19: District Heating area, marked in red the building under study.

The building was connected to an inefficient district heating grid from 1970 which was at the end of its technical life. It had gas boilers (originally oil boilers with the burner changed to use with gas). The distribution network had huge thermal losses.

As auxiliary boilers for peak demand 3 condensation boilers, with a heating individual power of 665 kW, were installed. Total gas installed power is 1995 kW. This way the total power installed is 3435 kW.

In the dwellings, there were any kind of individual regulation systems and any energy meters; the heating was paid according to dwelling's area. During the systems renovation, wireless thermostats were installed in every dwelling, maintaining old radiators with new regulation valves. Likewise energy meters were installed in every dwelling.

In Figure 20, the measured energy consumption of the last years for the whole district heating is summarized.

First of all, it is necessary to say that the energy used before the renovation was a bit lower than needed to maintain the internal temperatures required by legislation. But it is remarkably the consumption reduction after the district heating renovation taking into account that only 44 dwellings (of 486) belonging to the district heating has been retrofitted. This could be due to:

-Big previous thermal losses in the distribution.

-After the renovation, dwellers use less energy since now they are paying the energy they consume. This fact could lead to a situation where occupants don't use heating, making visible problems of fuel poverty in some dwellings.

It is necessary to say that the opportunity of reducing power capacity of the heating systems has been unexploited by not having first renovated all buildings.

		Operation time	Gas (m3)	Gas (kWh)	Pellet (kg)	Pellet (kWh)	Total (kWh)	Savings from origin
2010-2011	OLD SYSTEM	10:00-22:00	347.000	3.623.129	0	0	3.623.129	----
2011-2012	NEW SYSTEM	10:00-22:00	74.771	781.314	355.000	1.250.216	2.031.530	44%
2012-2012	NEW SYSTEM	24 h	37.591	405.983	340.870	1.470.096	1.876.079	48%

Figure 20: Measured energy consumption of the whole district heating for the last years

This district heating supplied heating to 486 dwellings with a total heated area 40.448 m².

Due to its poor condition, an integral renovation was carried out. The distribution system was replaced by insulated pipes; and boilers were replaced by more efficient biomass and gas ones.

The biomass boilers are 2 pellets and firewood boilers, of 720 kW individual power each of them. Total power installed is 1440 kW. Efficiency values are higher than 90%.

Figure 21: New boilers

Figure 22: District heating chimney

Buildings' consumption

Figure 19: District Heating area, coloured in blue the buildings that were renovated and surrounded by a blue line (CP 3 & CP 11) two buildings that weren't renovated (CP 1 & CP 9).

Once the district heating has been renovated, the energy consumption of each dwelling and building is being recorded.

As it can be seen in Figure 20, those buildings that had been renovated have an energy consumption more than 40% lower compared to those buildings where no renovation was carried out.

Therefore, despite the different use performed by the occupants an important reduction of the energy consumption is achieved through the energy efficiency measures performed in the buildings.

According to the calculations a 62% of reduction of the energy demand was expected, however its actual reduction is slightly lower. This performance gap may be due to a lower heating use in the existing buildings or a poor execution of building works.

Building	Time of heating use	1st winter 1/10/2011 - 20/03/2012 (kWh)	% of savings in buildings with renovated envelope *	2nd winter 1/10/2012 - 20/03/2013 (kWh)	% of savings in buildings with renovated envelope
CP 1	Day time	57.762,7		48.415,3	
	Night time			5.915,5	
	Global	57.762,7		54.330,8	
CP 3 (with renovated envelope)	Day time	38.663,7		26.681,2	
	Night time		33,06%	4.424,0	42,75%
	Global	38.663,7		31.105,2	
CP 9	Day time	50.228,9		43.939,6	
	Night time			7.419,1	
	Global	50.228,9		51.358,7	
CP 11 (with renovated envelope)	Day time	30.740,2		22.923,7	
	Night time		38,80%	4.729,3	46,16%
	Global	30.740,2		27.653,0	

*Figure 20: Measured energy consumption of four buildings of the same typology and construction. * This year the renovation of the buildings wasn't still finished when the heating period started.*

Hot water installations

Concerning to the domestic hot water no change has been performed, each dwelling has its own individual gas boiler and a few of them have electrical ones. These have been installed at different times by occupants and, therefore, their performance is variable.

Cooling

Some of the dwellings had individual cooling units installed by the owners. The cooling demand of the building prior to the renovation was low (around 6kWh/m²y) and only some days during the summer cooling is needed. During the renovation, these units were removed from the main facade and reinstalled in the interior courtyard.

Ventilation

There is not any system for mechanical ventilation neither in the existing building nor after the renovation. Nowadays, in residential buildings, there isn't any normative requirement for mechanical ventilation and, therefore, its installation is unusual.

Figure 21: Renovated courtyard with the cooling units.

Integrated Building Performance

Ecological/Environmental sustainability

The main goals of this process are: improve the habitability of dwellings through the thermal improvement of the envelope, improve the efficiency of the heating system and reduce emissions of existing district heating by renewable sources.

The choice of the materials was driven by technical reasons: suitability, durability, ease of installation and reduced maintenance costs.

Thereby, EPS insulation was chosen for the façade and XPS for the roof. In the ceiling of the ground floor rockwool was the insulation chosen. In Spain, recycling of insulating materials is not widespread so the choice of an insulation made of natural materials (cork, cellulose...) or rockwool is the most sustainable option.

Additional windows over the existing ones helps to reduce the amount of waste and the energy needed to produce a better quality window with the same performance than a double window.

In the case of the renovation of the district heating, it was necessary to replace the entire distribution network so the associated impacts are important. However, the choice of biomass as main energy carrier to cover the main demand for heating and gas for peak load is appropriate.

Economical sustainability

All the process was addressed by a willingness to make the bigger savings possible with a limited budget. During the decision making process all the choices were done to optimize the resources available –budget, materials, existing situation- to achieve reasonable savings and improve living conditions.

Building renovation had a reasonable costs although the district heating has bigger cost than other commonly used systems.

18 dwellings	Total by dwelling	Bank Credit €/month
Building retr.	21650 €	90 €
District heat.	4500 €	-

Figure 22: Total investment per dwelling.

Sociocultural sustainability

This neighbourhood was suffering a process of degradation, due to the poor quality of construction, living conditions and accessibility; the original population, very aged, is moving becoming an area with high concentration of immigrants. The process has led to an improved quality of life of the occupants through:

Better thermal comfort in winter and summer: thanks to the additional insulation and windows, dwellings can reach comfortable temperatures with lower energy use. It eliminates the need of cooling and reduces risk of overheating. Comfort is also increased by higher air tightness.

Indoor hygiene: Risk of mould growth and condensation has been reduced. However, air quality can only be controlled manually opening the windows.

Acoustical comfort: Additional windows gives a better acoustical insulation.

Individual control: thermostats and energy meters allow individual comfort and energy savings.

NO INSULATION INSULATION

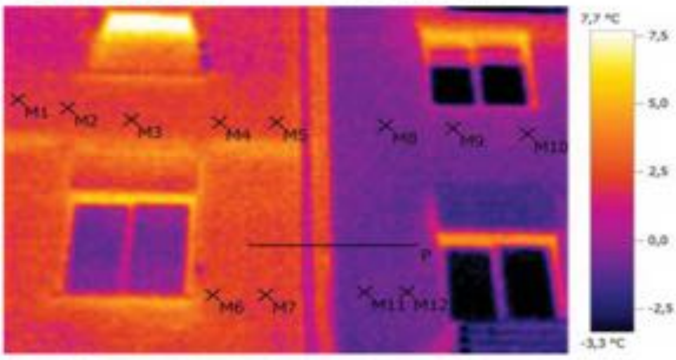


Figure 23: Thermography comparing insulated and not insulated facade.

Ecological/Environmental Sustainability

Global Warming Potential [$kgCO_{2-eq}/m^2a$]	21
Total Primary Energy [MJ/m^2a]	581
Non-renewable Energy [MJ/m^2a]	351

Integrated Building Performance - Construction sustainability

Construction process

Construction process tries to optimize all the resources available –budget, materials, existing building- to achieve reasonable results and living comfort.

Only the roof tiles and some old amenities were removed from the original building. New components hat have been installed in the building are: ETICS with EPS in facade, XPS and ceramic tiles in the roof, rockwool and hanging gypsum ceiling, new telecommunication lines and water pipe. Other distribution lines were rearranged in order to improve the appearance of the building.

Existing windows were maintained. New additional ones and aluminium modules are installed outside the existing ones. The standardization of windows modules and their production in factory reduce waste of material and construction time.

Keeping as many existing components as possible reduces the need of producing new materials and, therefore, the use of natural resources and energy.

Building material

Concerning recyclability, six significant materials should be considered: the most abundant, insulation, EPS, XPS and mineral wool, new ceramic tiles, new windows and aluminium modules windows and fixings:

EPS is recyclable and even often contains recycled material (not in this case). EPS is a suitable material for durability in facades although it should be highly protected against fire. XPS is not commonly recycled. And mineral wool isn't easily recyclable when combined with resins. Its recycling process has highly energy use.

An additional window has lower impacts than a new window with the same performance as both windows but it doesn't perform as good as a single window (air tightness isn't easily improved, condensation of between windows...).

A great energy impact is needed for recycling the aluminium from windows and coverings, but less harmful than creating aluminium from scratch. Only 5% of energy comparing to the production of new aluminium.

Special aspects of sustainability in the construction

One of the special aspect of this retrofit is the simplicity and effectiveness of the measures implemented to solve particular necessities. The limited budget was a challenge, the choice of standard market solutions and a good planning of construction works were key to avoid costs' increase.

The equality of window sizes and distribution along the façade are great advantages in the construction process. Due to this circumstance, the aluminium modules and window frames could be optimized, reducing its costs and waste produced.

Thanks to the reduced impact on the interior of the dwellings and a well planned construction work people kept living in their houses during the process. This process can be seen as an example of the feasibility and adequateness of the intervention performed for future renovations in this neighbourhood.

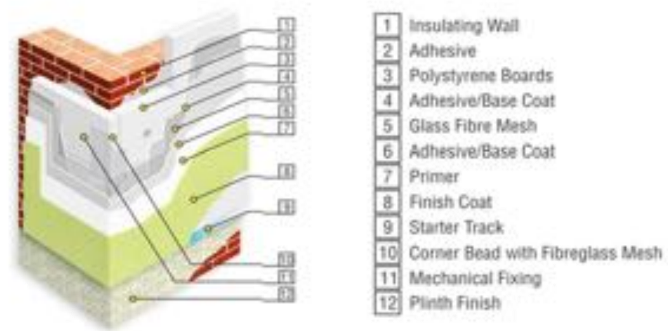


Figure 24: Exterior thermal composite system insulation.

Figure 25: Under construction.

Performance Data

Monitoring system

The monitoring system was renovated in the heating plant. All heating data is centralized, and supervised to control the system performance.

Individual control

Before renovation there were any kind of regulation in the dwellings and every dweller paid the same amount depending on the area of the flats.

During the renovation wireless thermostats and thermostatic valves in radiators were installed. Every dweller can control 24 hours the temperature inside their dwellings and administrate their own heating use.

Figure 26: Wireless thermostat is connected to the valves in radiators.

Performance comparison

In Figure 28, a comparison of temperature and daily energy consumption during eight days in our building renovated and a contiguous building that hasn't been renovated. The number represent the energy use to achieve these temperatures.

As we can see, the temperatures of the building without renovation drop dramatically at night with a 6-7ºC degrees difference. Instead retrofitted dwelling shows much more stable temperatures throughout the day, dropping 2-3 ºC when the heating is turned off.

Even taking into account that the temperatures reached in the dwelling without retrofit are much lower its consumption is 40% higher, becoming 70% higher the colder days.

This graph shows clearly the comfort improvement achieved through the retrofit.

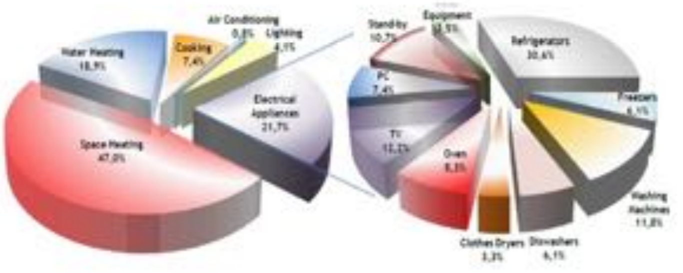


Figure 27: Energy Consumption by Uses in the Spanish Household sector, 2010.Source: IDEA Energy Efficiency Policies and Measures in Spain.

Energy consumption

Detailed monitoring is being done since District Heating was renovated, 2010. Since that moment, we can see the energy savings achieved through the renewal of the district heating are important, around 40%.

Nevertheless less than 10% of the dwellings of the group, 44 of 486 dwellings, have been renovated. Therefore the synergies of reducing power capacity of the system after a reduction of the heating demand has been unexploited.

In this case, an increase in operation time to 24 hours hasn't increased the energy consumption of the group.

Other energy uses as domestic hot water, lighting or common appliances haven't been improved.

Cooling is not need after the renovation, although those dwellings that had it already installed are keeping it.

— Indoor temperature renovated building

— Indoor temperature original building

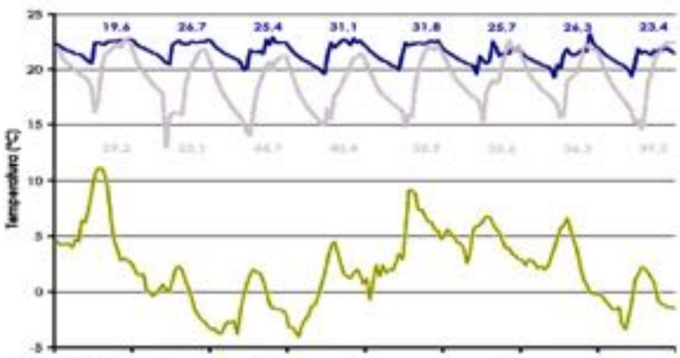


Figure 28: Indoor temperature before and after renovation and energy use.

Improvements & Co-benefits

Package	CO-BENEFITS	Thermal Comfort	Natural Lighting	Air Quality	Building Physics	Internal Noise	External Noise	Ease of Use / Control by User	Reduced Exposure to Energy Price Fluctuations	Aesthetics	Pride / Prestige	Safety (intrusion and accidents)	Ease of Installation / Reduced Annoyance	Feeling of easyness to sell or rent
Refer. Package	Replacement of heating system	P						P					N	
	Solar thermal systems													
	Photovoltaic systems													
Renovation Package 1	Windows replacement	P				N	P		P	P	P	P		
	Insulation of entire building envelope	P			P				P	P	P			P
	Replacement of heating system	P						P					N	
	Solar thermal systems													
	Photovoltaic systems													
Renovation Package 2	Windows replacement	P				N	P		P	P	P	P		
	Insulation of entire building envelope	P	N		P				P	P	P			P
	Replacement of heating system	P											N	
	MVHR systems	P		P										
	Solar thermal systems								P		P			
	Photovoltaic systems													
Renovation Package 3	Windows replacement	P				N	P		P	P	P	P	P	
	Insulation of entire building envelope	P			P				P	P	P			P
	Replacement of heating system	P						P	P				P	
	Solar thermal systems													
	Photovoltaic systems								P		P			

Legend: P - Positive Effect; N - Negative Effect

The original appearance of the building was maintained to **integrate** with contiguous buildings. The **aesthetics** has been improved since it was originally deteriorated and some cooling units and most of the lines (gas, communications, etc.) were installed without any in the main facade.

The **value and prestige** of this building has improved helping to reduced urban degeneration and energy poverty cases. Occupants are very satisfied with the results and the sense to belong to a community has been reinforced during the renovation process.

The works were **partly funded** and dwellers get personal financial credits and therefore no money ahead was given by them. There was an special attention to low income families.

Occupants were living in the building during renovation reducing their disturbance and associated costs of allocate them.

Performance improvements

A reduction of 60% of heating demand in the renovated building is expected, leading to a reduction of almost 50% of total energy use.

From measured data it is difficult to conclude that this expected saving have been reached since there was no individual meters before renovation. In any case, almost 50% of the energy consumption of the district heating group has been achieved.

Co-benefits

Thermal comfort has been greatly improved through better insulation, air tightness and individual heating control.

Air quality hasn't been improved through the process. The risk of **condensation and mould control** has been reduced by better insulation. In any case the air tightness has been improved so occupants have to perform a proper ventilation to renovate indoor air.

Noise has been greatly reduced through the installation of an additional window.

Operational comfort has been reached by individual regulation through the installation of temperature thermostats and energy meters.

Reduced exposures to energy price fluctuation due to reduced heating demand, improvement of district heating and reduced dependency on fossil fuels.

Key notes – improvement

The main improvements of the renovation were concerning the thermal comfort of the dwellings through the insulation of the envelope and the reduced exposure to energy price fluctuation due to the improvement of the efficiency of the district heating.

Nevertheless, it is important to say that the possibility of control of the heating by the occupant, despite being an important improvement, has make appear some cases were the heating isn't used to guarantee a minimum level of comfort whereas before the renovation all the dwellings were heated.

Methodology

Three different renovation scenarios have been studied in addition to an anyway renovation. From the minimum required by building regulation (at the moment of the renovation) to a deep renovation.

Existing building. Anyway renovation.

Maintenance actions are carried out in facade, roof and windows. Heating and DHW systems are replaced by a collective gasoil boiler with a standard efficiency.

Alternative scenario 1.

Minimum required by Spanish building code (2006).

The main objective of scenario 1 is to achieve only the minimum performance required by the Spanish regulation at the moment of this renovation.

The envelope and windows have been improved and a new condensation gas boiler for heating and DHW has been installed.

No additional measures have been performed to reduce other energy uses.

Alternative scenario 2.

Deep renovation. Enerphit Passivhaus Standard.

The performance of the envelope has been improved much more than is required by regulation and much more than in a business-as-usual new building.

An air-water pump is installed for the low heating demand needed and DHW. Solar panels contribute to covering the 50% of the DHW. Mechanical ventilation is installed.

Chosen renovation.

Average retrofit.

All the actions performed during the actual renovation are taken into account in this scenario: improvement of the envelope and district heating renewal.

Additional measures (not performed in reality) are taking into account for the scenario comparison: prefabrication and on-site photovoltaic system that covers 50% of the demand.

These four scenarios make it possible to compare the cost-effectiveness of different levels of energy efficiency of the building under consideration when carrying out a retrofit.

In the same way, for comparison purposes, in scenario 1 and 2, four different energy sources are used for heating and DHW. These are:

- Oil boiler.
- Condensing gas boiler.
- Air-water heat pump. Solar panels for 50% DHW supply.
- District heating with wood boiler and auxiliary condensing gas boiler. PV panels 50% electricity supply.

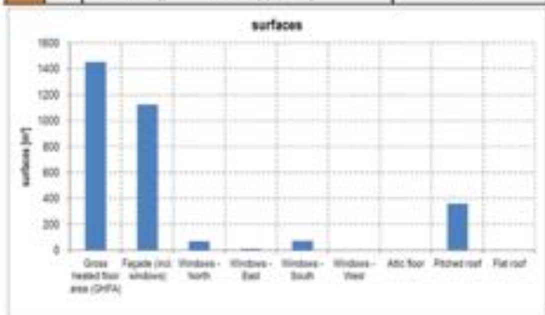
In none of the cases measures to improve the efficiency of lighting, domestic and common appliances has been taken into account.

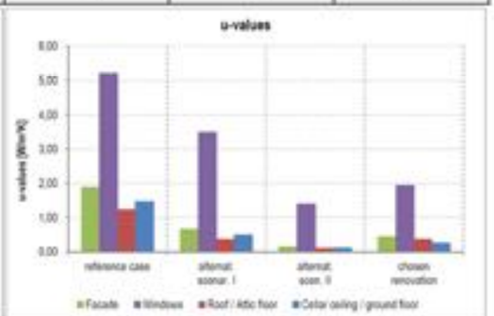
The strengths and the weaknesses of each scenario is summarized in the table below.

		reference case	alternative scenario I	alternative scenario II	chosen renovation
justification and statement	strengths, co-benefits		- A reduction of heating demand around 55% is achieved. - Risk of overheating in summer is reduced. it has not cooling demand. - The choice of a commonly used heating systems reduces investment costs.	- High energy saving measures reduces heating demand by 90%. - Energy use is extremely reduced making this option safe to future energy prices. - The lower capacity of the heating systems needed reduce their investment costs.	- Energy efficiency measures allow a reduction of 62% in heating demand and avoid cooling. - Use of wood for heating reduces the associated CO2 emissions. - Risk of overheating in summer is reduced. it has not cooling demand.
	weaknesses, additional costs	- Maintenance works aren't taken as advantage to perform energy efficiency improvements. - Higher energy cost, lower indoor comfort.	- Increasing the thickness of the insulation would have implied a small additional investment and energy savings. - Any on-site energy generation has been implemented.	- Higher investment costs on envelope systems. - The investment in solar panels and ventilation system are high. - It has a low cooling demand due to high insulation and lower losses through ventilation.	- Increasing the thickness of the insulation would have implied a small additional investment and energy savings. - The district heating carried out had a bigger investment than an convectional collective heating system. - DHW hasn't been improved, losing an opportunity of further reducement of CO2 emissions.
Conclusions	Conclusions of comparison, why was final solution chosen, how does it relate to refrence case and alternative scenarios?	- In the scenario chosen the level of insulation in the envelope is a bit higher than the minimum performance required by building code at the moment of renovation (scenario 1). - District heating was chosen since it was already existing, nevertheless the system was almost built from scratch, boilers were changed, new boiler rooms were built, all the distribution pipes were replaced... Therefore investment costs were high. - No change has been implemented to improve the efficiency of the existing individual DHW systems. - Any on-site generation of energy has been built, although in the comparison of scenarios a PV system that covers 50% of the electricity consumption has been implemented.			

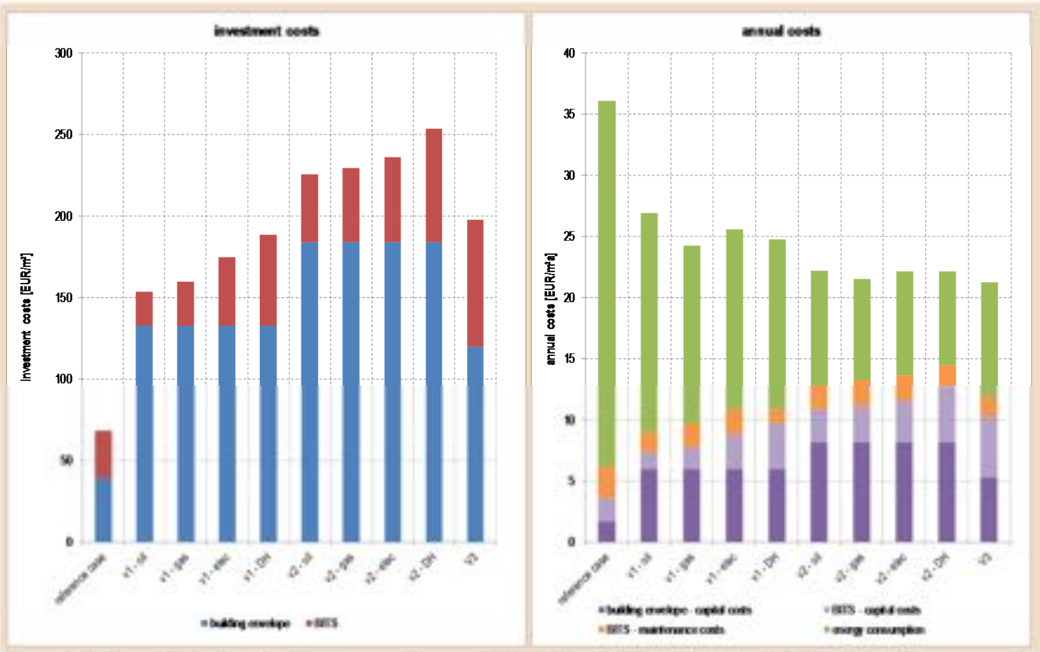
Comparison of renovation measures

			reference case	alternative scenario I				alternative scenario II				chosen renovation
renovation measures	Building envelope	roof	Pitched roof, no insulation, unheated attic	4 cm insulation (extruded polystyrene)				24 cm insulation (extruded polystyrene)				6 cm insulation (extruded polystyrene)
		facade	Mortar + 25 cm single brick wall + plaster, no insulation	4 cm insulation (expanded polystyrene)				22 cm insulation (expanded polystyrene)				6 cm insulation (expanded polystyrene)
		glazing/frame	Single glass/wood frame	Double glass/aluminium 4.6.6/aluminum Ug1.6/Uw3.2				Double LowE glass with argon/PVC 4.18.6/PVC Ug1.1/Uw1.8				Additional sliding alum. frame + Old window Double LowE glass 6.16.6/alum Ug1.6/Uw3.2
		floor	Concrete beam slab with ceramic hollow fillers, no insulation	4 cm insulation (mineral wool)				24 cm insulation (mineral wool)				10 cm insulation (mineral wool)
	BITS	Heating	Collective oil boiler. Power 240kW	Col Oil boiler 115kW	Col Gas boiler 115kW	Col. Air/Wa HP 115kW	DH Biom. & Gas 115kW	Col Oil boiler 40kW	Col Gas boiler 40kW	Col. Air/Wa HP 40kW	DH Biom. & Gas 40kW	District Heating Biomass & Gas 100kW
		DHW	Collective oil boiler	Col Oil boiler	Col Gas boiler	Col. Air/Wa HP	DH Biom. & Gas	Solar + Col Oil boiler	Solar + Col Gas boiler	Solar + Col. Air/Wa HP	Solar + DH Biom. & Gas	No changes (individual gas boilers, individual electric boilers in 25% dwellings)
		Cooling	Individual single cooling units (20% dwellings)	No cooling				Pre-cooled air through mech. ventilation				No cooling
		Auxiliaries	Electrical pumps, valves	Electrical pumps, valves				Electrical pumps, valves				Electrical pumps, valves PV installed
		Lighting	No special appliances	No special appliances				No special appliances				No special appliances
		Ventilation	No mechanical ventilation	No mechanical ventilation				Individual mechanical ventilation				No mechanical ventilation
		(Common appliances)	No intervention in common appliances	No intervention in common appliances				No intervention in common appliances				No intervention in common appliances
characteristic values	heating	Calculated energy demand for heating [kWh/m²a]	119.96	55.04				9.33				45.32
		Energy carrier of heating system	Oil	Oil	Gas	Elec.	Biom.	Oil	Gas	Elec.	Biom.	Biomass, wood pellets
		Conversion efficiency of heating system	0.88	0.88	1.08	2.80	0.90	0.88	1.08	2.80	0.90	0.90
		2nd energy carrier of heating system	-	-	-	-	Gas	-	-	-	Gas	Gas
		2nd conversion efficiency of heating system	-	-	-	-	1.08	-	-	-	1.08	1.08
		Share of 2nd energy carrier on heating energy demand	-	-	-	-	25.00	-	-	-	25.00	25.00
	DHW	Calculated energy demand for DHW [kWh/m²a]	25.39	25.39				25.39				25.39
		Energy carrier of hot water system	Oil	Oil	Gas	Elec.	Biom.	Solar	Solar	Solar	Solar	Gas
		Conversion efficiency of hot water system	0.70	0.70	1.00	2.07	0.80	0.60	0.60	0.60	0.60	0.85
		2nd energy carrier of hot water system	-	-	-	-	Gas	Oil	Gas	Elec.	Biom.	Elec.
		2nd conversion efficiency of hot water system	-	-	-	-	1.00	0.70	1.00	2.07	0.80	0.80
		Share of 2nd energy carrier on hot water energy demand	-	-	-	-	25.00	50.00	50.00	50.00	50.00	20.00
	cool.	Calculated energy demand for cooling [kWh/m²a]	5.76	0.00				2.15				0.00





Comparison of renovation measures - LCC



Description and analysis of the LCC results

In order to evaluate the cost-effectiveness of the different scenarios some assumptions were made.

The annual cost calculations are based on a LCC-period of 60 years, inflation rate is 0%, cost of capital of 3 %, yearly increase of energy cost by 2 %.

The investment, maintenance and energy cost correspond to average prices obtained from databases of construction prices, the study of budgets of actually executed renovations and suppliers.

The main conclusions obtained are:

- The investment costs in the building envelope are in all the cases much higher than the costs associated to building systems. In the chosen renovation, these costs were reduced by means of installing an additional exterior window of lower quality instead of replacing the existing ones by new ones of better quality. Nevertheless, the cost associated to the district heating is high comparing the investment costs of other systems. In chosen scenario, no change was made in DHW, although for comparison of the renovations concepts on-site photovoltaic system is included.

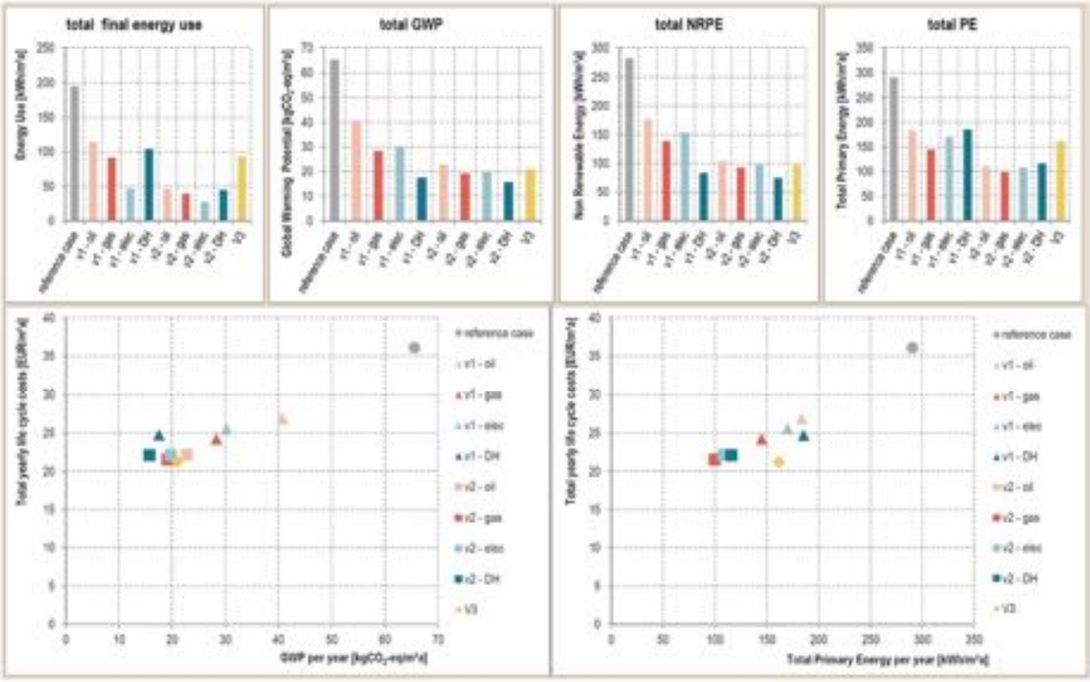
- In alternative scenario 1 and 2 the investment costs associated to the envelope are higher than in chosen renovation. The difference in the investment costs in building systems between these scenarios is due to the installation of solar thermal in scenario 2.

- All the renovation scenarios studied are cost-effective due to the high energy consumption of the existing building.

- The scenario with the lowest annual costs for energy is v2-DH. Therefore, if yearly energy cost is higher v2-DH will be the most cost-effective option, having the same scenario with a condensing gas boiler a option (v2-gas) a similar cost-effectiveness result.

- The most cost-effective scenario in terms of annualized costs is the chosen renovation. Nevertheless this result can change easily if energy prices increase more than 2% annually. That is why, a deeper renovation, as v2, has to be considered if a lower exposure to energy prices fluctuation has to be ensured.

Comparison of renovation measures - LCIA



Description and analysis of the LCIA results

These scenarios are also studied in terms of their impact on the environment. The analysis was made using Eco-Bat 4.0, which included embodied energy (manufacturing, replacement, transport and elimination) of the materials used for renovation. The life span of the building after renovation was assumed to be 60 years. The main conclusions of this assessment are:

- In all scenarios a reduction of at least 40% of the energy use its achieved, being the reduction of energy associated to the heating more than 55%; further reductions could have been achieved if additional measures in lighting or common appliances would have been implemented.

- All scenarios are cost-effective and CO_2 emissions are reduced more than 45% in all cases, being the higher reduction as high as 75% in v2-DH. This scenario corresponds also with the lowest non renewable energy use. In terms of total primary energy scenario 2, v2-gas, with gas as energy source has a slightly lower impact.

- Chosen renovation has similar total yearly life cycle costs than all the alternative scenarios 2, nevertheless CO_2 emissions and total primary energy per year are smaller in v2 which corresponds to a deeper renovation of the building. A further reduction in terms of CO_2 and primary energy use will be possible with the implementation of more on-situ energy production, more efficient lighting or electric appliances.

- In conclusion, all the scenarios studied are cost-effective. Therefore energy renovations should be encouraged. Deep renovation is the most cost-effective in terms of energy use and CO_2 emissions. In relation to cost, this option will be also the most cost-effective if energy prices keep on rising significantly. The biggest barrier is its higher investment costs so further work has to be focused on solutions that allow reduce their installation costs or financial formulas that allow their funding.

Summary and conclusion

This residential building was built in 1970 as a part of a big social neighborhood with low quality construction. Renovation was a necessity due to its degradation state, urban degradation and the increasing number of energy poverty cases.

Thanks to European, Spanish and local subsidies and the great support by the town hall of Tudela through the management team Nasuvinsa, transformation of this neighborhood is a reality.

It was a challenging process that demanded great coordination between administration, neighbors and technicians.

The main priorities of the process were grouped under two main concepts: renovation of the thermal envelope and district heating upgrade.

Finally, the building renovation agreement was reached only in a few buildings whereas the existing district heating was upgraded so the synergies of a global intervention is wasted. In any case energy consumption has been largely reduced due to the high distribution losses of the old system.

The existing district heating was renovated by replacing the boilers by biomass and gas ones and improving the distribution network's insulation, achieving a better global energy efficiency and CO2 emissions reduction.

The energy consumption in this neighborhood after the process is lower than the energy needed to maintain the dwellings in a comfortable temperature, so it is probably that exist numerous cases of fuel poverty. This situation has two consequences in the renovation process:

- An improvement in the thermal quality of the buildings is necessary in order to reduce energy demand so that the occupants can afford to use the heating adequately.

- Energy savings and the cost effectiveness of the proposed interventions do not match the reality of this situations (lower savings than expected since the heating is used scarcely). However the intervention in such areas is essential to avoid other associated problems of urban degradation, social exclusion and so on.

Figure 27: Image of the building in its location.

Practical experience

As a lesson learnt, the project conception involved the renovation of all the buildings in the neighborhood. Nevertheless the agreement was only reached in a few of them. On the other side, the renovation of the district heating was carried out in first place and this way the synergies of renovate the buildings' envelope and systems is not exploited.

In this respect, it is important to highlight the essential role of coordination between every part of the process involved. Decision and agreement becomes a fundamental barrier to overcome to achieve an effective solution. In this case the role played by Nasuvinsa, the team of management, made coordination possible between the three pillars of the process.

References

[1] Gerardo Molpeceres. MRM arquitectos. Architect and Renovation Project Manager

[2] Ana Bretaña & Isabel Izcue. Nasuvinsa. Management Team

[3] Dalkia. District Heating

[4] CONCERTO ECO-City http://www.ecocity-project.eu/TheProjectTudela.html

Appendix 6

Pilot project Backa röd – Katjas gata 119

Owner: Bostads AB Poseidon

Architect: Pyramiden Arkitekter

Energy concept: Andersson & Hultmark

Report: Lund University

Location: Gothenburg

Date: November 2014

Key technologies
- Additional insulation
- Balanced ventilation with heat recovery
- New balconies on freestanding support
- Individual metering of domestic heat water usage

View of the non-renovated (small picture) and the renovated building (large picture) (south elevation)

1

Background

The pilot project Katjas gata 119 is located in Gothenburg in the district of Backa röd, which consists of 1,574 apartments in high-rise buildings, low-rise buildings and low tower blocks built in the sixties during the 'million homes' program. The first building to be energy renovated, is a low tower block with 16 two bedroom apartments and 4 floors. The apartments have good floor plans, with generous and easily furnished rooms. However, the buildings needed to be renovated due to maintenance needs.

The buildings are typical for the seventies with a prefabricated concrete structure with sandwich facades panels, a triple layer wall. The facades were damaged by carbonation and were in need of renovation.

The building was leaky, through the façade and between the apartments. Draught occurred from the infill walls at the balcony and cold floors were caused by thermal bridges from the balconies.

The buildings are heated by district heating. In each apartment there were radiators under the windows.

Figure 1: View of the building before renovation

Domestic hot water is also heated by district heating. The district heating is renewable to 81%.

The apartments were ventilated by mechanical exhaust and supply ventilation without heat recovery.

The aim of the renovation was to upgrade the standard of the building and to reduce the high use of energy.

The U-values of the exterior walls were 0.31 W/m²K, the roof 0.14 W/m²K, the ground floor 0.40 W/m²K and the windows 2.40 W/m²K.

Figure 2: Typical floor plan

Project data of building before renovation

Altitude	35 m
Heating degree days	3307Kd
Cooling degree days	25 Kd
Year of construction	1971
Heated usable floor area	1,357 m²
Specific heating energy demand excl. hot water	134 kWh/(m²a)
Specific hot water energy demand	32 kWh/(m²·a)
Type of energy carrier for heating	district heating
Type of energy carrier for hot water	district heating
Specific heating energy consumption (excl. hot water)	138 kWh/(m²·a)
Specific hot water energy consumption	32 kWh/(m²·a)
Specific electricity consumption (excl. household)	8 kWh/(m²·a)
Energy costs (1 Euro = 9,20 SEK)	1,850 €/a

Renovation concept

Figure 3: View of renovated building (south elevation).

Design data for renovated building

Year of renovation	2009
Heated usable floor area	1,357 m²
Specific heating energy need excl. hot water	25 kWh/(m²a)
Specific hot water energy demand	25 kWh/(m²·a)
Type of energy carrier for heating	district heating
Type of energy carrier for hot water	district heating
Specific heating energy consumption (excl. hot water)	29 kWh/(m²·a)
Specific hot water energy consumption	25 kWh/(m²·a)
Specific electricity consumption (excl. household)	6 kWh/(m²·a)
Energy costs (1 Euro = 9,20 SEK)	6,300 €/a

Figure 4: View of renovated building

The aim was to combine the necessary renovation with a 65 % reduction in energy use.
The overall aim was therefore to renovate the building, to reduce the energy use and to reduce the energy use and to reduce the energy use and to improve the indoor climate.

The energy reduction was achieved by

- Additional insulation on the building envelope and new windows
- New balconies on freestanding supports to minimise thermal bridges
- Individual metering of and invoicing for hot water
- New radiator system with thermostat valves.
- Temperature sensors in the apartments.
- Installation of ventilation heat recovery.
- Installation of low energy lighting for fixed lighting.

Furthermore the renovation included:

- New water, sewage and electrical systems
- New bathrooms and kitchens
- New interior surface finish
- Safety doors for the apartments.
- Glazing of balconies

Figure 5: View of entrance of renovated building (west elevation).

Renovation design details

Facade Solutions

The structure of the building consists of prefabricated concrete. The insulation of the triple layer sandwich façade elements was improved by adding 200 mm of expanded polystyrene to the exterior. The polystyrene was covered by thin wall plaster. The U-value was improved from 0.31 W/m²K to 0.12 W/m²K.

At the balconies, a new infill wall was built with a U-value of 0,2 W/m²K.

An important measure when renovating in order to lower the energy use and reducing air leakage is to improve the airtightness of the building. A prefabricated sandwich element facade can be airtight if junctions and joints are airtight, which was no longer the case due to wear and tear. Polystyrene was chosen as it is providing the needed airtightness.

To ensure airtightness the, polystyrene boards were joined by tongue and groove and displaced junctions of the two layers of polystyrene. The junctions were also glued. Besides, no framework system is needed.

The airtightness was improved from 1.2 l/sm² to 0.1 l/sm² at 50 Pa.

Roof Solutions

The existing roof construction was kept. The attic was changed into a cold attic with limited ventilation. The outside of the tongued and grooved board was insulated with 50 mm insulation to avoid condensation on the inside. New asphalt paper roofing was installed. Inside the attic loose fill insulation was added, which resulted in total insulation thickness of 500 mm. The U-value was improved from 0.31 W/m²K to 0.12 W/m²K.

New shading eaves were built and the roof has been raised due to the new ventilation system.

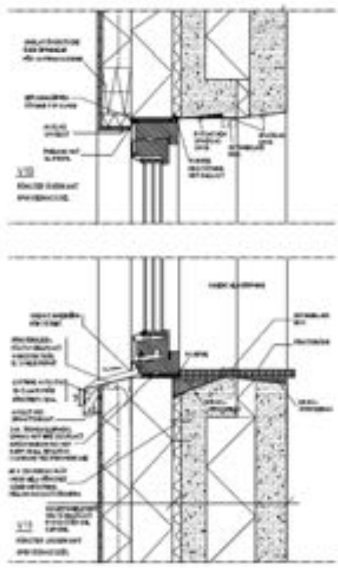


Figure 7: Window details.

Window solution

New triple-pane low energy windows were installed instead of the old double-pane windows. This was done in the new exterior insulation to avoid having the windows too deep into the façade, which would have shaded part of the windows. It was also done to avoid thermal bridges. The U-value of the windows were improved from 2.40 W/m²K to 0.90 W/m²K. To avoid high indoor temperatures due to solar radiation a light solar protection glazing was chosen with a g-value of 0.5.

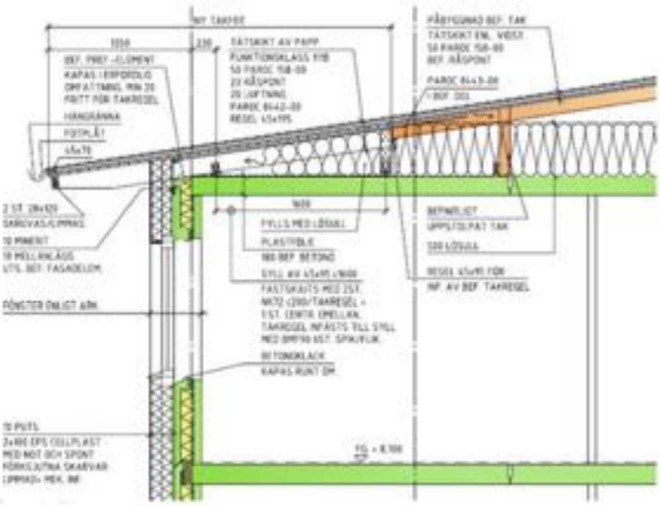


Figure 6: Cross section of exterior wall and roof construction.

Ground floor solution

The crawl space was made airtight and 500 mm of Leca was added. By this, a warm crawl space was created, eliminating the moisture risks of a well insulated crawl space ventilated by outdoor air. The crawl space was also included in the new balanced mechanical ventilation system with heat recovery (see Ventilation). The U-value of the floor construction was improved from 0.40 W/m²K to 0.10 W/m²K.

The base wall was insulated with 100 mm polystyrene. This was done on the outside lowering the U-value from 0.48 W/m²K to 0.30 W/m²K.

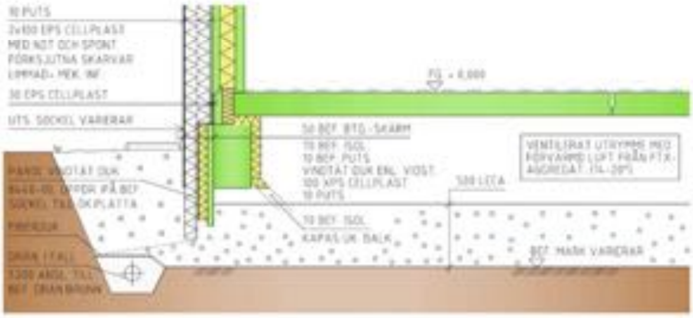


Figure 8: Cross section of exterior wall and floor-foundation construction

Element	U-value before renovation, W/m²K	U-value after renovation, W/m²K
Exterior walls	0.31	0.12
Roof	0.14	0.10
Crawl space	0.40	0.10
Base wall	0.48	0.30
Windows average	2.40	0.90

Figure 9: U-values before and after renovation.

Element	After renovation
Exterior walls	200 mm of additional insulation
Roof	Total of 500 mm of insulation i.e. adding 100 mm to a previous additional insulation of 200 mm
Crawl space	500 mm of additional insulation 'Leca' and heat supply by supply air
Base wall	100 mm of additional insulation
Windows	New triple-glazed low energy windows

Figure 10: Improvements of thermal insulation.

Heating

Before the renovation, space heating was done by hot water central heating with radiators in each room. Heating cost was included in the rent. The radiators are located under windows and the heat source is district heating, which to 81 % is renewable. The heating pipes were single pipe central heating system and the flow was controlled by a hand wheel. The flow temperature was controlled by the exhaust air temperature and the outdoor air temperature. In some apartments, where it was cold, the tenants installed electric radiators which were located in front of the water radiators. This meant, that the temperature by which the heating system was controlled, showed incorrect values, that resulted in less supply of heat. Thereby the tenant downstream in the radiator circuit got less heat or no heat.

A completely new pipe system was therefore installed, a two pipe central heating system. New radiators have also been installed as well as new thermostatic radiator valves. The district heating substation is located in another building and supplies an additional building with heat. The consequence was that the new system had to be designed in the same way as the old system with the same flow temperature and radiator size. The flow temperature is still controlled by the exhaust air temperature and the outdoor air temperature. The heating cost is still included in the rent.

In the bathrooms an electric towel dryer was installed with a timer.

Before the above decision was made, two alternatives were considered. One was to supply the heat with the supply air. This would have been too expensive and it could not be guaranteed that no odour problems would occur (a burning smell from the heated air caused by high temperatures). Another alternative was to install separate electric radiators, but was determined to not be feasible .

Hot water installations

No major changes to the hot water installations were made. The domestic hot water is heated by the district heating substation. However, hot water circulation was installed, which will reduce the water consumption and might increase the energy use. Before renovation, the cost of domestic hot water was included in the rent. The renovation included implementation of individual metering and invoicing of hot water.

Lighting

The stair opening is located in the middle of the building and has therefore little access to daylight. Artificial lighting is necessary. Before the renovation, the lighting of the stair opening came from lighting fittings with fluorescent tubes. The lighting of bathrooms and kitchens were mostly lighting fittings with incandescent lamps. After the renovation, the lighting of the stair opening comes from compact fluorescent tubes, which are switched on and off by movement detectors on each floor. The lighting of the bathrooms and kitchens has been converted to light fittings where only compact fluorescent tubes can be used. The choice of lighting source in the remaining part of the apartments is up to the tenants.

Figure 11: View of the renovated building (west elevation)

Ventilation

When the building originally was built, the building was ventilated by a balanced mechanical ventilation system without heat recovery. One unusual feature of the system was that the exhaust ducts were located inside the supply ducts, which meant some degree of heat recovery. This made it difficult to clean the supply ducts, therefore Bostads AB Poseidon removed them during the nineties. Since then the ventilation system has been operated as a mechanical exhaust only ventilation system, where the air flow was controlled as a function of pressure and temperature (exhaust air and outdoor air temperature).

In order to save energy, the ventilation system was rebuilt to a balanced mechanical ventilation system with heat recovery. The roof had to be raised in order to place the new ventilation unit at the top of the building. The air flow is continuous and is controlled against pre-set pressure drops. The ventilation system, which provides the building with supply air, is equipped with a rotary heat exchanger, which pre-heats the supply air, but there is no additional heating with a heating coil or suchlike.

The reason for, choosing a rotary heat exchanger for heat recovery was the high heat recovery. During the planning phase ideas were developed to use the supply air for space heating. An investigation was carried out to determine the best alternative, warm air central heating or hot water central heating.

A separate hot water central heating system was chosen, which is described under Heating. To use the ventilation system as a heat carrier was not chosen as the costs were higher for this alternative.

To minimize sound from the ventilation system, sound attenuators were installed. Sound attenuators were installed after the ventilation unit on the supply side and additionally two in each apartment. In a well insulated airtight building, interior sound is more noticeable as the sound from outside is reduced.

Cooker hood ventilators (fan) above the stove have been installed in each apartment and their own duct to the roof, so this hot air does not get recycled. This was done in order to reduce the maintenance of the rotary heat exchanger and the filters.

The supply air terminal devices are located in interior walls close to the ceiling.

When installing the new ventilation system, a fair amount of new ducts were needed. The floor area of the closets was reduced to make space for shafts for ventilation ducts. In the apartments, ventilation ducts also had to be installed below the ceiling and built in.

Household appliances

The kitchens are furnished with refrigerators and freezers by the property owner. After renovation all refrigerators and freezers are of energy class A+.

Integrated Building Performance

Ecological/Environmental sustainability

The environmental impacts of the different materials needed for the energy renovation were calculated and the parameters "Total Primary Energy (CED)" in kWh/m²a, the "Non-renewable Primary Energy (NRE)" in kWh/m²a and the "Global Warming Potential (GWP)" in $kgCO_{2\text{-}Eq}$/m²a were analysed. The result of this analysis is shown in Figure 12.

The environmental impact of the materials used for the energy renovation during the lifetime is approximately 40 % of the total impact. The materials with the highest impact are the expanded polystyrene of the additional insulation of the façade, the expanded clay added to the crawlspace and the new windows. Improvement of the environmental is possible by modifying these materials (see under Description and analysis of the LCIA results).

Economical sustainability

The actual costs have been divided by the housing company into refurbishment (14.3 mio SEK) and energy efficiency measures (3.75 mio). The actual total costs are 18.1 mio SEK.

The investment costs consist of standard-raising measures (6.0 mio SEK), operating cost reducing measures (1.8 mio SEK). Costs which are paid directly are long due maintenance (8.3 mio SEK) and energy measures with low profitability (1.95 mio SEK).

The payback time of the energy savings is estimated to be 25 years. The housing company mainly focus on the management reguired yield (profitability).

Rent (before): 694 SEK/m²/year incl. space heating and dhw

Rent (after): 938 SEK/m²/year incl. space heating excl. dhw

Yearly energy savings: 160 MWh or 112,000 SEK (83 SEK).

A LCC-analysis with different assumptions is presented under Description and analysis of the LCC results.

Sociocultural sustainability

According to a questionnaire before and after the renovation, the tenants perceive that

- Draughts from external walls and windows, and cold floors have been eliminated
- The room temperature is more comfortable, although it gets warm indoors at times in the summer.
- Unpleasant odors and noise levels have decreased

Only 4 out of 16 apartments were occupied by the same tenants after renovation. Some of the tenants preferred to stay in the apartments they were evacuated to during the renovation. A likely reason is the rent increase in the renovated building.

Ecological/Environmental Sustainability	
Global Warming Potential [$kgCO_{2\text{-}Eq}$/m²a]	7.9
Total Primary Energy [kWh/m²a]	38.8
Non-renewable Energy [kWh/m²a]	28.5

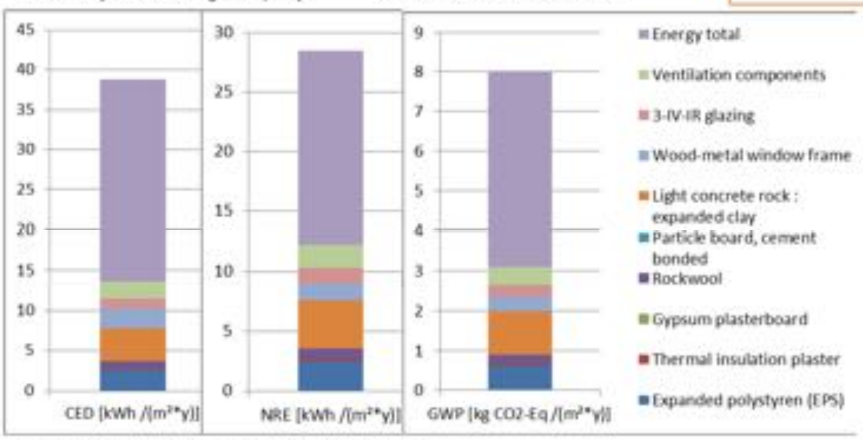


Figure 12. Environmental impact of the renovation

Integrated Building Performance - Construction sustainability

Construction process

As for most of the energy saving measures new materials were added or replaced existing ones. For a building which mainly consisted of prefabricated elements, demolition should be fairly straightforward.

The renovation project was started in 2008 with a pilot study, that lasted five months. The following step was an evaluation using LCC analysis. Then followed the actual design work, which lasted six months, during which new LCC analysis were made. At the end of the design phase the design was approved at a board meeting of Bostads AB Poseidon. In April 2009, the actual construction work started and lasted for six months. After the scaffolding was erected, the entire building was covered by a tent. This ensured that most of the construction could be carried during dry conditions avoiding moisture problems.

The tenants were evacuated during the construction phase.

The energy efficiency measures were developed in close cooperation between the consultants, the main contractor and the loose fill insulation contractor etc..

A reference group with Lund Technical University, Chalmers Technical University was consulted during the design work.

The Technical Research Institute of Sweden evaluated moisture consequences of the renovation.

Building material

The recyclability of the chosen building material was not considered and not analyzed in detail.

An internal directive (of Bostads AB Poseidon) was applied, which calls for phasing out health and hazardous materials above certain levels of content when renovating or rebuilding existing buildings. Examples of hazardous materials are: bromined external flame retardants, phthalates, copper and PVC.

All construction products used for the renovation were products that meet BASTA's properties criteria. The aim of the BASTA system is to phase out substances with particularly hazardous properties from construction products. BASTA is Swedish database with sustainable construction materials.

Special aspects of sustainability in the construction

The replacement of more short-living component layers without destroying the more long-living components is an aspect that has to be considered. During the construction or renovation phase it is recommended to integrate predetermined breaking points.

The construction of the façade shows a special aspect of sustainability regarding separability and dismantling. The new insulation elements were fixed on the existing building where the old exterior concrete hasn't been removed. This concrete can now be seen as a predetermined breaking point between the wall and the insulation. While removing the insulation the wall cannot be destroyed since the exterior concrete acts as a protective layer.

Figure 13: Renovation under a tent.

Performance Data

Monitoring system

Before renovation, the following parameters were monitored:

- Exhaust air temperature of each apartment
- Outdoor air temperature
- Energy use for heating i.e. sum of district heating for space heating and dhw for a group of similar buildings (12,500 m²)
- Property electricity
- Household electricity (not public)

After renovation, the following parameters were monitored:

- Exhaust air temperature of each apartment
- Outdoor air temperature
- Energy use for heating i.e. sum of district heating for space heating and dhw
- Property electricity
- Household electricity (not available without permit from the tenants)
- Domestic hot water of each apartment
- Water consumption
- Temperature efficiency of rotary heat exchanger

The following parameters are included in the building automation system:

- Exhaust air temperature
- Temperature efficiency of air-to-air heat recovery
- Outdoor air temperature

The ventilation system is monitored and controlled in detail.

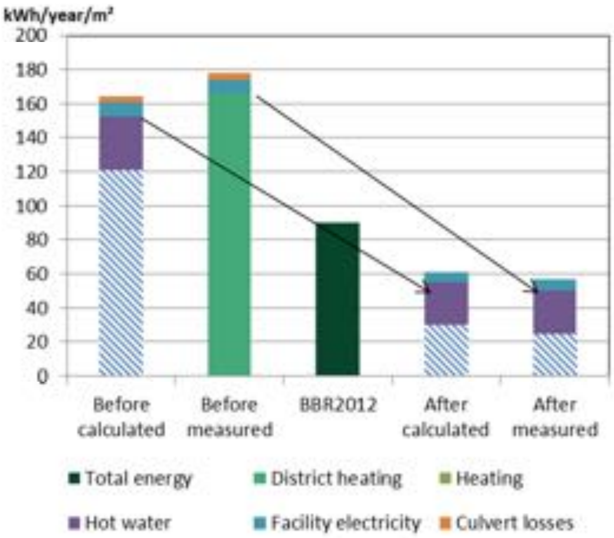


Figure 14: The energy use before and after renovation. BBR2012 is the building code requirement for new construction.

Energy consumption

The detailed monitoring of the building was started in 2010.

The yearly energy savings thanks to reduced energy losses and individual metering of domestic hot water was calculated to be 132 MWh or 98 kWh/m² for space heating and domestic hot water heating. The monitored reduction was 168 MWh or 116 kWh/m².

After renovation the use of facility electricity has not increased in spite of more fans. The reason for this is the installation of energy efficient fans and energy efficient lighting in common spaces.

The Swedish building code

[The Swedish National Board of Housing, Building and Planning] Boverket's Building Regulations consists of regulations and recommendations for construction projects in Sweden. In the chapter of energy management, there is a description of Sweden's three different climate zones. The division into different zones are due to the relatively big difference in temperature when comparing north and south. The zones have their varying building specific energy usage, This project is built in the mildest zone and therefore needs to meet the requirement of 90 kWh/year/m². In principle the energy requirements of the current building code have to be fulfilled for a renovation, but a renovation should be economically sound and features of interest have to be considered such as to preserve architecturally and historically.

Improvements & Co-benefits

	CO-BENEFITS	Thermal Comfort	Natural Lighting	Air Quality	Building Physics	Internal Noise	External Noise	Ease of Use / Control by User	Reduced Exposure to Energy Price Fluctuations	Aesthetics	Useful Living Area	Pride / Prestige	Safety (intrusion and accidents)	Ease of Installation / Reduced Annoyance	Feeling of easyness to sell or rent	Independence from energy sources
Refer. Package	New district heating substation	P														
	Thin wall plastering of facade	P								P						
Renovation Package 1	Windows replacement	P					P		P							
	Insulation of entire building envelope	P			P				P	P						
	Replacement of heating system	P														
	MVHR systems	P		P	P	N										
Renovation Package 2	Windows replacement	P					P		P							
	Insulation of entire building envelope	P			P				P	P						
	Replacement of heating system	P														
Renovation Package 3	Windows replacement	P					P		P							
	Insulation of entire building envelope	P			P				P	P		P				
	Solar protection glazing	P														
	Glazing of balconies	P														
	Replacement of heating system	P														
	MVHR systems	P		P	P	N										
	New lighting in common areas												P			

Legend: P - Positive Effect; N - Negative Effect

Improvements

Besides energy efficiency measures the renovation involved several other improvements. Examples are:

- New water and sewage systems installed instead of the old ones
- Hot water circulation installed
- New electrical installations made instead of the old on
- Bathrooms and kitchens renewed
- Change to parquet floor in living rooms and bedrooms
- New surface finish in apartments
- Safety doors for the apartments
- New extended glazed balconies, which also reduce the thermal bridges

Co-benefits

Several of the energy efficiency measures also result in other benefits.

The main co-benefits are:

- Draught, important aspect of thermal comfort, is almost eliminated thanks to the insulation of the entire building envelope and new windows that reduced air leakage.

The main co-benefits are:

- Thermal comfort is improved by the increased operative temperature thanks to the above mentioned improvement.
- Thermal comfort is improved by the improvement of the thermal insulation of the building envelope, the reduction of air leakage and the installation of mechanical supply, which to some extent pre-heats the air,.
- External noise is reduced by the added thermal insulation and the improvement of air leakage.
- Indoor air quality is improved by the installation of balanced mechanical ventilation.
- Appearance of the exterior of the building is improved by the additional thermal insulation with thin plaster on the façade.
- The exposure to energy price fluctuations is improved by the substantial reduction in energy use.

Key notes – improvement

The building was improved in many ways and almost achieved the standard of new low energy housing.

Methodology

The alternative to demolish the buildings and to build a new one was considered, but not considered politically realistic as there is a severe lack of apartments in Göteborg. Besides it constituted as a pilot project for energy renovation, to gain experience for future renovations.

Three different renovation packages are developed, analyzed and assessed. Those range from the minimum required renovation measures, to the high thermal insulation of the building envelope, right up to the high performance renovation of the building i.e. the renovation package 3 which was realized. The other two renovation packages were developed after construction of package 3, to compare this with less ambitious renovation measures.

Different heating alternatives are evaluated for package 1 and 2: oil, gas, electricity, district heating based mostly on renewables.

Renovation package 1

The objective of renovation package 1 is to fulfill only the minimum requirements of the Swedish building code BBR 2012 for new construction. These minimum requirements concern the building's energy use, that, in normal use during a reference year, needs to be supplied to a building (often referred to as "purchased energy") for heating, comfort cooling, hot tap water and the building's facility energy.

In the renovation package the U-values the building envelope (exterior walls, roof, floor and windows) is improved and mechanical ventilation with heat recovery (cross flow heat exchanger) is installed. New thermostatic radiator valves are installed.

Renovation package 2

In renovation package 2, the building has the same U-values as the real renovated building in renovation package 3.

The difference between renovation package 2 and 3 is that renovation package 2 includes no heat recovery unit on ventilation. The results in terms of energy, LCA and costs are similar to renovation package 1.

Renovation package 3

Renovation package 3 represents the actually realized renovation of the demonstration building, and is the most ambitious one, with questionable profitability, if the owners yield requirements are applied. Assuming less stringent yield requirements result in the lowest LCC. This renovation package also results in the lowest energy use and global warming potential.

The realized renovation of the building includes substantial improvement of the thermal insulation of the building envelope with e.g. new triple-pane low energy windows with a light solar protection glazing.

A new mechanical balanced ventilation system with rotary heat exchangers were installed.

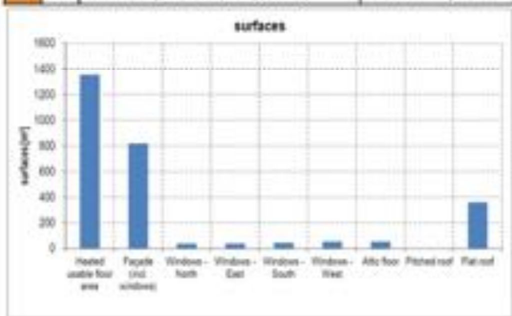
To reduce the use of hot water individual metering was installed.

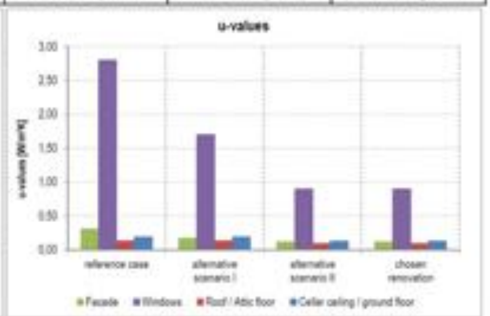
The building was already connected to district heating, based on 81 % renewable energy, and using green electricity.

		reference case	alternative scenario I	alternative scenario II	chosen renovation
justification and statement	strengths, co-benefits	The apartments have good floor plans, with generous and easily furnished rooms.	Renovation and energy retrofit, saving 50 % of the energy. The thermal comfort and indoor air quality are improved.	Renovation and energy retrofit, saving 50 % of the energy. The thermal comfort is improved.	Renovation and energy retrofit, saving 65 % of the energy. The thermal comfort and indoor air quality are improved. Lowest LCC.
	weaknesses, additional costs			Does not improve the ventilation and the indoor air quality.	Rent increased by 35 %.
Conclusions	Conclusions of comparison; why was final solution chosen, how does it relate to refrence case and alternative scenarios?	Not an alternative. The highest LCC and the building needs a renovation	Lower LCC	Similar LCC to alternative 1	The most ambitous renovation package with the highest GWP reduction, which the owner wanted as a demonstration and to learn from.

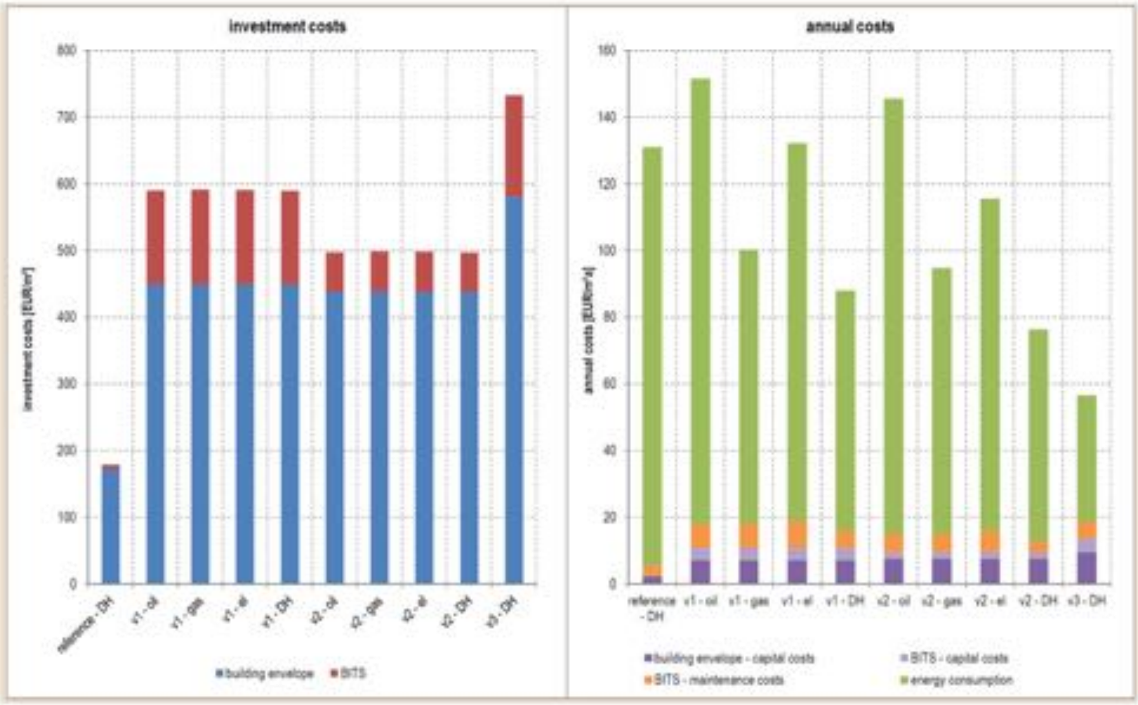
Comparison of renovation measures

			reference case	alternative scenario I	alternative scenario II	chosen renovation
renovation measures	Building envelope	roof	200mm insulation	New ventilation ducts, the roof had to be raised. 100mm of insulation added to a total of 300mm	300mm of insulation added to a total of 500mm of insulation.	New ventilation ducts, the roof was raised. 300mm of insulation added to total of 500mm
		facade	Cracks and problems with leakage, therefore plaster was applied	The leaks and cracks repaired and 100mm of insulation added. Plaster added as a finish	Leaks and cracks repaired and 195mm of insulation added. Plaster added as a finish.	Leaks and cracks repaired and 195mm of insulation added. Plaster added as a finish
		glazing/frame	Old double-glazed windows	New cheaper triple-glazed windows installed. U-value 1.7	New triple-glazed windows installed. U-value 0.9	New triple-glazed windows installed. U-value 0.9
		floor	Thermal bridge, cracks and air leakage	100mm insulation added to the foundation. A new layer of 100mm expanded clay added in the crawl space.	195mm more insulation added to the foundation. A new layer of 500mm expanded clay added in the crawl space	195mm more insulation added to the foundation. A new layer of 500mm expanded clay added in the crawl space
	BTS	Heating	District heating and radiators. New district heating substation	District heating and radiators	District heating and radiators	District heating and radiators
		DHW	District heating for hot water. Dhw recirculation installed	District heating for hot water. Individual metering installed	District heating for hot water. Individual metering installed	District heating for hot water. Individual metering installed
		Cooling	No cooling in residential buildings	No cooling in residential buildings	No cooling in residential buildings	No cooling in residential buildings
		Auxiliaries	Old building automation system	Old building automation system	A new building automation system installed	A new building automation system installed
		Lighting	Older lighting	Older lighting	New low-energy lighting	New low-energy lighting
		Ventilation	Mechanical exhaust system without heat recovery	A new ventilation room built on the roof in order to install a new ventilation system. Balanced mechanical ventilation with traditional heat recovery	Mechanical exhaust system without heat recovery	A new ventilation room built on the roof in order to install a new ventilation system. Balanced mechanical ventilation with rotary heat exchanger
		(Common appliances)	-	An upgrade in standards is made	An upgrade in standards and energy is made	An upgrade in standards and energy is made
characteristic values	heating	Calculated energy demand for heating [kWh/m²a]	121.00	57.00	58.00	30.00
		Energy carrier of heating system	Water (Radiators)	Water (Radiators)	Water (Radiators)	Water (Radiators)
		Conversion efficiency of heating system	95.00	95.00	95.00	95.00
		2nd energy carrier of heating system	-	-	-	-
		2nd conversion efficiency of heating system	-	-	-	-
		Share of 2nd energy carrier on heating energy demand	-	-	-	-
	DHW	Calculated energy demand for DHW [kWh/m²a]	32.00	25.00	25.00	25.00
		Energy carrier of hot water system	-	-	-	-
		Conversion efficiency of hot water system	-	-	-	-
		2nd energy carrier of hot water system	-	-	-	-
		2nd conversion efficiency of hot water system	-	-	-	-
		Share of 2nd energy carrier on hot water energy demand	-	-	-	-
	cool.	Calculated energy demand for cooling [kWh/m²a]	There is no cooling in Sweden	There is no cooling in Sweden	There is no cooling in Sweden	There is no cooling in Sweden





Comparison of renovation measures - LCC



Description and analysis of the LCC results

Bostads AB Poseidon made several LCC calculations of their own. Their main goal has been to determine cost efficient renovations with focus on lowering the annual costs. Therefore the focus on lowering carbon emissions and other environmental benefits was not of highest priority.

For their LCC calculations the housing company had the following requirement: cost of capital is 5,75%, inflation rate is 2,25%, LCC-period is 30 years and yearly increase of energy cost of 2%.

These requirements are different from the assumptions made here. The annual cost calculations are based on a LCC-period of 60 years, inflation rate is 0%, cost of capital of 3 %, yearly increase of energy cost by 0 %.

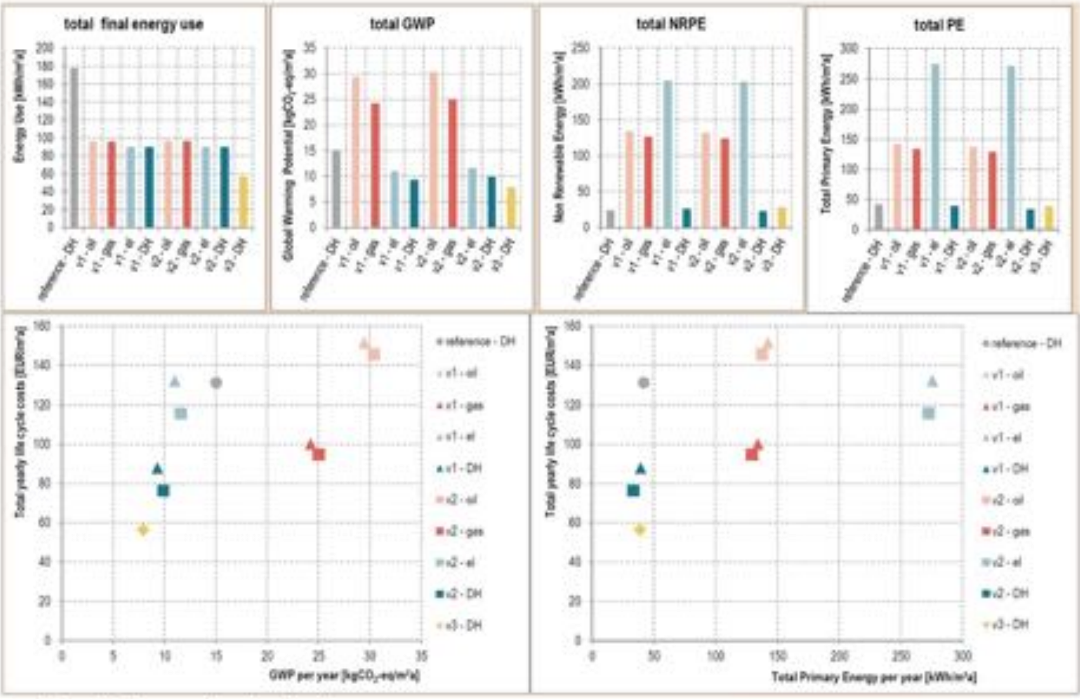
The price for district heating varies over the year, however for the calculations an yearly average price was used i.e. weighted according to the monthly variation in energy use. District heating (0.076 Euro/kWh) is year 2014 the cheaper energy carrier compared with oil (0.14 Euro/kWh), natural gas (0.084 Euro/kWh) and electricity (0.12 Euro/kWh).

The reference case includes air tightening and thin wall plastering of the façade, a new district heating substation, and dhw recirculation, which are for maintenance reasons, but only have minor effects on the energy use. The façade renovation includes scaffolding, which is also needed for all the renovation packages.

The highest investment cost and lowest annual cost occur for renovation package 3 (s3), which is the realized one.

As long as district heating is considered all renovation packages result in lower annual costs.

Comparison of renovation measures - LCIA



Description and analysis of the LCIA results

The analysis was made using Eco-Bat 4.0, which included embodied energy (manufacturing, replacement and elimination) of the materials used for renovation. Transportation was however not included. The only adaptation of Eco-Bat was the inclusion of Swedish district heating, from Göteborg with 20 % fossil fuel use. The used figures for energy use are a combination of measured and calculated results. The life span of the building after renovation was assumed to be 60 years.

Some of the energy renovation packages slightly increased the non-renewable use of primary energy compared with the reference case. All energy renovation packages reduce the final energy use, the total use of primary energy and the global warming potential. If environmentally friendly materials were used for renovation, which was not the case, for the actually realized renovation package the total use of primary energy is reduced by 9 % and the use of non-renewable primary energy will be reduced by 12 %. Hence it is important to choose the right materials.

Renovation package 2 has the lowest primary energy use of all renovation packages, although the difference is small i.e. assuming district heating. This can be explained by lower embodied energy due to no renewal of the ventilation system.

The reference case and the executed renovation are based on district heating, which applies to 91 % of the multi-family building built been 1961 and 1975. 2 % of buildings use electricity, 1 % gas and 0.3 % oil. The use of primary energy and the global warming potential are much higher for those alternatives.

Summary and conclusion

The renovation was necessary due to wear and tear. The renovation resulted in substantial improvements of the standard of the building, and a substantial reduction in energy use, 65 %, while keeping a similar architectural appearance, however, with a different color. The standard improvements included new installations, new bathrooms and kitchens, and new surface finish. The energy saving measures included added thermal insulation to the entire building envelope, low energy windows, installation of ventilation heat recovery and individual metering of dhw.

The tenants have appreciated the improvements in thermal comfort, indoor air quality and noise climate.

According to the owner the energy efficiency measures have not been profitable. Given the rather stringent yield requirements of the owner (profitability requirement of 6.25 %, energy price increase according to inflation) only half of the energy investment will pay back.

However, if energy efficiency measures which improve the indoor climate could be considered as standard-raising and allow a rent increase the profitability would be reasonable even with the stringent yield requirements.

Major energy renovations make sense only in buildings which need a major renovation. The profitability of renovations increases for bigger multi-family buildings and if many buildings can be renovated at the same time here.

The owner has therefore continued with similar energy renovations of five tower blocks of the same type in the same area. An additional feature is adding two floors on the roof. This way the profitability requirement of the owner will be met.

However, with a 60 year perspective the realized pilot renovation package is profitable and good for the environment.

Figure 15: Vertical densification in ongoing following renovations of Backa röd

Practical experience

For the building owners the energy renovation was not profitable in this pilot project. However, for the following identical buildings to be renovated the profitability requirement will be met thanks to a high number of buildings and by adding two floors on top of the building.

The interior deep renovation necessitated evacuation of the tenants. Only 25 % of the tenants moved back after the renovation, but no apartments are uninhabited.

Shortly after the renovation was finished, it was discovered that there was an unnecessary increase of the supply air along the supply ducts. This was due to uninsulated supply ducts, so the ventilation system needed to be re-adjusted.

References

1] Byman, K., Jernelius, S., 2012, Economy for reconstr-uctions with energy invest-ments, Energy center of environmental administration of Stockholm city.

[2] Mjörnell, K., et.al. 2011, Milparena – Million homes program arena Innovative action proposals for renovation of the building envelope and installations (in Swedish), SP Rapport 2011:39, Technical research institute of Sweden.

[3] Bostads AB Poseidon, 2009, Design documentation and drawings.

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