D1.3:
Result-Oriented Concluding Report

COST REDUCTION AND MARKET ACCELERATION FOR VIABLE NEARLY ZERO-ENERGY BUILDINGS

Effective processes, robust solutions, new business models, and reliable life cycle costs to support user engagement and investors' confidence towards net zero balance.

CRAVEzero - Grant Agreement No. 741223
WWW.CRAVEZERO.EU

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Result-Oriented Concluding Report

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FOREWORD

The CRAVEzero concluding report was produced through extensive collaboration with experts and stakeholders across Europe over a three-year period. Six work packages were formed with significant subject matter expertise to discuss the challenges of cost reduction and marked acceleration of nearly zero energy buildings (nZEBs) in different regions in Europe. The working groups focused on life cycle costs, business models, processes, and technologies. Feedback was received via the CRAVEzero case study projects and national implementation working groups.

Cost optimal and nearly zero energy performance levels were initiated by the European Union's (EU) Energy Performance of Buildings Directive, which was recast in 2010. These principles will be significant drivers in the construction sector in the next few years because all new buildings in the EU must be nearly zero energy buildings (nZEBs) from 2021 onwards (public buildings needed to achieve this standard by 2019).

While nZEBs realized thus far have clearly shown that the nearly zero energy target can be achieved through existing technologies and practices, most experts agree that a broad-scale shift towards nZEBs requires significant adjustments to current building market structures. The cost-effective integration of efficient solution sets and renewable energy systems are the major challenges.

CRAVEzero focuses on proven and new approaches to reduce the costs of nZEBs at all stages of the life cycle (see Figure 1). The primary goal is to identify and eliminate the extra costs of nZEBs related to processes, technologies, and building operations as well as promote innovative and cost-effective business models considering all stakeholders in the building's life cycle.

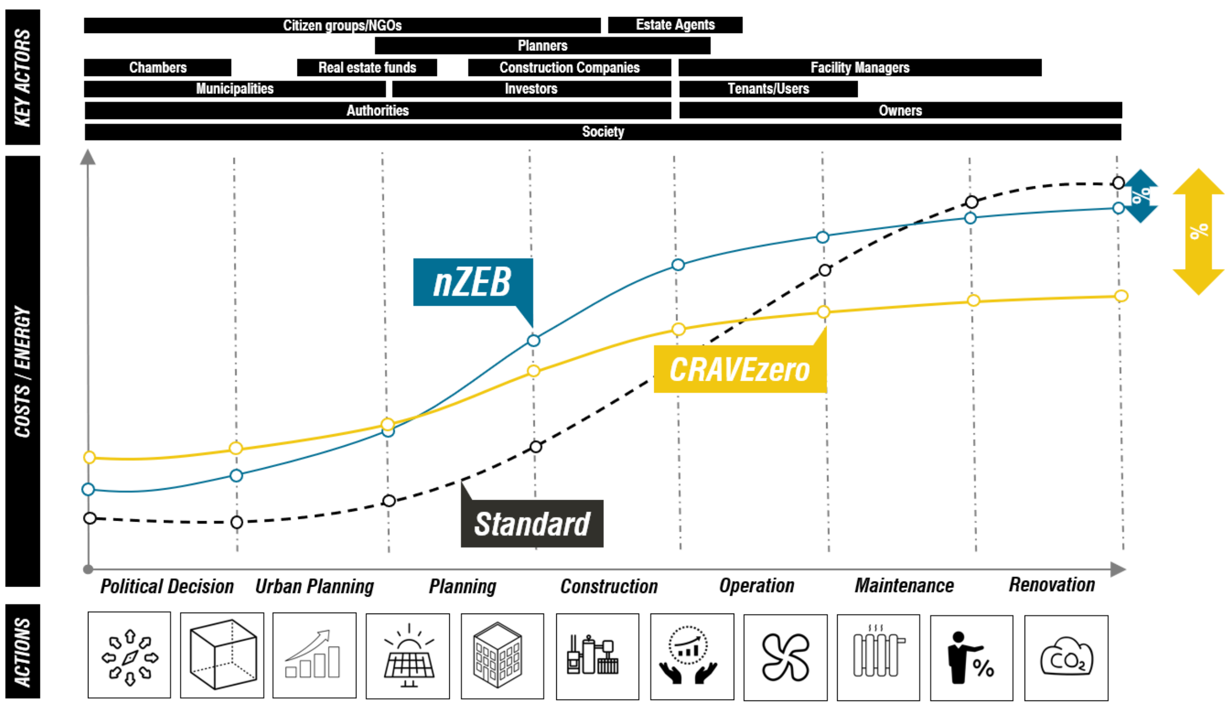

Figure 1: CRAVEzero approach for cost reductions in the life cycle of nZEBs.

Cost reduction and marked acceleration for nZEBs have been achieved using the following guiding principles established by the CRAVEzero consortium:

1. Define energy and related project goals.
2. Define actions to track and reach goals throughout the life cycle.
3. Create win-win situations for all stakeholders.
4. Select optimal nZEB technical solution sets.
5. Conduct life cycle cost analysis of variants.
6. Quantify co-benefits for nZEBs.
7. Learn from frontrunners and avoid pitfalls and bottlenecks.
8. Consolidate all insights in the business case for nZEBs.

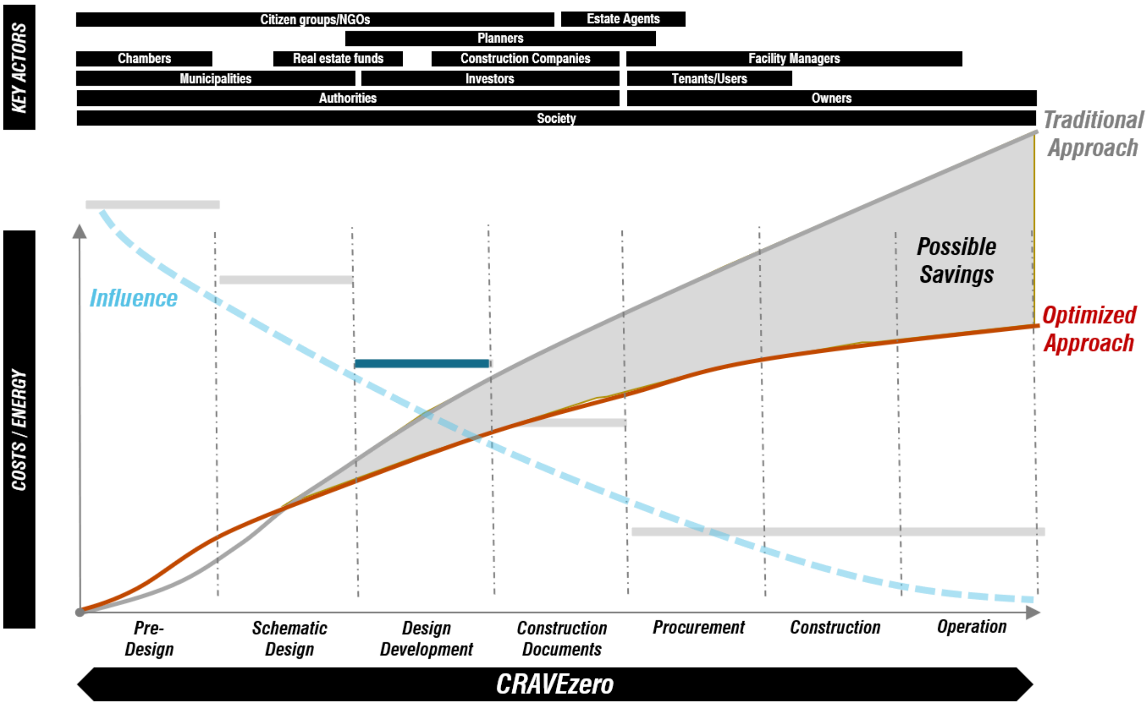

Figure 2: Cost and energy savings potential of nZEBs based on the MacLeamy curve (IDEAbuilder 2012).

The CRAVEzero consortium extends its deepest gratitude to all of its national working group members, the case study project teams, and the members of the Advisory Group with special thanks to the European Commission for their financial support.

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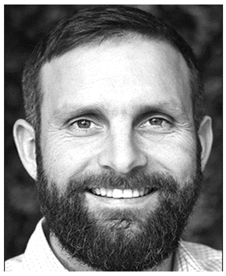

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EXECUTIVE SUMMARY

Effective processes, robust solutions, new business models, and reliable life cycle costs support user engagement and investors' confidence towards net zero balance. CRAVEzero focuses on proven and new approaches to reduce the costs of nearly Zero Energy Buildings at all life cycle stages.

Cost optimal and nearly zero energy performance levels are principles initiated by the European Union's (EU) Energy Performance of Buildings Directive, which was recast in 2010. These will be major drivers in the construction sector in the next few years. While nearly Zero Energy Buildings (nZEBs) realized so far have clearly shown that the nearly-zero energy target can be achieved using existing technologies and practices, most experts agree that a broad-scale shift towards nZEBs requires significant adjustments to prevailing structures in the building market.

This final report summarizes proven and new approaches to reduce the costs of nZEBs at all stages of the life cycle. Within several case studies all over Europe, extra costs for nZEBs are revealed in relation to processes, technologies, and building operations. The focus of this report lies in the potential for cost reductions and innovative business models that would make further uptake of nZEBs cost-effective for all stakeholders.

It is important to note that the nZEBs promoted by CRAVEzero are not unique models to be simply duplicated; rather, they are composed by a set of customisable solutions to be combined according to the local context and the needs of the users. This will ensure the high quality of the built environment, preserve the identity of each building, increase user acceptance, and maintain high real estate value. The impacts of the CRAVEzero project include life cycle cost reductions of nZEBs, measurable energy balance improvements, enhanced use of RES, improved indoor environmental quality and building usability, greater nZEB economic value in connection with high performance (in terms of low non-renewable energy consumption), high quality lifespan, and reduced life cycle costs. CRAVEzero defined an integrated approach for planning and constructing a new nZEB that reduces the current design phase up to 20%. In particular, the process map offers a comprehensive overview of the phases, activities, and actors involved during the life cycle of a nZEB, identifying the possible pitfalls and bottlenecks and relevant countermeasures (Chapter 3). Thanks to an optimised nZEB design with the CRAVEzero parametric method (Chapter 5), it was shown that it is possible to save up to 16% of the financing costs, 23-29% of the operational costs, up to 30% of the replacement and investment costs.

Main Results:

1. Reference schemes for nZEB urban planning and building design process (Chapter 3)
2. Structured methodological approach to optimise integration of renewable and nZEB technologies (Chapter 4)
3. Potential to reduce life cycle costs demonstrated by relevant case studies (Chapter 2/Chapter 5)
4. Demonstration of co-benefits: optimal architectural/building configurations for high-quality living/working environments and real estate value (Chapter 6):
5. nZEBs lean management protocols
6. 60+ Low LCC nZEB business models (Chapter 7)
7. CRAVEzero pinboard (www.pinboard.cravezero.eu)[1]

[1] The Pinboard is a structured framework of all necessary information and tools to build reliable nZEBs at a low life cycle cost. All major results and outcomes are included in this interactive web tool.

CRAVEzero CASE STUDIES

*A **high-performing "nearly Zero Energy Building"** is a very energy efficient building that produces onsite (or procures) carbon-free renewable energy or high-quality carbon offsets in an amount sufficient to offset the annual carbon emissions associated with building materials and operations.*

Väla Gård, Sweden - Skanska

Aspern IQ, Austria - ATP

Green Home Nanterre, France - Bouygues

Solallén, Sweden - Skanska

Résidence Alizari, France – Bouygues

NH Tirol, Austria - ATP

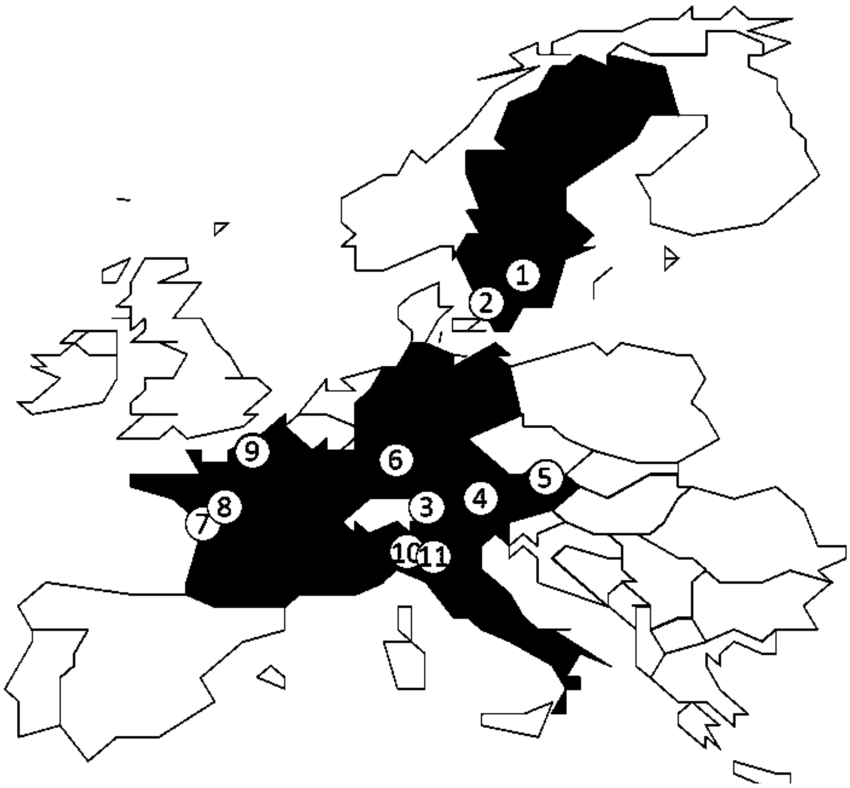
Isola Nel Verde, Italy - Moretti

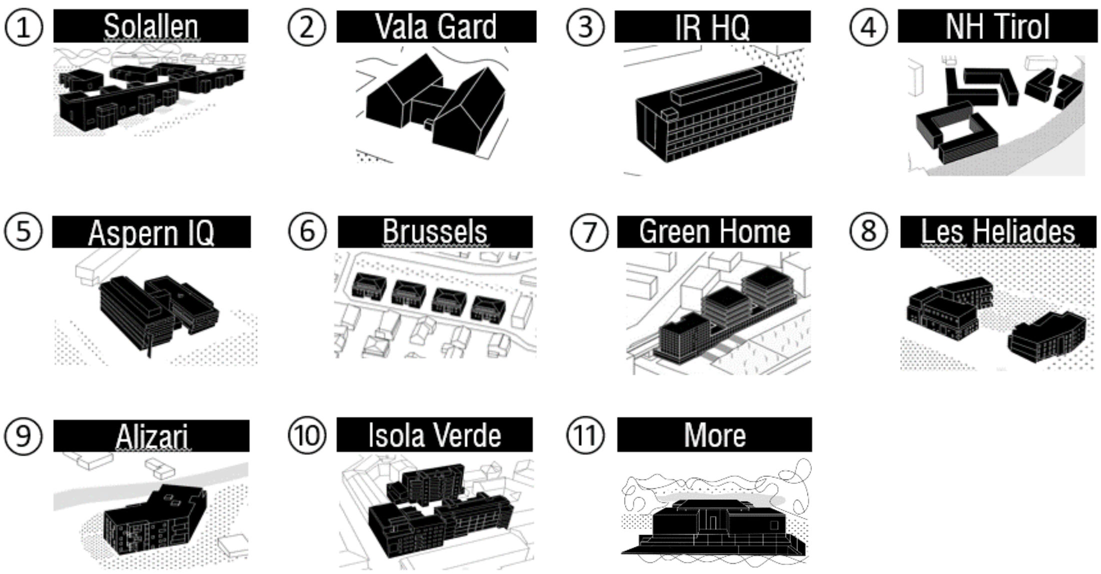
Brussels, Germany – Köhler & Meinzer

Les Héliades, France - Bouygues

I+R Headquarters, Austria - ATP

Moretti More,
Italy - Moretti





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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

CRAVEzero's primary goals are to identify and eliminate extra processing and technological costs for nZEBs and to promote innovative business models that are cost-effective for all stakeholders during the entire life cycle.

CRAVEzero case study Aspern IQ in Austria

Figure 4: Aspern IQ (Austria) – ATP Sustain (c) ATP/Pierer.

Cost-optimisation and nearly zero energy performance levels are initiated by the European Union's 2010 Energy Performance of Buildings Directive (EPBD). These principles guide the construction of all new buildings in the EU that are expected to be nearly zero energy from 2021 onwards.

While nearly zero energy buildings (nZEBs) realized so far have clearly shown that the nearly zero energy target can be achieved through existing technologies and practices, most experts agree that a broad-scale shift towards nZEBs requires significant adjustments to prevailing building market structures. The major challenge is the cost-effective integration of efficient solution sets and renewable energy systems in a manner that fits the whole life cycle.

The 2020 EU-Horizon project "CRAVEzero" focuses on proven and new approaches to reduce costs and improve nZEBs at all stages of the life cycle. Its main goals are to identify and eliminate the extra costs for nZEBs related to inefficient processes and technologies and to promote innovative business models that are cost-effective for all stakeholders.

Cost-reduction potentials are to be found in all life-cycle phases of nZEBs – from urban planning to building design to construction and building operations. Indirect co-benefits to architectural quality, indoor environment, comfort, and health must be considered. The high technical complexity of nZEBs along with their detailed planning/construction/operation processes are the main reasons performance and cost targets are not met. Clear prerequisites must be created to define project objectives. Too often, promising building concepts fail to achieve cost and energy goals because project participants are not sufficiently aware of the manifold interactions of holistic planning contexts.

The idea of CRAVEzero is to promote a well-organized and transparent interdisciplinary process along the whole life cycle of a nZEB, focussing on both environmental and economic concerns (see Figure 5).

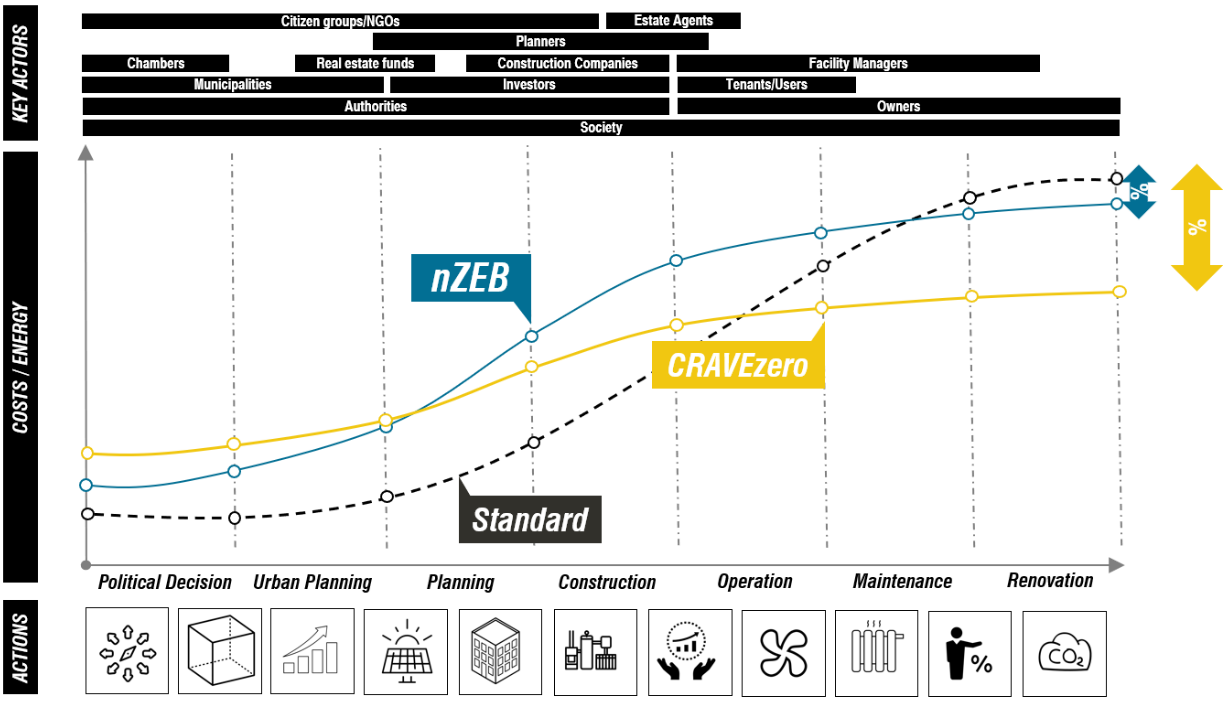


Figure 5: CRAVEzero - The influence on the process decreases while the costs increase during the life cycle of a nZEB.

To minimize risks and possible bottlenecks, obstacles must be identified at an early stage. It is necessary to establish a common plan among all actors as early as possible. As shown in Figure 6 and Figure 7, new nZEBs maximize passive design while limiting energy consumption from the grid. To implement this, planners need to challenge traditional design norms.

Each building has its own unique process in which architects start from scratch to collect information on the local context and its constraints, design the building, carry out cost optimal performance analyses, and evaluate the renewable energy potential. This involves extra time and planning costs for the design process. Without a standardized process, different stakeholders repeat almost identical procedures A systematic approach for the life-cycle process of low-cost nZEBs is needed as a starting point. A clear connection between building performance and related costs is essential. The introduction of a performance-based procurement approach must be common practice not only for public tendering but private construction as well.

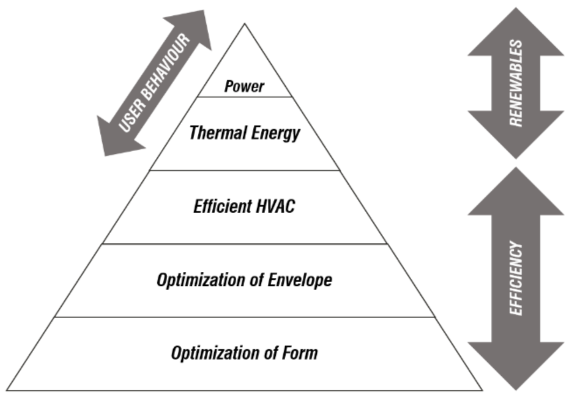


Figure 6: Steps to reach nZEB standard.

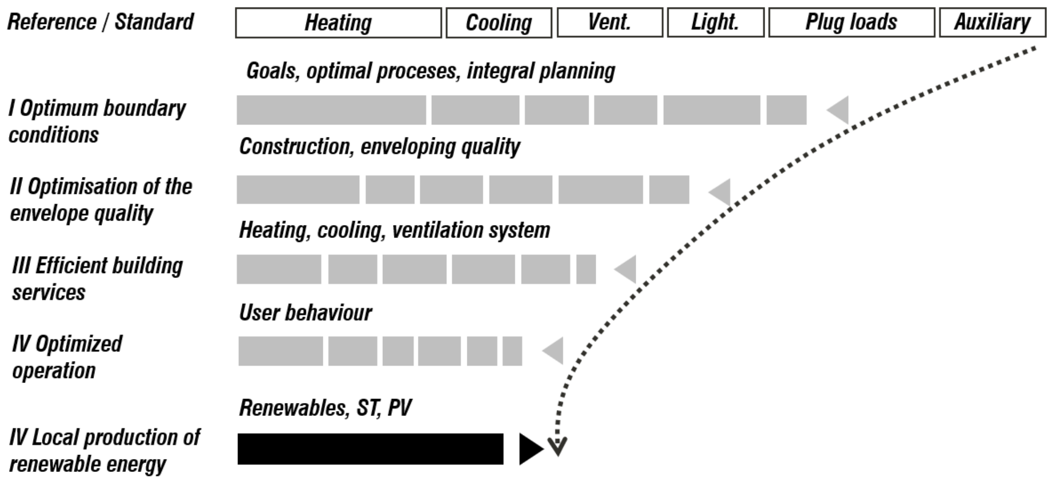


Figure 7: Process steps to reach nZEB-standard along life cycle.

1.1. STATE OF THE ART

Figure 8: Green Home Nanterre – Bouygues Construction (France).

nZEBs with high energy performance have become technically feasible but are not yet cost-effective. To overcome this barrier to implementation, the principle of cost optimisation has been introduced to align national minimum energy performance requirements with economically feasible nZEB targets, considering operating, replacement, and disposal costs. As evaluated within the current ZEBRA 2020 project, the average extra cost in the EU for a nZEB (compared to a new building in compliance with the minimum standard requirements) is approximately 171 €/m² due to higher design and construction costs.

D'Agostino and Parker (2018) have presented a framework for cost optimal nZEB design containing costs, energy prices, and climate data. One important conclusion is that the most common optimized nZEB configuration foresees a combination of good insulation and building airtightness as well as class A++ appliances, lighting, and home energy management systems, along with PV. Airtightness, the efficiency of appliances, and the reduction of solar gains or insulation (depending on the climate) must first be addressed.

Recent European studies have shown that construction costs of buildings close to the passive house standard increase by 4 to 6% compared to those that meet minimum nZEB requirements, but these highly efficient variants reduce the primary energy demand by up to 72% (Ploss et al., 2017). Berggren, Wall, and Togerö (2018) depart from traditional ways of calculating nZEB profitability with life-cycle cost analysis (LCC) by trying to quantify the added value of a green building in monetary terms. Their assessment is based on a planning process that also includes socio-economic parameters influenced by the quality of the building.

It shows how the optimal set of measures can be found. But how can the knowledge of optimal building design strategies and technical solution sets be tied to the building process? Which actors should be involved? Which actions must be taken, and at what time? Is the traditional development process for buildings suitable for high-level nZEB buildings to penetrate the market?

To answer these questions, an important first step is to clarify the construction procedure of the project. One prominent example of different construction procedures affecting the interface between phases lies in the decision of the project delivery system (Konchar and Sanvido, 1998). In Europe, the standard project delivery system is *design-bid-build*. This means that there is a clear cut between the design phase and the building phase, which is marked by the procurement of the construction companies ("bidding"). Important implications are that construction companies do not take part in the planning phase, and the owner has to invest additional time in assigning construction contracts. An alternative approach is the *design-build* approach, which is increasingly used worldwide.

Torcellini et al. (2004) have studied the nZEB realization process by examining various case studies on nZEB construction processes. They investigated the project delivery system of high-performance/ low-energy buildings and concluded that the performance-based design-build approach was best to achieve high quality at low cost (Crawford, Czerniakowski, & Fuller, 2011; Pless, Torcellini, & Shelton, 2011). In performance-based design-build, the planning and construction phases are strongly interconnected since the owner engages a team of planners and constructors with well-defined targets to realize the whole building for a thoroughly defined function and at a fixed cost. Moreover, the owner financially rewards the team for achieving higher standards throughout the process. The salient point is that performance-based design-build can be used to integrate the planning and construction phases to achieve the specific goal of a high-performance nZEB. Konchar and Sanvido (1998) conclude that design-build shows major cost and performance advantages compared to other project delivery systems.

What does this mean for the goal of promoting nZEBs? It means that it is not enough to solely consider the individual actions of single users in determining building phases, planners – constructors need to work interactively. Pless, Torcellini, and Shelton (2011) argue that design-build permits higher achievements in energy-efficient buildings and nZEBs because of the integration of planning and construction.

Possible cost-saving potentials in the planning and construction of high-performing nZEBs have not been sufficiently assessed in the traditional planning process. In many countries, planning and analysis have not been carried out in parallel, and the alternative technical options or business models are discarded at an early stage. However, a realistic comparison of nZEB solutions in the planning phase would promote more well-informed decisions.

Just as integrating planning and construction can enhance outcomes, so too can urban planning considerations and the inclusion of operational actors in the planning phases, as demonstrated by the "Renew School" project (Kondratenko, Van Loon, & Poppe, 2014).

1.2. THE "CRAVEZERO FRAMEWORK"

THE FUNDAMENTALS OF nZEB DESIGN

① Reduce the building's energy demand in order to meet its needs with efficiency.
② Select high-efficiency space heating, cooling, and water heating.
③ Generate renewable energy on-site and use renewable energy supply systems.

THE CRAVEZERO FRAMEWORK

❶ Define energy and related project goals.
❷ Define actions to reach the goals and track them throughout the life cycle.
❸ Create win-win situations for all stakeholders.
❹ Select optimal nZEB technical solution sets.
❺ Conduct life-cycle cost analysis and variants.
❻ Quantify co-benefits for nZEBs.
❼ Learn from frontrunners to avoid pitfalls and bottlenecks.
❽ Consolidate all insights from business cases.

nZEB design is a multi-objective challenge where stakeholders' interests often conflict with each other. Through the provision of knowledge, the "CRAVEzero framework" aims to promote confidence in decision-making to reach nZEB goals (particularly in relation to energy and cost performance). The main targets pursued in the project can be summarized as follows:

❶ The reduction of nZEB construction costs compared to the present costs of a new conventional building that would meet current building regulations.

❷ Nearly zero energy consumption or less (including on-site or nearby renewable energy sources) and nearly zero impact of materials used over the whole life cycle.

❸ Co-benefits such as increased real estate value and working environment quality.

❹ A cost-effectiveness investment from a business model perspective.

For practical implementation, the proposed CRAVEzero methodology is an addition to the fundamentals of nZEB designs. It aims to reach nZEB targets in eight major steps:

① Define energy and cost-related project goals

It is important to clearly define energy consumption and life-cycle cost-related goals for the project in the first step. This step lays the foundation to define key actions needed to achieve those goals, and avoid pitfalls and bottlenecks.

② Define actions to reach the goals and track them throughout the life cycle

Considering the complexity of reaching the nZEB target with cost optimal solutions for diverse stakeholders, multiple actions are required. However, these are usually missing from standard planning processes. Therefore, it is important to promote a shared interdisciplinary understanding of the complexity of the nZEB planning processes for all involved stakeholders. A well-organized and transparent process is key to achieving the goal of cost optimal and sustainable nZEBs throughout the entire life cycle. The CRAVEzero consortium provided its experience in the area of holistic project management with a focus on integrated building planning. It defined how key performance parameters should be prioritized and tracked along the life cycle. Additional advantages of holistic project managements are:

- Risk reduction
- Quicker construction and delivery
- Control over costs and energy performance
- Integrative design and Optimal use of team members' expertise
- Establishment of measurable success criteria

See also CRAVEzero Report: "Guideline I: nZEB processes" and: "Optimized nZEB process map" for detailed information.

③ *Create win-win situations for all stakeholders*

A win-win situation for the involved stakeholders needs to be created and translated into a business model.to push nZEB market uptake. Business models are usually based on cooperative strategies where different stakeholders bundle their expertise to create positive outcomes, synergies, and "win-win" situations. New and existing examples of win-win nZEB business models have been analysed during the CRAVEzero project and offer advantages to different types of stakeholders (e.g., planners, developers, construction companies, and users) while positively contributing to the environment and society.

See also CRAVEzero Report: "Typology canvas of business models" and "Report describing nZEB business models" for detailed information.

④ *Select optimal nZEB technical solution sets*

To realize cost-efficient nZEBs for all stakeholders throughout the life cycle, knowledge of the most important technical solution sets and their associated costs is essential.
Cost-effectively implementing comprehensive solution sets (based on key industrialized components and renewable energy systems) into the design and construction process poses major challenges. The CRAVEzero approach has identified technical and life-cycle cost-reduction potentials for each nZEB technology set to define robust solution sets based on industrialized multifunctional building components that are easy and flexible to produce, install, and maintain.

See also CRAVEzero reports: "Guideline II: nZEB technologies" and "Optimized nZEB solution sets" for detailed information.

⑤ *Conduct life-cycle cost (LCC) analysis*

According to ISO 15686-5:2008, the life-cycle cost of a building is the net present value, which is the sum of the discounted costs and revenue streams during the selected phase of the life cycle. The life-cycle phases generally included in the assessment are the cost of initial investment (design and construction), cost for operation and maintenance, and end-of-life residual value.
This methodology has the advantage of transparency in the operational phase, an awareness of total costs, and the possibility to reduce costs during the design phase. This approach:

- balances the cost of ownership and occupation, analyses initial investment and running cost;
- assesses risks and costs associated with maintenance/replacement due to failure; and
- supports sustainable decisions.

Furthermore, the LCC calculation can be adopted to compare building variants, alternative technology sets, or mutually replaceable design alternatives.

This is illustrated in the CRAVEzero report: "Spreadsheet of LCC."

⑥ *Quantify co-benefits for nZEBs*

It is essential to quantify the added value of green buildings and their impact on life-cycle costs. The objective is to present new business advantages and opportunities to potential investors that transcend technical performance analysis. Co-benefits include increased productivity, improved health, publicity value, higher renting potential, reduced employee turnover, and reduced absenteeism.
See CRAVEzero report: "Framework for co-benefit analysis."

⑦ *Learn from frontrunners and avoid pitfalls and bottlenecks*

Due to unclear requirements and technological ambiguity, there are cost and time constraints in the construction of nZEBs and plus-energy buildings alike. The CRAVEzero project showcases model nZEB projects, which have been realized in a cost-efficient way and future projects may adapt to avoid pitfalls and bottlenecks.

Three CRAVEzero reports on "Parametric models for buildings and building clusters" analyse these exemplary buildings.

⑧ *Consolidate all insights from business case studies.*

The goal was to develop an effective methodology to achieve the best conditions for cost-optimised nZEBs by exploring the concept of integrating nZEB technologies and business models into the entire planning, construction, and operation process. The generation and evaluation of innovative business models is also part of the study of nZEBs. To generate new business models, it is necessary to identify which types already exist in the markets and what makes them successful or inconsistent.
See CRAVEzero reports "Database of all found services and business models" and "Guideline III: nZEB Business models."

01 THE FUNDAMENTALS OF nZEB DESIGN

① ***Reduce the building's energy demand. Meeting a building's energy needs efficiently is a critical next step that helps reduce energy use and emissions.***
② ***Select high efficiency heating, cooling, and water heating.***
③ ***Generate onsite renewable energy and use renewable energy supply systems***

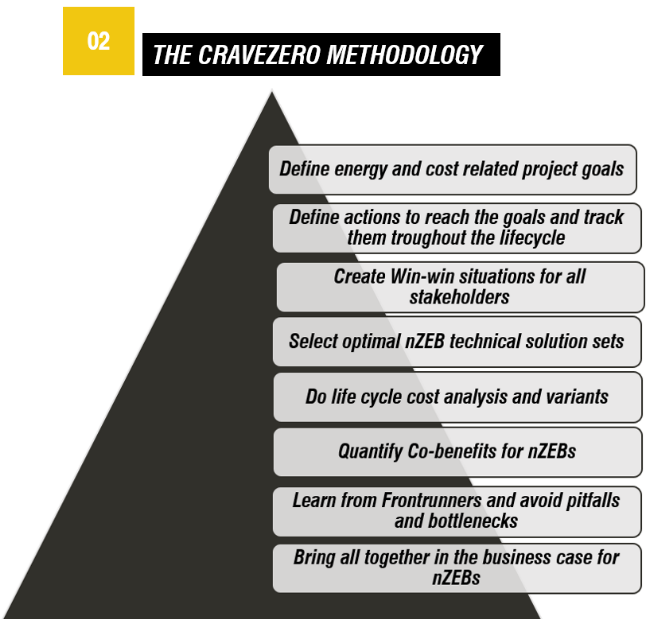


Figure 9: The fundamentals of nZEB design and the CRAVEzero methodology.

nZEBs – BARRIERS AND CHALLENGES

Over the course of the 2018 ISEC Conference in Graz, Austria and within national implementation working groups in Germany and Italy, a survey of planners, researchers and contractors (200 participants) was conducted. Drawing on the varied professional experiences, the survey inquired about challenges witnessed in the implementation of nZEBs, what is needed to make them more marketable, and how they add value to society. The results of the survey are ordered according to their importance in descending order.

What are the main challenges barriers to realizing nZEBs?

1. Investment costs are higher on average
2. Additional effort is required to understand, apply, and qualify for the nZEB standard/Integrated planning requires more effort and communication
3. Processes and responsibilities are unclear among stakeholders
4. Lack of communication/documentation/collaboration among stakeholders
5. Mismatch between renewable energy generation and demand
6. Lack of knowledge about technologies and costs/Concern about high maintenance costs of nZEBs
7. Higher investment costs must be disbursed on a resale of the building (investors' or real estate agents' models often do not consider energy)
8. Too many regulations and standards/Lack of support from authorities/Financial value of subsidies often unclear
9. Lack of communication or documentation
10. Lack of knowledge of optimal solution sets/Over-dimensioning of HVAC systems
11. Falling nZEB technology prices (especially for batteries and PV) can lower value of capital invested

What is needed for the market uptake of nZEBs?

1. Strengthened binding legal requirements
2. Earlier collaboration within the planning team
3. More technological know-how
4. Robust life-cycle costs of nZEB technologies
5. The necessary skills and experience for construction among stakeholders

What is the added value of building nZEBs?

1. Climate protection and environmental savings
2. Increased future property value
3. Greater independence from future energy price increases/energy autonomy
4. High indoor air quality/health benefits
5. Reduced energy costs
6. Reduced total cost of ownership, net monthly cost of living, and life-cycle costs
7. Potentially higher resale value
8. Property is prepared for legislative restrictions and carbon emission penalties
9. Better reputation and good image building
10. nZEB-related national funding opportunities

1.3. CRAVEZERO PINBOARD

An interactive web-based structured framework to build effective low life cycle cost nZEBs: http://pinboard.cravezero.eu/

Figure 10: The CRAVEzero Pinboard – pinboard.cravezero.eu.

The CRAVEzero pinboard is a structured framework organizing all required information and tools to establish:

1. An effective low LCC nZEB business model,
2. Reliable LCC databases outlining the cost reduction potential for processes,
3. Robust technologies, methodologies, and solutions for low LCC nZEBs.

The outcomes of the CRAVEzero project have been condensed in the pinboard, which can be considered the backbone of the CRAVEzero project. It allows the design and construction approach to new nZEBs to be altered based on the tools and solutions developed. A brief overview of the pinboard's main features is required to better understand the prototypical implementations carried out by project partners (see the report on the "CRAVEzero pinboard" for a complete description).

Figure 11: Pinboard landing page on CRAVEzero website (pinboard.cravezero.eu).

All the steps mentioned in the CRAVEzero methodology in the previous chapter have been translated into an interactive modular set of nine web-tools, which are free to use and modify on the CRAVEzero pinboard illustrated in Figure 12.

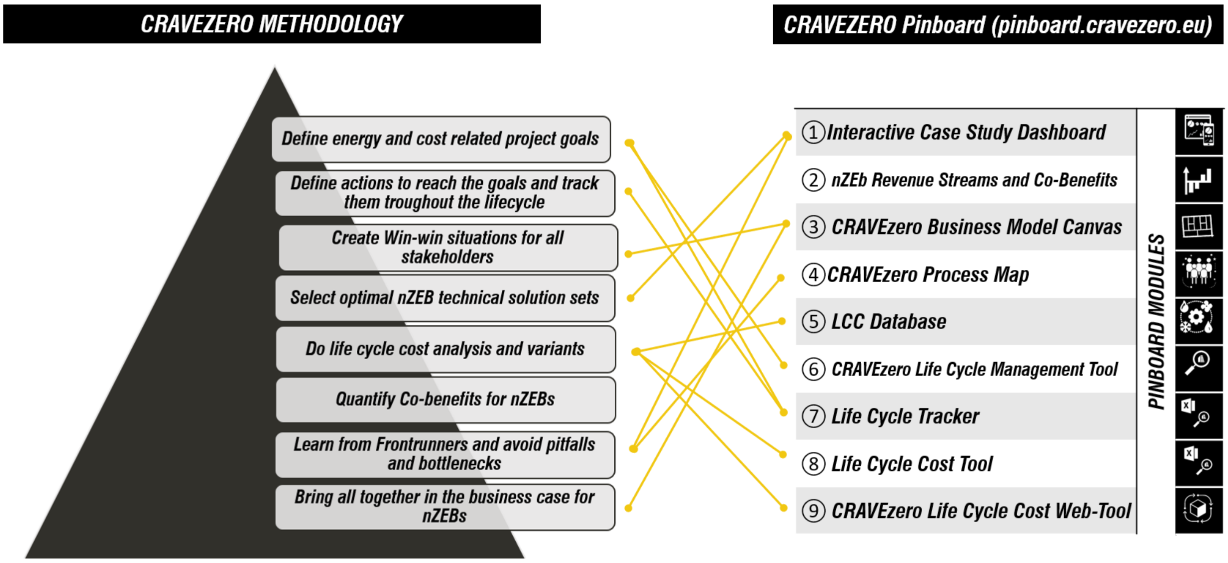
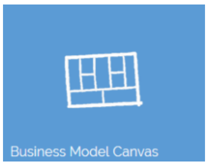
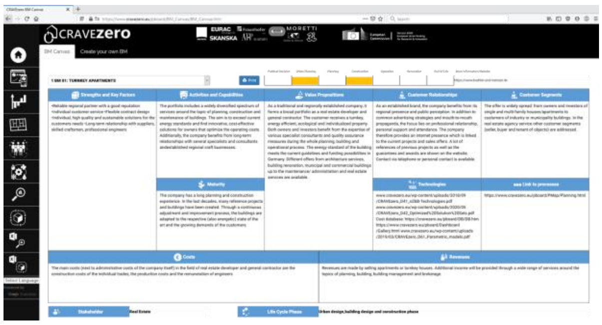


Figure 12: CRAVEzero method concerning the pinboard.

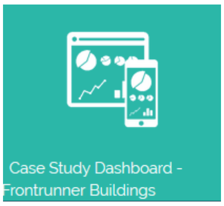
Business Model Canvas



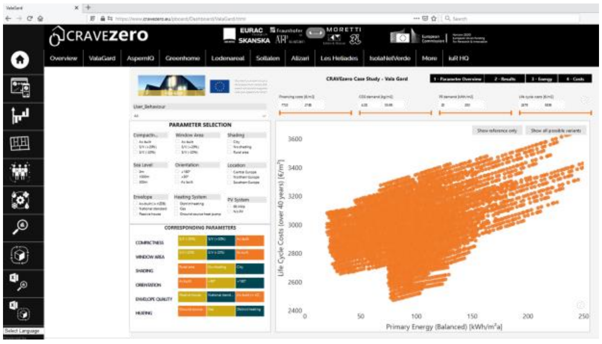
A lean startup template for developing new or documenting existing nZEB business models. This a tool to understand a business model in a straightforward and structured way. It offers the possibility to browse existing business models or to create new ones from scratch. The business model repository contains over 70 existing nZEB business models in which the life-cycle phases are indicated. The information on each business model is displayed according to the Osterwalder Business Model Canvas structure: a visual chart with elements describing a company's or product's value proposition, infrastructure, customers and finances.



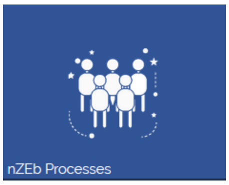
Case-study dashboard – Frontrunners



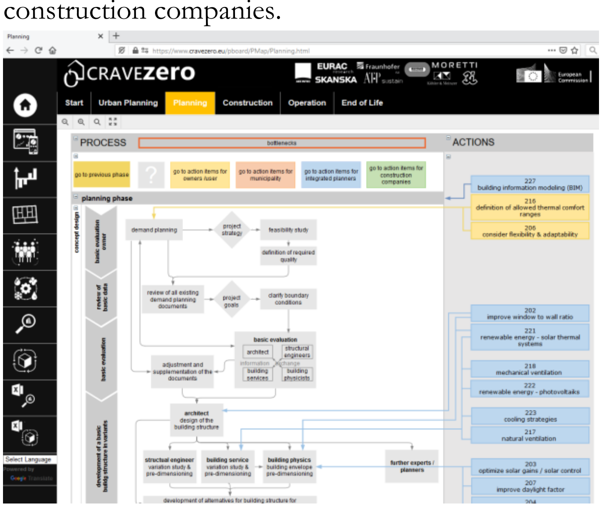
The idea of this interactive dashboard is to allow pinboard users to dig into the data, gain insights, and look for optimal solutions based on the CRAVEzero case studies. The web report is highly interactive and highly customizable. Within the dashboard, users can add and remove data, change visualization types, and apply filters to thousands of technical variants and life-cycle costs.



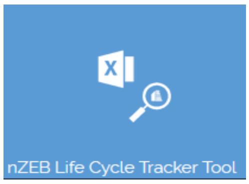
Process Map



A process tool that enables the project team to integrate additional actions in their own planning, construction and execution routines to achieve the nZEB standard. It gives an initial overview of the complexities of doing so. In the interactive process map, stakeholders can display individual nZEB To-Do items or see which tasks other project participants have. The whole process is divided into urban planning, planning, building construction, utilization, and end-of-life steps. Action items and bottlenecks can be displayed for the owner/user, municipalities, the integrated planning team, and construction companies.



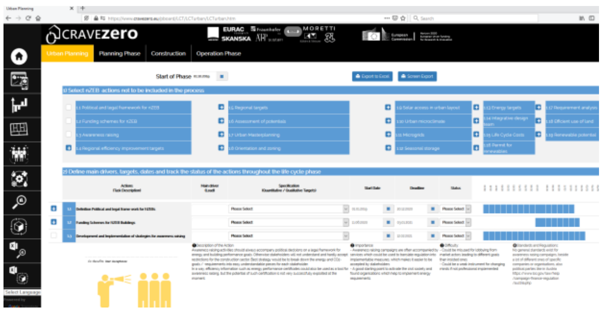
Life Cycle Tracker



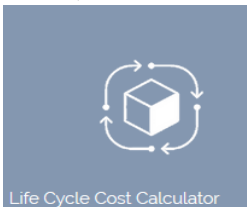
An electronic document that can be easily adapted to the specific needs of any practice, team, or project. It organizes the processes of briefing, designing, constructing, maintaining, operating and using building projects into several key stages. It details the tasks and outputs required at each stage, which may vary or overlap to suit specific project requirements. It is a web tool and downloadable spreadsheet, containing customizable tables allowing easy creation of the project roles, design responsibility matrix and multidisciplinary schedules of services.

Life Cycle Management

An online tool which allows a nZEB project to be tracked and managed throughout the whole life cycle.



Life cycle cost tool



A tool for LCC calculation was developed and is available in two versions: a full version with all functionalities and a limited online version to make a preliminary LCC calculation. The data collection within the tool is organized following the LCC structure introduced by the standard, ISO 15686-5:2017. Furthermore, the source used to structure the construction costs is the European Code of Measurement elaborated by the European Committee of Construction Economists. The analysis of maintenance costs of heating, ventilation, and air conditioning (HVAC) systems is based on standard values from EN 15459:2018, which provides annual maintenance costs for each element, including operations, repair, and service, as a percentage of the initial construction cost. The lifespan for system replacement is also provided by the standard. According to ISO 15686-5:2017, the LCC deals with activities connected to the design, construction, and operation of the building. End-of-life costs have not been implemented in the tool yet. The Whole-Life Cost (WLC) includes the non-construction cost (e.g., cost of land enabling activities) and the fees required to set up the building from a technical and administrative standpoint.

A summary of all pinboard tools and their respective stakeholder target groups is shown in Figure 13.

✓ Main Target Group
☐ Extended Target Group

PINBOARD MODULES	Tenant / user	Real estate agents	Construction Companies	Planner	Property management	Investor	Building owner / landlord	Building owner (public)	Society
① Interactive Case Study Dashboard	✓	✓	☐	✓	☐	☐	☐	☐	☐
② nZEb Revenue Streams and Co-Benefits	✓	✓	☐	✓	✓	✓	☐	☐	☐
③ CRAVEzero Business Model Canvas	☐	✓	✓	✓	✓	✓	☐	☐	☐
④ CRAVEzero Process Map	✓	☐	✓	✓	☐	✓	☐	✓	✓
⑤ LCC Database	✓	✓	✓	✓	✓	✓	✓	✓	☐
⑥ CRAVEzero Life Cycle Management Tool	☐	☐	✓	✓	☐	☐	☐	☐	✓
⑦ Life Cycle Tracker	✓	☐	✓	✓	✓	☐	✓	✓	✓
⑧ Life Cycle Cost Tool	☐	✓	☐	✓	☐	✓	✓	✓	☐
⑨ CRAVEzero Life Cycle Cost Web-Tool	☐	✓	☐	✓	☐	✓	✓	✓	☐

(STAKEHOLDER)

Figure 13: CRAVEzero pinboard – Web Tools (modules) and target group.

1.4. EU IMPLEMENTATION OF nZEBS

The 2010 Energy Performance of Building Directive (EPBD 2010/31/EU), the Energy Efficiency Directive (EED 2012/27/EU), and the Renewable Energy Directive (RED 2014/53/EU) represent the key regulatory framework adopted at the European level to promote and support the market uptake of nZEBs in Europe.

Article 9 of the EPBD sets the timeline for the implementation of the nZEB definition: all new public buildings after 1st January 2019 and all private buildings after 1st January 2021 must reach the nZEB target. Figure 15 summarises the main measures promoted by the three directives. The EPBD does not provide minimum or maximum harmonized requirements for nZEBs but it notes that very high emergency performance and demand must be covered (to a very significant extent) by energy from renewable sources. The analysis of definitions/specified requirements shows how the countries chose different approaches and system boundaries. In most cases (e.g., the CRAVEzero countries), the requirements are set at a single-building level and include targets for new and renovated buildings, both public and private. The balance period to calculate the building energy performance and normalization factors is generally homogeneous among member states: one year and the conditioned floor area, respectively.

Figure 14: Isola Nel Verde – Moretti.

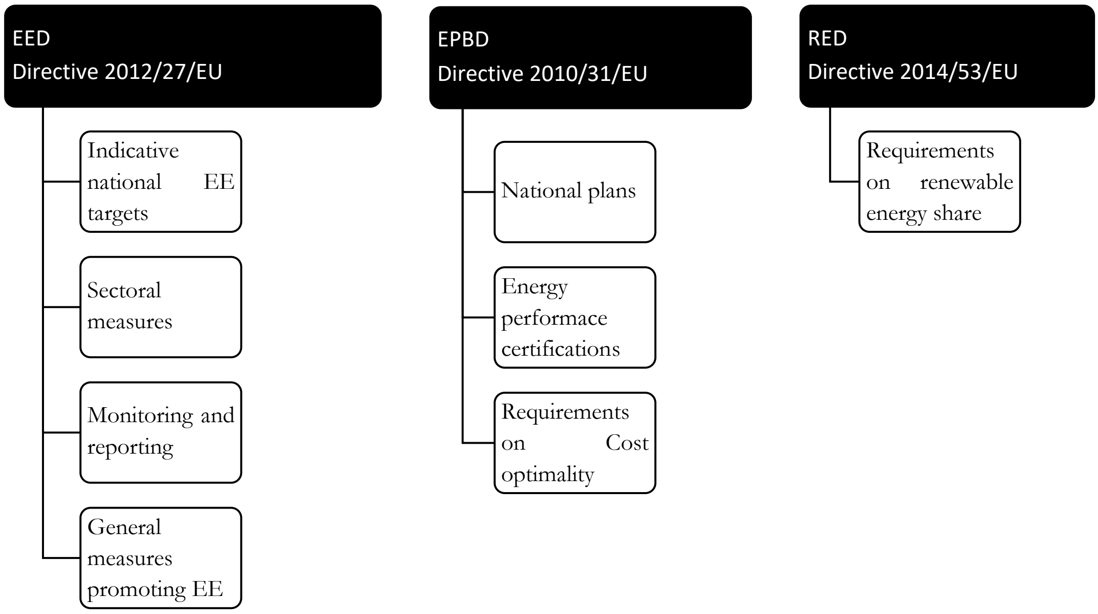


Figure 15. Key elements of European Directives (EED, EPBD and RED).

Cost optimality

The EPBD stated that the achievement of high performance in nZEBs must be compatible with the cost optimality assessment. The idea is that the building design, from an envelope to technical systems, has to offer energy-efficient solutions at minimal life-cycle cost.

EU construction market

To better understand the field of application of the EPBD, an overview of the construction market and the European building sector is provided. The objective of the CRAVEzero project is to identify and propose solutions while reducing costs associated with nZEB construction (Figure 16). As stated in the ZEBRA 2020 project, the lack of structured financing schemes and the need to increase professional knowledge of best practices are currently the main barriers to the transition to nZEB implementation.

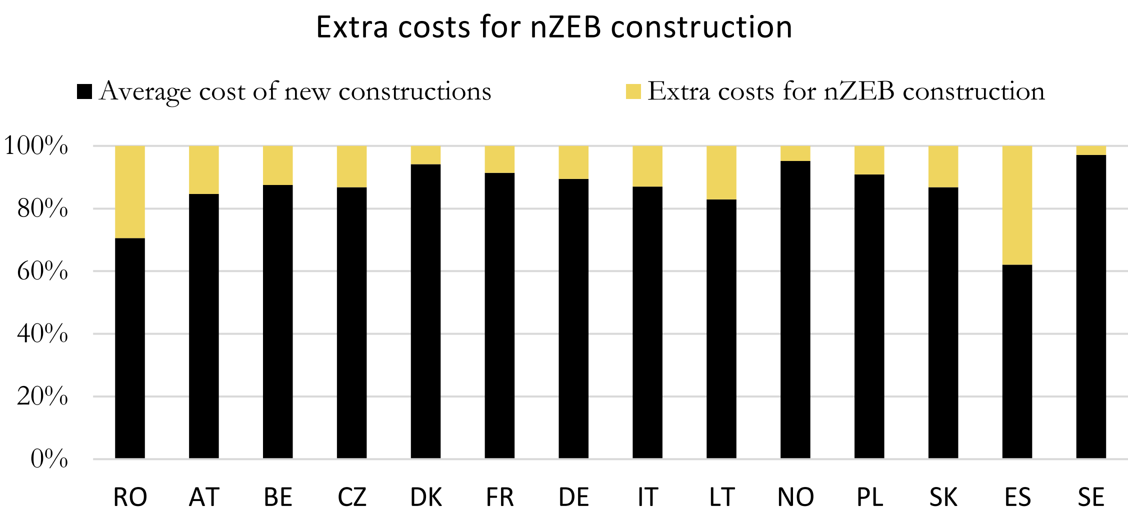


Figure 16. Extra costs for nZEB construction versus average cost of new constructions (Pascual et al., 2016).

Focus at the national level

To carry out a comparative analysis among countries, an overview of the regulatory framework at the national level is needed. The countries involved in the CRAVEzero project are Austria, Germany, France, Italy, and Sweden.

Austria - The "national plan" document includes minimum standards for four energy indicators: heating demand, primary energy demand, CO_2 emissions, and a "total energy efficiency factor" specific to Austria. Guideline 6 of the OIB includes requirements for the renewable energy share of both new constructions and major building renovations.

Germany - The regulatory framework, which deals with energy efficiency and renewables in buildings, is structured in three parts: the Energy Saving Act (EnEG), the Energy Saving Ordinance (EnEV), and the Renewable Energy Heat Act (EEWärmeG). In several reports to the European Commission, the German federal government expressed the intention to define the future nZEB level based on "KfW efficiency houses," a subsidy scheme for buildings that exceed current energy-saving requirements. KfW standards for new buildings are not expressed by absolute values, but by referencing an existing building to performance (calculated using the maximum U-values indicated).

France - The Thermal Regulation RT2012 expresses five ways to meet requirements for primary energy consumption. Total primary energy consumption is defined for heating, cooling, hot water production, lighting, ventilation, and any auxiliary systems. RT 2012 requires the use of a renewable energy source for individual houses.

Italy - The decree D.M. 26 of June 2015 set the requirements for new construction and nZEB. As in the case for Germany, the decree introduced the reference building (a building with the same geometrical configuration and specific values for the envelope thermal transmittance as well as HVAC system efficiency) to define the maximum limit of primary energy.

Sweden - The Swedish Building Code (BBR) defines building energy performance; at the beginning of this project BBR 25 (BFS 2017:5) was in force. The Swedish regulation sets the requirements for building energy consumption, indicated by "specific energy use." The Swedish regulation does not include a minimum renewable energy requirement.

Comparative analysis

Since there are no common methodologies, a comparative analysis of nZEB targets in the CRAVEzero reference countries was carried out by simulating the performance of a reference building with the Passive House Planning Package (PHPP) tool (Feist et al., 2007). The reference building was modelled to calculate the nZEB requirements in Italy and Germany. It is a single-family house representative of the EU stock (FP7 project "Inspire"). Different technical configurations were adopted to show the effect of each on the primary energy demand, keeping the U-values constant (as indicated in the requirements). The four different cases simulated in PHPP, using the climate data of Italy and Germany, are as follows.

- **Case 1**: The building has a heat pump for heating and domestic hot water (COP=3) but no mechanical ventilation. An air change rate at the pressurization test (n_{50}) of 4 volumes per hour (4 1/h) was adopted. This is a standard value with no particular focus on airtightness level.
- **Case 2**: The same building has mechanical ventilation with a heat recovery system.
- **Case 3**: The same building with the maximum air change rate for the Passive House Standard and high airtightness (0.6 1/h).
- **Case 4**: The same as case 2 but with the heat pump replaced by a gas condensing boiler.

In Figure 17, the primary energy requirements of Austria, France, and Sweden are compared with those reached by Italy and Germany with their reference building in two configurations: case 2 and case 4. Figure 18 shows how the installation of a ventilation system results in a reduction of 10.1% of the primary energy demand in case 2. A building design with special attention to airtightness permits a further reduction of 9.8% of primary energy (case 3). The primary energy demand in case 4 is 28.7% higher than with a heat pump.

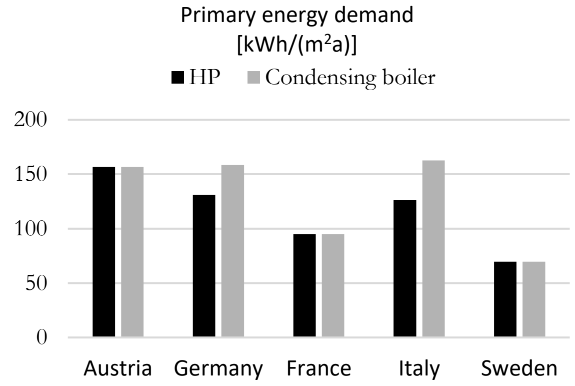


Figure 17. Primary energy demand for heat pump and gas condensing boiler in CRAVEzero countries.

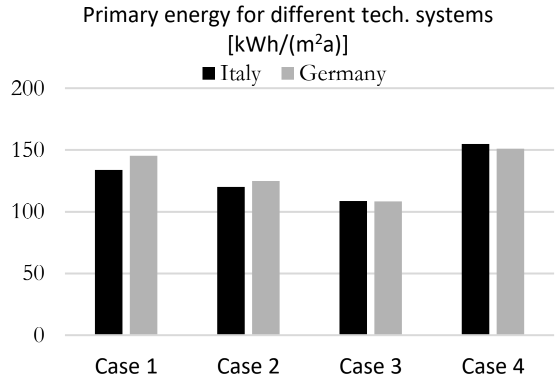


Figure 18. Primary energy demand for the reference building in Germany and Italy with different technical systems.

CHAPTER 2

CRAVEzero case studies

2. CRAVEZERO CASE STUDIES

As part of the project's backbone, 12 case studies have been selected and analysed in terms of Life Cycle Costs. Industry Partners provided information on 12 existing reference buildings considered representative of the current best practices in the construction of new nZEBs. The Industry Partners participated in the design, construction, or operational phase of the buildings, and thus have access to detailed relevant data. These case studies include both residential and office buildings and are located in the CRAVEzero countries: Italy, France, Germany, Sweden, and Austria.

2.1. KEY PERFORMANCE INDICATORS

Key Performance Indicators (KPIs) were introduced to measure the building performance and provide easily accessible information on the topic. Within the CRAVEzero project, a set of KPIs provides a comprehensive evaluation of nZEB costs/performances and introduces reference benchmarks for nZEBs in the EU.

The list of KPIs was defined through a selection starting from a pre-defined set of indicators taken from literature and relevant research projects dealing with the building performance evaluation.

The list was submitted to project partners with the request to rate the KPIs on a scale of 1-3 ("3 - very interesting," "2 – interesting," and "1 - not interesting"). According to the ranking, KPIs with an average score from 2 to 3 were included in the final list. Table 1 reports the selected indicators.

Table 1: List of selected KPIs (rated according to importance)

RATING	KPI	RATING	KPI
3	LCC/usable floor surface	2.4	Cooling energy demand for cooling
2.8	Investment cost/usable floor surface	2.4	Energy demand for hot water production
2.6	Operation cost/usable floor surface	2.4	Annual renewable energy generation
2.6	Renewable energy share	2.2	Maintenance cost/usable floor surface
2.6	PV annual electricity yield	2.2	Maintenance cost/investment cost
2.6	Annual CO_2 emissions	2.2	Final energy consumption
2.5	Life cycle CO_2 emissions	2.2	Specific heating demand
2.4	LCC	2.2	Specific cooling energy consumption
2.4	WLC	2.2	Specific hot water energy consumption
2.4	Investment cost	2.2	Specific electricity energy demand
2.4	Operation cost	2	LCC/renewable energy installed capacity
2.4	Maintenance cost	2	Operation cost/PV energy production
2.4	Primary energy consumption	2	Electricity energy demand
2.4	Heating demand for heating	2	Energy demand for ventilation

2.2. LCC CALCULATION METHOD

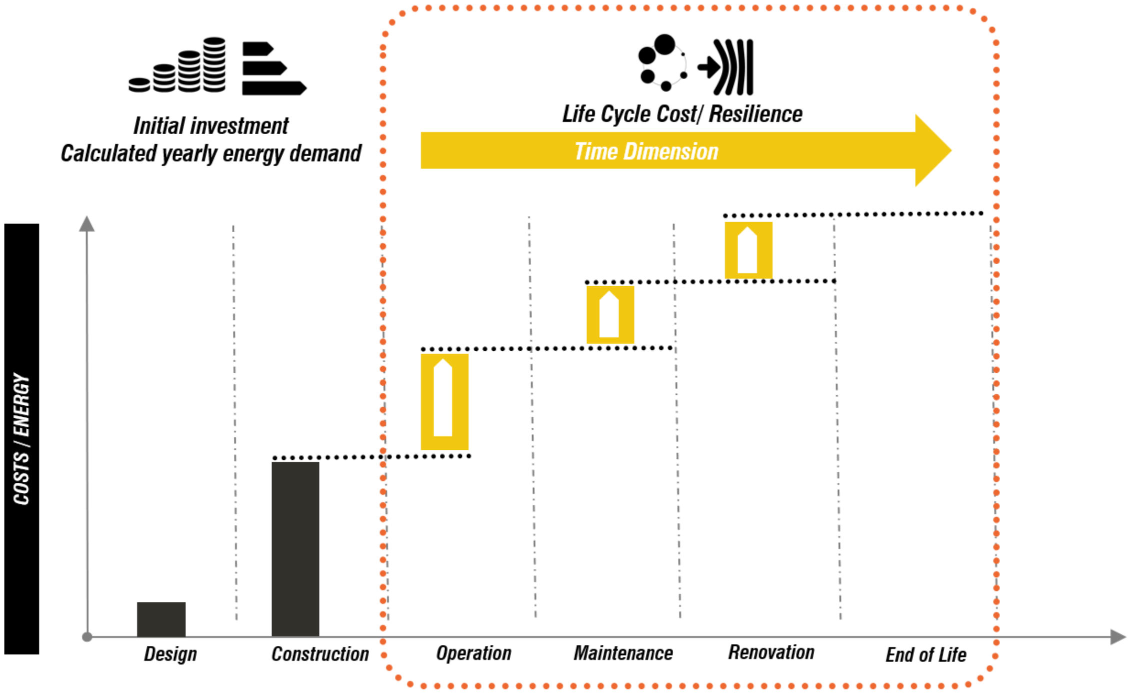


Figure 19. Life cycle cost approach

The ISO 15686-5:2008 provides the main principles and features of an LCC calculation, while the European Code of Measurement is the EU-harmonised structure that breaks down the building elements, services, and processes, in order to comprehensively evaluate its life costs in this study.

According to the aforementioned ISO standard, the LCC of a building is the Net Present Value (NPV): the sum of the discounted costs, revenue streams, and value during the selected phases of the life cycle. The NPV is calculated as follows:

$$X_{NPV} = \sum_{n=1}^{p} \frac{C_n}{(1+d)^n}$$

C: costs incurred in year (n);

d: expected real discount rate per annum (assumed as 1.51%);

n: number of years between the base date and the occurrence of the cost;

p: period of analysis (40 years).

Figure 20 shows the main references adopted for the LCC calculation. Construction, operation, and maintenance phases were considered whereas end-of-life stage was discarded, as the analysed period is 40 years – less than an average building lifespan.

The LCC calculation was implemented in two steps: first, the analysis of the 12 case studies coming from project partners and secondly, the parametric analysis.

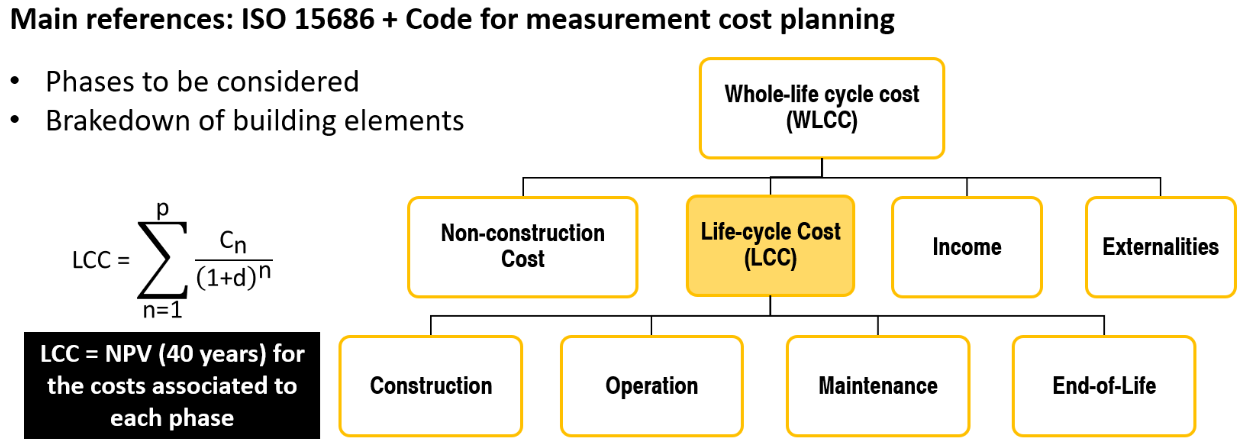


Figure 20. Main references.

Assumptions and Boundary Conditions

This section is divided into two parts since different approaches were adopted for the LCC calculation during the project, although the construction costs were provided by the project partners in both cases. The buildings were already constructed, and real cost data was available.

First, for calculating future costs, including annual energy and maintenance costs, over a 40 year lifespan, an average interest rate of 1.51% for the period from 2009 to 2016 (years of construction of the oldest and the most recent case study) was adopted. General inflation was not taken into account since this parameter influences all case studies the same way.

Second, the costs for the varied technologies and building elements were also directly provided by the project partners. If necessary, assumptions were made according to the CRAVEzero database. All costs are reported as "net costs" (excluding VAT). Land and excavation costs were taken into account. The buildings are located in Austria, France, Italy, Germany and Sweden, so climate data files were generated with Meteonorm 7.1.8.29631. As mentioned above, the economic evaluation of the variants is based on an observation period of 40 years. This observation period was chosen because it is a feasible duration for private housing as well as property developers. As a financing scheme, a bank loan was chosen with a credit period of 25 years and an interest rate of 3 %. The equity interest rate for the equity investment was set to 1.51 %, the inflation rate 2 %, and the discount rate of the used capital investment was 3 % as can be seen in Table 2. All these values were taken from the CRAVEzero LCC tool (see also the "Spreadsheet with LCCs" for the different technical maintenance costs and lifespans of components. Individual parameters concerning costs were evaluated in consideration of the following items: total costs, financing costs, energy costs (including basic fees), replacement investments, operation costs, maintenance costs, repairs, and residual values. The energy costs also account for the revenues from electricity generated on the building with renewable sources. No additional follow-up costs (e.g., administration, insurance, cleaning, security services, building services, or demolition costs) are included in this report. Rental incomes were not taken into account.

Table 2: Boundary condition for economic evaluation

Economic boundary conditions	Reference
Observation period of life-cycle cost	40 years
Equity interest rate	1.51 %
Inflation rate	2 %
Discount rate	3 %
Credit period	25 years
Bank credit interest rate	3 %

Operational Costs

The PHPP evaluation tool was used to provide a homogeneous estimation of the energy costs (based on the calculated energy demand). To estimate both the costs and revenues (due to the renewables installed), the energy produced from renewables is considered in the energy balance as a positive contribution to energy consumption from which renewables have been discounted from energy costs.

Energy Prices and Price Increase

Based on the energy demand calculated in PHPP of each variant, the resulting energy cost of each carrier was determined based on final energy consumption. If PV is present in the specific variant, the electricity demand was reduced by the share of self-consumption of the PV electricity. The PV surplus electricity, which cannot be used directly in the building, was fed back to the grid at significantly lower rates. The electricity prices were provided by the partners and are reported in Table 3. The overall annual energy costs were determined based on final energy consumption and the associated energy prices. The resulting life cycle cost accounted for energy price increase over the observation period by an annual percentage (Table 4).

Table 3: Energy prices as boundary conditions of the economic efficiency calculation

ENERGY CARRIERS	AUSTRIA	FRANCE	ITALY	SWEDEN	UNIT
Natural Gas	0.060	0.086	0.095	0.125	EUR/kWh
Electricity	0.187	0.146	0.216	0.220	EUR/kWh
District heating	0.090	Not applicable	0.100	0.090	EUR/kWh
Wood pellets	0.050	Not applicable	0.070	0.050	EUR/kWh
PV feed-in tariff	0.048	0.060	0.070	0.060	EUR/kWh

Table 4: Energy price and feed-in tariffs in the four levels of the parameter „sensitivity“

	LEVEL 1: STANDARD	LEVEL 2: HIGH	LEVEL 3: LOW	LEVEL 4: DEFAULT
Energy price increase per year	1.0 %	2.0 %	0.5 %	0 %
Increase of PV feed-in tariff per year	1.7 %	2.7 %	0.7 %	0 %

Maintenance costs

Maintenance costs were determined as a fraction of the initial investment costs per year. The parameters are not covered in the case studies but were decided using the CRAVEzero database. The most important building elements are listed in Table 5. The operation and maintenance costs affect only the building life cycle after the construction phase. These costs are particularly relevant for future owners, building operations, and property managers. The analysis is based on standard values from EN 15459:2018, which provides yearly maintenance costs for each element, including operation, repair, and service, as a percentage of the initial construction cost.

Table 5: Summary of the most significant maintenance costs and maintenance intervals

POSITION	ACTIVITY	INTERVAL	SHARE OF INVESTMENT COSTS	UNIT
Exterior wall	Maintenance	Annually	1.5 %	EUR/a
Floor construction	Maintenance	Annually	1.5 %	EUR/a
Flat roof construction	Maintenance	Annually	1.5 %	EUR/a
Windows and doors	Maintenance	Annually	1.5 %	EUR/a
Ventilation system with heat recovery	Maintenance	Annually	4.0 %	EUR/a
Air distribution system	Cleaning and maintenance	Annually	6.0 %	EUR/a
District heating transfer station	Maintenance	Annually	3.0 %	EUR/a
Ground source heat pump	Maintenance	Annually	3.0 %	EUR/a
Air heat pump	Maintenance	Annually	3.0 %	EUR/a
Thermal collectors	Maintenance	Annually	1.0 %	EUR/a
PV system	Maintenance	Annually	1.0 %	EUR/a

Replacement and renewal

The replacement of the construction components is necessary, especially for active components, which are typically renewed several times during the lifetime of the building. The components of the building envelope have a high technical lifetime and will be not rebuilt, but demolition costs arise at the end of the life cycle. This report uses an observation period of 40 years, which is a relatively low expected lifetime for the building envelope. The building elements with a lifespan lower than the observation period were reinvested, and the remaining residual value was deducted after the observation period. Note: The end-of-life analysis was not included in the parametric energy and cost calculations.

Table 6: Technical lifetime of prototypical nZEB elements

POSITION	TECHN. LIFETIME (YEARS)	POSITION	TECHN. LIFETIME (YEARS)
Exterior wall	40	Air heat pump	20
Floor construction	40	Buffer storage	20
Flat roof construction	40	Thermal collectors	20
Windows and doors	40	Ventilation unit with heat recovery	15
External sun protection	40	Air ducts, air distribution system	30
Interior wall and elements	40	Compressor cooling	15
Kitchen and bathroom furniture	40	Free cooling	40
Electric network	25	PV - modules	25
Heat distribution network	30	PV - inverter	15
Floor heating	40	Cables for PV and inverter	40
District heating transfer station	20	Building automation system	40
Ground source heat pump	20		

2.3. CRAVEZERO CASES

DEMO CASE 1: "SOLALLÉN" – SKANSKA

LCC: 2.261 €/m²
Invest: 1.485 €/m²
CO_2: 27.5 kg/(m²a)
PE: 129 kWh/(m²a)

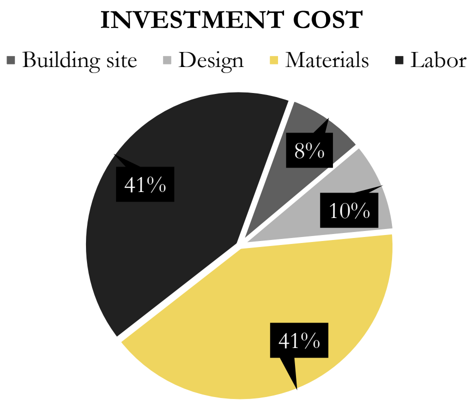
General Information

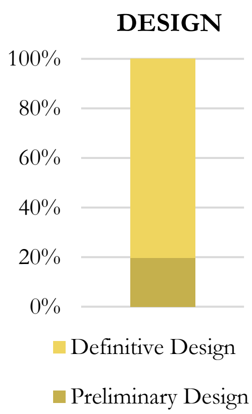
Solallén is well insulated building complex using 50% less energy than Swedish code requirements. Its photovoltaic system and geothermal heating and cooling systems have led to a net zero primary energy balance.

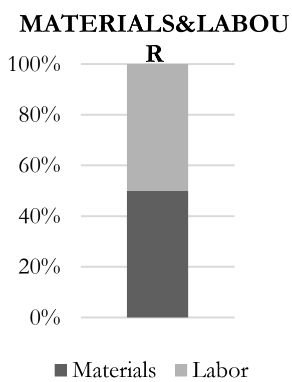
Architect: Tengbom
Energy concept: Net ZEB
Location: Helsingborg (Sweden)
Construction Date: 2012

Net floor area: 1670 m²
Primary Energy Demand: 129 kWh/(m²a)
Key technologies: well insulated and airtight, balanced ventilation with heat recovery, ground source heat pump, photovoltaics.

INVESTMENT COSTS





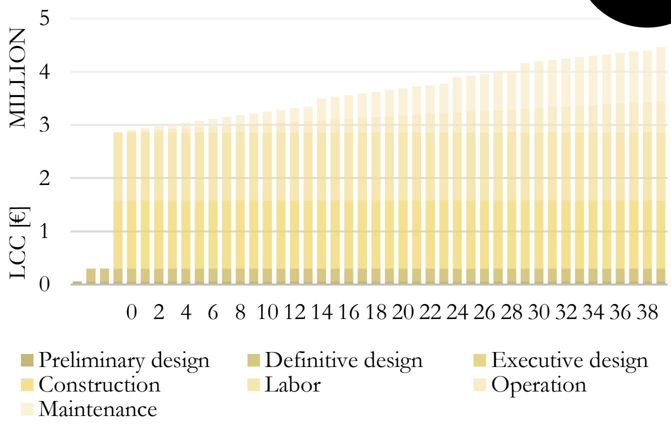


INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
3,124,250 €	300,000 €	260,000 €	2,564,250 €

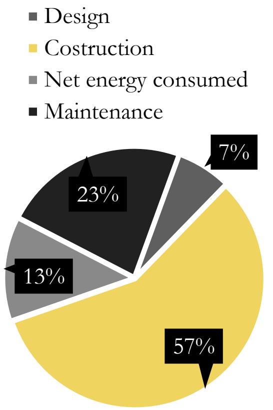
LIFE CYCLE COSTS

LCC over 40 years

LIFE-CYCLE COST (40 YEARS)

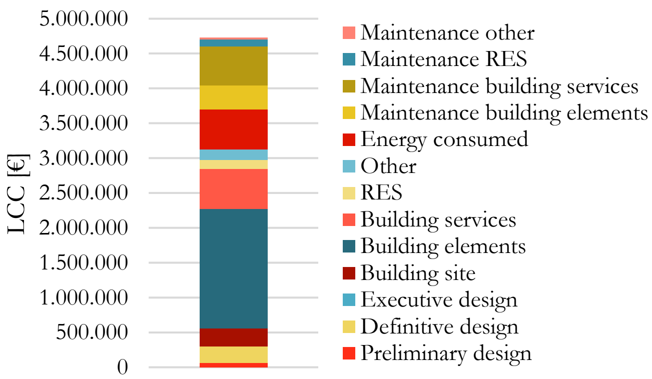


COST DISTRIBUTION

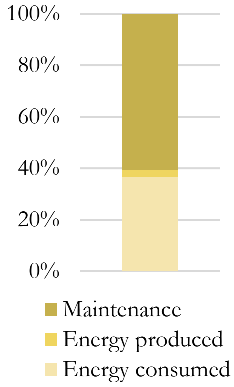


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
5,686,608 €	1,025,769 €	33%	4,726,708 €	576,689 €	3%

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY& MAINTENANCE



BREAKDOWN OF THE UNITARY LCC

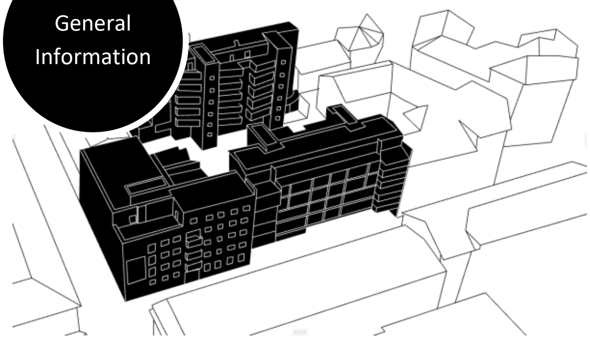
TOTAL LCC 2261€/m²

	Design	Preliminary		28 €/m²
		Definitive		115 €/m²
		Executive		0 €/m²
	Construction 1221 €/m²	Materials 610 €/m²	Building Elements	361€/m²
			Building Services	162€/m²
			RES	43€/m²
			Other 43 €/m²	
		Labour 611 €/m²		
	Building site management	124 €/m²		
Operation 763 €/m²	Energy 275 €/m²	Consumed 296 €/m²	Heating	105€/m²
			Cooling	3 €/m²
			DHW	36€/m²
			Household el.+ aux.	152€/m²
		Produced 21 €/m²		
	Maintenance 488 €/m²	Envelope	162 €/m²	
		HVAC	269 €/m²	
		RES	45 €/m²	
	Other 13 €/m²			

DEMO CASE 2: "ISOLA NEL VERDE A" – MORETTI

LCC: 3.709 €/m²
Invest: 1.816 €/m²
CO2: 50.6 kg/m²
PE:255 kWh/(m²a)

General Information



The apartments are heated by radiant floor panels, and the conditioning is supplied by a fan coil plant. Moreover, the insulated green roof reduces the cooling demand. The energy is supplied by a geothermal heat pump for heating and cooling. Photovoltaic and solar thermal panels

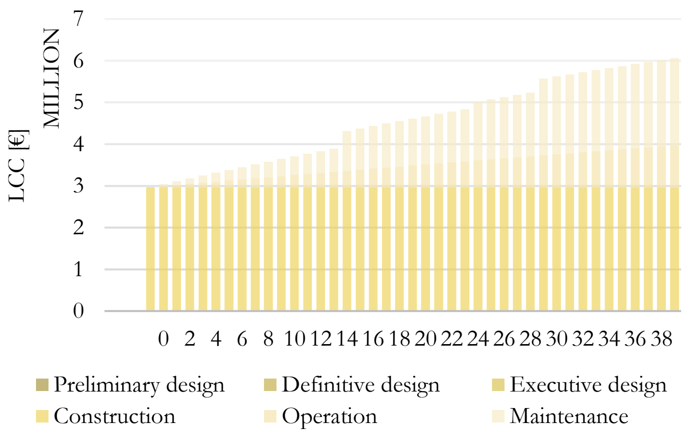
Architect: Studio Associato Eureka
Energy concept: cogeneration system, geothermal heat pump photovoltaic and solar thermal panels supply
Location: Milan (Italy)
Net floor area: 1,409 m²

Primary Energy Demand: 255 kWh/(m²a)

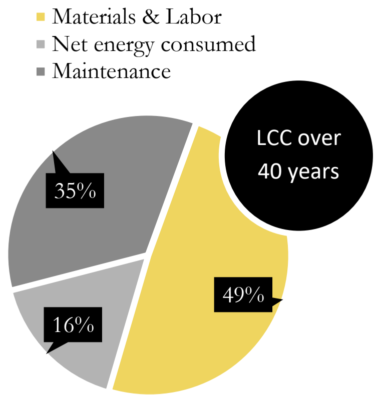
Key technologies: cogeneration system, geothermal heat pump, photovoltaic and solar thermal panels.

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

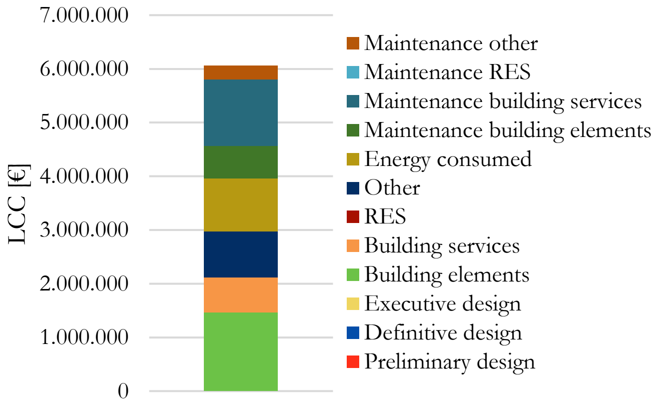


COST DISTRIBUTION

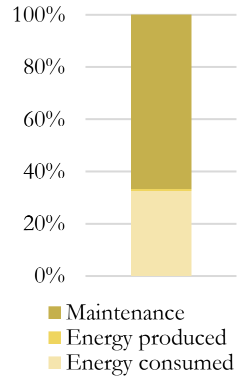


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
6,064,420 €	2,096,987 €	71%	6,062,392 €	997,028 €	-%

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE



LCC UNITARY BREAKDOWN

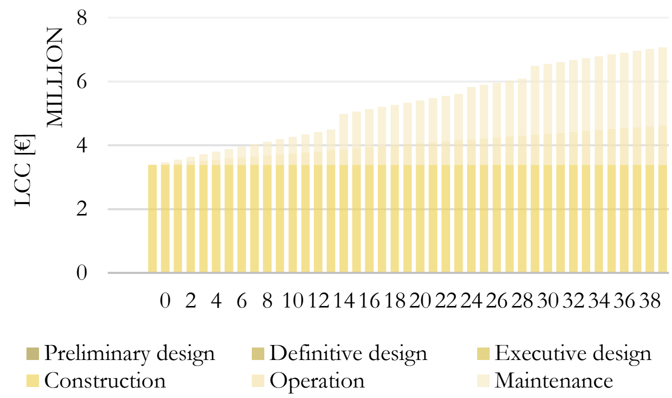
TOTAL LCC 3709€/m²

LCC (40) 3709 €/m²	**Investment** 1816 €/m²	**Design** - €/m²	Preliminary		- €/m²
			Definitive		- €/m²
			Executive		- €/m²
		Construction 1816 €/m²	Materials 1124 €/m²	Building Elements	816€/m²
				Building Services	396€/m²
				RES	-€/m²
			Labour 83 €/m²	Other 520 €/m²	
		Building site management	- €/m²		
	Operation 1893 €/m²	**Energy** 610 €/m²	Consumed 610 €/m²	Heating	202€/m²
				Cooling	51 €/m²
				DHW	158€/m²
				Household el.+ aux.	232€/m²
			Produced 16 €/m²		
		Maintenance 1283 €/m²	Envelope	366 €/m²	
			HVAC	762 €/m²	
			RES	- €/m²	
		Other 155 €/m²			

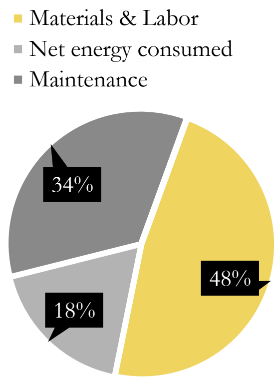
DEMO CASE 3: "ISOLA NEL VERDE B" – MORETTI

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

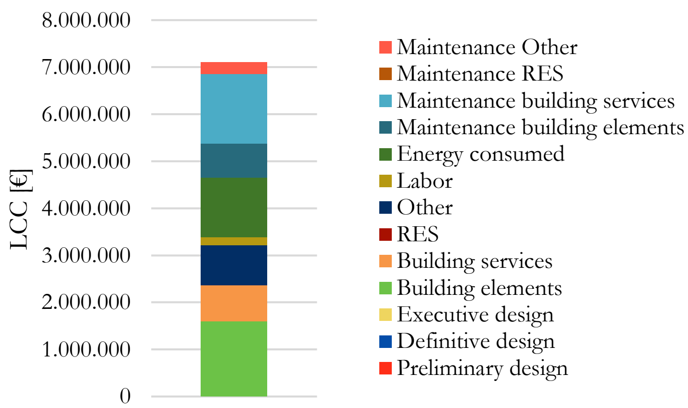


COST DISTRIBUTION

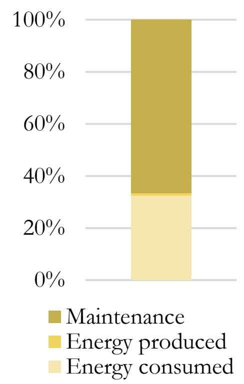


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)
7,109,995 €	2,451,070 €	72%	7,109,995 €	1,273,348 €

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE

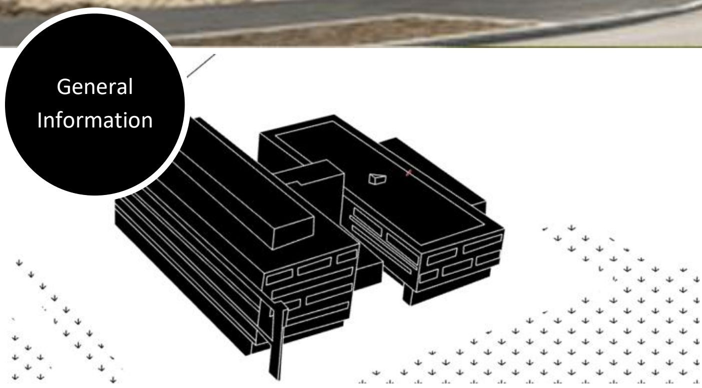


BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 3513€/m²

LCC (40) 3513 €/m²	**Investment** 1673 €/m²	**Design** - €/m²	Preliminary		- €/m²
			Definitive		- €/m²
			Executive		- €/m²
		Construction 1673 €/m²	Materials 1593 €/m²	Building Elements	789€/m²
				Building Services	384€/m²
				RES	-€/m²
				Other	420 €/m²
			Labour 80 €/m²		
		Building site management	- €/m²		
	Operation 1840 €/m²	**Energy** 629 €/m²	Consumed 642 €/m²	Heating	205€/m²
				Cooling	44 €/m²
				DHW	157€/m²
				Household el.+ aux.	237€/m²
			Produced 13 €/m²		
		Maintenance 1211 €/m²	Envelope		353 €/m²
			HVAC		732 €/m²
			RES		- €/m²
		Other 125 €/m²			

DEMO CASE 4: "ASPERN IQ" – ATP SUSTAIN



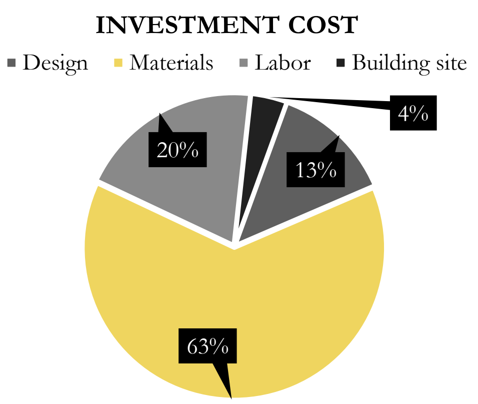
The building was designed in line with plus energy standards. The energy demand of the building has actively been lowered by design measures such as a balanced glazing percentage, the highly insulated thermal envelope, optimized details for reduced thermal bridges and an airtight envelope.

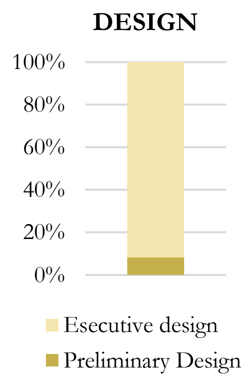
Architect: ATP Wien
Energy concept: Renewable power, environmental heat, and waste heat
Location: Vienna (Austria)
Construction Date: 2012

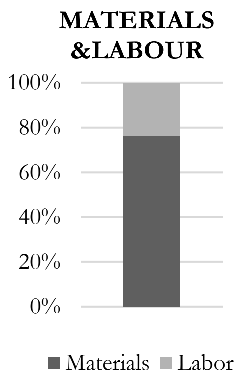
Net floor area: 8817 m^2
Primary Energy Demand: 58 kWh/(m^{2}a)

Key technologies: Groundwater heat pump, photovoltaics, small wind turbine.

INVESTMENT COSTS



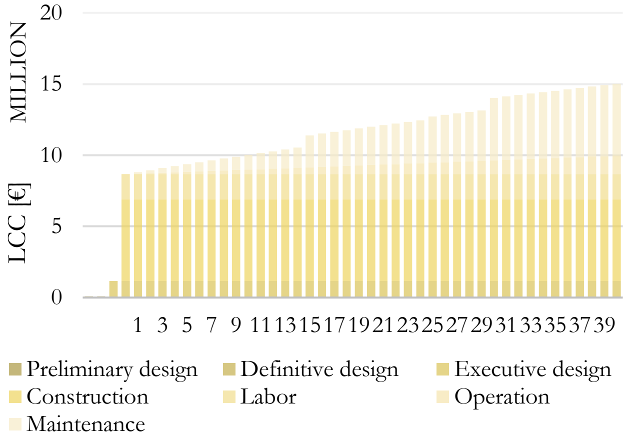




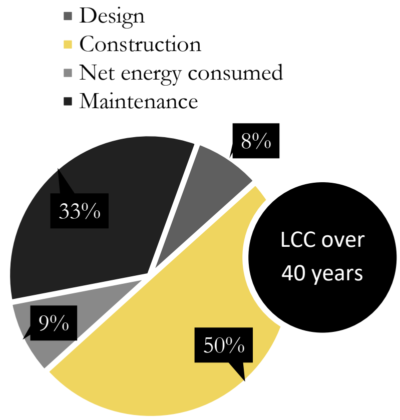
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
9,011,746 €	1,170,000 €	343,695 €	7,498,051 €

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

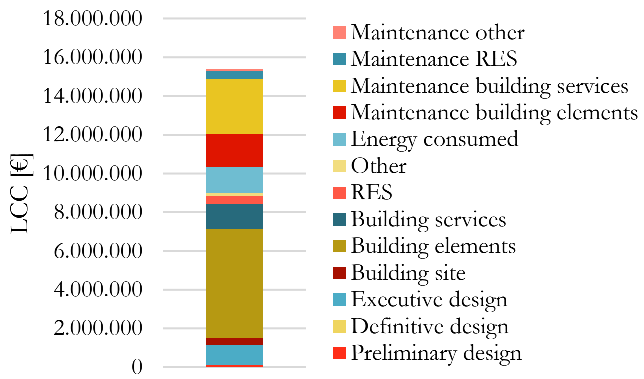


COST DISTRIBUTION

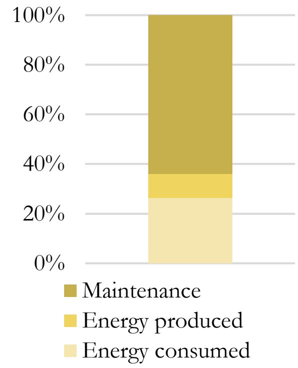


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
18,594,121 €	5,041,073 €	56%	15,357,856 €	1,305,038 €	2%

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE



BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 1446€/m²					
LCC (40) 1446 €/m²	**Investment** 848 €/m²	**Design** 110 €/m²	Preliminary	9 €/m²	
			Definitive	- €/m²	
			Executive	101 €/m²	
		Construction 706 €/m²	Materials 538 €/m²	Building Elements	360€/m²
				Building Services	127€/m²
				RES	33€/m²
				Other 19 €/m²	
			Labour 167 €/m²		
		Building site management	19 €/m²		
	Operation 597 €/m²	**Energy** 123 €/m²	Consumed 195 €/m²	Heating	50 €/m²
				Cooling	1 €/m²
				DHW	21 €/m²
				Household el.+ aux.	123€/m²
			Produced 72 €/m²		
		Maintenance 475 €/m²	Envelope	161 €/m²	
			HVAC	268 €/m²	
			RES	40 €/m²	
		Other 6 €/m²			

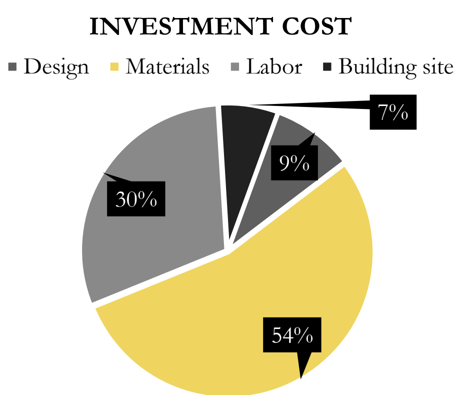
DEMO CASE 5: "VÄLA GÅRD" – SKANSKA

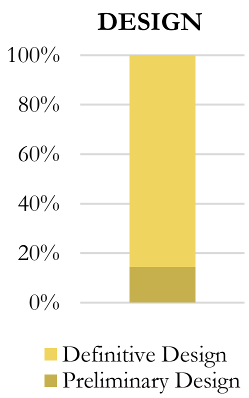
Väla Gård is Skanska's largest green project to date. Its aim is for the office building to be a zero-energy or energy-plus building. In other words, the building should produce at least as much energy as it consumes (for heating, cooling, and utilities) over one year.

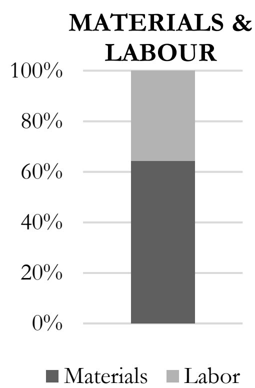
Architect: Tengbom
Energy concept: Net ZEB
Location: Helsingborg (Sweden)
Construction Date: 2012

Net floor area: 1670 m²
Primary Energy Demand: 119 kWh/(m²a)
Key technologies: well insulated and airtight, balanced ventilation with heat recovery, ground source heat pump, photovoltaics

INVESTMENT COSTS



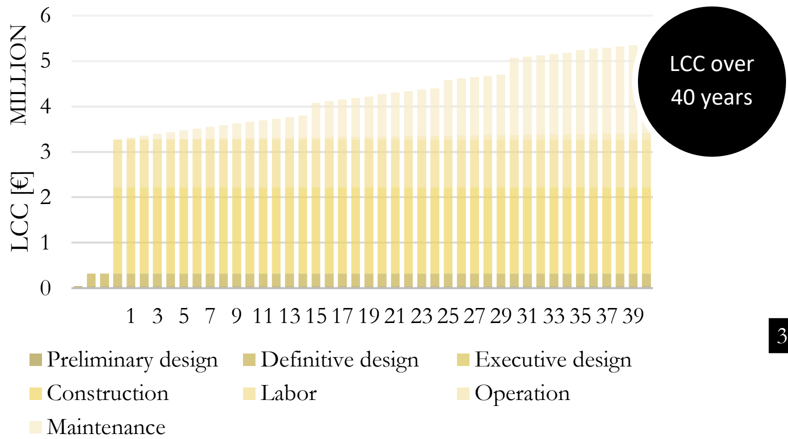




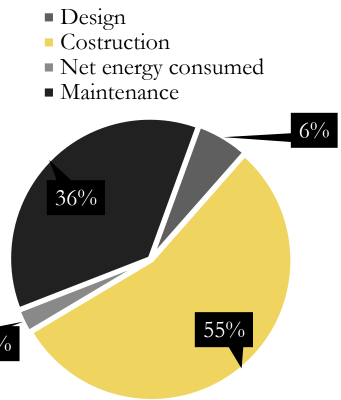
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
3,229,744 €	319,000 €	228,650 €	2,955,474 €

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

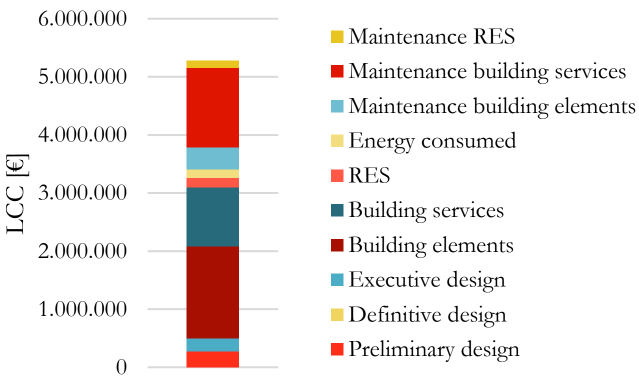


COST DISTRIBUTION

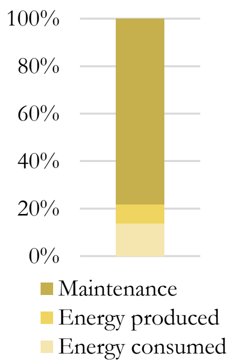


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
5,514,214 €	1,961,305 €	61%	5,104,214 €	141,815 €	5%

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE

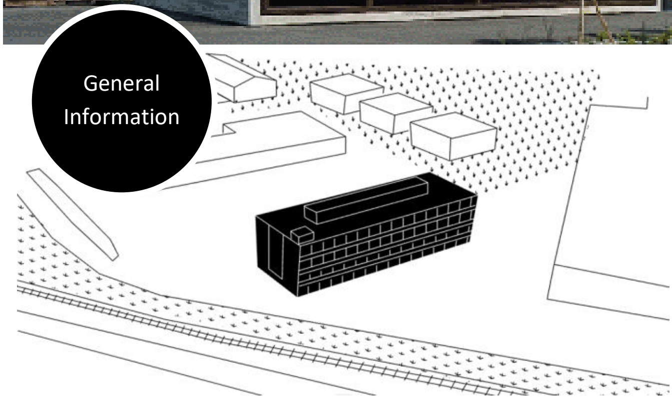


BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 2812€/m²

LCC (40) 2812€/m²	**Investment** 1653 €/m²	**Design** 25 €/m²	Preliminary	151 €/m²	
			Definitive	- €/m²	
			Executive	126 €/m²	
		Construction 1628 €/m²	Materials 1012 €/m²	Building Elements	473€/m²
				Building Services	403€/m²
				RES	70€/m²
				Other 100 €/m²	
			Labour 592 €/m²		
		Building site management	- €/m²		
	Operation 1159 €/m²	**Energy** 78 €/m²	Consumed 190 €/m²	Heating	64 €/m²
				Cooling	12 €/m²
				DHW	6 €/m²
				Household el.+ aux.	114€/m²
			Produced 112 €/m²		
		Maintenance 1081 €/m²	Envelope	212 €/m²	
			HVAC	750 €/m²	
			RES	71 €/m²	
		Other 48 €/m²			

DEMO CASE 6: " I.+R. HEADQUARTERS" – ATP SUSTAIN

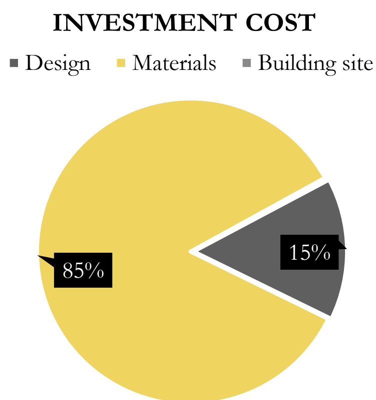


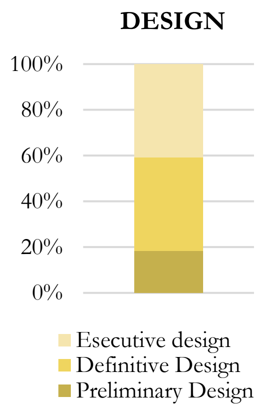
The building has been designed to obtain the LEED Certification. It is notable for its high comfort levels, high-quality daylight, renewable energies (heat pumps, geothermal heat, and photovoltaic plant), compact building form, recycled materials, and use of timber as a natural material.

Architect: Dietrich Untertrifaller Architekten
Energy concept: -
Location: Lauterach (Austria)
Construction Date: 2011-2013

Net floor area: 2759 m^2
Primary Energy Demand: 169 kWh/(m^2a)
Key technologies: Reversible geothermal heat pump.

INVESTMENT COSTS

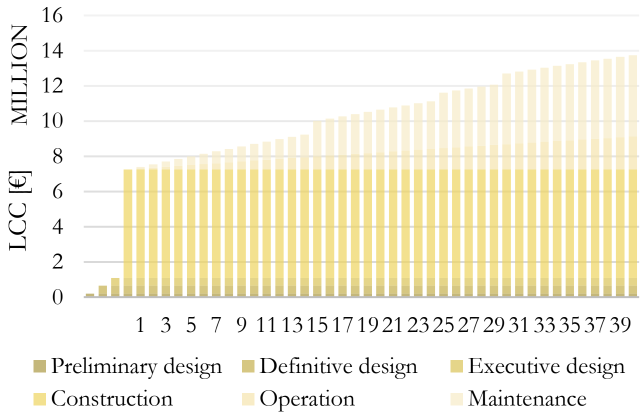




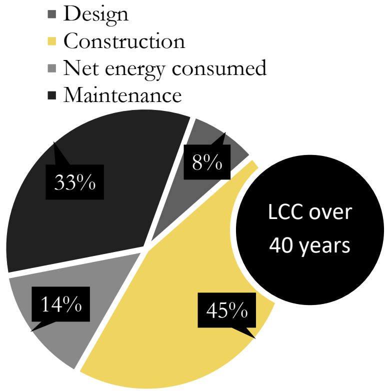
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
7,262,882 €	1,091,910 €	16,800 €	6,154,172 €

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

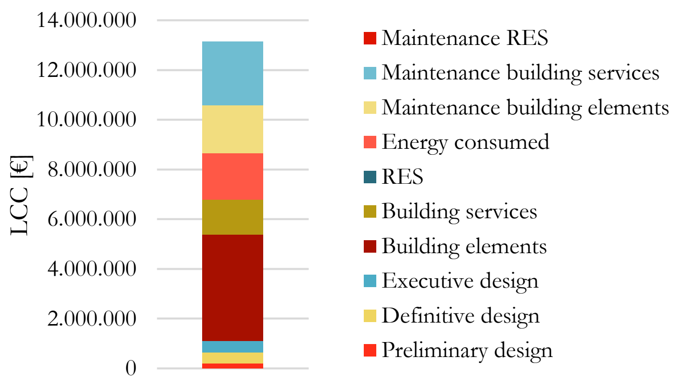


COST DISTRIBUTION

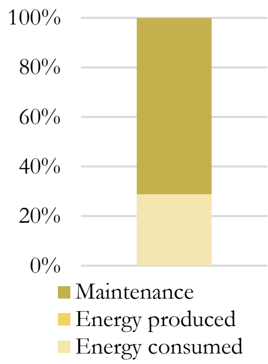


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)
13,928,047 €	4,620,016 €	64%	13,762,717 €	1,879,819 €

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE



BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 4267€/m²

LCC (40) 4267€/m²	**Investment** 2252 €/m²	**Design** 339 €/m²	Preliminary	63 €/m²	
			Definitive	138 €/m²	
			Executive	138 €/m²	
		Construction 1908 €/m²	Materials 1012 €/m²	Building Elements	1332€/
				Building Services	435€/m²
				RES	70€/m²
				Other	
			Labour	141 €/m²	
		Building site management	5 €/m²		
	Operation 2015 €/m²	**Energy** 583 €/m²	Consumed 583 €/m²	Heating	111€/m²
				Cooling	1 €/m²
				DHW	1 €/m²
				Household el.+ aux.	
			Produced - €/m²		
		Maintenance 1432 €/m²	Envelope	596 €/m²	
			HVAC	794 €/m²	
			RES	- €/m²	
		Other 42 €/m²			

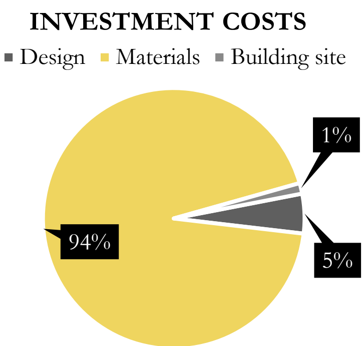
DEMO CASE 7: "NH Tirol" – ATP SUSTAIN

This is one of the largest residential complexes built according to the passive house approach in Europe. Heating is supplied by a pellet boiler and a gas condensing boiler whereby approximately 80% of the annual energy requirements is covered by the pellet boiler.

Architect: Architekturwerkstatt DIN A4
Energy concept: Cogeneration unit wood, solar thermal energy (DHW), and ventilation with heat recovery
Location: Innsbruck (Austria)
Construction Date: 2008-2009

Net floor area: 44,959 m²
Primary Energy Demand: 77 kWh/(m²a)
Key technologies: Centralized pellet boiler.

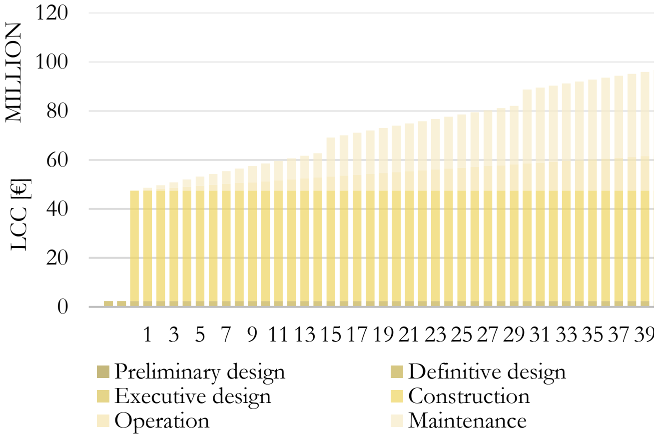
INVESTMENT COSTS



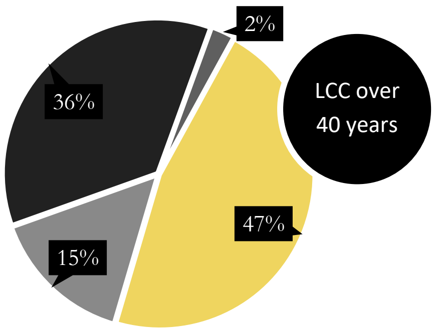
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
48,022,514 €	2,358,000 €	634,106 €	45,030,408 €

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

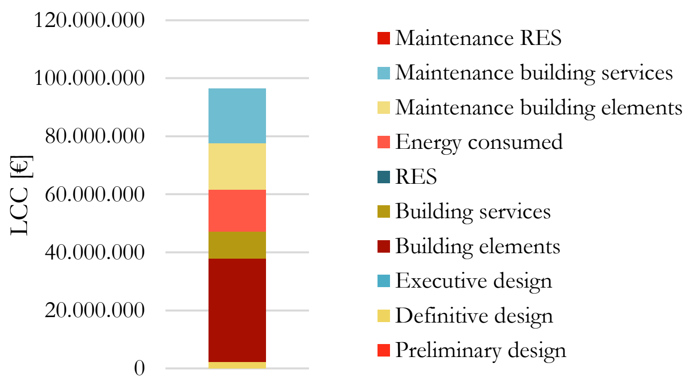


COST DISTRIBUTION

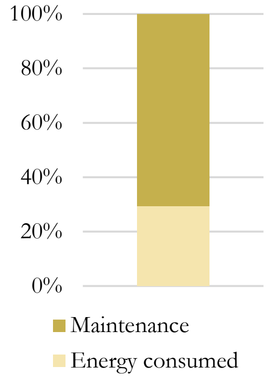


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)
97,973,382 €	34,824,616 €	73%	97,339,276 €	14,492,145 €

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE

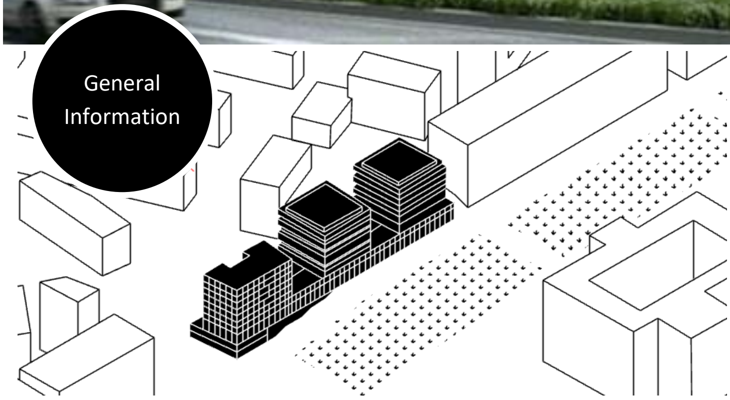


BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 1852€/m^2

LCC (40) 1852€/m^2	**Investment** 914 €/m^2	**Design** 45 €/m^2	Preliminary	- €/m^2	
			Definitive	45 €/m^2	
			Executive	- €/m^2	
		Construction 857 €/m^2	Materials 857 €/m^2	Building Elements	675€/m^2
				Building Services	178€/m^2
				RES	-
				Other 4 €/m^2	
			Labour - €/m^2		
		Building site management	12 €/m^2		
	Operation 938 €/m^2	**Energy** 276 €/m^2	Consumed 276 €/m^2	Heating	25 €/m^2
				Cooling	- €/m^2
				DHW	39 €/m^2
				Household el.+ aux.	203
			Produced - €/m^2		
		Maintenance 663 €/m^2	Envelope	302 €/m^2	
			HVAC	359 €/m^2	
			RES	- €/m^2	
		Other 1 €/m^2			

DEMO CASE 8: “GREEN HOME” – BOUYGUES

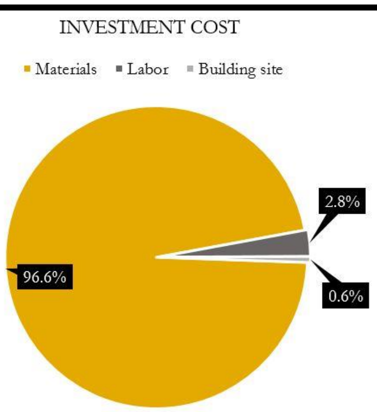


Green Home is a plus-energy residential building, which operates without heating and cooling systems, thanks to a bioclimatic approach and a well insulated envelope close to the passive house standard (external insulation, triple glazing, and thermal bridge optimization).

Architect: Atelier Zündel Cristea
Energy concept: Plus-energy residential building
Location: Nanterre (France)
Construction Date: 2016

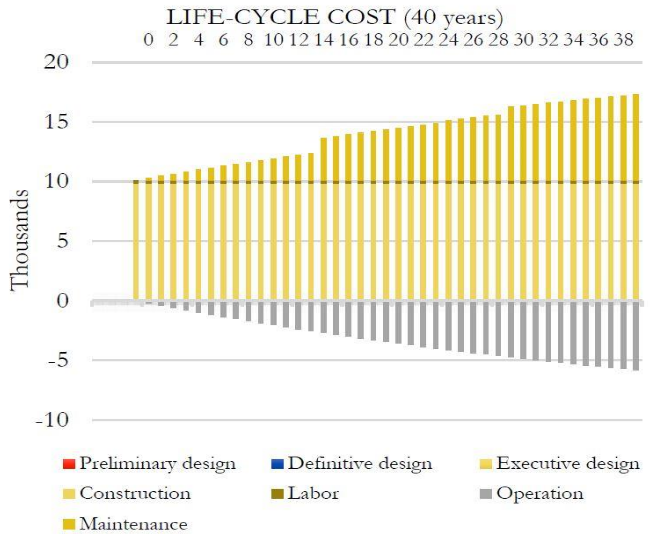
Net floor area: 9267 m²
Primary Energy Demand: 108 kWh/(m²a)
Key technologies: triple-glazed windows, decentralized ventilation with 96% of heat recovery, heat recovery on grey water.

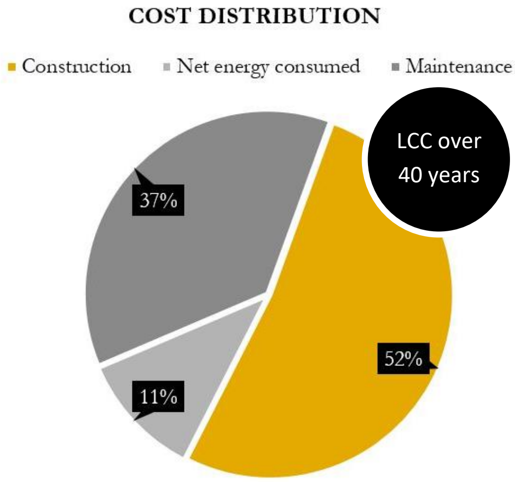
INVESTMENT COST



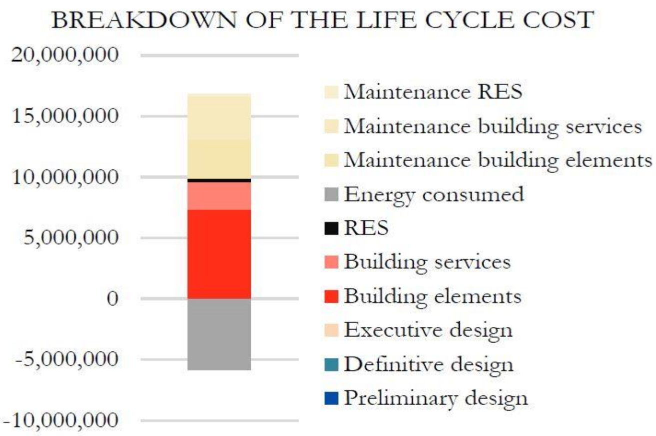
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
10.189.126 €	- €	63.310 €	10.125.816 €

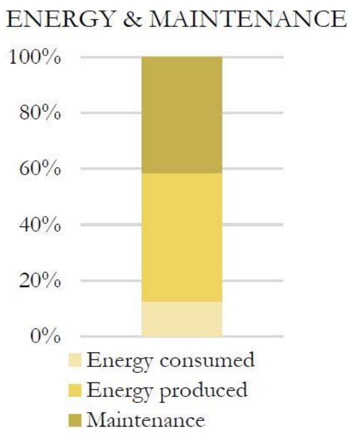
LIFE CYCLE COSTS





WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)
11.580.243 €	7.205.196 €	71%	11.580.243 €	-5.814.079 €





BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 1069€/m²

LCC (40) 1069 €/m²	**Investment** 941 €/m²	**Design** - €/m²	Preliminary	- €/m²	
			Definitive	- €/m²	
			Executive	- €/m²	
		Construction 935 €/m²	Materials 1012 €/m²	Building Elements	660€/m²
				Building Services	203€/m²
				RES	24€/m²
				Other 21 €/m²	
			Labour 27 €/m²		
		Building site management	6 €/m²		
	Operation 128 €/m²	**Energy** -537 €/m²	Consumed 296 €/m²	Heating	42 €/m²
				Cooling	8 €/m²
				DHW	31 €/m²
				Household el.+ aux.	
			Produced 736 €/m²		
		Maintenance 665 €/m²	Envelope	296 €/m²	
			HVAC	323 €/m²	
			RES	24 €/m²	
		Other 23 €/m²			

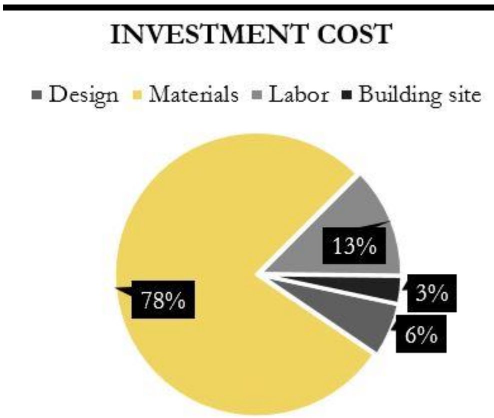
DEMO CASE 9: "LES HÉLIADES" – BOUYGUES

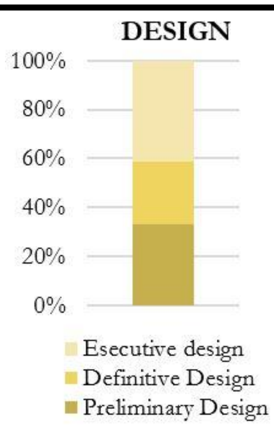
This highly compact building is connected to the biomass-based urban heat network (for the production of heating and domestic hot water) complemented by solar thermal and photovoltaic panels installed on the roof.

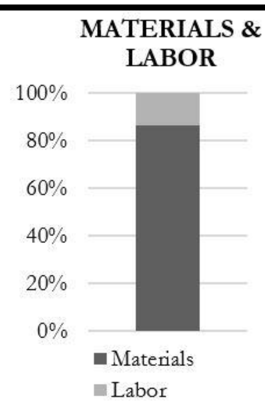
Architect: Barré - Lambot
Energy concept: ZEB
Location: Angers (France)
Construction Date: 2015

Net floor area: 4590 m^2
Primary Energy Demand: 60 kWh/(m^{2}a)
Key technologies: Well insulated and airtight, balanced ventilation with heat recovery, ground source heat pump, photovoltaic panels.

INVESTMENT COSTS

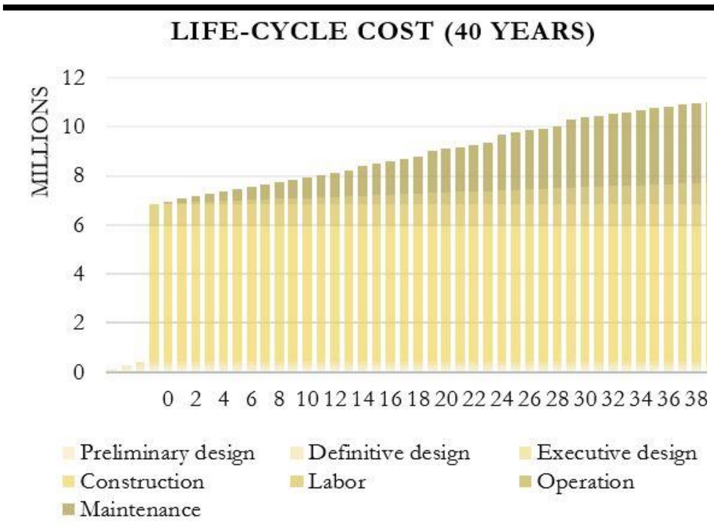


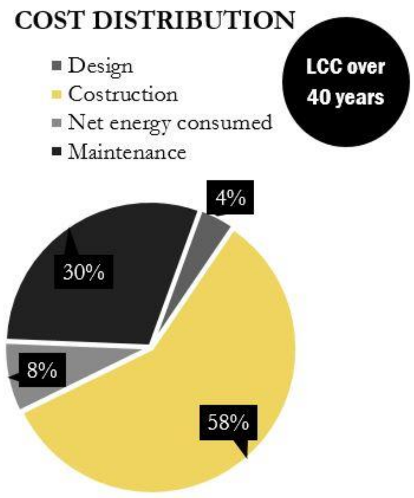




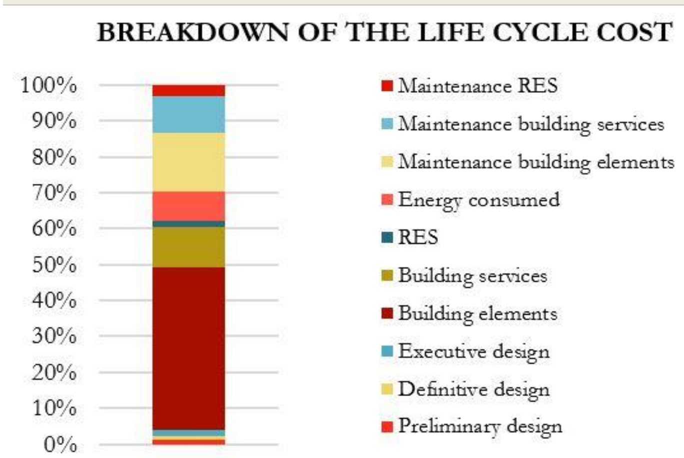
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
6.180.705 €	434.400 €	222.566 €	5.523.739 €

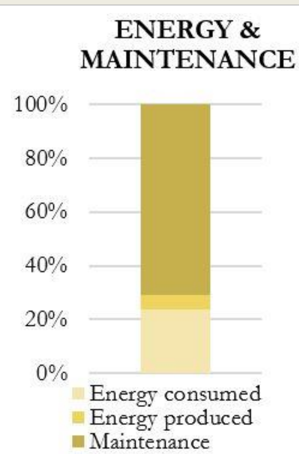
LIFE CYCLE COSTS





WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
10.374.736 €	3.296.385 €	53%	10.358.436 €	881.346 €	2%



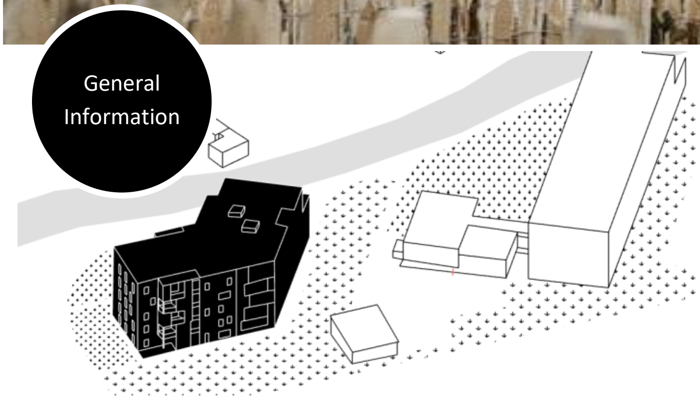


BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 1918€/m²

LCC (40) 1918 €/m²	**Investment** 1145 €/m²	**Design** 80 €/m²	Preliminary	26 €/m²	
			Definitive	21 €/m²	
			Executive	33 €/m²	
		Construction 1023 €/m²	Materials 1023 €/m²	Building Elements	734€/m²
				Building Services	223€/m²
				RES	39€/m²
				Other 27 €/m²	
			Labour - €/m²		
		Building site management	41 €/m²		
	Operation 774 €/m²	**Energy** 163 €/m²	Consumed 208 €/m²	Heating	71 €/m²
				Cooling	2 €/m²
				DHW	60 €/m²
				Household el.+ aux.	80€/m²
			Produced 74 €/m²		
		Maintenance 610 €/m²	Envelope	329 €/m²	
			HVAC	204 €/m²	
			RES	60 €/m²	
		Other 18 €/m²			

DEMO CASE 10: "RÉCIDENCE ALIZARI" – BOUYGUES

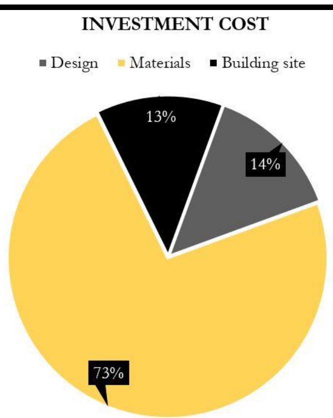


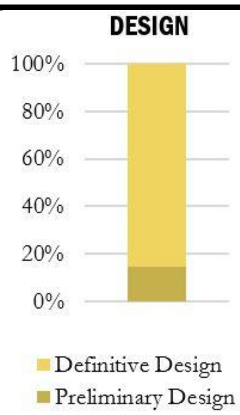
The building is characterized by a compact structure with the search for optimization of solar gains. The external concrete walls were insulated from both sides to limit heat loss. The building is heated by a collective wood boiler combined with air injection. It also ensures the production of hot water. A photovoltaic system has also been installed on the roof.

Architect: Atelier des Deux Anges
Energy concept: ZEB and PassivHaus
Location: Malaunay (France)
Construction Date: 2015

Net floor area: 2776 m²
Primary Energy Demand: 106 kWh/(m²a)
Key technologies: High-performance, double-flux ventilation with heat recovery, centralized wood boiler, photovoltaics.

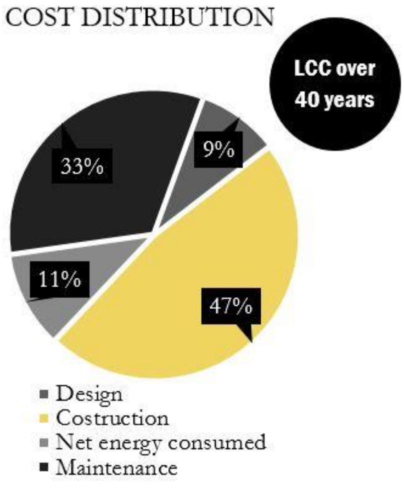
INVESTMENT COSTS



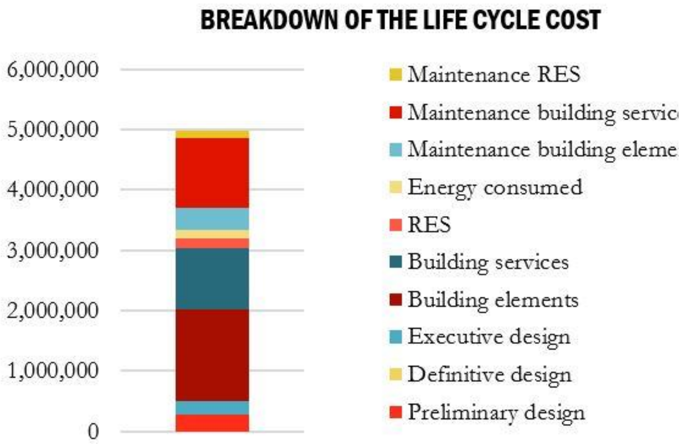


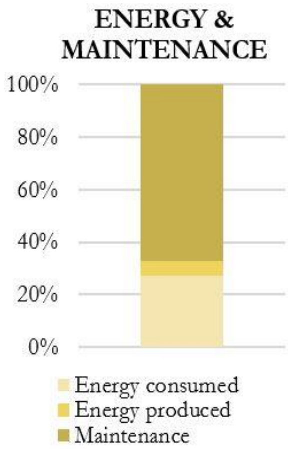
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
3.356.341 €	465.400 €	430.961 €	2.459.980 €

LIFE CYCLE COSTS



WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)
5.640.310 €	1.699.010 €	51%	5.612.019 €	556.669 €



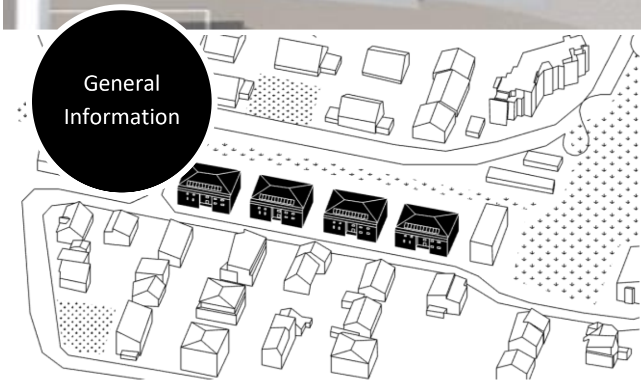


BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 1987€/m²

LCC (40) 1987 €/m²	**Investment** 1188 €/m²	**Design** 165 €/m²	Preliminary	18 €/m²	
			Definitive	0 €/m²	
			Executive	147 €/m²	
		Construction 871 €/m²	Materials 871 €/m²	Building Elements	552€/m²
				Building Services	186€/m²
				RES	29€/m²
				Other 103 €/m²	
			Labour - €/m²		
		Building site management	153 €/m²		
	Operation 798 €/m²	**Energy** 197 €/m²	Consumed 296 €/m²	Heating	21 €/m²
				Cooling	11 €/m²
				DHW	57 €/m²
				Household el.+ aux.	162
			Produced 48 €/m²		
		Maintenance 601 €/m²	Envelope	247 €/m²	
			HVAC	291 €/m²	
			RES	32 €/m²	
		Other 31 €/m²			

DEMO CASE 11: "PARKCARRÉ (HAUPTSTR. 131)" – KÖHLER & MEINZER



This building consumes 40% less energy than the national standard. The envelope is highly insulated and airtight. Decentralised ventilation systems with heat recovery have been installed. DHW, heating, and electric energy are supplied by gas power and a heat plant and a PV system on each building.

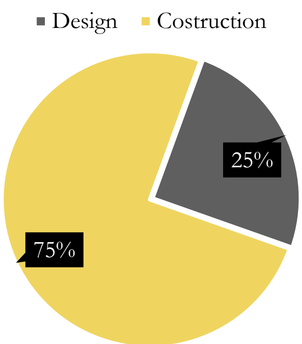
Architect: Alex Stern/Gerold Köhler
Energy concept: Contracting model for the quarter energy supply
Location: Eggenstein (Germany)
Construction Date: 2014

Net floor area: 1,109 m²
Primary Energy Demand: 67 kWh/(m²a)

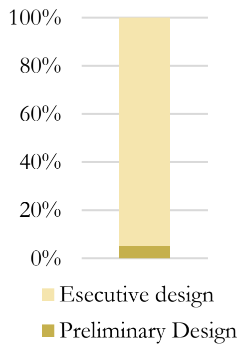
Key technologies: Best quality thermal insulation and airtight envelope. Decentralized ventilation system with heat recovery.

INVESTMENT COSTS

INVESTMENT COST



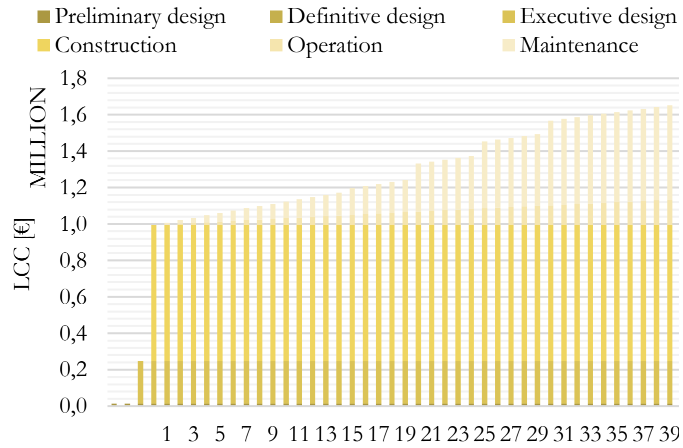
DESIGN



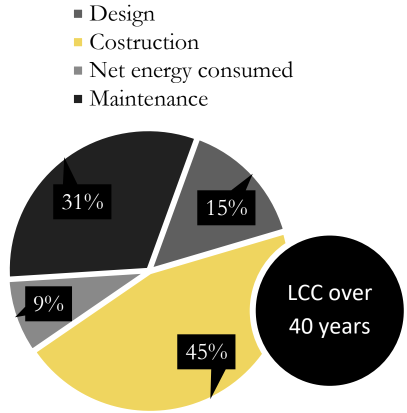
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
993,531 €	246,820 €	- €	746,711 €

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 years)

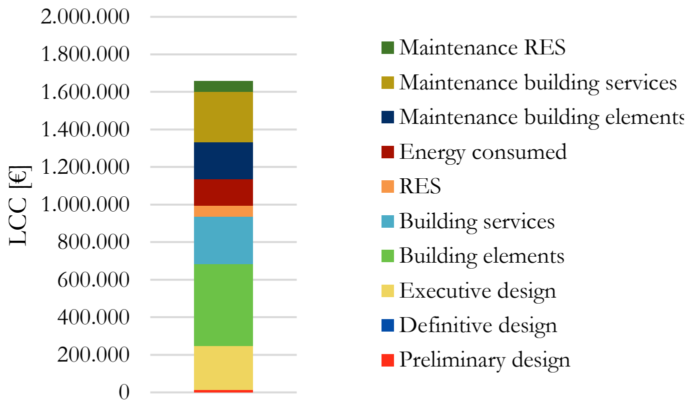


COST DISTRIBUTION

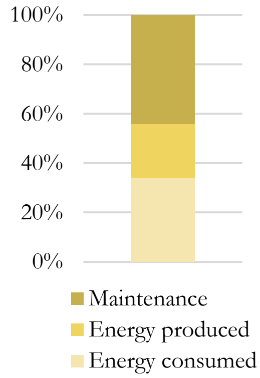


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
1,966,143 €	523,576 €	53%	1,659,470 €	142,363 €	3%

BREAKDOWN OF THE LIFE CYCLE COST



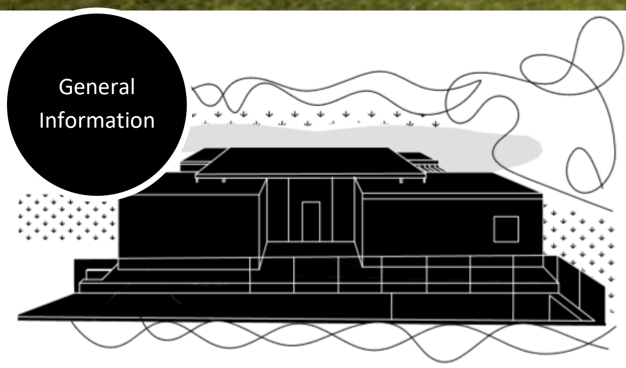
ENERGY & MAINTENANCE



BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 1291€/m²		**Design** 192 €/m²	Preliminary	10 €/m²	
			Definitive	- €/m²	
			Executive	182 €/m²	
	Investment 773 €/m²	**Construction** 581 €/m²	Materials 581 €/m²	Building Elements	340€/m²
				Building Services	197€/m²
				RES	44€/m²
				Other - €/m²	
			Labour - €/m²		
		Building site management	- €/m²		
LCC (40) 1291€/m²	**Operation** 518 €/m²	**Energy** 111 €/m²	Consumed 313 €/m²	Heating	73 €/m²
				Cooling	11 €/m²
				DHW	46 €/m²
				Household el.+ aux.	
			Produced 202 €/m²		
		Maintenance 407 €/m²	Envelope	152 €/m²	
			HVAC	209 €/m²	
			RES	46 €/m²	
		Other - €/m²			

DEMO CASE 12: "MORE" – MORETTI



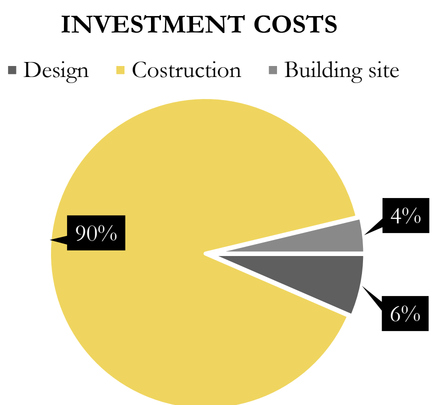
The envelope and all the equipment have been designed with the aim of achieving high performance. Therfore thermal equipment consists of an air-water heat pump, distribution through a floor heating system, and balanced ventilation with heat recovery. In summer, a natural chimney activates air circulation inside the house.

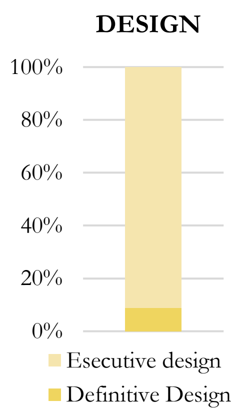
Architect: Valentina Moretti
Energy concept: Heat pump and condensing boiler, solar heating panel
Location: Lodi (Italy)
Construction Date: 2014

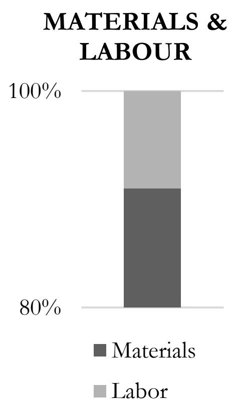
Net floor area: 128 m²
Primary Energy Demand: 135 kWh/(m²a)

Key technologies: Precast component, compact model, central core, flexible and modular.

INVESTMENT COSTS



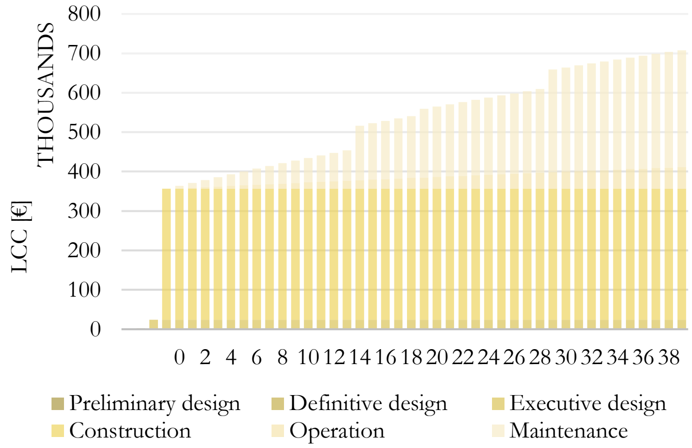




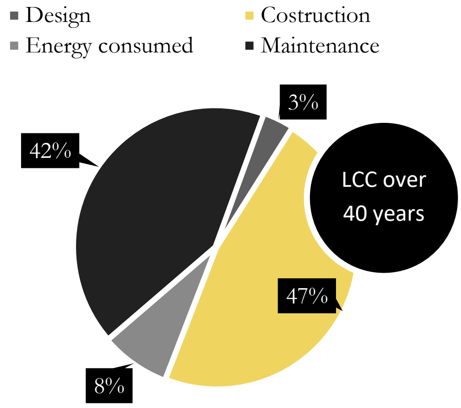
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
370,125 €	24,106 €	13,844 €	332,175 €

LIFE CYCLE COSTS

LIFE-CYCLE COST (40 YEARS)

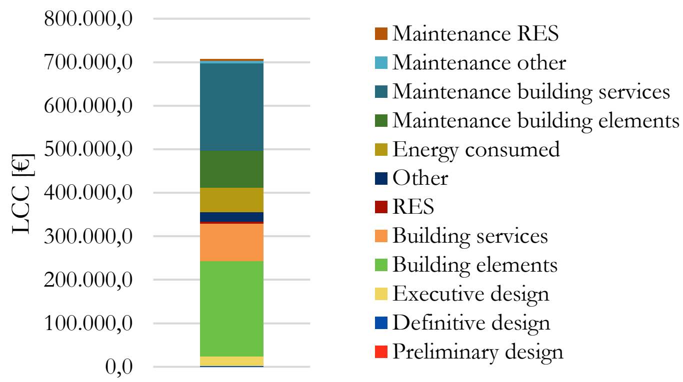


COST DISTRIBUTION

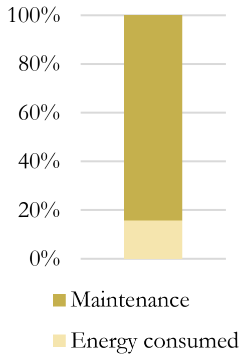


WLCC (40)	MAINTENANCE	MAINT./INVEST.	LCC (40)	ENERGY (40)	RES/LCC
729,434 €	296,533 €	80%	721,929 €	55,271 €	1%

BREAKDOWN OF THE LIFE CYCLE COST



ENERGY & MAINTENANCE



BREAKDOWN OF THE UNITARY LCC

TOTAL LCC 4102€/m²

LCC (40) 4102€/m²	**Investment** 2103 €/m²	**Design** 137 €/m²	Preliminary	- €/m²	
			Definitive	12 €/m²	
			Executive	125 €/m²	
		Construction 1887 €/m²	Materials 1718 €/m²	Building Elements	1078€/m
				Building Services	482€/m²
				RES	26€/m²
				Other 130 €/m²	
			Labour 170 €/m²		
		Building site management	79 €/m²		
	Operation 1999 €/m²	**Energy** 314 €/m²	Consumed 314 €/m²	Heating	105€/m²
				Cooling	45 €/m²
				DHW	42 €/m²
				Household el.+ aux.	131€/m²
			Produced - €/m²		
		Maintenance 1685 €/m²	Envelope	483 €/m²	
			HVAC	1136 €/m²	
			RES	27 €/m²	
		Other 39 €/m²			

2.4. CASE STUDY RESULTS - OVERVIEW

This section reports a general overview of the calculations for the case studies, comparing costs and the impact of the different phases on the overall LCC.

To do so, the results were normalized according to the following criteria:

- Construction cost index across Europe
- Year of construction
- Climate conditions of the different locations
- Energy prices

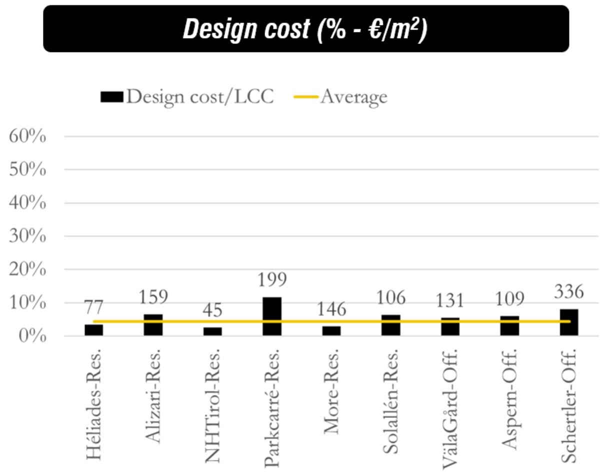


Figure 21. Design cost/LCC.

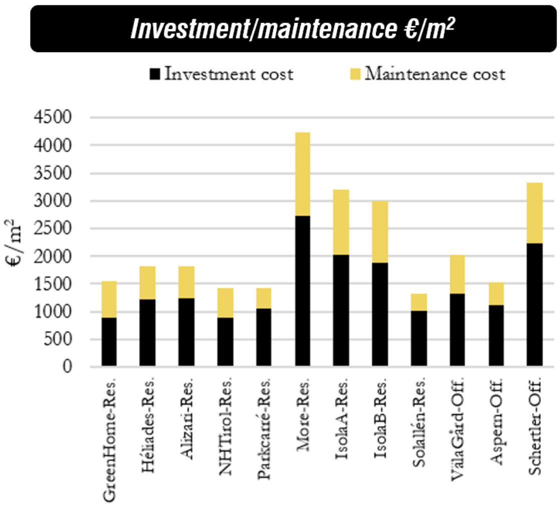


Figure 22. Investment cost vs. maintenance cost.

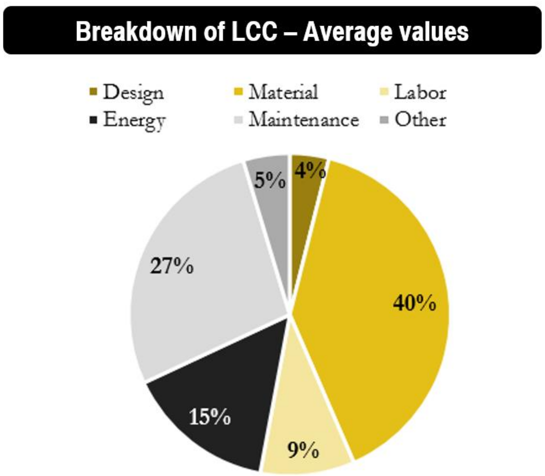


Figure 23. LCC Breakdown – Average values.

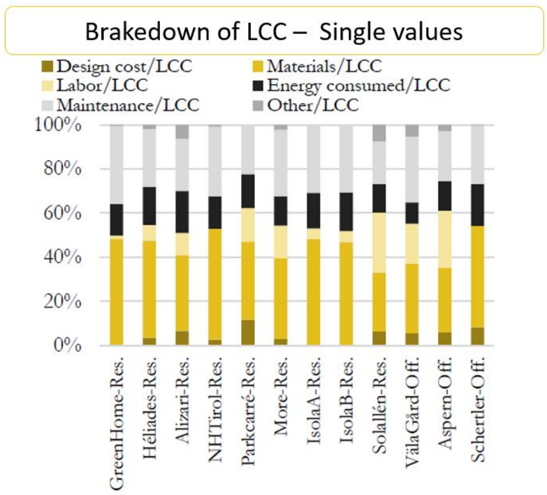


Figure 24. LCC Breakdown – Single values.

Figure 21 shows the overview of the design costs, reported as a percentage of the overall LCC and in absolute value (cost per unit surface). The design cost has a reduced impact on the LCC, ranging from 3% (NHTirol) to 15% (Parkcarré). Apart of the general complexity of the building design, the differences in impact could be attributed to the higher design costs for the integration of the RES. In fact, in Parkcarré, 41% of the energy is supplied by a photovoltaic system (30 W/m² installed). In.

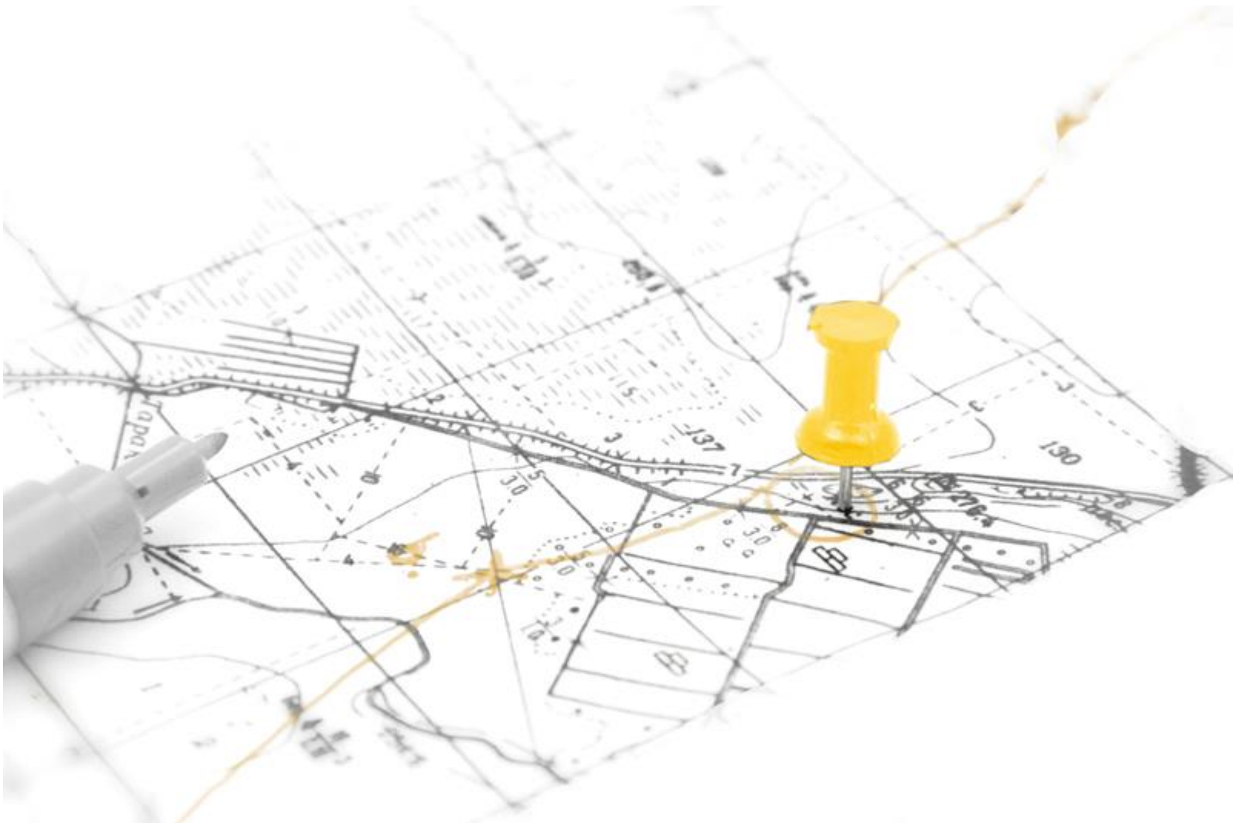
Figure 22, the unitary investment costs for the design and construction are compared to maintenance costs, considering the net floor area of the buildings. Since the maintenance costs were an estimated percentage of the initial investment according to the technologies installed, there is a strong relationship between initial investment and maintenance. The high impact of the maintenance cost is highlighted in the overall life cycle of the buildings, which is comparable to the initial investment costs.

Figure 23 is an overview of the average impact of all the phases on the LCC: the investment costs for design, material, labour and other initial expenditures is around 53% of the LCC, while the energy and maintenance account for around 47%. As was expected, the energy costs during the life cycle of a nZEB represent a minor contribution to the LCC – around 12% on average.

Figure 24 shows the overview of LCC calculated with a breakdown of the cost over the whole life-cycle. In particular, it reports the percentage value of the impact of each phase on the LCC, considering design, materials, labour, maintenance, and other costs (including the building site management). The cost of materials ranges from around 27% (Solallén) to 53% (Héliades). The impact of the labour varies from around 2% towards 28%; the lowest value occurs for Green Home and Isola Nel Verde and the highest for Solallén. It is important to note that the detailed breakdown of the labour and the material costs is, in most cases, not available. However, labour is particularly low because the breakdown between materials and labour is not complete for all the building elements; rather, the construction costs (i.e., the sum of materials and labour) are reported as a whole – ranging from around 44% to 60%.

CHAPTER 3

nZEB life cycle processes



3. nZEB LIFE CYCLE PROCESSES

Tasks and schedules must be clear for each stakeholder order to optimise nZEB-related processes, project specific roles, and interactions. Building owners, investors, tenants, construction companies and planners have different interests and are involved in different phases in the life cycle of buildings. There is a general lack of understanding, transparency, and uniform methods in nZEB processes..

Clear and comprehensive life cycle processes are needed to ensure goals are met in a cost-effective manner. The following chapter presents the optimal framework to do so by outlining the key actions and presenting replicable planning, design, construction, and operation processes. More information can be found in the CRAVEzero process reports.

3.1. INTRODUCTION – STAKEHOLDER-RELATED PROCESSES

Figure 25: Vala Gard – Skanska Sweden.

Besides legal and urban boundaries, buildings are essentially defined by owners and investors. Technical quality and high comfort standards have to be achieved within project specific budget limitations. Architects and specialized planners typically translate the client desires into real plans and are responsible for the appropriate execution. Construction companies and craftsmen from numerous disciplines are involved in constructing the building. There is a constant coordination process between the client, the planners, and the contractors to prepare the construction of a building and, if necessary, react to changing conditions like costs, schedules, the climate, etc. (Arnold 2005).

The range of services provided to buildings in the modern urban context has also changed over time. nZEBs have increasingly become active participants in our energy supply infrastructure and raise new planning, construction, and operational challenges. This results in innovative energy concepts (for both buildings and districts) that arise at different building life cycle phases and different points in the industry value chain. To reduce costs, accelerate processes, and assure nZEBs' quality, the right decisions have to be made at the ideal time.

In the early stages of building design, it is easy and inexpensive to make significant design changes to reach the best solution. Each design stage adds more and more details to the project, so it becomes more challenging and costly to make alterations. Traditionally, during the design process for a building's energy system, the architects send the initial designs to engineers who then test out a variety of energy system scenarios for a few weeks. Before the engineers can return an analysis, the architects have often made significant design changes. Not only does this lead to less efficient and more expensive HVAC systems, renewable energy systems and envelope qualities, there will be longer project timelines, unexpected construction issues, and budget overruns.

The following process-framework developed in the CRAVEzero project makes it easier, faster, and cheaper to plan new nZEBs. Risks of redesign, delays, and budget overruns can be reduced by optimizing overall processes.

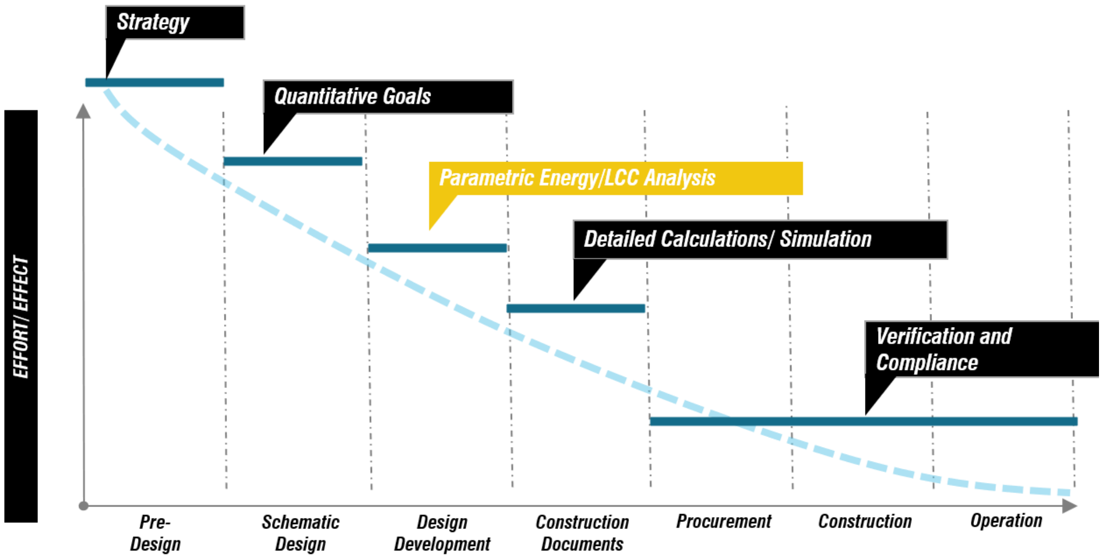


Figure 26: Influence, measures, and decisions in life cycle phases.

Figure 26 is based on the MacLeamy curve (IDEAbuilder 2012). MacLeamy's curve is a well-known concept of how shifting decision making in building design early in the process leads to great benefits in building performance and cost. Figure 26 shows how the effort and cost of design changes can be minimized to integrate building energy and LCC calculations to maximize the effect. It is very costly to change the technical solution sets for a nZEB at a late design stage. Early-stage energy and LCC analysis is thus vital for cost-effective nZEBs.

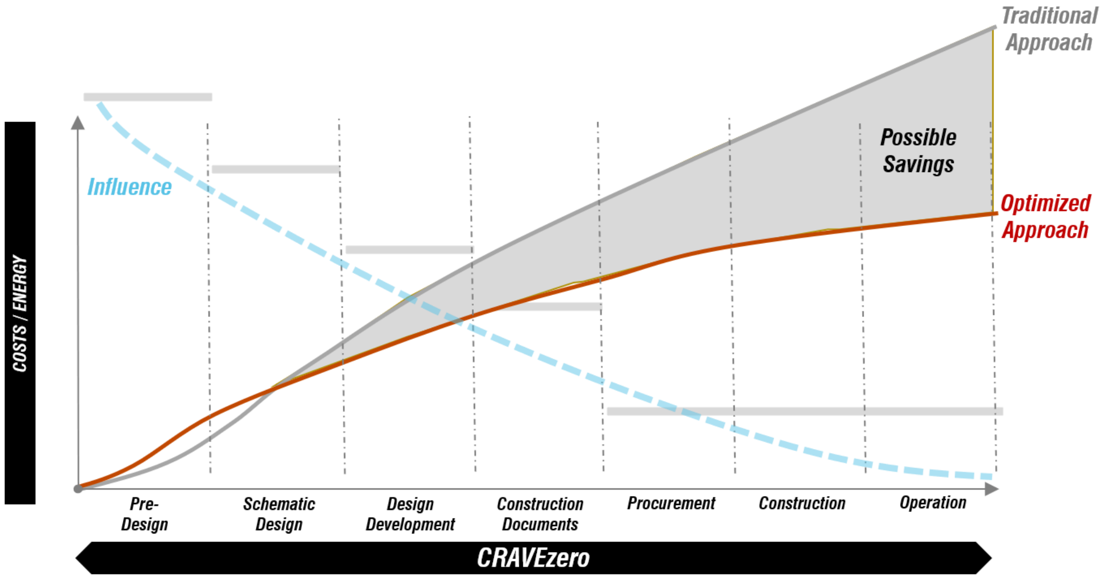


Figure 27: Decisions in the early phases of project development have a strong influence on life cycle costs.

During the life cycle of a building, the actors' different interests produce different perspectives, observation periods, and target values. There is the tenant/user, the real estate agent, the building contractor, planner, property manager, investor, owner, and the company (which is directly or indirectly involved in the building process). As shown in Figure 29, these actors are involved in the overall process over a certain period of time. While the tenant is primarily interested in the operational phase, the planner likely only deals with the building until its completion. If a property is financed and used by the resident himself, he is usually interested in the entire life cycle until there is a change in use. Depending on the approach, this can be between 25 and 50 years, after repayment of the bank loan and increased consideration of the use, respectively. For society as a whole, the entire service life of a building, including its demolition and disposal. This can also be shown in the influence and interest of stakeholders in different life cycle phases (Figure 28). The period under consideration must, therefore, be determined in advance with the parties involved. Between 25 and 50 years has proven reasonable for most considerations of an entire building (Figure 29).

☐ Indirect Influence
☑ Direct Influence

	Lifecycle Phase						
Stakeholders	Urban Planning / spatial planning	Planning	Construction	Operation	Maintenance and repair	Renovation	End of life
Tenant / user				☑	☑	☐	
Real estate agents			☐	☑			
Builder/ Construction company			☑			☑	☑
Planner	☑	☑	☑			☑	
Property management				☑			
Investor			☐	☑			
Building owner / landlord		☑	☑	☑	☐	☑	
Building owner (public)		☑	☑	☑	☑	☑	
Society	☑	☑	☑	☑	☑	☑	☑

Figure 28: Stakeholders' influence in nZEB life cycle phases.

Stakeholders	Time expectancy
Tenant / user	3 – 30 years
Real estate agents	1 – 2 years
Builder/ Construction company	1 – 5 years (Guarantee)
Planner	1 years
Property management	1 – 50 years (Contract duration)
Investor	1 – 5 years
Building owner / landlord	20 - 50 years
Building owner (public)	50 – 100 years
Society	> 100 years

Figure 29: Stakeholders' time expectancy for a nZEB project.

The process of nZEBs

This chapter describes the "CRAVEzero process," a common interdisciplinary framework of nZEB life cycle processes for all involved stakeholders. This well-organized and transparent process is the key to achieving the goal of cost optimal and sustainable nZEBs throughout the entire life cycle.
The complexity of nZEB processes is one of the main reasons why nZEB developments fail in the planning, construction, or operational phases. Already from the very beginning, pre-requisites must be created in order to define the requirements and clear project objectives. Too often, promising building concepts fail to achieve costs and energy goals because project participants are not sufficiently aware of the manifold interactions of holistic planning contexts.

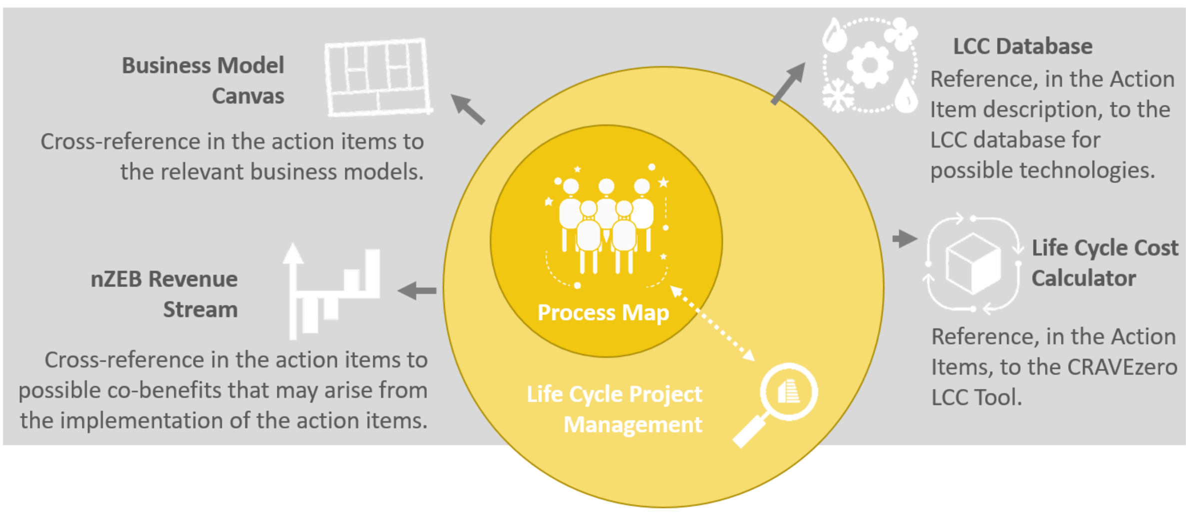


Figure 30: The CRAVEzero process and its connection to the CRAVEzero pinboard.

Each building has its own unique process, in which architects often start from scratch, collect the information and constraints of the local context, develop the building, carry out cost optimal performance analyses, and (hopefully) evaluate the potential for renewable energy. This incurs extra costs for the design process. Stakeholders repeat almost the same procedures without a coordinated and standardized process. An organized framework for a systematic approach for the life cycle process of low-cost nZEBs is needed as a starting point. A clear connection between building performance and related costs is essential to ensure the clarity of the process. A strategic element is the introduction of a performance-based procurement approach as a common practice not only for public tendering but for private construction as well.

In order to minimize risks and possible bottlenecks, obstacles must be identified at an early stage. It is necessary to establish a common planning understanding for nZEBs among all actors early on. The design of new nZEBs begins with maximizing passive design, yet limiting energy consumption from the grid. To do this, planners often need to challenge the norms of traditional designs.

CRAVEzero life cycle process phases

To achieve the nZEB goal at reduced costs, additional strategies and refinements of existing planning, construction, operation, and maintenance practices are required. In CRAVEzero, a process has been developed, mapped, and supplemented by key information to highlight the changes to common practice. The CRAVEzero Process Map and the associated CRAVEzero Process Tracker outline the key actions required to ensure the ongoing achievement of energy and cost-related targets. This clear and comprehensive life cycle process crucially includes specific and measurable actions.

The CRAVEzero process is the centrepiece of this research project. In the graphical representation of the process map, all participants in the building life cycle can identify their role and recognize their tasks and obstacles. The tools, methods, and information developed in the research project can be accessed via the CRAVEzero Process Map. The user can also find the following information:

- **Existing process:** The overall process and steps to be taken for all related stakeholders for all phases of a project's lifecycle.
- **Actions:** Tasks/actions promote the ability to plan, build and operate a nZEB. Activities were assigned to stakeholders and existing process steps.
- **Process evaluation results:** Actions are assigned to the main drivers and other stakeholders to clarify responsibilities. In addition, the correlations between all actions and stakeholders are shown.
- **Pitfalls and bottlenecks:** These can endanger nZEB project deadlines, budgets, and overall quality.

3.2. URBAN PLANNING PROCESS

The political decision-making and urban planning process lays the foundation for all upcoming phases of new nZEBs in the common interest of low-emission, low-cost public services.
Such planning usually proceeds from a large scale (e.g., regional planning) to a local one.
The main tasks on each decision and planning level are:

- Investigation and analysis of the existing situation
- Definition of a strategy
- Consideration of demand
- Definition of targets for spatial order
- Documentation and implementation of strategy and targets

These documents, which may be legally binding, can come in the form of plan material and recommendations, regulations, laws, or treaties with third parties (e.g., energy suppliers, landowners etc).

Several actions can be taken on a regional planning level to promote nZEBs; for example, defining the political and legal framework and funding schemes. Actions can have the intention to encourage, enable or enforce Defining targets is an important action

on the regional level since regions are linked to specific climates which impact building design.
nZEB design focuses on environmental conditions like sunshine, microclimate and wind lanes, and infrastructural conditions at a neighbourhood level (e.g., thermal and electrical microgrids, seasonal storage, renewable energy use, and building envelope attributes and targets).
The most common pitfalls and bottlenecks that can endanger the urban planning phase are:

- Planning demands in the urban planning phase
- Lack of potential for renewable energies on-site
- Political motives
- High demand for housing
- Development goals do not correspond to nZEB standard

The political decision-making and urban planning phase are layered into different levels. It is of utmost importance to have well-defined and verifiable mechanisms for information exchange between the levels. For example, it makes no sense to offer subsidies for certain energy supply systems on a regional level if, on a local level, other systems are preferred. Moreover, in some cases, it could be useful to integrate actions on different levels (e.g., a joint planning team of regional, urban, and energy planners would best consider both the urban population and the extra-urban environment).

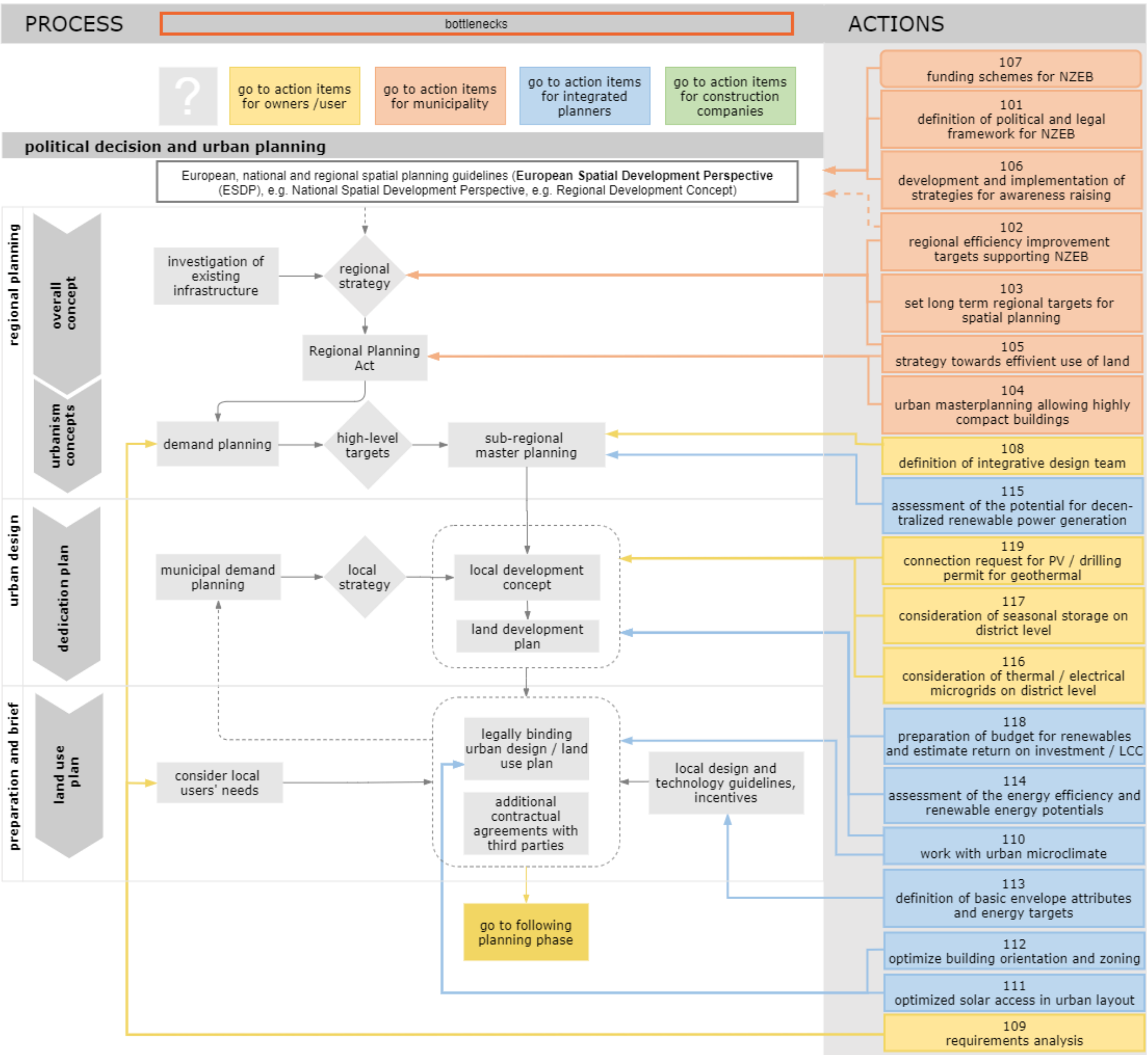


Figure 31: Optimal CRAVEzero nZEB urban planning process with stakeholder-related actions.

A detailed description of the individual actions in this phase and the overall optimal urban planning process (Figure 31) can be found in the "Guideline I – nZEB Processes" report.

To ensure the successful cooperation of stakeholders, it is important to underline the interdependency of individual nZEB-related actions in this phase to other stakeholders and actions. The coloured fields in Figure 32 describe the dependencies of the different actions on each other. The red fields describe a bilateral, while the blue fields describe partial correlation (e.g., Action 1 "Definition of political and legal framework" has a bilateral correlation marked in red with Action 2 "Funding Schemes for nZEBs).

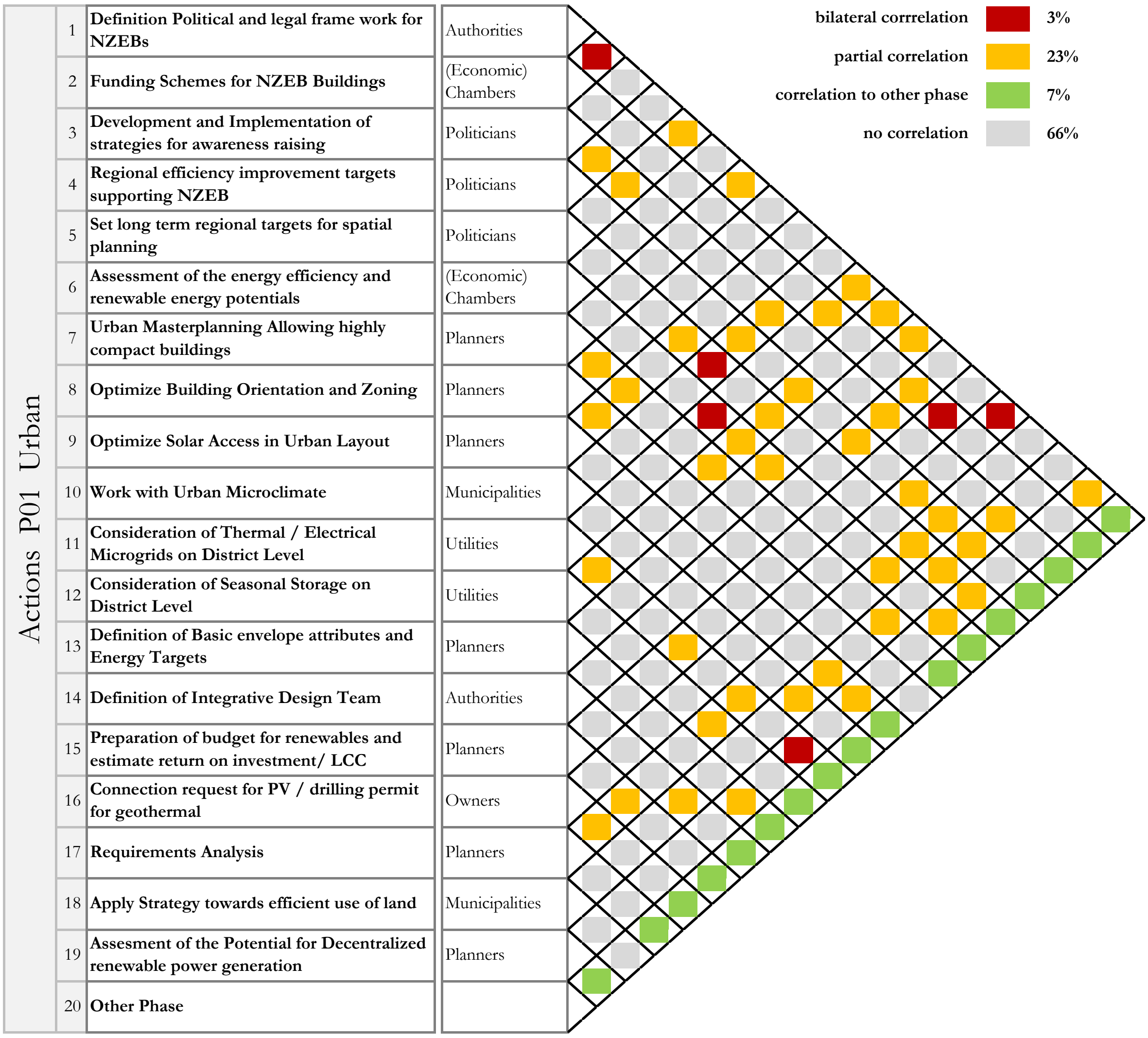


Figure 32: Urban planning process with stakeholder-related actions.

3.3. INTEGRATED BUILDING DESIGN PROCESS

An integrated building design process may generally be considered a holistic approach which considers interactions rather than optimizing actions separately (e.g., building layout/plans from a user perspective may have major effects for the superstructure of the building, which in turn creates unnecessary additional costs).

The process must be supported by the entire design team. Its outcome should be the creation of a building with high architectural quality and energy efficiency, low environmental impact, and a healthy indoor climate.

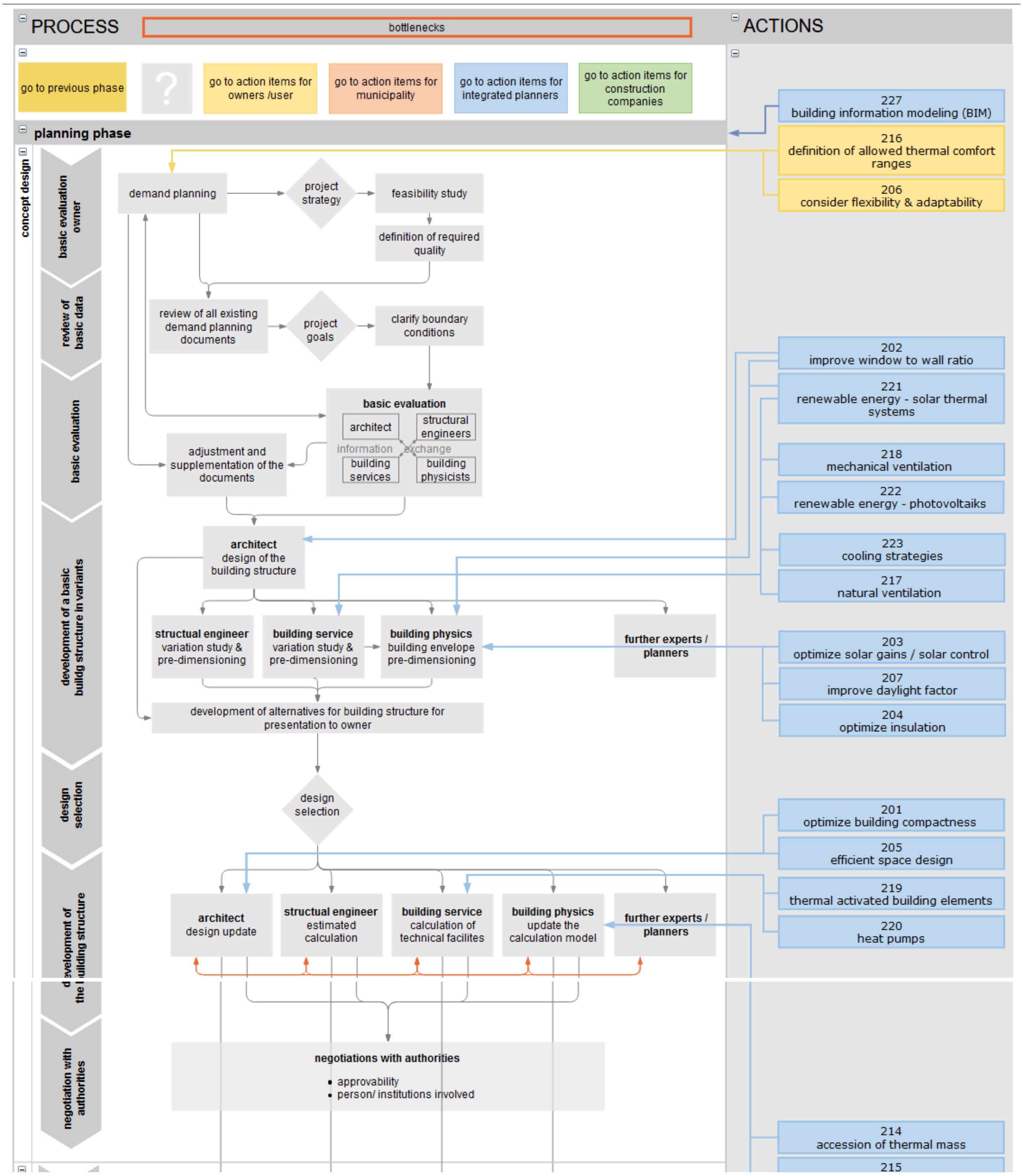
To be able to start the demand planning, it is important to understand the client´s requirements and clearly define the project goals. The entire design team must understand that the work needs to be iterative and depends on cooperation. For projects with considerably higher goals like nZEBs, the design process should start with a feasibility study showing important technical solutions, costs, savings and potential solution sets that work well together. This provides the basis to decide the main targets for the project.

The quality of the processes depends on the project organization and the information provided on goals and framework conditions. Only the most comprehensive interdisciplinary project team can fully deal with the dependencies between function, form, and energy and thus identify and evaluate the manifold cost effects of actions in the process.
This particularly applies to the financial consequences of architectural decisions on energy costs that cannot be determined by the LCC calculation. Close and iterative cooperation also reduces information losses and planning collisions.
The exchange of information between partners is increasingly relevant with the growing complexity of construction projects. The main reason for planning errors and missed deadlines is inadequate and incorrect information. Therefore, proper communication channels are of great importance for the reduction of data and time loss. Smooth and transparent communication must be maintained throughout the entire process, as subsequent decisions must be based on all information from previous decisions and dependencies.

Integral planning is the prerequisite for a lifecycle-oriented process that meets economic, ecological, and socio-cultural objectives. Architects and engineers work in tandem on the most innovative solution and constantly check if qualitative and quantitative goals are reached. A data model, building information modelling (BIM), maps the process from the initial idea to all virtual planning variants to the real construction and lifelong operation of the building. The integral design phase is divided into different phases which unite specialized knowledge carriers who investigate variants and evaluate concepts based on ecological and economic considerations.
When the **authorization planning phase** begins, the design team members may have changed, so it is important to review the project goals. During authorization planning, the final design is not defined in detail. However, in order to handle critical issues that may affect the project goals (identified in the concept design), some technical solutions may need to be studied in detail.
This part of the process is iterative and depends on cooperation. Interdisciplinary work is crucial in this part of the process.
During **technical design**, the project goals are verified and the commissioning tests are defined. In order to manage information effectively, all members of the design team must have access to information (e.g., specifications, Gantt schemes, drawings, etc.). This is effectively handled by using cloud-based management tools.
During the **concept design**, critical pitfalls and bottlenecks which may endanger deadlines, budgets, and quality of the nZEB project need to be identified. Common ones during the integrated building design process pertain to the following areas:

- Client demands during planning
- Integral planning
- Project management/coordination
- Consulting expertise
- Tools
- Database
- New technologies
- Supply with (renewable) energies
- Subsidies
- Environmental engineering services
- Process definitions
- Information exchange/cooperation

Below, Figure 33 shows the predominant activities and actions to be set at the appropriate times.



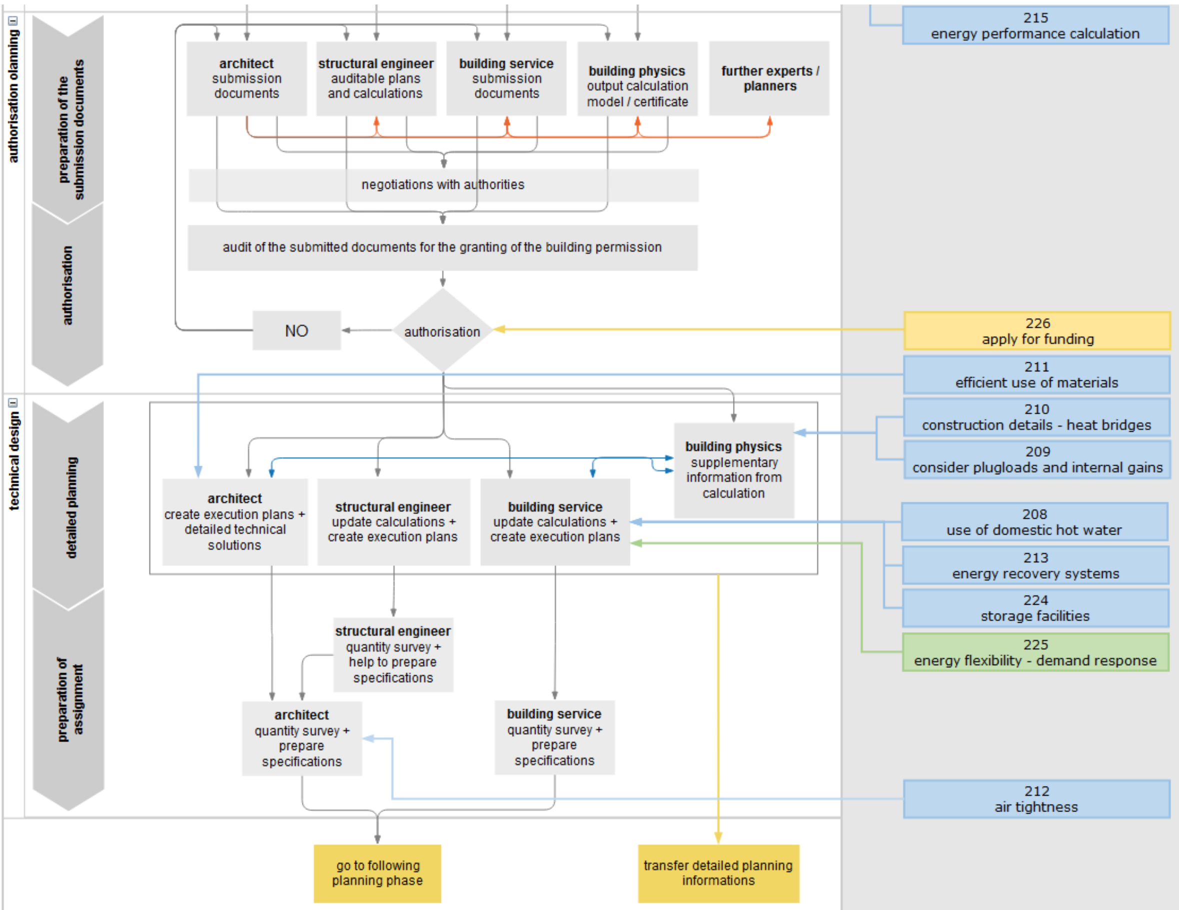


Figure 33: Integrated building design process with stakeholder related actions.

A detailed description of all actions can be found in “Guideline I - nZEB Processes”.

3.4. CONSTRUCTION PROCESS

Considering the building as a manufactured product permits the application of lean management strategies, which began in the automotive sector. In the building sector, there have only been a few examples, mainly performed in big, complex construction sites but also in some smaller and highly industrialized concepts (e.g., BoKlok, a housing product by IKEA and Skanska). CRAVEzero focuses on lean construction and operational protocols, which can also be applied to low and mid-rise investment for low LCC nZEBs.

Lean construction is an approach developed to improve the efficiency and effectiveness of the construction process. Managing a lean construction means minimizing any waste of time, resources, or materials, thereby maximizing value. The presence of a general contractor who manages and coordinates all suppliers and operators, makes it possible to optimize the entire system through collaboration, the elimination of obstacles and to fluidize the process, to achieve the value desired by the customer.

A key premise of successful lean construction is that design, materials, tools, and people are in place when an operation is scheduled to start. Several construction phases can break down the work with a focus on letting the different disciplines work separately as much as possible in an area and handling the interfaces between them. The constructions have to reach maximum functionality with the satisfaction of the final users. Manufacturers and suppliers have to be involved in the design as soon as possible to achieve integration and control costs. Current achievements, progress, and compliance with project requirements must be continuously verified by specific measures. It is best to facilitate quality control throughout the construction process rather than doing it at the end when correcting problems is much more difficult and expensive. Allowing open communication between the owner, project manager, contractors and engineering consultants guarantees a better outcome.

The use of prefabricated systems and the displacement of construction off-site as much as possible is a winning strategy. Off-site construction reduces on-site work and relocates it to a factory where technologies may be reorganized for greater efficiency and quality. Here are the main improvements off-site methods offer compared to the standard method of construction:

- Guarantee of better control and quality of the product. Thanks to the industrialized systems, the production is optimized and performance guaranteed;
- Reduced production times thanks to the effectiveness and precision of production processes;
- Reduced risk of unforeseen events, delays and additional costs when on-site methods are at a minimum;
- The scheduled times and costs are more stable, reduction of uncertainty throughout the project.

The reliability of the goods produced, the traceability of the components, their programmable maintenance, and containment of energy costs are deciding factors for off-site construction. Health and safety and job satisfaction are improved because the work environment guarantees better cooperation and fewer conflicts.

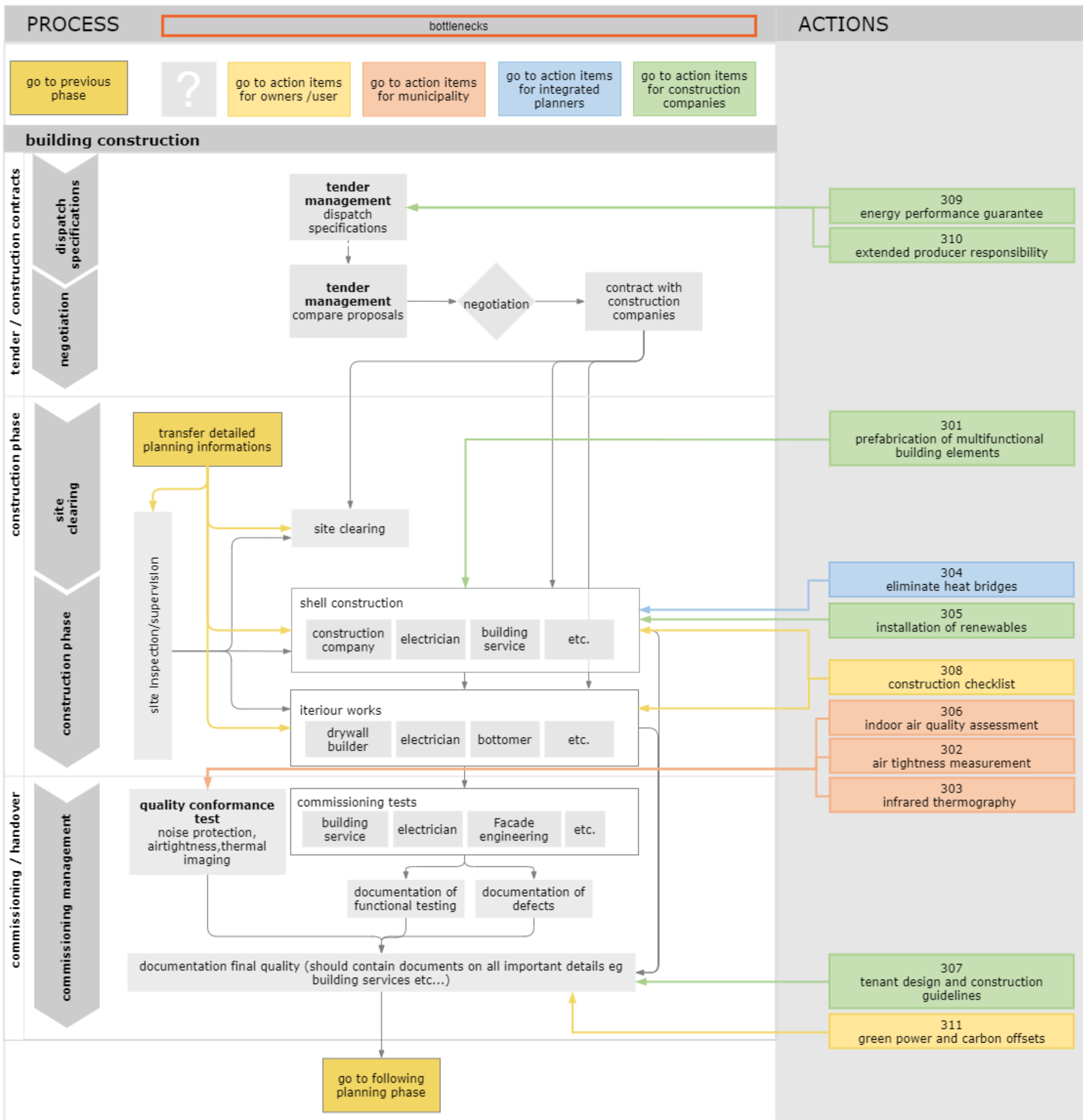


Figure 34: Construction process with stakeholder-related actions.

3.5. BUILDING OPERATION PROCESS

At the end of the construction process, once the building is commissioned, tested, certified, and the user has moved in, it is important to ensure the proper building operation. Facility operations and maintenance include a broad spectrum of processes, tools, and services required to ensure that the building will perform the functions for which it was designed and constructed. Appropriate user behaviour, occupant involvement, continuous monitoring and optimized maintenance raise the potential for cost reduction and savings.

During the operation phase, the tenants and owners of the building are the main actors. An operation and maintenance plan can be used to ensure that the building functions in the manner defined in the planning phase. This addresses component life expectancy, recurring operating and maintenance sessions, deceptive routines, and target values and performance indicators. Updated and complete documentation of the building, services, and the plant technology is required during operation to be control building services engineering and to avoid damage due to incorrect operation, care, or maintenance.

All facilities require maintenance during their service life. It is possible to perform preventive, predictive, and corrective maintenance. *Preventive Maintenance* (PM) consists of a series of time- and IT-based requirements that provide a basis for planning, scheduling, and executing scheduled maintenance. PM includes lubricating, cleaning, adjusting and replacing components. *Predictive maintenance* attempts to detect the onset of degradation to correct it before it significantly affects the component or equipment. *Corrective maintenance* is a repair necessary to return the equipment to properly functioning condition or service and may be either planned or unexpected. Some equipment, at the end of its service life, may need an overhaul (a restoration to a completely serviceable condition as prescribed by maintenance serviceability standards).

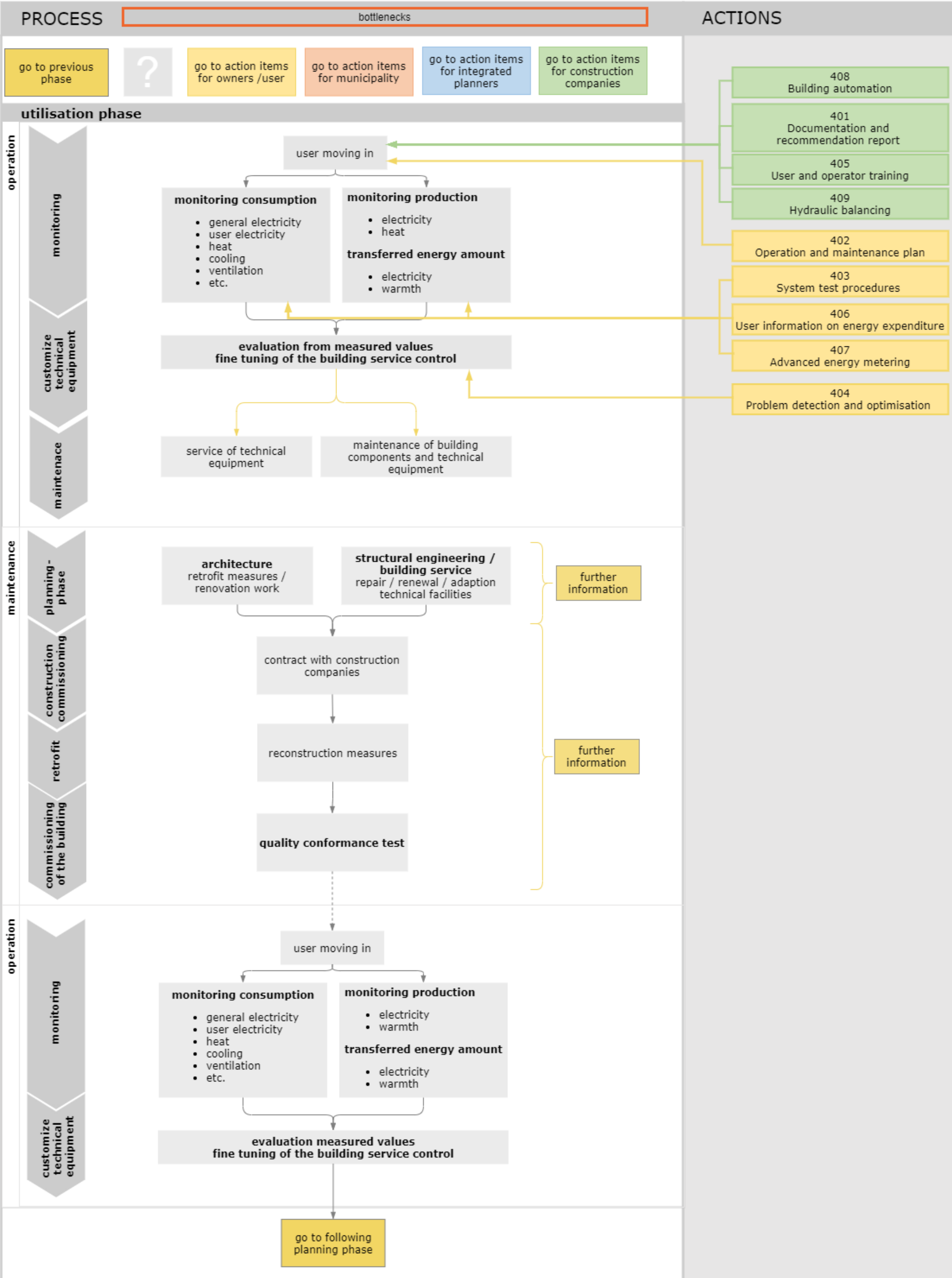


Figure 35: Building operation process with stakeholder-related actions.

3.6. END OF LIFE

The volume of waste from the construction sector, 871 million tons (EU, 2018), is the largest man-made waste stream in the EU (ECORYS, 2016). The DGNB, LEED and BREEAM certification systems have been assessing the recyclability of buildings for several years to reduce the environmental impact of buildings (DGNB, 2018; USGBC, 2018; BREEAM, 2016). With the “Levels assessment system,” the EU promotes the idea of a circular economy. A two-year test phase for this system began in 2018, which notably evaluates a building's resource efficiency (Level(s), 2019).

88 % of construction and demolition waste in the EU was recycled on average in 2014. According to an EU publication, most materials contained in construction and demolition waste are easy to recycle. This allows the waste stream from the construction sector to produce secondary raw materials. The EU Waste Framework Directive (2008/98/EC) set a recycling target of 70% for 2020 (EU, 2018). In this evaluation, recycling is assessed in terms of reuse, recycling, material recovery, and backfilling.

The recycling data differ considerably in European countries. Here, for example, 11 Member States have a recycling rate of over 95 %, but two Member States have a recycling rate of less than 40 % (EU, 2018).

To further increase the recycling rate, the “EU Construction & Demolition Waste Management Protocol” (Directorate-General for Environment, 2016)” outlines the waste management process. Waste identification is carried out based on a detailed inventory of the building to be demolished. The waste is then separated into its various components: hazardous waste and recyclable materials. Furthermore, for efficient recycling, a transparent management system must register the different types of waste and their quantities. An efficient logistics system should be set up to pay special attention to shorten transport distances. Further processing of construction waste must then take place in highly efficient sorting and processing plants in order to guarantee the consistent quality of recycled material (ECORYS, 2016).

In addition to this European Union protocol, many research projects address the management of waste in the construction sector. The IBO Institute in Austria has developed the EI Waste Disposal Indicator, a planning tool that assesses the amount of waste generated in the planning process to assess the potential recycling path of each type (IBO, 2018). The research project “Urban Mining” of the TU Berlin is developing guidelines for the city of Berlin to evaluate the recyclability of constructions (Vogdt, 2018). Within the framework of the research project "MAVO BauCycle," the Fraunhofer Institute develops recycling processes for heterogeneous building rubble in order to process it into homogeneous building products in new production facilities. New sorting technologies based on optical computing are being developed to produce new recyclates and secondary raw materials from construction waste. New innovative logistics platforms must be developed to implement this goal of raw material cycles (Fraunhofer Institut, 2016).

Besides the developments towards an improved understanding of raw material recycling, SuperUse Studios in the netherlands (2015) promotes the view that reuse is the optimal recycling. With harvest map, they have created a portal that offers materials that can be expanded for reuse from an existing building.

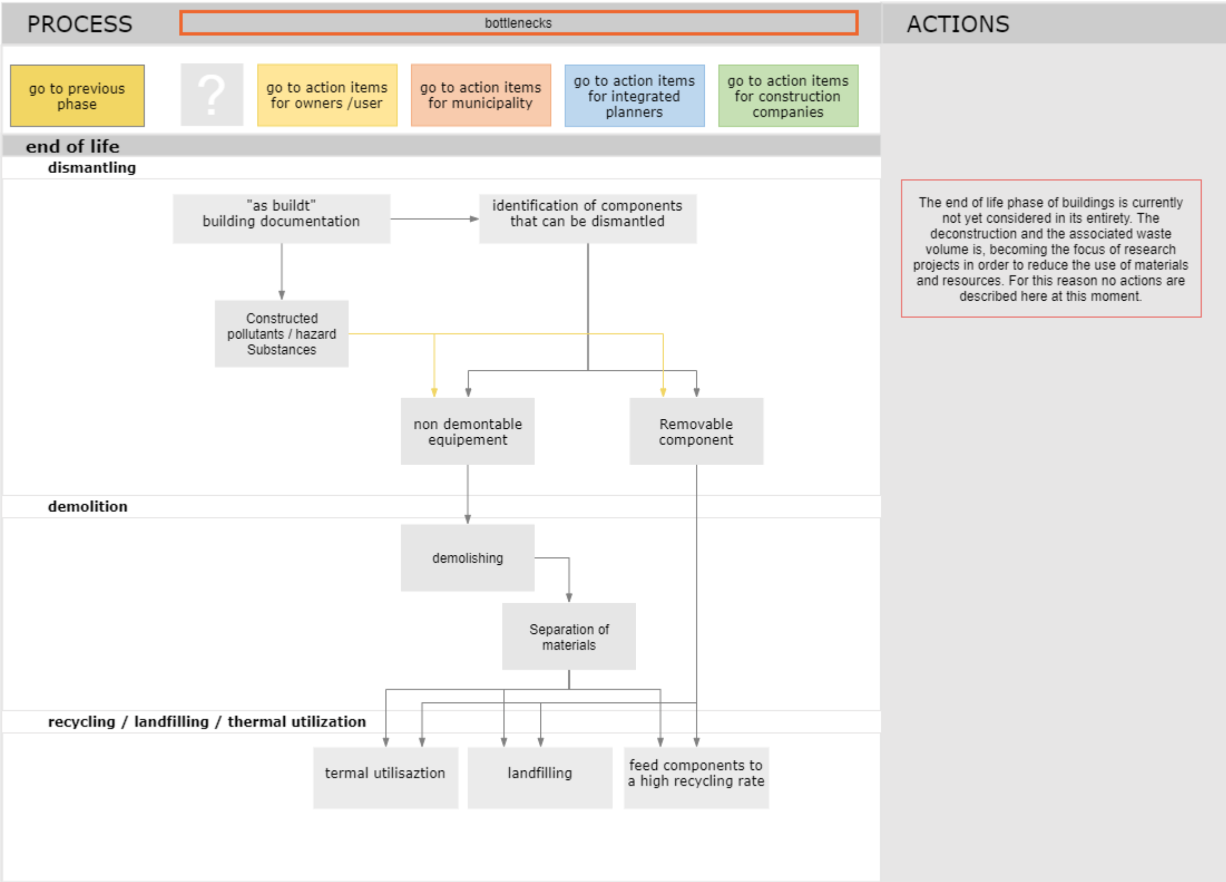


Figure 36: Building end of life process.

3.7. CONCLUSION

The focus of the described CRAVEzero process is to promote a common, interdisciplinary understanding of the complexity of nZEB planning processes for all involved stakeholders. A well organized and transparent process is key to achieving the goal of cost optimal and sustainable nZEBs throughout the entire life cycle phase.

In the previous chapters, the overall life cycle process of briefing, designing, constructing and operating nZEBs was illustrated in phases. Actions, stakeholder relations, and pitfalls were pointed out in detail. Key actions to ensure the achievement of energy and cost-related goals for replicable planning, design, construction, and operation processes were presented.

Based on the results from these guidelines and to further provide an operative methodology to achieve the best conditions towards cost optimal nZEBs, all results of the report have been summarized and structured in a "lean management protocol" known as the "life cycle tracker tool." This is an easy-to-use Excel file with VBA macros that combines project roles, actions, and design responsibility matrices. It is based on the experience of the whole consortium in the area of holistic project management with a focus on integral nZEBs planning. It outlines how key performance parameters to achieve successful nZEBs should be prioritized and can be tracked along the whole life cycle process.

Overall, the life cycle tracker tool helps stakeholders in different phases structure the whole planning, construction, and operation processes in a high-quality framework for new nZEBs. It can be downloaded here: pinboard.cravezero.eu

CHAPTER 4

nZEB Technologies

4. nZEB TECHNOLOGIES

To realise nZEBs that are cost-efficient for all stakeholders throughout the life cycle, knowledge of the most important technologies, solution sets, and possible cost developments is essential.

The focus should always be on the minimization of energy demands (heating, cooling, ventilation, lighting) by passive approaches. The remaining energy demands must be efficiently supplied to a large extent by renewable energy on-site.

Passive approaches and active technologies to supply heat, cooling power and fresh air and to generate energy on-site from renewable sources are the heart of each nZEB. An optimal combination of the available approaches and technologies can lead to high cost savings immediately and over the whole life cycle of a building by minimizing (i) initial and replacement investment costs and (ii) operation and maintenance costs. Optimal building design and the application of passive approaches not only reduce the energy demand and cost during operation but the lower amount of required installed power reduces investment costs for active technologies.

Besides the considerations and assessments from the perspective of a building owner/operator, additional considerations and factors gain importance as buildings increasingly become an active and interactive part of the overall energy system. How buildings can integrate fluctuating renewable energy on a broader scale is also assessed and described in the following section.

4.1. INTRODUCTION

Many nZEB technologies already exist today. However, their current market share is somewhat low. With an increasing market share and technological developments, cost reductions are expected for most relevant technologies. The following technologies were identified as most important for nZEBs based on the various case study buildings of the CRAVEzero project and further literature review:

- Renewables: PV and solar thermal systems
- Heating: heat pumps
- Air conditioning
- Central and decentralized ventilation with heat recovery
- Thermal and electricity storage
- Insulation and other passive strategies

To calculate potential cost reductions, a suitable methodology based on past market developments and the current status (e.g., efficiency, costs) of a specific technology was applied. The top-down experience curve method (based on learning rates for each technology) and a bottom-up method were used to identify specific cost drivers and their respective cost reduction potentials.

The central assumption of the top-down approach is that costs decrease as the cumulative production increases due to learning effects. More experience during market development leads to cost reductions from technological improvements and economies of scale.

For the bottom-up method, more detailed information is needed, which is not available for all assessed technologies. Therefore, the method was only applied to PV systems, solar thermal systems, and stationary lithium batteries, as they are considered the most important for nZEBs and the energy system as a whole.

For the top-down approach and to develop experience curves for the assessed technologies, current cost and cumulative volume levels, possible market development, and learning rates based on past developments were determined. A cost database with all data can be accessed in the CRAVEzero pinboard. The focus of the analyses was the EU. However, the availability of data was limited for several technologies, so the analysis was limited to Germany.

The calculated cost reduction potentials until 2050 vary from approximately 1% to 65%. Stationary batteries have the highest potential with 65% while oil and gas boilers have the lowest potential of less than 10%. The potential cost reductions until 2030 and 2050 for the major technologies are summarized in Table 7 and graphed in Figure 37.

Most cost reductions due to optimizations are expected to be achieved in storage systems and renewable and energy-saving technologies such as PV and ventilation with heat recovery.

The generation and storage of electricity and heat from renewable energy provide technological combinations in buildings with considerable cost reduction potential. They can increase the self-sufficiency of buildings (see also chapter 4.4) and reduce their carbon footprint.

Table 7: Ranges of cost reduction potential in 2030 and 2050

Technology	Potential range until 2030	Potential range until 2050
PV	20.0% - 29.0%	41.0% - 55.5%
Solar thermal	9.1% - 23.9%	22.0% - 50.8%
Gas boiler:	4.1% - 9.2%	4.9% - 11.1%
Oil boiler	0.3% - 0.7%	0.8% - 1.9%
Biomass boiler	7.2% - 13.4%	9.6% - 17.8%
Air-based HP	4.8% - 21.6%	11.0% - 43.9%
Ground-based HP	5.9% - 25.8%	7.9% - 33.4%
Thermal storage	9.5% - 26.9%	15.7% - 41.4%
Electrical storage	34.9% - 62.7%	47.9% - 77.7%
Air conditioner	9.3% - 25.2%	17.8% - 44.3%
Decentralised ventilation	30.3% - 49.3%	40.4% - 62.2%
Centralised ventilation	24.4% - 41.0%	34.6% - 55.1%

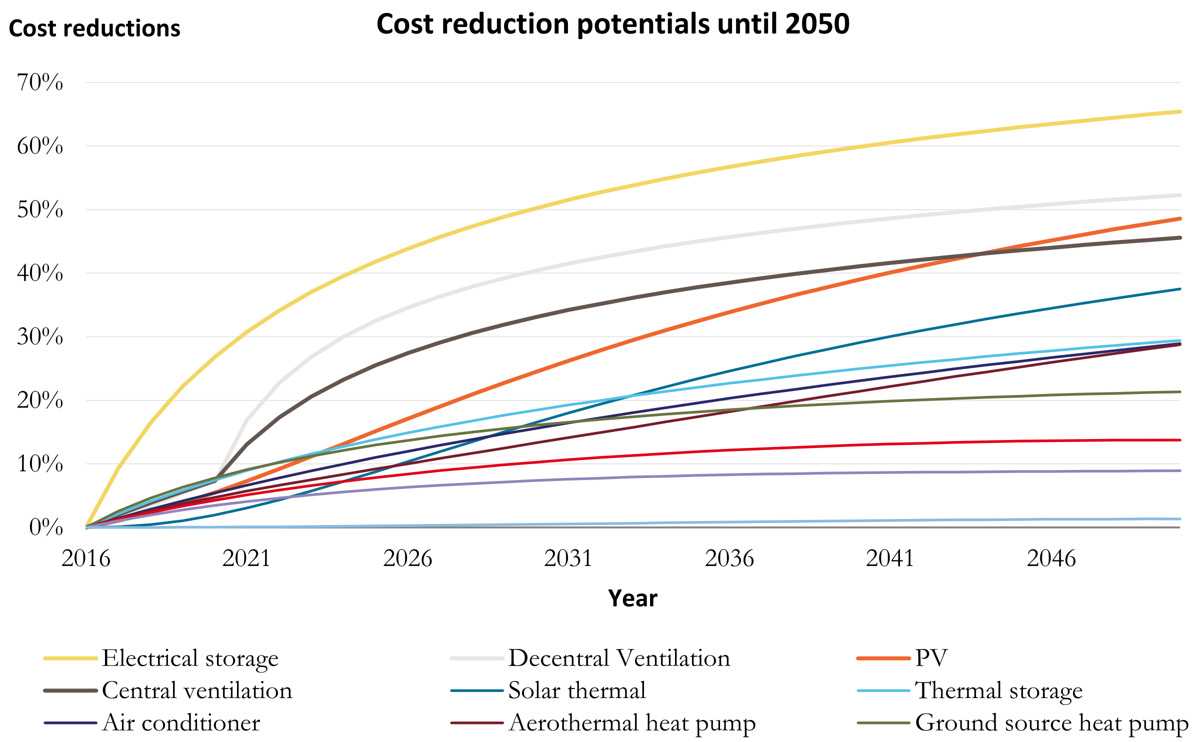


Figure 37: Cost reduction potentials of major nZEB technologies calculated with the top-down learning curve approach.

The cost reduction potentials include several uncertainties and many unexpected policy/economic changes (e.g., due to the current COVID-19 pandemic) that may occur until 2050. These changes can influence specific technologies and the building sector as a whole by changing targets or promoting and subsidizing specific technologies.

With the bottom-up analysis, several specific potential cost reduction drivers for PV, solar thermal systems and electricity storage were identified. For PV, the most important factors are efficiency optimization and lower material input for the modules. For solar thermal systems, the major factors are using less material and switching to cheaper materials. Furthermore, simplification of or changes in production methods and faster assembly could lead to future cost savings. The latter is also highly dependent on processes in planning and construction. For electricity storage, cost reductions can be achieved by economies of scale and technological improvements like increased energy density and reduced use of materials.

Besides the mainly active technologies described above, a central part of the solution sets/low LCC nZEBs are passive low-tech strategies.

4.2. MINIMISING ENERGY DEMANDS BY PASSIVE APPROACHES

An important aspect of energy-efficient buildings is the reduction of energy demand by better insulation and passive strategies. In all case studies, thermal insulation to reduce heating demands was a central measure to achieve the nZEB standard.

Passive methods like increasing solar gains in winter to reduce the heating energy demand and minimizing the gains in summer to reduce cooling demands are promising (and necessary) to realize cost optimal nZEBs. In summer, passive cooling and (night) ventilation strategies can lower the energy demand for air conditioning and ventilation. In nZEBs, low-energy demand achieved through insulation and passive strategies is essential in order to meet the remaining energy demand for building operations (heating, cooling, ventilation, domestic hot water, and lighting) with on-site renewable energy.

Therefore, technology sets, which (i) minimize the energy demand by applying passive (design) approaches and (ii) reduce the life-cycle cost of the building as a whole were identified and described in detail in the report "Optimized nZEB solution sets." Even though most necessary technologies to realize nZEBs are already available, the identification of suitable technology sets focusing on passive approaches to minimize the energy demand remains a challenge. Furthermore, certain developments over the past years led to high loads in buildings (large glass facades) and the trend was (and often still is) geared toward high-tech rather than low-tech buildings. As a result, only a few of many possible technology sets are considered in traditional planning processes.

A detailed optimization and parametric analysis of different technology sets for the CRAVEzero case study buildings, with a focus on active technologies, is provided in report D4.2. The following descriptions analyse different passive approaches to reduce the energy demand under different climatic conditions.

For the detailed analysis of passive approaches and measures to reduce the energy demand of a building, the Parkcarré case study, located near Karlsruhe in Southern Germany, was used as a reference (with some simplifications in the architectural design). Parkcarré is a residential multi-family building with four storeys and a net floor area of 1189 m². Several variations of the investigated approaches were assessed:

- Building orientation
- Changes in the window-to-wall ratio (WWR)
- Additional fixed and controlled shading
- Daylighting control
- Natural free ventilation based on the ambient air temperature

Furthermore, three different climatic data sets were used to analyse the effect of different meteorological/climatic conditions on the effectiveness of the passive approaches (except for free ventilation, where only the effect on the cooling demand in Italy was analysed).

The climate data sets used are:

- Stuttgart (Southern Germany; base case/ moderate climate)
- Kiruna (Northern Sweden; cold climate)
- Palermo (Southern Italy; hot climate).

Each apartment as well as the stairwells in the building is defined as a thermal zone. There are three apartments on each storey (one two-room, one three-room, and one four-room; twelve in total). Figure 38 illustrates the building.

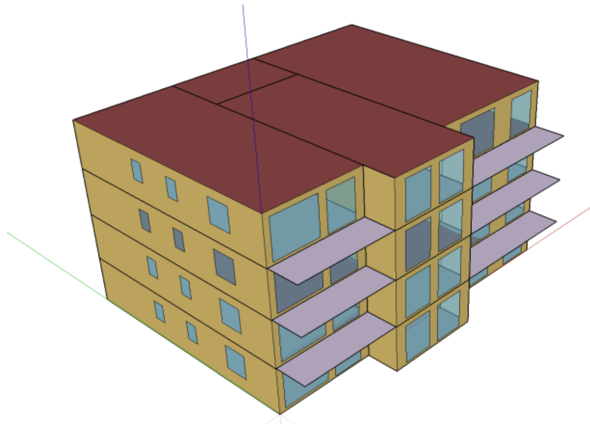


Figure 38: Illustration of the Parkcarré case study; screenshot from SketchUp Make.

In the climatic regions with a high heating demand (Germany and Sweden) a deviation from the south orientation of the building leads to an increase in the heating energy demand, thereby having a negative effect on the LCC of the building. Every deviation from the south orientation reduces solar gains. Further increasing the window-to-wall ratio (WWR) decreases the heating demand in most cases (an exception is increasing the WWR only on the west side of the building). The most significant effects concerning the heating energy demand are achieved when the WWR on the east and west sides of the building is increased; the heating energy demand decreases by 12 % in Germany and 2 % in Sweden). However, an increase of the WWR increases the LCC, as the specific cost of windows is higher than the specific cost of an excellently insulated external wall. The reduced heating demand does not refinance the increased costs over the 40 years considered.

Using daylighting control strategies does decrease the electricity demand for lighting by 3 to 6 %. However, the effect on the overall energy demand and energy costs is low, as the electricity demand for lighting has a share of only 4 to 5 % in Germany and 1 to 2 % in Sweden.

The assessed passive approaches have a greater effect in climatic regions with high cooling demand. With rising global temperatures due to climate change, designing buildings to minimize cooling demands becomes more important in moderate climates where cooling demands might rise. Orienting the case study building north instead of south can reduce the cooling energy demand by 5 %. An even higher effect is achieved by free ventilation in combination with controlled shading at the windows, which reduce the cooling energy demand by 18 – 22 % compared to the base case.

Increasing the WWR has a strong negative effect on the cooling energy demand; without adding additional external shading, the cooling demand is increased by 64 % when the WWR is increased on the east and west sides of the building. Generally, large window areas should be avoided in hot climates as the high solar gains in summer (i) negatively influence the comfort and (ii) lead to very high cooling energy demands and cooling loads, increasing the need for active cooling technologies.

As more daylight is available in southern regions, applying daylighting control there has a greater effect than in northern climates. Daylighting control can reduce the electricity demand for lighting in Italy by up to 9 %.

The best variants of the different parameters for the different climatic regions are summarized in Table 8. In an additional simulation, the identified best variants were combined to assess the achievable overall savings (see Figure 39). In the optimum case for Germany, the specific energy demand for lighting and heating is 19.3 kWh/m²a. The achieved saving is 11.4 %. The combination of the individual approaches leads to slightly better results than the sum of the separate approaches. The different approaches are complementary and do not affect each other negatively. The achieved savings for the optimum case in Sweden are 2.5 % and 21.5 % in Italy. The theoretical savings obtained by assessing the individual approaches separately in Italy are 26.6 % – higher than achieved with the combined simulation. There are some interactions between the best individual approaches which influence each other negatively when they are combined. A major reason is that by orienting the building to the north, the cooling demand is already reduced. As a result, additional measures have lower saving effects in absolute numbers than in a building oriented to the south.

Table 8: Best variants of the assessed passive approaches in the different climatic regions. The achieved energy demand reduction is presented in brackets.

	Building orientation	**Window-to-wall ratio**	**Daylighting**	**Natural ventilation**
Germany	South (Base case)	WWR3 (heating demand -12 %)	WWR3 with day-lighting control (electricity demand for lighting -6 %)	-
Sweden	South (Base case)	WWR3 (heating demand -2 %)	WWR3 with day-lighting control (electricity demand for lighting -5 %)	-
Italy	North (cooling demand -5 %)	Base case	WWR3 with day-lighting control (electricity demand for lighting -9 %)	Vent3 (cooling demand -22 %)

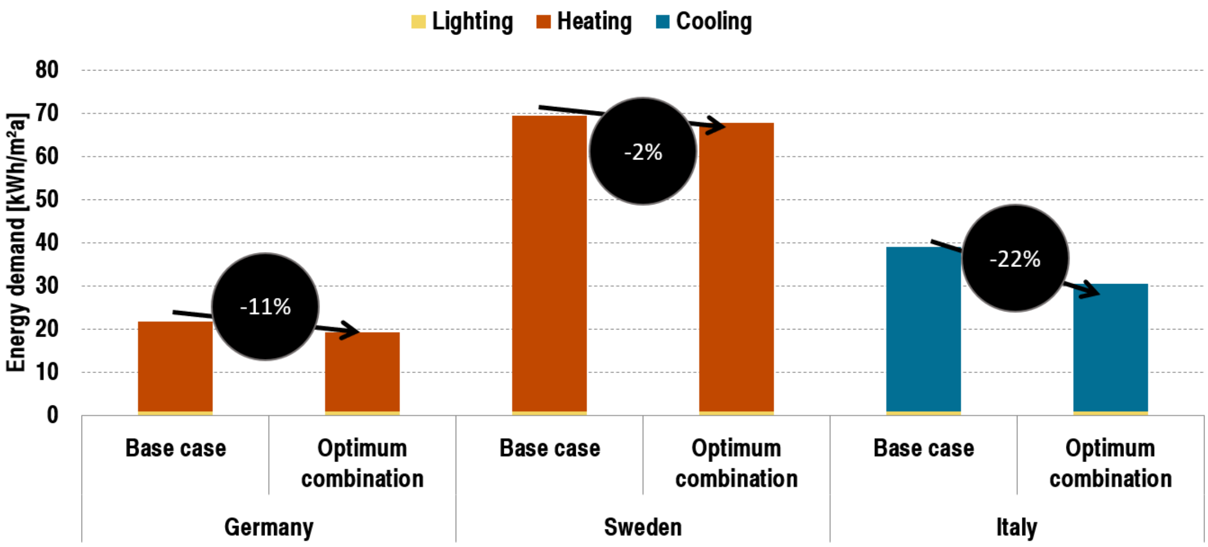


Figure 39: Combination of the best variants of passive approaches in Germany, Sweden, and Italy compared to the respective base cases.

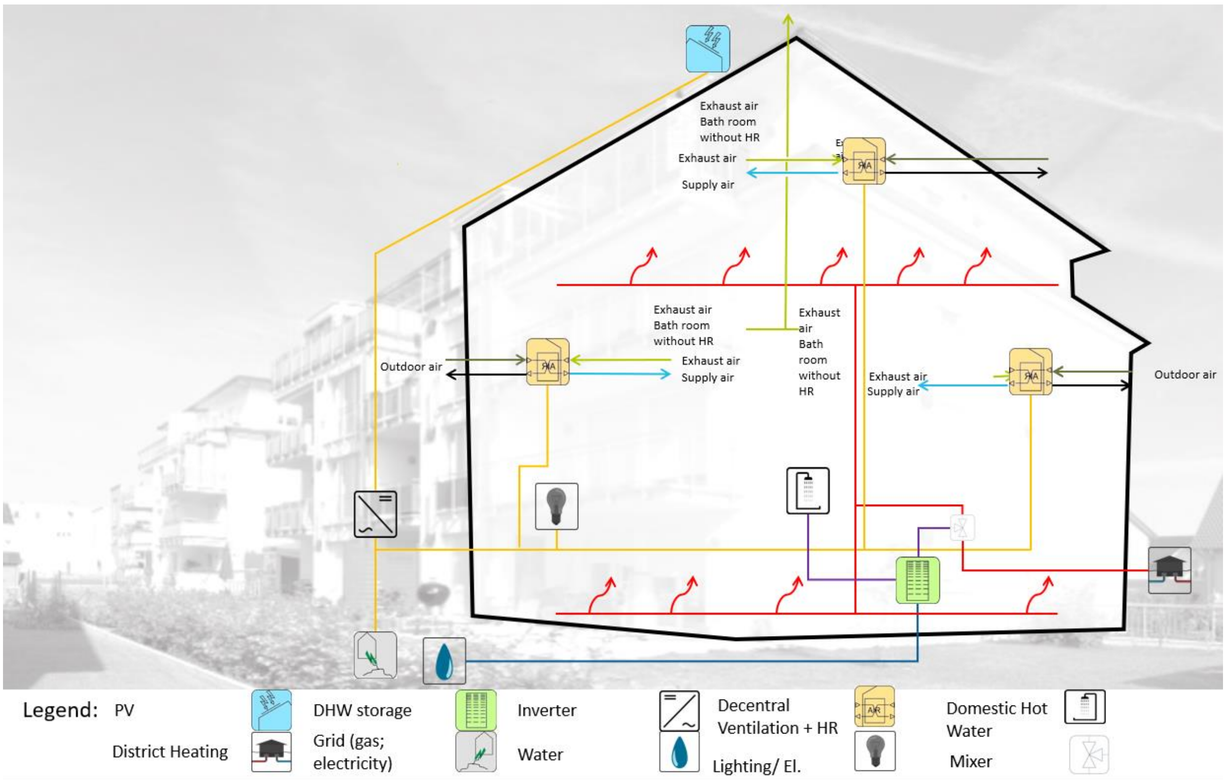


Figure 40: Technical solution set of case study "Parkcarré."

4.3. OPTIMAL TECHNOLOGY SETS

The CRAVEzero project mainly builds on twelve case studies provided by the project partners. The case studies are located in Austria, Italy, France, Germany, and Sweden. For several case studies, parametric simulations have been conducted. From the results, the variants with the highest and lowest net present value (NPV) as well as the highest and lowest CO_2 emissions were identified. For these variants, similarities and main differences were assessed to identify drivers to optimize nZEB costs.
The analysis of the variants with the highest and lowest NPV as well as those with the highest and lowest CO_2 emissions based on the parametric analysis conducted in WP06 shows that non-technical factors have a strong influence on the energy demand, emissions, and NPV of a building. These are, among others, the user behaviour and climatic conditions. Furthermore, a building envelope complying with the nZEB standard – in many cases, even a higher standard – is an important component of low-emission and low-cost buildings. In such buildings, DHW dominates the final energy demand in most cases. An interesting finding of analysing the variants with the lowest NPV and lowest emissions is that in most cases these variants have fewer technical installations than the base cases and can be considered low-tech buildings. Minimizing technical installations, reduces the investment as well as operation and maintenance costs on the one hand and minimizes the auxiliary energy demand on the other. Furthermore, the active use of solar energy (mainly PV but also solar thermal) is essential to minimize CO_2 emissions. Solar technologies are often competitive with other technologies, especially in the case of PV, which has positive effects on the costs/NPV. From the analysis, possible best solutions achieving low emissions with comparably low costs were identified (see Table 9 on Résidence Alizari).
The analyses of the passive approaches and the results of the parametric analysis show that there is no singular optimal solution for every setting and all boundary conditions. Furthermore, the goal (minimal costs, minimal emissions) of a design team/building owner strongly influences the technology set and building concept.

Table 9: Variants with low CO_2 emissions and comparably low costs of the Résidence Alizari case study, based on parametric simulations. The variant number shown is based on the results matrix of the parametric analysis and is equivalent to the number of the variant in the interactive case study dashboard in the CRAVEzero pinboard.

Variant Number	**12098**	**12099**	**11907**	**12162**	**12163**
Envelope insulation	External wall 250 mm	External wall 250 mm	External wall 250 mm	External wall 300 mm	External wall 300 mm
PV	30 kWp; efficiency 15 %	34 kWp; efficiency 17 %	34 kWp; efficiency 17 %	30 kWp; efficiency 15 %	34 kWp; efficiency 17 %
NPV [€/m²]	**1,512**	**1,516**	**1,517**	**1,518**	**1,521**
CO_2 emissions [$kg_{CO2}/(m^2a)$]	**23.31**	**23.14**	**23.61**	**23.22**	**23.05**

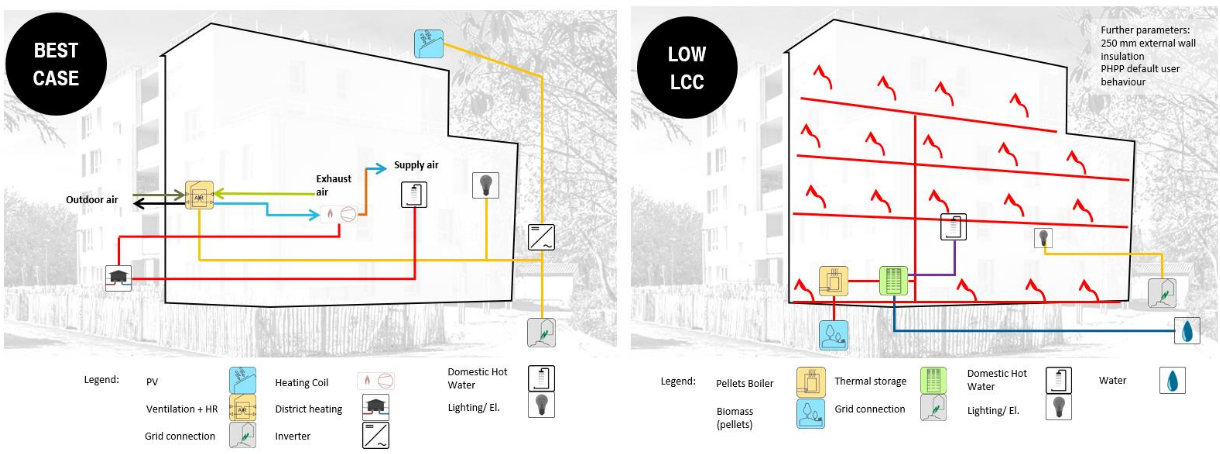


Figure 41: Exemplary technical solution sets for the Alizari case study.

4.4. ENERGY FLEXIBLE BUILDINGS

The increasing share of fluctuating renewable energy generation in the electricity grids requires new technical measures, market designs, and models to balance generation and demand. As buildings are major energy consumers and electricity consumption (for heating, domestic hot water and cooling as well as on-site electricity generation from renewables) is increasing, the integration of building energy systems/buildings into the energy system is increasingly important. Renewable electricity is generated on-site and stored in batteries which could also be used to balance the local distribution networks. Heat pumps and electric vehicles are new electricity consumers in buildings with relatively high connected power... There are many established or new technologies which must be integrated into the system in a way that stabilizes the electricity grids.

There are several different options, flexibility goals and KPIs regarding the field of energy efficiency and flexibility described in the CRAVEzero report "Energy flexible building managing models." The different technologies and methods applied in some of the CRAVEzero case study buildings were compared using three different approaches/ KPIs, namely:

- Self-sufficiency/autarky rate based on results of the PVopti tool
- Analysis of the Grid Support Coefficient (GSC) developed at Fraunhofer ISE
- Analysis of the Smart Readiness of the buildings based on its current definition, which may be introduced at the European level in the future.

The aim of the work is to develop and describe models and methodologies for (i) continuous commissioning of buildings and (ii) building-grid interaction with a focus on renewable energy on-site. Therefore, two major challenges of the future are addressed: (i) the reduction of the energy consumption in buildings and avoidance of malfunctions in the building energy system, and (ii) the integration of fluctuating renewable energy into the electricity grid by adjustments in the building operation.

The process of continuous commissioning is described based on a detailed literature review as well as results from projects focusing on fault detection in large and complex building energy systems.

The findings from the IEA EBC Annex 67 "Energy Flexible Buildings" form the basis of the integration of renewable energy into the electricity grid by adjusting building operations. Possibilities for an improved building-grid interaction are described qualitatively and assessed quantitatively using different approaches/tools and a comparison of the results. The quantitative analysis uses the PHPP models of case studies as a starting point. With the tool PVopti[2], the self-consumption and autarky level of the base case and several other technology sets are assessed, and hourly electricity profiles are generated for each case. The hourly profiles are used in a second step to analyse the grid supportiveness of the building/technology set using a methodology and GSC indicator. The case study buildings have also been rated using a simplified "online quick scan" method for the Smart Readiness of Building (Smart Readiness Indicator SRI; Reynders, 2019).

The differences between the approaches and the respective results are compared and analysed to identify different implications for the building technology sets resulting from the different focuses (self-consumption, grid-supportiveness, etc.).

Buildings interact with surrounding energy systems by importing and exporting energy (Salom et al., 2014). Usually, the focus is on the **interaction** with the electricity grid. With the increasing usage and integration of fluctuating renewable energy technologies like wind power and photovoltaics in buildings and electricity grids, the interaction between all participants (energy consumers and producers, as well as prosumers) is gaining importance. In order to support the integration of fluctuating renewables, the power import and export of buildings should be oriented to the current state of the superordinate power grid by increasing the flexibility of the energy supply and demand of the buildings. In Weiß et al. (2019a), flexibility is described as the maximum time a power draw can be postponed or additionally consumed at a specific moment during the day.

In Voss et al. (2010), the importance of building-grid interaction to realize net-zero-energy buildings (NZEBs) is emphasized. The interaction/energy exchange with a grid infrastructure helps overcome limitations of on-site seasonal energy storage. Grid interaction is defined in Voss et al. (2010) as "the temporal match of the energy transferred to a grid with the needs of a grid" (p. 2). The following section describes important terms and approaches to manage and optimize the interaction between energy grids and buildings as well as strategies to increase their intelligence. Furthermore, approaches are introduced to quantify the ability and level to operate buildings in a way which helps stabilize and manage the grids, thereby integrating an increasing share of fluctuating renewables.

Demand Side Management (DSM) can be used to manage the load curve of buildings, applying measures such as shifting demand in time (load-shifting), reducing the peak in the energy demand (peak-clipping/load shaving) or temporarily increasing the load when the incentives are high or the electricity prices are low (valley-filling) – see Figure 42. The relevance of and possibilities for the DSM approaches in several European countries and Alberta are shown in Figure 43, which illustrates the electric load in 2011 in January (winter), April (spring), July (summer) and October (autumn).

[2] http://annex67.org/publications/software/pvopti/

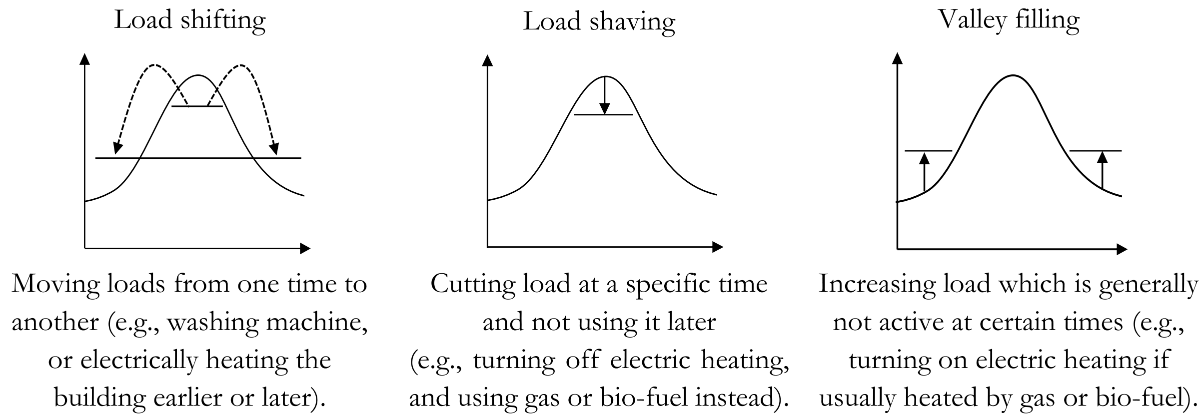


Figure 42: Flexible mechanisms: load shifting, load shaving, and valley filling (Lindberg, 2017).

DSM is defined from a utility perspective as "the planning and implementation of those electric utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape" (Gellings, 1985). DSM can be divided into two categories: **energy efficiency** - EE and **demand response** – DR (Palensky and Dietrich, 2011). The benefit of DR strongly depends on the available energy flexibility and successful program implementation. Hence, most state-of-the-art literature focuses on demonstrating the extent that this can reduce energy cost, shift peak power, increase the use of local renewable electricity generation, or achieve stability in the power grids by utilizing the flexibility of buildings.

In this context, the term **grid-supportive** operation of buildings is introduced and discussed in the scientific literature (e.g., Klein, 2017). The goal of analysing and quantifying the grid supportiveness is to understand how and to what extent buildings can contribute to "efficient integration of a high share of intermittent renewable energy into the energy system" (Klein, 2017, p. 17). The focus is on the support of the overall upstream energy system, not only local/regional grids. "Grid supportiveness" is defined by Klein (2017) as the operation of variable electrical loads that consume power predominantly in periods with low relative electricity demand in the system thereby considering power load needs and the availability of fluctuating renewable energy. On the other hand, a grid-supportive generator produces mainly when the relative electricity demand in the whole energy system is high (Klein, 2017). The opposite behaviour is termed **grid-adverse**. For measuring/quantifying the grid supportiveness, Klein developed the absolute Grid Support Coefficient GSC_{abs} and the relative GSC_{rel}.

One of the key barriers jeopardizing the market uptake of smart technologies is the lack of clarity about the energy benefits. There are few studies about the impacts of implementing smart home devices in buildings, and there is a lack of independently verified empirical data on savings impacts (Urban et al., 2016) The EPDB Recast 844/2018 (The European Parliament and the Council of the European Union, 2018) introduced the **Smart Readiness Indicator (SRI)**, in order to raise awareness of the value of smart devices and services among building owners and occupants, giving them confidence in the actual savings resulting from those new enhanced functionalities. The SRI measures the readiness of the building "to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings" (The European Parliament and the Council of the European Union, 2018).

From the building perspective, the logic behind this EPBD amendment is that it is intelligent with minimal provision of smart technologies and services. However, some elements might be missing, misplaced, or even capable of provoking resistance:

- These technologies and services do not guarantee that the building is intelligent in the context of the surrounding energy networks (electricity, heat, and gas) or that it lowers CO_2 emissions of the overall energy system. In the context of a neighbourhood or the surrounding network, however, the energy flexibility and "smartness" of buildings are essential resources for reducing CO_2 emissions in line with the IEA EBC Annex 67.

- Measured or achieved "smartness" could cause additional costs which preclude the required affordability of housing. There are fears that "grid supportiveness" - if it is applied - would by no means be remunerated adequately by the utilities.

A consortium led by the Flemish Institute for Technological Research NV ("VITO") has been awarded the contract for the implementation of the concept of the SRI. If their proposal is accepted by the European Commission through parliament and council, its implementation will be up to the individual states. The preparation of a possible national SRI specification as well as its integration into the process of energy performance calculation can still be influenced since the process is ongoing.

AEE INTEC is involved in the development of the calculation methodology, which is based on a technology and services rating system, weighting different services by their functionality level with respect to predefined impact criteria (Reynders, 2019; Verbeke et al., 2018). Such effects are pre-calculated for the smart devices and services available on the market, but they are not associated with either physical or performance quantities. This should be noted and kept as background knowledge for reference when new SRI developments are integrated into the CRAVEzero demonstration projects to assess the technologies' and building services' smartness.

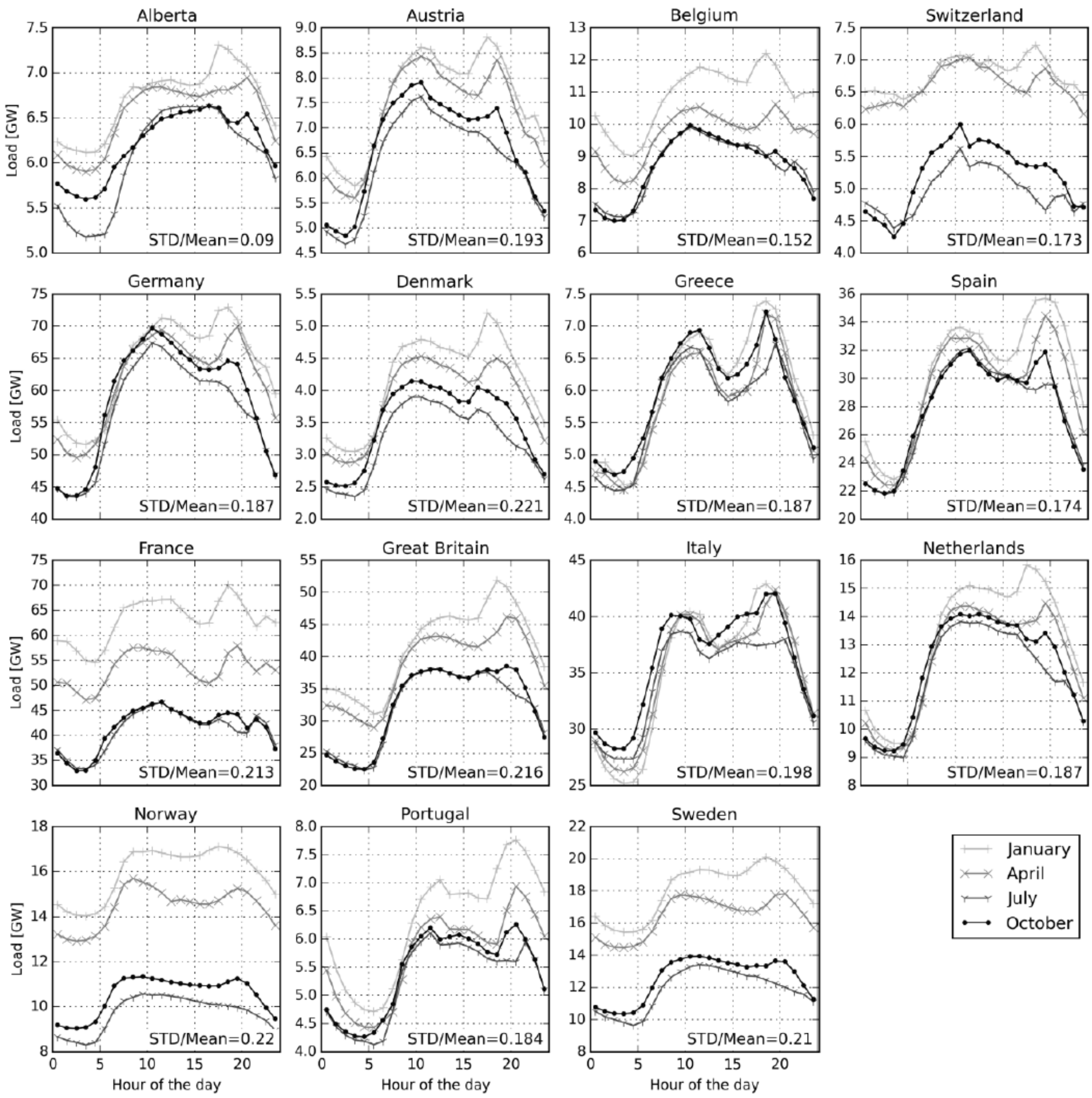


Figure 43: Aggregated daily profiles of the electric load in several European countries and Alberta in 2011 for one month in winter, spring, summer and autumn (Klein et al., 2016a).

The "Brussels/Parkcarré" and "Moretti More" case studies were analysed concerning different KPIs; namely, self-consumption, GSC autarky with respect to EEX prices, GSC for residual load, and smart readiness. For all KPIs except smart readiness, several variants were assessed to identify the driving (technical) factors. However, a positive factor for increasing self-consumption is not necessarily positive for the GSC and vice versa. The main positive and negative factors identified for the "Brussels/Parkcarré" and "Moretti More" case studies are summarised in Table 10 and Table 11, respectively.

The primary drivers for high self-consumption are the installation of electricity storage equipment and the size of the PV system in relation to electricity consumers. The presence of large electricity consumers, especially in summer (cooling units, heat pump) is a crucial factor as well. Generally, the smaller the PV system compared to the electricity demand, the higher the self-consumption, as (almost) all electricity is used on-site throughout the year. The challenge in buildings without high electricity demands in summer (high PV generation) is the usage of the electricity generated in the summer months. For a high autarky rate as well as good GSC values, however, large PV systems are positive.

For good GSC values, the installation of battery storage, as well as the use of electrically powered heating systems, is positive, especially when a PV system is installed. In climatic regions with mainly heating demands, a large PV system in combination with heat pumps increases the GSC concerning EEX prices.

The absence of large electricity consumers, especially heat pumps with thermal storage is crucial for self-consumption and GSC as this affects (i) the possibility to use PV electricity generated on-site and (ii) the load-shifting possibilities necessary to operate a building grid-supportively. Bivalent heat pumps offer even higher shifting/switching potentials and are also positive for the autarky rate.

The followed strategy strongly affects the technical installation needed; to increase self-consumption, small PV systems are generally positive, whereas large systems are necessary for high autarky. Furthermore, it is crucial that the PV system is sized accurately to meet the demands of each building and that sufficient storage possibilities are available.

As the analysis of the smart readiness is based on a more qualitative approach, positive and negative factors for the SRI are not included in the tables below. The dimensioning of renewable energy technologies on-site does not influence the SRI result, but the presence (or absence) of these technologies does. However, what is more important is the availability and use of storage based on external (grid) demands. The installation of batteries, which positively influences all other KPIs, also has a positive effect on smart readiness. For a high SRI score, the control strategies supporting the stability and management of higher level grids are positive. Implementing these strategies in buildings increases self-consumption, autarky and the GSC. The quantitative effects were not assessed in this study, as detailed building models and optimizations would be needed for the analysis, which was not part of the project. It can be concluded, however, that considering the high-level services described in the SRI services catalogue positively affects all other quantitative KPIs assessed in the framework of this study.

Table 10: Comparison of factors positively and negatively affecting the assessed KPIs in the case study "Parkcarré"

	Self-consumption	Autarky	GSC_EEX	GSC_Residual
Positive	• Battery storage • Accurate dimensioning of PV in relation to el. demand (by trend smaller PV) • Installation of heat-pump	• Large PV system • Large battery storage capacity • No large el. consumer like a heat pump during winter (bivalent heat pumps achieve better results)	• Medium – large PV system in combination with heat pump and battery storage	• Heat pump + large PV system • If no heat pump and battery are installed, smaller PV system is positive
Negative	• No large el. consumers in summer • No battery storage • Overly large PV system	• No battery storage • Small PV system • Heating system only using electricity → bivalent heat-pumps are better	• Non-electric heat generation / district heat → only low shifting potential • No battery storage	• Non-electric heat generation / district heat → only low shifting potential • No battery storage

Table 11: Comparison of factors positively and negatively affecting the assessed KPIs in the case study "Moretti More"

	Self-consumption	**Autarky**	**GSC_EEX**	**GSC_Residual**
Positive	• Battery storage • Accurate dimensioning of PV in relation to el. demand especially in summer	• Bivalent heat pump • Large PV system • Battery storage	• Installation of battery + large PV	• Battery • Optimisation of operation
Negative	• Large PV-system • No battery storage	• No battery storage • Small PV system	• Large PV without battery	• Installation of PV

The project aimed to develop and describe models and methodologies for continuous commissioning of buildings and building-grid interaction with a focus on the on-site use of renewable energy. The project thereby addresses two major challenges in buildings for the future:

- Reduction of energy use and avoidance of malfunctions in energy systems
- Integration of fluctuating renewable energy into electricity grids by operational adjustments

The process of continuous commissioning is described based on a detailed literature review as well as results from projects focusing on fault detection in complex building energy systems. The importance of reliable and robust operation of a building is highlighted and suggestions to integrate continuous commissioning into the building life cycle are provided.

The IEA EBC Annex 67 “Energy Flexible Buildings” form the basis of the integration of renewable energy into the electricity grid by adjusting building operations. Possibilities for an improved building-grid interaction are described qualitatively and assessed quantitatively. PHPP models of case studies and the tool PVopti are used to assess the self-consumption and autarky level of several technology sets. The results show that appropriate dimensioning of on-site renewable energy technologies in combination with electricity and thermal storage is essential. A difference between the goal of increasing self-consumption and increasing the autarky is the magnitude of on-site renewable generation. For a high autarky rate, a high generation capacity is needed to provide the needed electricity. during periods with low specific on-site generation. This approach reduces self-consumption at times with high specific on-site generation. In the “Brussels/Parkcarré” case study, achieved self-consumption rates between 19 % and 100 % and autarky rates of 14 % to 77 %. The variants with a high autarky always have a relatively low self-consumption compared to similar technology sets and vice versa.

Table 12: Analysed variants in PVopti for the “Brussels/Parkcarré” case study; PH refers to passive house

Variant	Envelope	Heating	Cooling	PV	El. Storage
1		as built/reference		38.9 kWp	no
2	as built	heat pump	no	38.9 kWp	no
3	as built	heat pump	no	19.3 kWp	no
4	as built	heat pump	no	57.8 kWp	no
5	PH	heat pump	no	38.9 kWp	no
6	PH	heat pump	no	19.3 kWp	no
7	PH	heat pump	no	57.8 kWp	no
8	as built	district heat	no	38.9 kWp	no
9	as built	district heat	no	19.3 kWp	no
10	as built	district heat	no	57.8 kWp	no
11	PH	district heat	no	38.9 kWp	no
12	PH	district heat	no	19.3 kWp	no
13	PH	district heat	no	57.8 kWp	no
14	as built	heat pump	no	38.9 kWp	100 kWh
15	as built	heat pump	no	19.3 kWp	100 kWh
16	as built	heat pump	no	57.8 kWp	100 kWh

17	PH	heat pump	no	38.9 kWp	100 kWh
18	PH	heat pump	no	19.3 kWp	100 kWh
19	PH	heat pump	no	57.8 kWp	100 kWh
20	as built	district heat	no	38.9 kWp	100 kWh
21	as built	district heat	no	19.3 kWp	100 kWh
22	as built	district heat	no	57.8 kWp	100 kWh
23	PH	district heat	no	38.9 kWp	100 kWh
24	PH	district heat	no	19.3 kWp	100 kWh
25	PH	district heat	no	57.8 kWp	100 kWh
26	as built	heat pump	no	38.9 kWp	270 kWh
27	as built	heat pump	no	19.3 kWp	270 kWh
28	as built	heat pump	no	57.8 kWp	270 kWh
29	PH	heat pump	no	38.9 kWp	270 kWh
30	PH	heat pump	no	19.3 kWp	270 kWh
31	PH	heat pump	no	57.8 kWp	270 kWh
32	as built	district heat	no	38.9 kWp	270 kWh
33	as built	district heat	no	19.3 kWp	270 kWh
34	as built	district heat	no	57.8 kWp	270 kWh
35	PH	district heat	no	38.9 kWp	270 kWh
36	PH	district heat	no	19.3 kWp	270 kWh
37	PH	district heat	no	57.8 kWp	270 kWh

Variants with a large PV system and battery but no heat pump (see variants 22, 25, 34, 37) have a high autarky rate; a large part of the electricity demand during winter can be provided by on-site PV generation. On the other hand, variants with a small PV system and a heat pump (27 and 30) have high self-consumption but very low autarky.

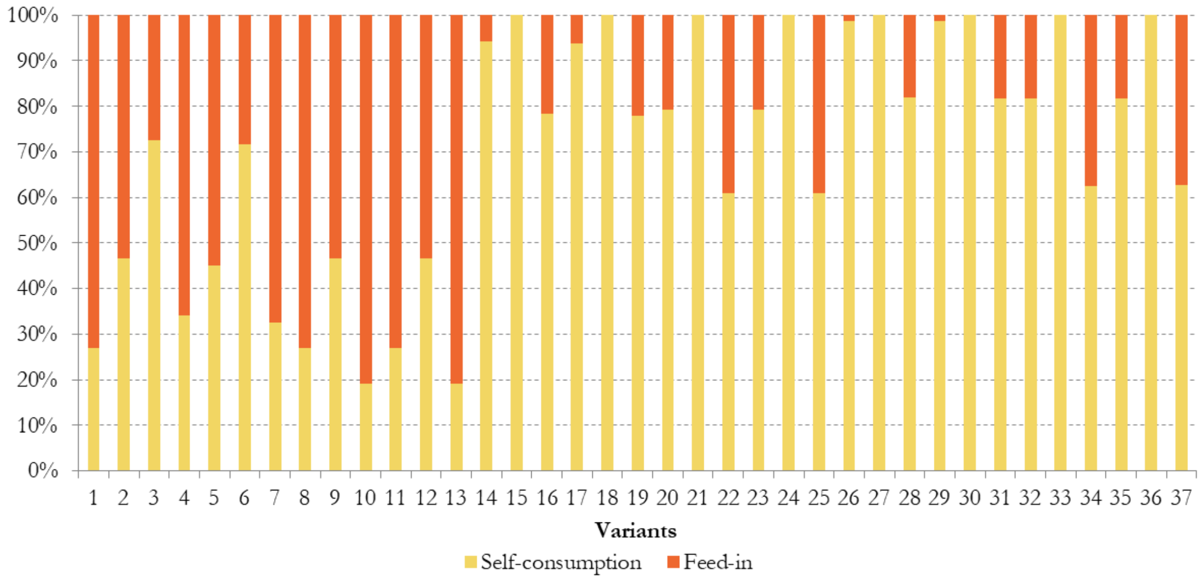


Figure 44: Relation between self-consumption and feed-in of the assessed variants of the "Brussels/Parkcarré" case study; graph based on results obtained with PVopti.

Similar results were obtained in the "Moretti More" case study. However, due to a more constant electricity demand throughout the year due to the electric cooling units installed, the importance of a battery for both the self-consumption and autarky in "Moretti More" is less than "Brussels/Parkcarré" where the electricity demand fluctuates more throughout the year. Correct dimensioning of the PV system is of major importance in this case.

With the tool PVopti, hourly profiles for the electricity purchased from the grid were generated and used to analyse the grid supportiveness concerning two external grid signals: EEX prices and residual load

Almost all analysed technology sets are grid-adverse and no set is really grid-supportive. However, a combination of the installed technologies offers the possibility to increase GSC. The control strategies of single technologies as well as the whole building energy system have to be adjusted, especially the use of storage and the operating times of large electricity consumers like heat pumps and cooling units. To quantify the effects of different control strategies, detailed simulations and optimisations are required, which were not part of this study.

In addition to the quantitative assessment, the smart readiness of two case study buildings is rated using a simplified method of the proposed online quick scan. Here, only the base case (as built/as planned) is rated. Both buildings achieve an SRI below 50 %. Both buildings have good performance in terms of on-site energy savings and comfort. The flexibility and smartness of building operation is just starting to gain traction, and the current energy markets do not yet offer promising business cases for smart and flexible operation. However, many technologies currently installed in buildings already offer increased flexibility with some adjustments in control strategies (thermal storage, heat pumps).

Besides technical implementation, the market design has to be adjusted, including sufficient incentives to provide flexibility in/of the building for the operation and management of higher-level electricity grids. Currently, only large switchable and shiftable loads can participate in the electricity market. However, the required power for participation is much higher than most buildings can provide. Different approaches to close the gap are currently being assessed in different projects (e.g., pooling small loads to reach the required load size, lowering the required size limit, or new ways of trading among energy market participants).

To summarise, the addressed KPIs strongly influence the technologies needed. The autarky rate in particular has very different needs compared to the other KPIs. Furthermore, most technologies needed for flexible building operation are already available. However, some are still comparably expensive and therefore not widespread. The main challenge is the operation and management of buildings in a way that renewable energy can be integrated into the energy system at different levels (on-site, regional, national, European). On the one hand, control strategies in buildings have to be adjusted and optimized; on the other hand, adequate grid signals have to be available for building management and control systems.

CHAPTER 5

Life cycle cost reduction of nZEBs – Parametric simulations

5. LIFE CYCLE COST REDUCTION OF nZEBS – PARAMETRIC SIMULATIONS

Possible cost saving potentials in planning and construction of high-performing nZEBs with advanced energy standards are often not sufficiently assessed, as only a few variants of technology sets are considered in the traditional planning process. Planning and analysis are often not carried out in parallel, and the alternative technical options may be discarded at an early stage. If, on the other hand, possible variants are realistically compared in the planning phase, a profound decision can be made. nZEB-design is also a multi-objective optimization problem with stakeholders' conflicting interests. In the CRAVEzero project, an exhaustive search method was assessed for ten CRAVEzero case studies, which systematically investigates all possible variants. The derived results are applied to multiple objectives and optimization goals for a multi-target decision-making framework so that different actors can decide between optimal solutions for different objectives. This approach seeks to explore a set of optimal solutions rather than a singular one. The results were analysed energetically and economically over the life cycle of the building with the objectives of identifying coherences, trends, and optimizations over a period of 40 years.

5.1. METHODOLOGY

Multi-objective building life cycle cost and performance optimisation

In the traditional planning process, the client, architect, and specialist consultant develop a building with the relevant technical equipment and building services. In many cases, everyone optimizes their associated area, and thus the building vision as a whole is out of sight. In the traditional planning process, only a few variants are considered and are often not planned and analysed in unison but discarded at an early stage. It can thus be discovered once a building is constructed that the costs to run it are extremely high. If, on the other hand, several variants are compared in the planning phase, including life cycle costs, a sound decision can be made in advance.

The term "multi-objective parametric analysis" in this report defines a method in which a series of calculations are run by a computer program, systematically changing the value of parameters associated with one or more design variables. The key feature of this approach allows the effects of individual design variables on energy, costs, and environmental parameters to be evaluated in one step.

Building design problems are often comprised of conflicting or contradictory objectives such as minimizing energy consumption while increasing investment costs or reducing CO_2 emissions and increasing life cycle costs. As a result, in recent years the multi-objective optimization analysis has become more popular than the single-objective analysis (Hamdy and Mauro, 2017).

The multi-objective approach is based on the concept of the Pareto frontier: a solution is optimal when no other feasible solution improves one of the objectives without affecting at least one of the other. In that case, the multi-objective algorithms generate a set of solutions, known as the Pareto front. If the problem includes only two objectives, the Pareto front is a two-dimensional curve. This concept can also be applied to three or more objectives, although the results are more difficult to analyse. It is also important to note that this approach seeks to explore a set of optimal solutions (not a singular solution) and evaluate various trade-offs among them (Chiandussi et al., 2012).

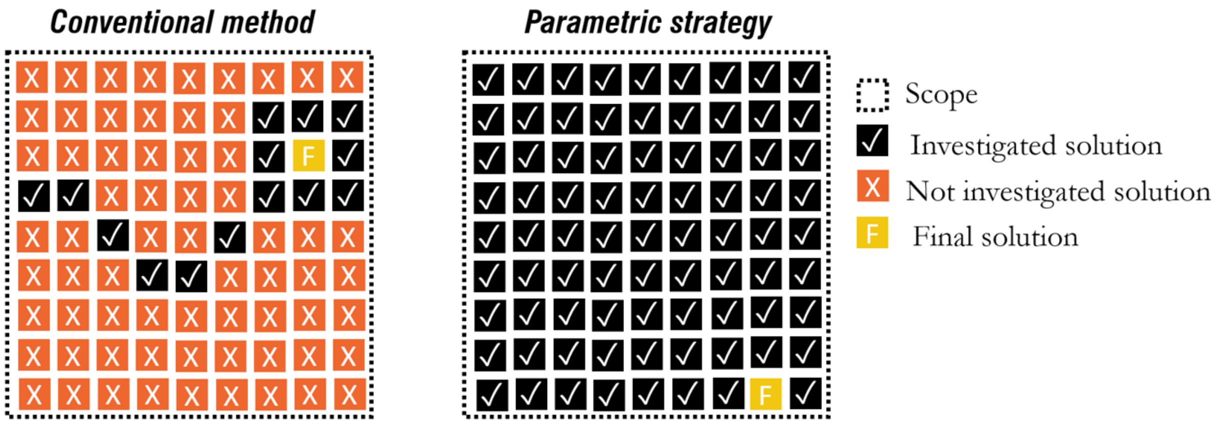


Figure 45: Multi-objective building life cycle cost and performance optimization.

- Conventional optimization: "search" for possible solutions based on empirical values (Figure 45, left picture)
- Optimization using "extreme value search algorithms"
- "Brute-force method" with a study of all possible solutions (Figure 45, right picture)

The advantage of the manual search for the optima lies in the manageable number of variants, hence the moderate effort. The disadvantage, as shown in Figure 45, is that only a local optimum may be found – not the best global solution.

Variants optimized using a "parametric optimizer" for a specific goal or cost function are advantageous because they can be found with a fair amount of precision. However, it does not allow any statement on maxima, minima, or statistical distributions of the variants. It is also difficult to consider the aforementioned benefits as they are not hard target (i.e., monetary) values.

With the brute-force method or the investigation of all possible variant combinations, all solutions are considered. It offers the advantage that statistical evaluations can be made, distributions can be derived, and the additional benefits can also be considered for selected variants. A big disadvantage is a very large number of variants (several thousand), can only be calculated automatically. This method also restricts the calculations (e.g., if dynamic building simulations are used to optimize a building, and each simulation takes several hours, it is not possible to calculate thousands of variants in a manageable amount of computing time). Through multi-objective building life cycle cost and performance optimization, it is possible to find optimal solutions, among huge numbers of possible combinations of variables. Various decision variables can be considered for the building envelope, the HVAC systems, on-site energy generation systems, or financing schemes/business models. Examples of the objectives include minimization of environmental impacts (energy consumption, carbon emissions, etc.), costs (investment, operating, life cycle) and equipment size (energy generation units, HVAC system etc.). The maximization of indoor air quality and energy efficiency is also important. These objectives can be achieved individually or simultaneously (multi-objective optimization). The constraint functions indicate whether different criteria (e.g., thermal comfort level, total investment cost limit, primary energy limit) are satisfied. (Wright et al., 2002).

The method of energy-economic optimization is shown in Figure 46:

- Design, first pre-optimizations
- Determination of target values and goals
- Determination of the parameters to be varied and their levels (e.g., envelope quality, heating system, window size, window quality)
- (Automated) energy demand calculations according to energy certificates or the passive house project planning package, dynamic building simulation

- Calculation of the life cycle costs of each variant, including promotion, maintenance, replacement investments and residual value
- Evaluation and presentation of results

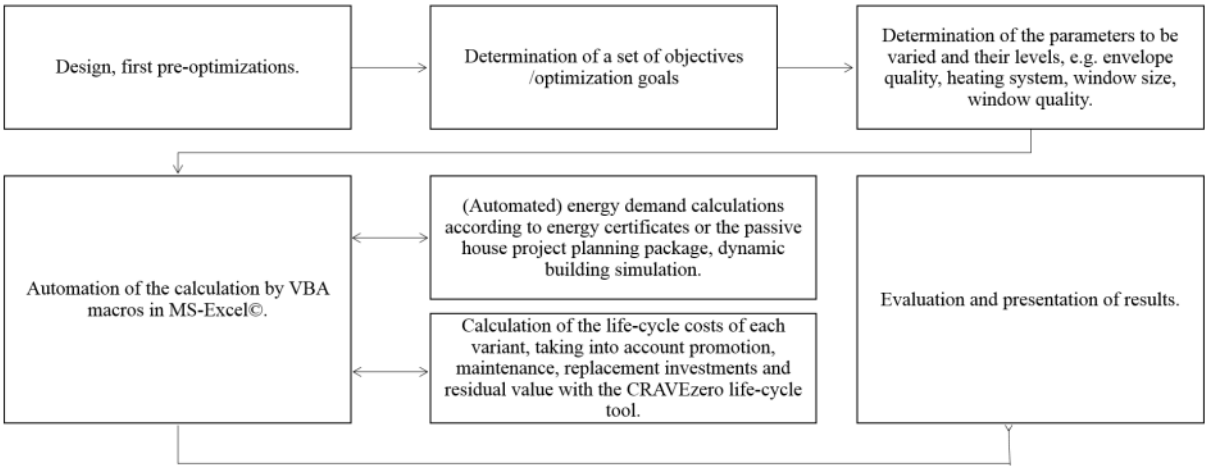


Figure 46: Method of energy-economic analysis - coupling between PHPP and CRAVEzero LCC tool.

Figure 47 demonstrates the definition and variation of a typical parametric design space for a CRAVEzero case study.

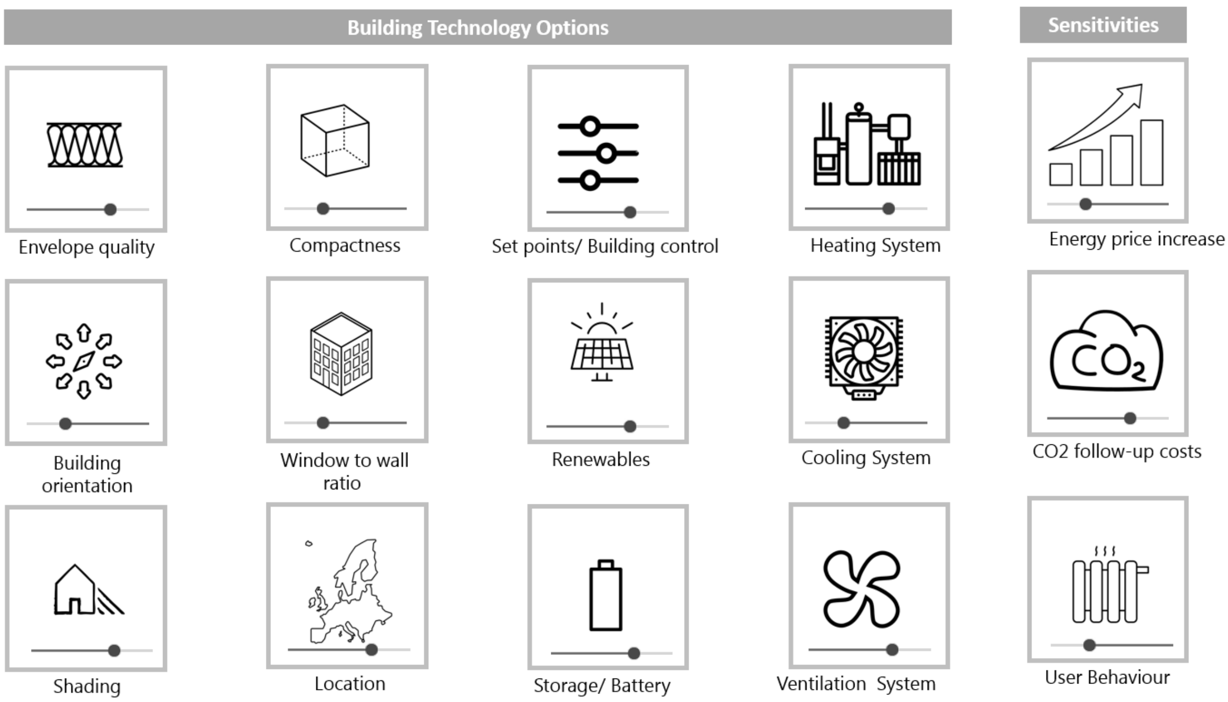


Figure 47: Definition and variation of a typical parametric design space for the CRAVEzero case studies.

The CRAVEzero calculation method allows the automated calculation for thousands of variants, and is based on:

- Energy demand calculations of a building with the passive house project planning package (PHPP)
- Life cycle cost calculated with the CRAVEzero life cycle tool
- Automation of the calculation by VBA macros in MS-Excel©

The software PHPP 9 for energy performance analysis summarises all information on the energy-related features of the building components and services to provide a comprehensive overview of the technologies installed. The calculations are not directly comparable to national requirements (e.g., those regarding energy efficiency nor are they considered in the definition, calculation and analysis of variants. This would require a separate control.

ANALYSIS OF USER BEHAVIOUR

A sensitivity analysis investigated the influence of different user behaviour on the results. As previously indicated in the description of the investigated parameters of each case study, four different user behaviours were used (see Table 12). They range from inefficient user behaviour (level 1) to standard user behaviour (level 2) to efficient user behaviour (level 3). The default settings from PHPP were also employed for comparison (level 4).

Table 13: Description of the four different user behaviours

PARAMETER	LEVEL 1: NOT EFFICIENT	LEVEL 2: STANDARD	LEVEL 3: EFFICIENT	LEVEL 4: PHPP DEFAULT
T_{room} (during heating period)	23 °C	22 °C	21 °C	20 °C
DHW-demand (at 60°C)	48.5 l/d	33.3 l/d	29 l/d	33.3 l/d
Misuse of external blinds during winter time	+20 %	+10 %	0 %	0 %
Electrical loads	35 kWh/m²a	26.6 kWh/m²a	20 kWh/m²a	26.6 kWh/m²a
Additional window ventilation during winter time	+0.1 1/h	+0.05 1/h	0.0 1/h	0.0 1/h

5.2. CASE STUDIES – INVESTIGATED PARAMETERS AND RESULTS

On the following pages, the results of the parametric calculations are presented for each case study. The description is divided into two pages. The first presents a general overview of the case study with the investigated parameters and levels. Page two shows certain results from the specific case study.

More information on the case studies can be found in chapter 2 of this report. Chapter 4 includes a detailed description of the investigated technologies. For more information on the results of the parametric calculations please visit the CRAVEzero website or use the CRAVEzero pinboard. You may also refer to the following reports: "Parametric models for buildings and building clusters: Building features and boundaries," "Results of optimized nZEB parametric models, "and" Report on nZEB life cycle costs."

Solallén

General information

- Owner: Brf Solallén (tenant-owned)
- Architect: Skanska Teknik
- Energy concept: Net ZEB
- Location: Växjö (Sweden)
- Construction Date: 2015
- Net floor area: 1778 m²

Key technologies:

- Well insulated and airtight
- Balanced ventilation with heat recovery
- Ground source heat pump
- Photovoltaic panels

Table 14: Investigated parameters and levels of the case study Solallén

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Parameter 1: Insulation	Floor-slab: 200 mm insulation Exterior walls: 250 mm insulation Roof: 450 mm insulation	Floor-slab: 300 mm insulation Exterior walls: 455 mm insulation Roof: 600 mm insulation	Floor-slab: 400 mm insulation Exterior walls: 600 mm insulation Roof: 750 mm insulation	
Parameter 2: Airtightness	n50: 1,5 1/h	n50: 0,84 1/h	n50: 0,04 1/h	
Parameter 3: Windows	1,10 W/(m²K)	0,90 W/(m²K)	0,70 W/(m²K)	
Parameter 4: Ventilation	SFP: 1,75 η: 80 %	SFP: 1,5 η: 85 %	SFP: 1,25 η: 90 %	
Parameter 5: Heating	District heating 8 kW_{th} SCOP: 1,0	Ground source heat pump: 4 kW_{th} SCOP: 3,5	Ground source heat pump: 5 kW_{th} SCOP: 5,0	Extract air heat pump 1,8 kW_{th} SCOP: 2,5
Parameter 6: PVs	No PV	0,0347 kW_p/m^2_{GFA}	0,0624 kW_p/m^2_{GFA}	
Parameter 7: Solar Thermal	No solar thermal	0,0334 m^2_{col}/m^2_{GFA}, standard flat plate collector used for DHW	0,0667 m^2_{col}/m^2_{GFA}, vacuum tubes used for DHW and heating	
Parameter 8: Cooling	Compressor cooling: 3 kW_{th} SCOP: 3	Free cooling/boreholes: 1 kW_{th} SCOP: 20	Free cooling/boreholes: 2 kW_{th} SCOP: 20	

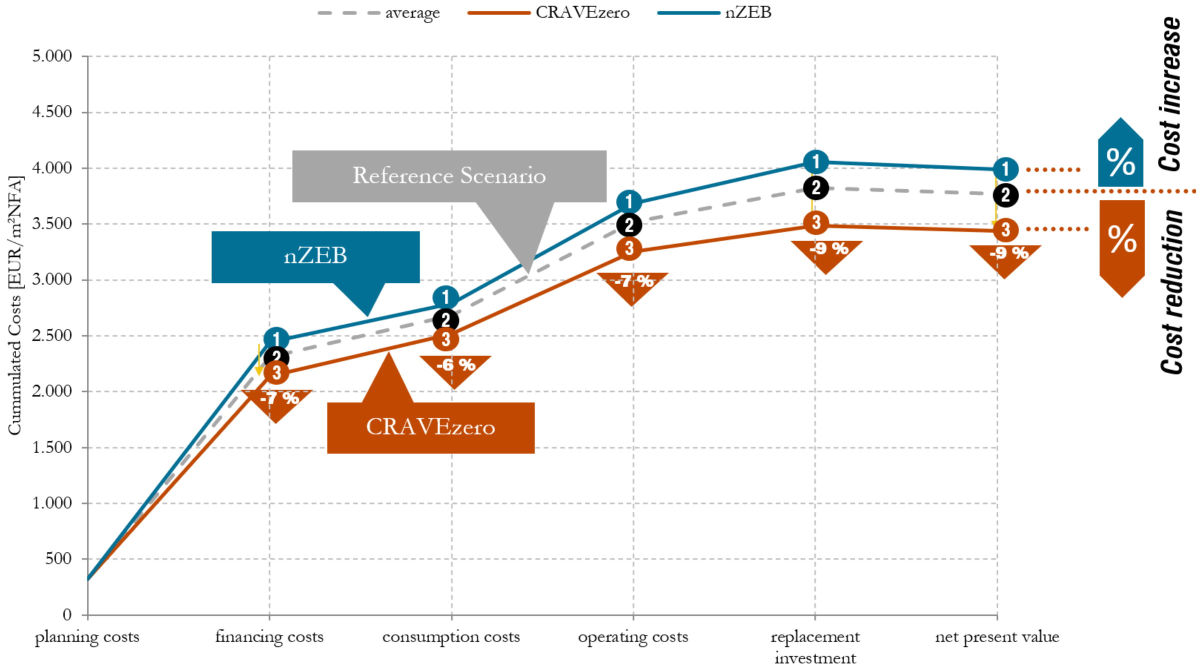


Figure 48: Solallén cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the reference scenario from Figure 17 (energy tariff standard/user behaviour standard/excluding subsidies).

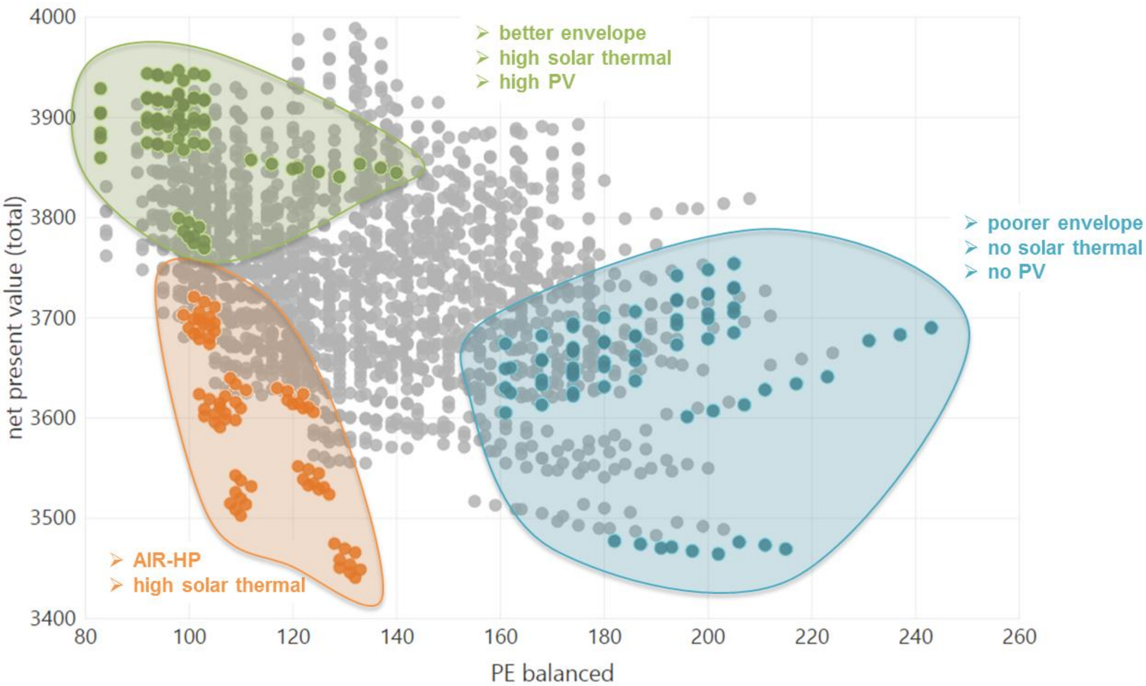


Figure 49: Analysis of the balanced primary energy demand related to the net present value for the different technology combinations (related to the treated floor area of the PHPP/energy tariff standard/user behaviour standard /PE factors PHI/without consideration of subsidies/no PE credit for electricity fed into the grid).

Aspern IQ

General information

- Owner: City of Vienna
- Architect: ATP Wien
- Energy concept: Renewable power, environmental and waste heat
- Location: Vienna (Austria)
- Year of construction: 2012
- Net floor area: 8817 m²

Key technologies

- Groundwater heat pump
- Photovoltaics
- Small wind turbine

Table 15: Investigated parameters and levels of the case study Aspern IQ

PARAMETER	LEVEL 1 ◔	LEVEL 2 ◓	LEVEL 3 ◕	LEVEL 4 ●
Sensitivity	Standard	High	Low	PHPP default
CO_2 follow-up costs	Low	Standard	High	No
User behaviour	Not efficient	Standard	Efficient	PHPP default
Envelope quality	National standard	nZEB	Passive house	-
Ventilation	Window ventilation	Mechanical ventilation with heat recovery	Extract air unit	-
Heating	Gas condensing boiler	Ground source heat pump	Air source heat pump	District heating
Cooling	Absorption cooling	Ground source heat pump cooling	Air source heat pump cooling	-
Solar thermal	No solar thermal	28 m² flat plate collector for domestic hot water	148 m² for domestic hot water	-
PV	No PV	74 kWp	148 kWp	-
Battery storage	No battery storage	25 kWh	50 kWh	-

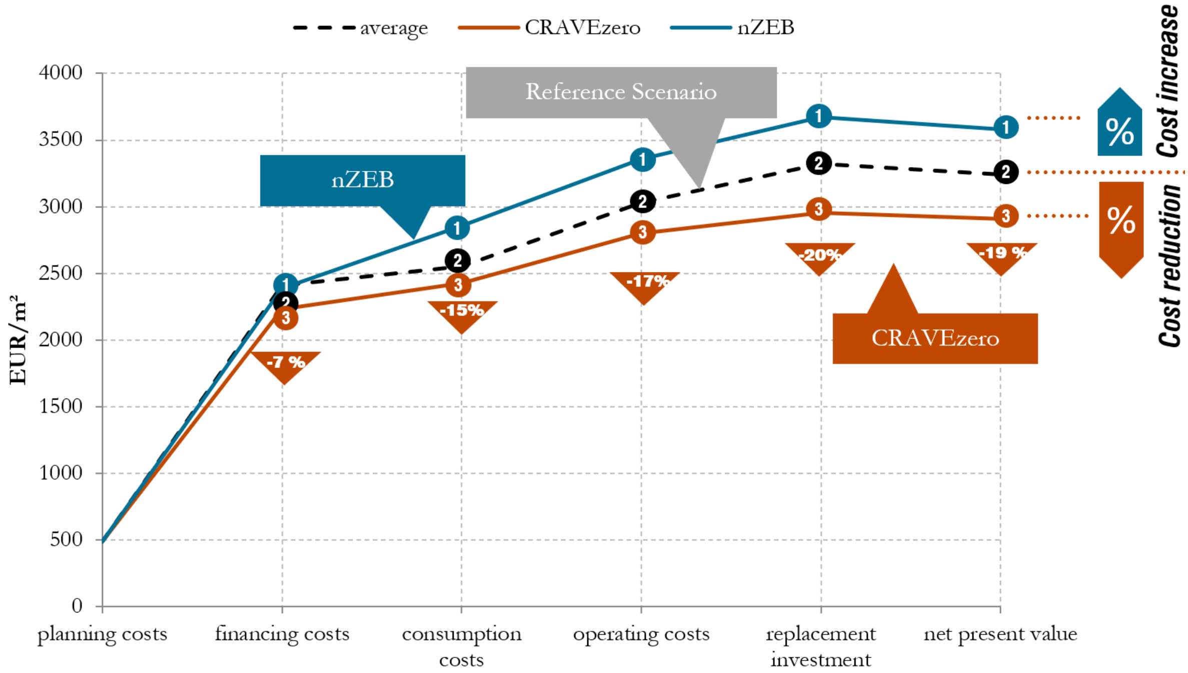


Figure 50: Aspern IQ cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and average value.

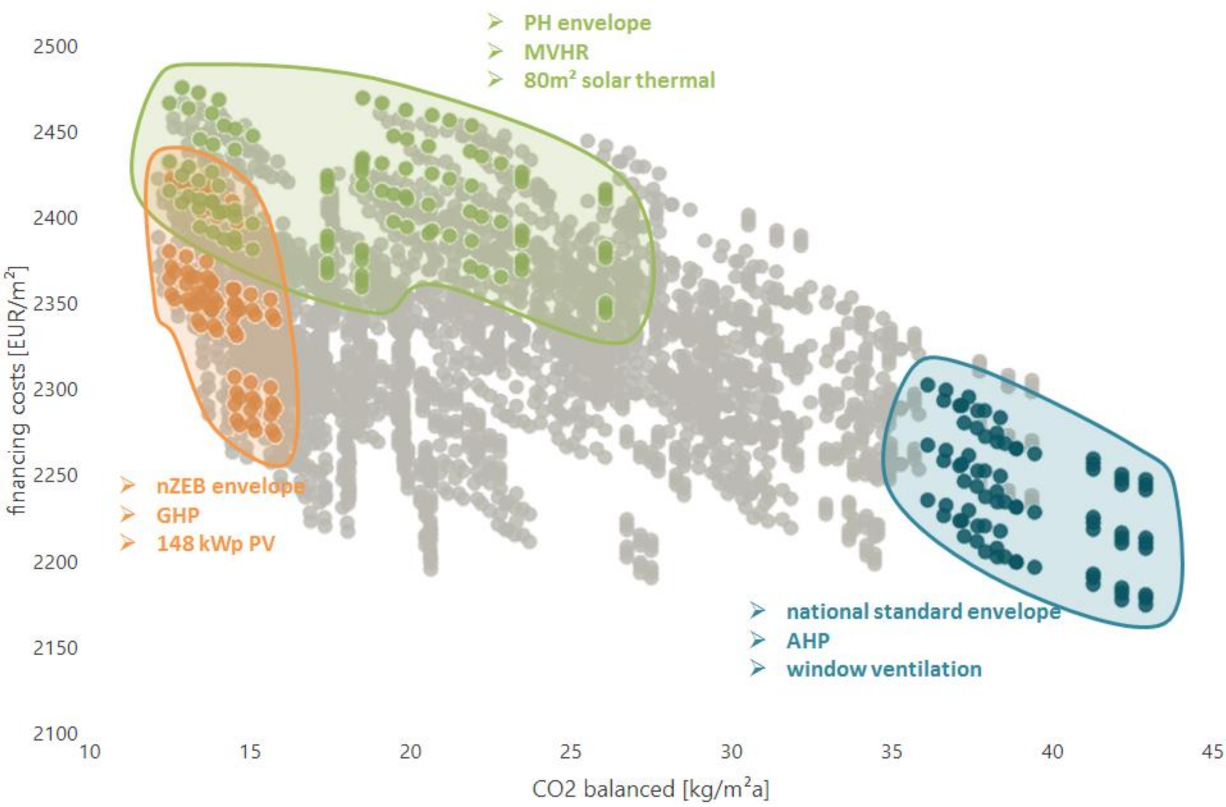


Figure 51: Aspern IQ analysis of the balanced CO_2 emissions related to the financing costs for different technology combinations.

MORE

General information

- Owner: Groppi-Tacchinardi
- Architect: Valentina Moretti
- Energy concept: Heat pump and condensing boiler, solar thermal installation
- Location: Lodi (Italy)
- Year of construction: 2014
- Net floor area: 128 m²

Key technologies

- Precast component
- Compact model home
- Central core
- Flexible and modular

Table 16: Investigated parameters and levels of the case study MORE

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Sensitivity	Standard	High	Low	PHPP default
CO_2 follow-up costs	Low	Standard	High	No
User behaviour	Not efficient	Standard	Efficient	PHPP default
Envelope quality	National standard	nZEB	Passive house	-
Ventilation	Window ventilation	Mechanical ventilation with heat recovery	Extract air unit	-
Heating	Gas condensing boiler	Air source heat pump + gas boiler	Air source heat pump	District heating
Climate	Trento	Lodi	Roma	Palermo
Cooling	Compressing cooling	No cooling	Air source heat pump cooling	-
Solar thermal	No solar thermal	5 m² for domestic hot water	10 m² for domestic hot water	-
PV	No PV	5 kWp	10 kWp	-

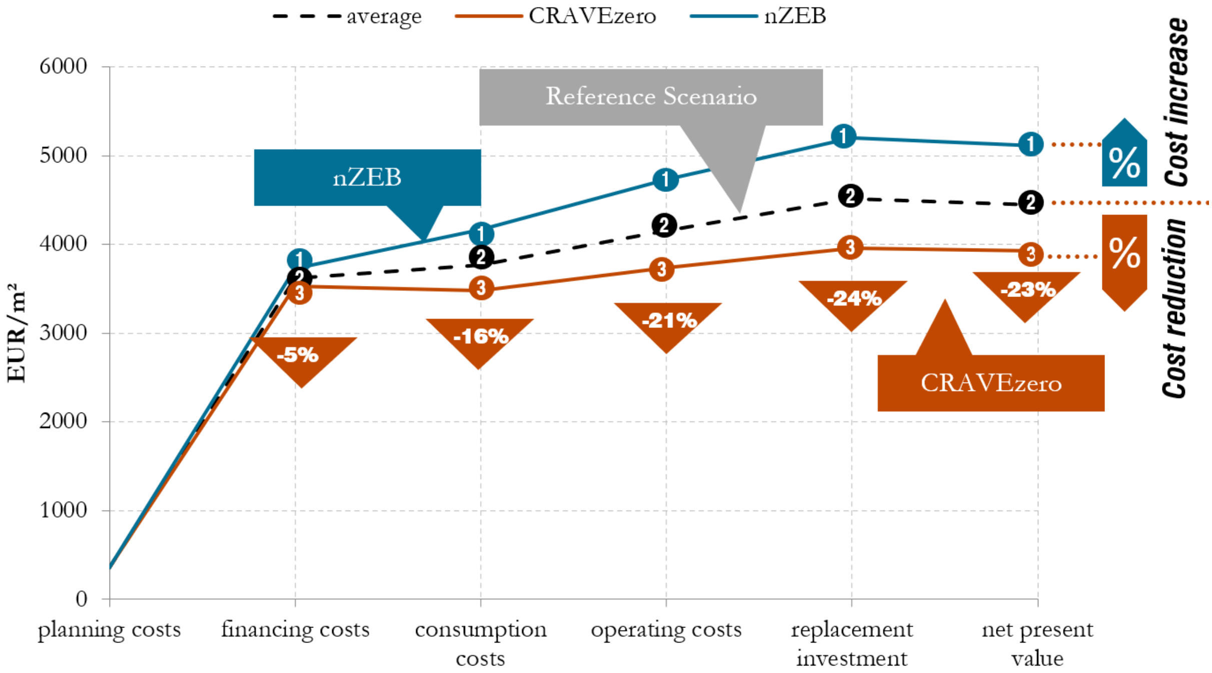


Figure 52: "More" cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value.

Table 17: deviation of each individual variant from the mean value of the "More" case study; separate consideration of the four indicators financing costs, net present value, primary energy balanced, and CO2 balanced

		financing costs	net present value	PE balanced	CO2 balanced
CO_2 costs	Low_CO2	0,00%	-0,40%	0,00%	0,00%
	Std_CO2	0,00%	0,40%	0,00%	0,00%
	High_CO2	0,00%	1,19%	0,00%	0,00%
	no_CO2	0,00%	-1,19%	0,00%	0,00%
user behavior	Not_eff_user	0,00%	0,97%	17,03%	15,96%
	Std_user	0,00%	-0,13%	-2,16%	-2,04%
	Eff_user	0,00%	-0,84%	-14,87%	-13,92%
Climate	Trento	0,00%	1,36%	30,67%	30,49%
	Lodi	0,00%	2,00%	27,28%	25,52%
	Roma	0,00%	-0,76%	-16,57%	-16,32%
	Palermo	0,00%	-2,59%	-41,38%	-39,70%
PV	no_PV	-1,54%	1,92%	33,84%	35,97%
	5_kWp	0,11%	-0,40%	-14,08%	-14,96%
	10_kWp	1,43%	-1,51%	-19,76%	-21,01%
solar thermal	no_ST	-0,84%	-0,08%	15,29%	10,05%
	5m2_DHW	0,10%	-0,34%	-7,65%	-5,03%
	10m2_DHW	0,74%	0,42%	-7,65%	-5,03%
cooling	Compressor	0,18%	0,65%	-0,53%	-0,57%
	No_cool	0,18%	0,71%	1,07%	1,13%
	AHP_cool	-0,37%	-1,36%	-0,53%	-0,57%
heating	Gas_Boiler	0,49%	0,89%	13,63%	28,10%
	Gas_AHP	0,49%	-1,57%	-14,86%	-5,45%
	AHP_heat	1,44%	4,25%	-11,72%	-7,22%
	District_HEating	-2,42%	-3,57%	12,95%	-15,43%
ventilation	Window	-1,07%	-1,97%	-4,08%	-4,64%
	MechVent_HR	1,25%	2,05%	0,77%	1,71%
	ExtractAir	-0,19%	-0,08%	3,31%	2,93%
envelope	Nat_Std	-1,59%	-1,20%	8,83%	7,94%
	nZEB	-0,67%	-1,01%	-4,98%	-4,66%
	PH	2,26%	2,21%	-3,85%	-3,28%

Isola Nel verde A+B

General information

- Owner: Isola nel Verde s.r.l.
- Architect: Studio Associato Eureka
- Energy concept: cogeneration system, geothermal heat pump, photovoltaic and solar thermal panels
- Location: Milan (Italy)
- Year of construction: 2012
- Net floor area: 1409 (A)+1745 (B) m²

Key technologies

- Cogeneration system
- Geothermal energy
- Green roof

Table 18: Investigated parameters and levels of the case study Isola Nel verde

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Sensitivity	Standard	High	Low	PHPP default
CO_2 follow-up costs	Low	Standard	High	No
User behaviour	Not efficient	Standard	Efficient	PHPP default
Envelope quality	National standard	nZEB	Passive house	-
Ventilation	Window ventilation	Mechanical ventilation with heat recovery	Extract air unit	-
Heating	Gas condensing boiler	Geothermal heat pump + district heating	Air source heat pump	District heating
Cooling	Compressor cooling	Geothermal heat pump cooling	Air source heat pump cooling	-
Solar thermal	No solar thermal	36 m² for domestic hot water	72 m² for domestic hot water	-
PV	No PV	7 kWp	14 kWp	-

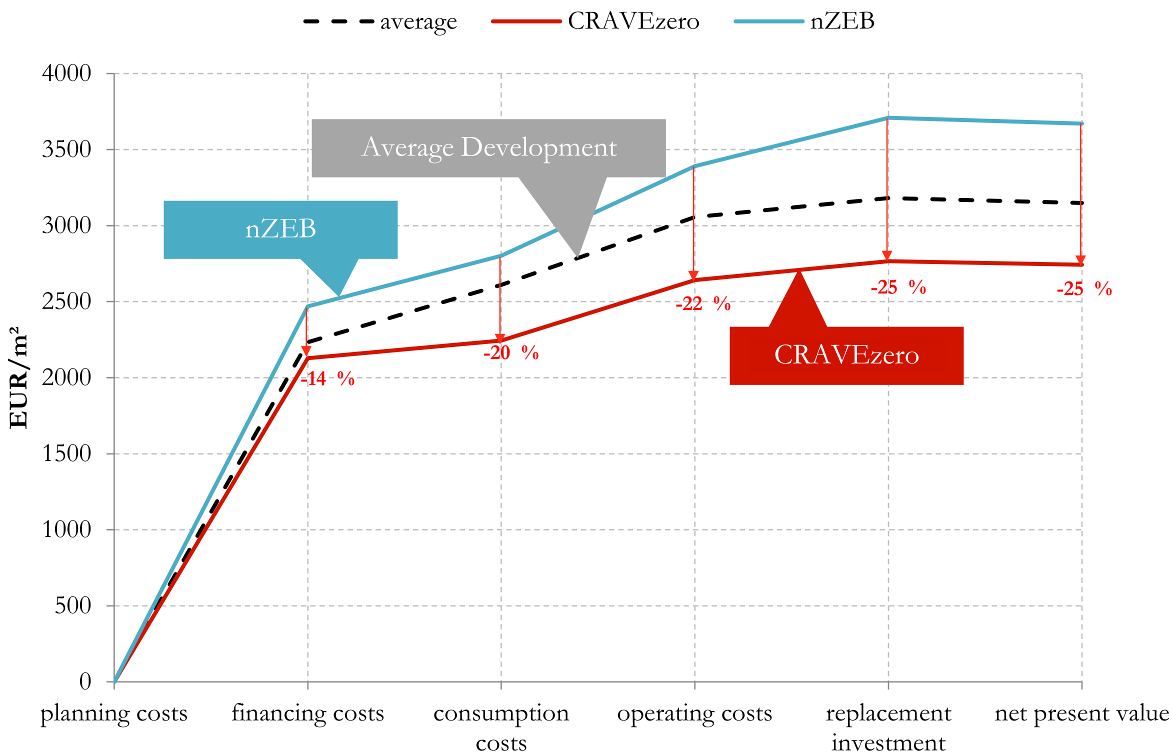
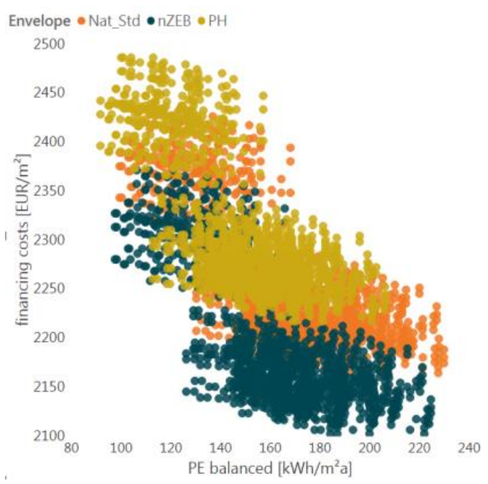


Figure 53: Isola Nel Verde cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value.



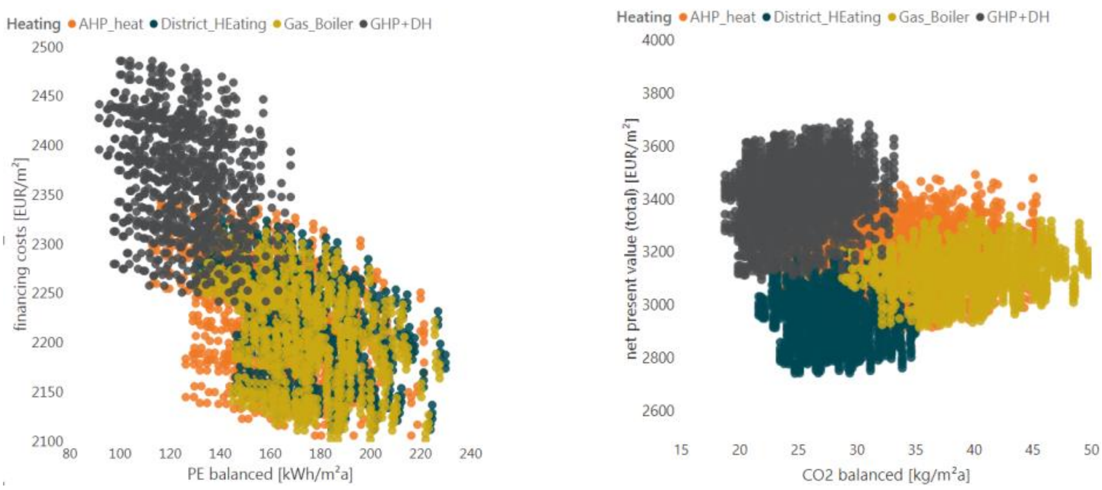


Figure 54: Isola Nel Verde analysis of the influence of the building envelope and the heating system on the financing costs, the balanced primary energy demand (left), the life cycle costs and the balanced CO_2 emissions (right). Related to treated floor area of the PHPP/energy tariff standard / user behaviour standard/CO_2 and PE factors PHI/without consideration of subsidies/no CO_2 or PE credit for electricity fed into the grid.

Les Heliades

General information

- Owner: Podeliha
- Architect: Barré - Lambot
- Energy concept: zero-energy building (heating, cooling, ventilation, lighting, and DHW)
- Location: Angers (France)
- Year of construction: 2015
- Net floor area: 4590 m²

Key technologies

- Well insulated and airtight
- Balanced ventilation with heat recovery
- Ground source heat pump
- Photovoltaic panels

Table 19: Investigated parameters and levels of the case study Les Heliades

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Sensitivity	Standard	High	Low	PHPP default
CO_2 follow-up costs	Low	Standard	High	No
User behaviour	Not efficient	Standard	Efficient	PHPP default
Envelope quality	National standard	nZEB	Passive house	-
Ventilation	Window ventilation	Mechanical ventilation with heat recovery	Extract air unit	-
Heating	Gas condensing boiler	District heating	Air source heat pump	-
Climate	Lille	Orleans	Montpellier	Nantes
Solar thermal	No solar thermal	42 m² for domestic hot water	110 m² for domestic hot water	-

PV	No PV	56 kWp	82 kWp	-

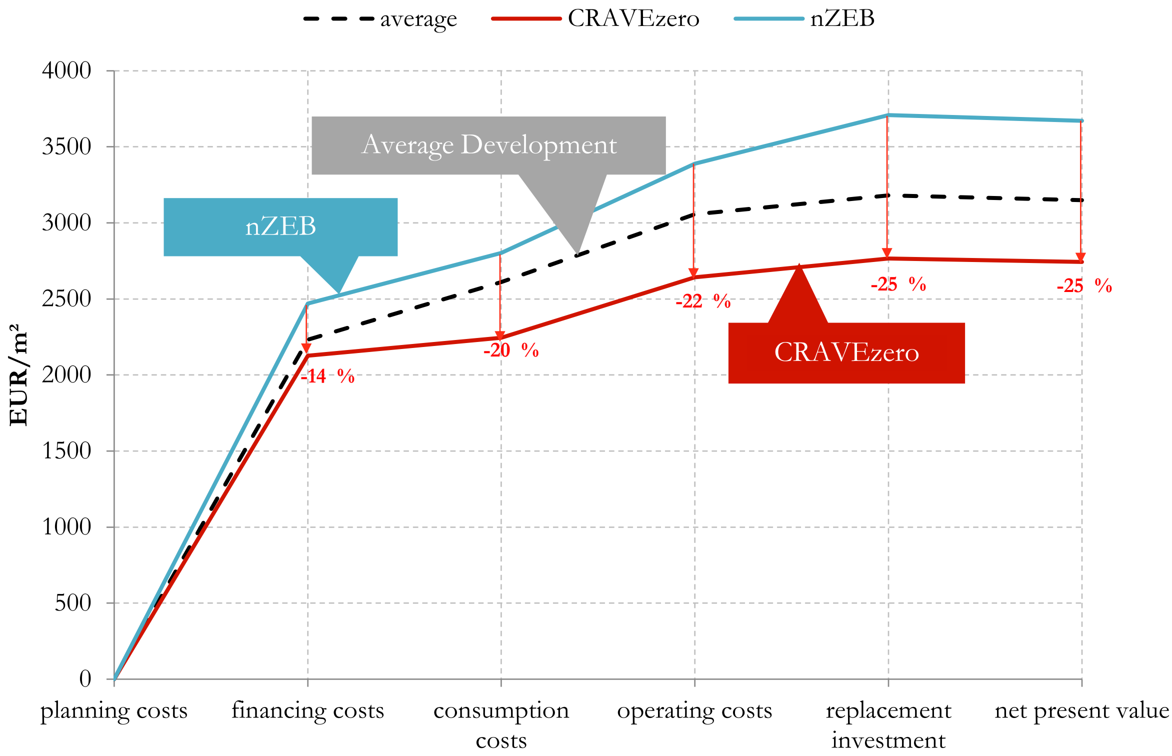


Figure 55: Les Heliades cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value.

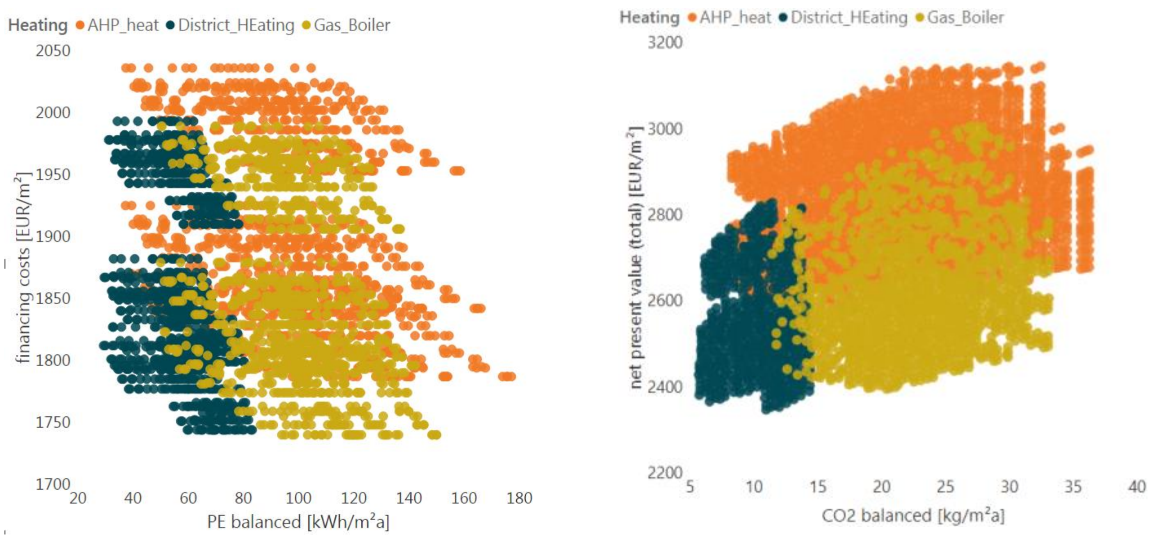


Figure 56: Les Heliades analysis of the influence of the heating system on the financing costs, the balanced primary energy demand (left), the life cycle costs and the balanced CO_2 emissions (right). Related to treated floor area of the PHPP/energy tariff standard/user behaviour standard/CO_2 and PE factors PHI/without consideration of subsidies/no CO_2 or PE credit for electricity fed into the grid.

Alizari

General information

- Owner: Habitat 76
- Architect: Atelier des Deux Anges
- Energy concept: ZEB (heating, cooling, ventilation, lighting, and DHW) and Passivhaus
- Location: Malaunay (France)
- Year of construction: 2015
- Net floor area: 2776 m²

Key technologies

- High-performance envelope (triple glazing, internal and external insulation)
- Balanced ventilation with heat recovery
- Centralized wood boiler
- Photovoltaics

Table 20: Investigated parameters and levels of the case study ALIZARI

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Sensitivity	Standard	High	Low	PHPP default
CO_2 follow-up costs	Low	Standard	High	No
User behaviour	Not efficient	Standard	Efficient	PHPP default
Insulation envelope	250 mm external	300mm external	200 mm external + 100 mm internal	-
Ventilation	Window ventilation	Rotatech ventilation unit	Helios ventilation unit	Swegon ventilation unit
Heating	ETA boiler	Hargassner boiler	Ökofen boiler	Co-generation plant
PV	No PV	30 kWp / 15 % efficiency	34 kWp / 17 % efficiency	41 kWp / 21 % efficiency

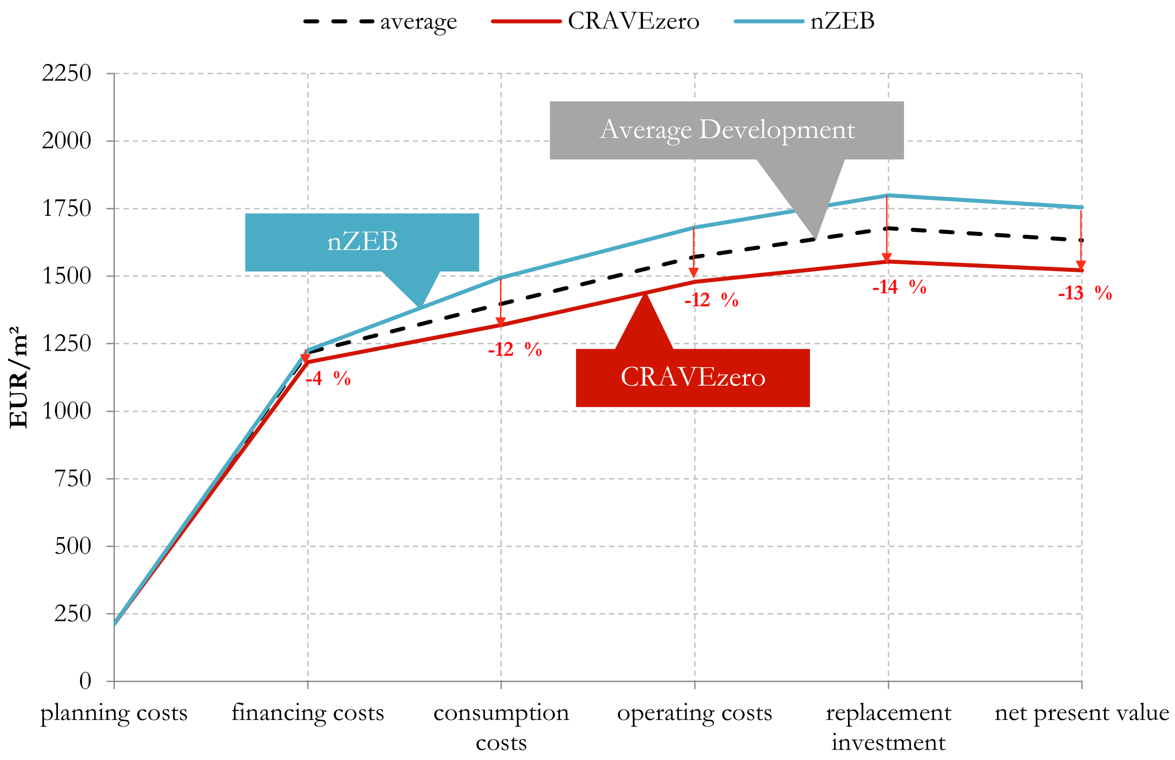


Figure 57: Alizari cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value.

Table 21: Deviation of each individual variant from the mean value of the case study Alizari; separate consideration of the four indicators financing costs, net present value, primary energy balanced and CO_2 balanced

		financing costs	net present value	PE balanced	CO2 balanced
CO_2 costs	Low_CO2	-0,05%	-0,98%	-0,35%	0,01%
	Std_CO2	0,03%	0,92%	-0,35%	0,01%
	High_CO2	0,03%	2,82%	-0,35%	0,01%
	no_CO2	0,03%	-2,76%	-0,35%	0,01%
user behavior	Not_eff_user	-0,05%	0,25%	5,63%	5,57%
	Std_user	0,03%	0,06%	0,65%	0,27%
	Eff_user	0,03%	-0,12%	-2,34%	-2,64%
	phpp_user	0,03%	-0,18%	-3,34%	-3,21%
PV	no_PV	-1,85%	-0,06%	13,60%	14,00%
	30_kWp_015	0,20%	-0,18%	-3,34%	-3,77%
	34_kWp_017	0,52%	-0,06%	-4,33%	-4,61%
	41_kWp_021	1,10%	0,31%	-5,33%	-5,63%
heating	ETA	-0,79%	-1,59%	0,65%	0,42%
	Hargassner	-0,38%	-0,74%	0,65%	0,27%
	Okofen	-0,21%	-0,49%	-0,35%	-0,22%
	co-gen	1,34%	2,82%	-0,35%	-0,48%
ventilation	Window	-0,21%	-1,59%	-4,33%	-4,19%
	Rotatech	0,03%	0,61%	2,64%	2,81%
	Helios	0,11%	0,49%	0,65%	0,88%
	Swegon	0,11%	0,49%	0,65%	0,50%
envelope	250mmext	-0,54%	-0,55%	0,65%	0,24%
	300mmext	-0,13%	-0,18%	-0,35%	-0,14%
	200mmext_100mmint	0,60%	0,74%	-0,35%	-0,11%

Väla Gård

General information

- Owner: Skanska Sverige AB
- Architect: Tengbom
- Energy concept: Net ZEB
- Location: Helsingborg (Sweden)
- Year of construction: 2012
- Net floor area: 1670 m²

Key technologies

- Well insulated and airtight
- Balanced ventilation with heat recovery
- Ground source heat pump
- Photovoltaic panels

Table 22: Investigated parameters and levels of the case study Väla Gård

PARAMETER	LEVEL 1 ◓	LEVEL 2 ◕	LEVEL 3 ●
User behaviour	Inefficient	Standard	Efficient
Compactness (area of the thermal envelope)	-20 %	As built	+ 20 %
Window area	-20 %	As built	+ 20 %
Shade from neighbouring buildings	No shading	Rural area	City
See level	0 m	300 m	1000 m
Location	Northern Europe	Central Europe	Southern Europe
Orientation	As built	+90°	+180°
Envelope quality	National standard	As-built (= nZEB)	Passive house
Heating system	Natural gas	As-built (= ground source heat pump)	District heating
PV	No PV	68 kWp	

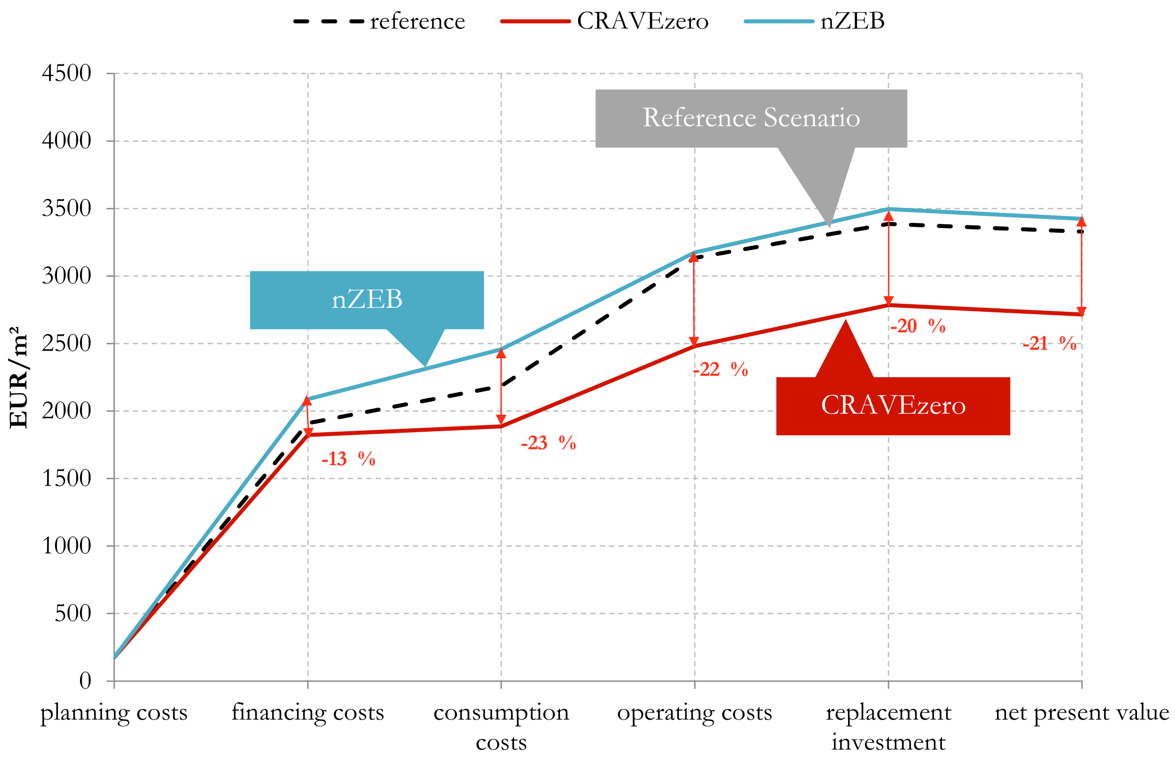


Figure 58: Väla Gard cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the reference scenario.

		User behaviour		Compactness		Window to Wall Ratio		Sea Level		Orientation		Location		Envelope Quality	
	National Reference	Not efficient	Efficient	-20%	20%	-20%	20%	300 m	1000 m	+90°	+180°	Central Europe	Southern Europe	nZEB	Passive house
Investment Costs [€/m²]	1.718	0%	0%	-4%	4%	-1%	1%	0%	0%	0%	0%	-1%	-4%	1%	-1%
Life Cycle Costs [€/m²]	2.354	1%	0%	-4%	4%	-1%	1%	0%	2%	0%	0%	-4%	-7%	-1%	-2%
CO2 Emissions [kg/m²]	25	6%	-5%	-3%	3%	-1%	1%	3%	21%	3%	1%	-15%	-27%	-16%	-12%
PE Demand [kWh/m²a]	105	6%	-5%	-3%	4%	-1%	2%	4%	21%	3%	1%	-14%	-26%	-15%	-11%

Figure 59: Väla Gard heat map compared to the reference scenario.

NH Tirol

General information

- Owner: Neue Heimat Tirol
- Architect: Architekturwerkstatt din a4
- Energy concept: cogeneration unit wood + solar thermal energy (DHW) + air system with heat recovery
- Location: Innsbruck (Austria)
- Years of construction: 2008-2009
- Net floor area: 7493 m² (1 building)

Key technologies

- Centralized pellet boiler

Table 23: Investigated parameters and levels of the case study NH Tirol

PARAMETER	LEVEL 1 ◓	LEVEL 2 ◕	LEVEL 3 ●
User behaviour	Not efficient	Standard	Efficient
Compactness (area of the thermal envelope)	-20 %	As built	+ 20 %
Window area	-15 %	As built	+ 15 %
Shade from neighbouring buildings	No shading	Rural area	City
Sea level	0 m	300 m	1000 m
Location	Northern Europe	Central Europe	Southern Europe
Orientation	As built	+45°	+90°
Envelope quality	National standard	Mean value	As-built (=passive house)
Heating system	Natural gas	As-built (=district heating)	District heating + pellets

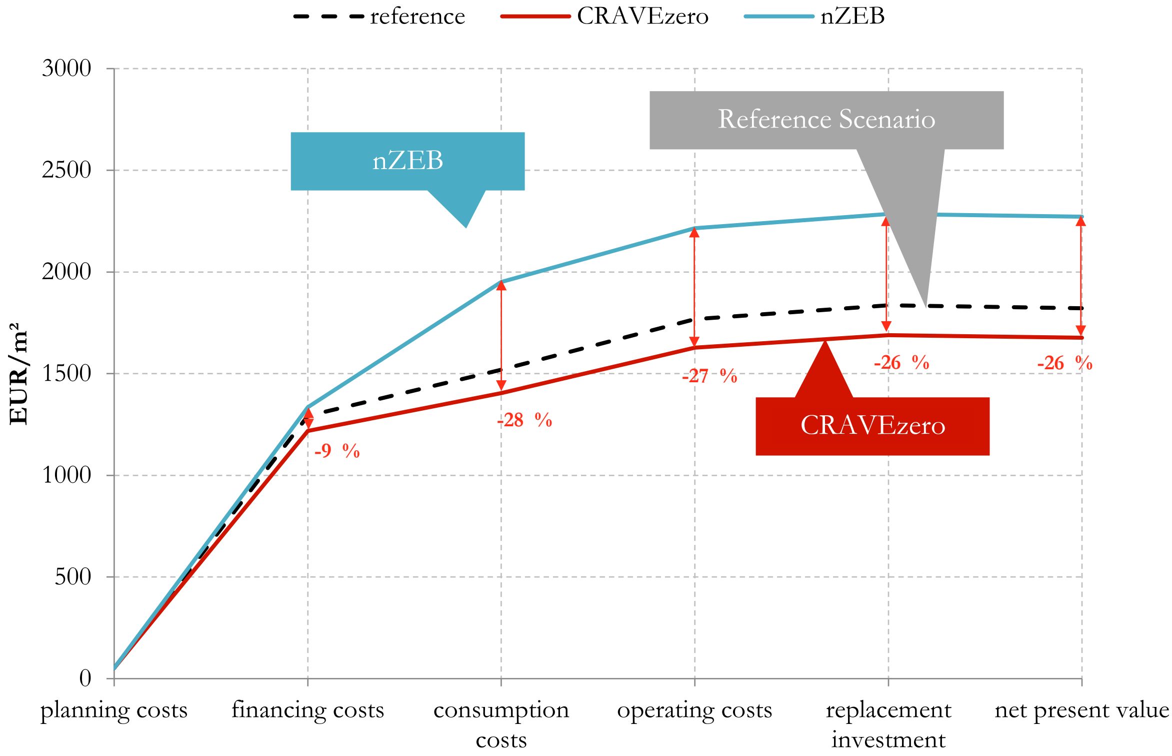


Figure 60: NH Tirol cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the reference scenario.

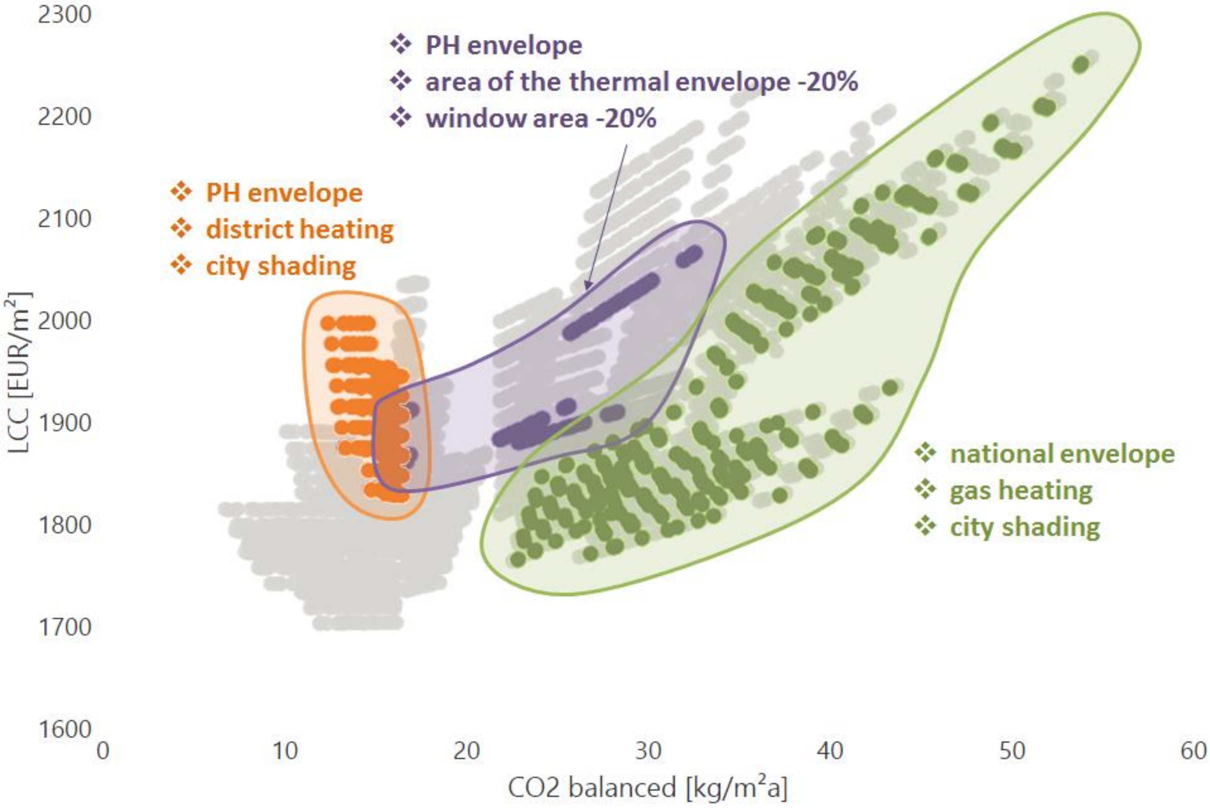


Figure 61: NH Tirol analysis of the balanced CO_2 emissions related to the LCC for different technology combinations.

iR-Headquarters

General information

- Owner: I.+R. Headquarters Alge GmbH
- Architect: Dietrich Untertrifaller Architekten
- Location: Lauterach (Austria)
- Years of construction: 2011-2013
- Net floor area: 2759 m²

Key technologies

- Reversible geothermal heat pump

Table 24: Investigated parameters and levels of the case study iR-Headquarters

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Sensitivity	Standard	High	Low	PHPP default
CO_2 follow-up costs	100 EUR/t_{CO2} a	200 EUR/t_{CO2} a	300 EUR/t_{CO2} a	0 EUR/t_{CO2} a
User behaviour	Not efficient	Standard	Efficient	PHPP default
Envelope quality	National standard	Mean value	As-built (=passive house)	
Ventilation	Window ventilation	Mechanical ventilation with HR	Extract air unit	
Heating	Natural gas	As-built (= heat pump)	Wood pellets	
Cooling	Window cooling	As-built	Compression cooling	
PV	No PV	245 kWp	491 kWp	
Shading (fixed elements on the south side)	0.5 m overhang	1.5 m overhang	2.5 m overhang	

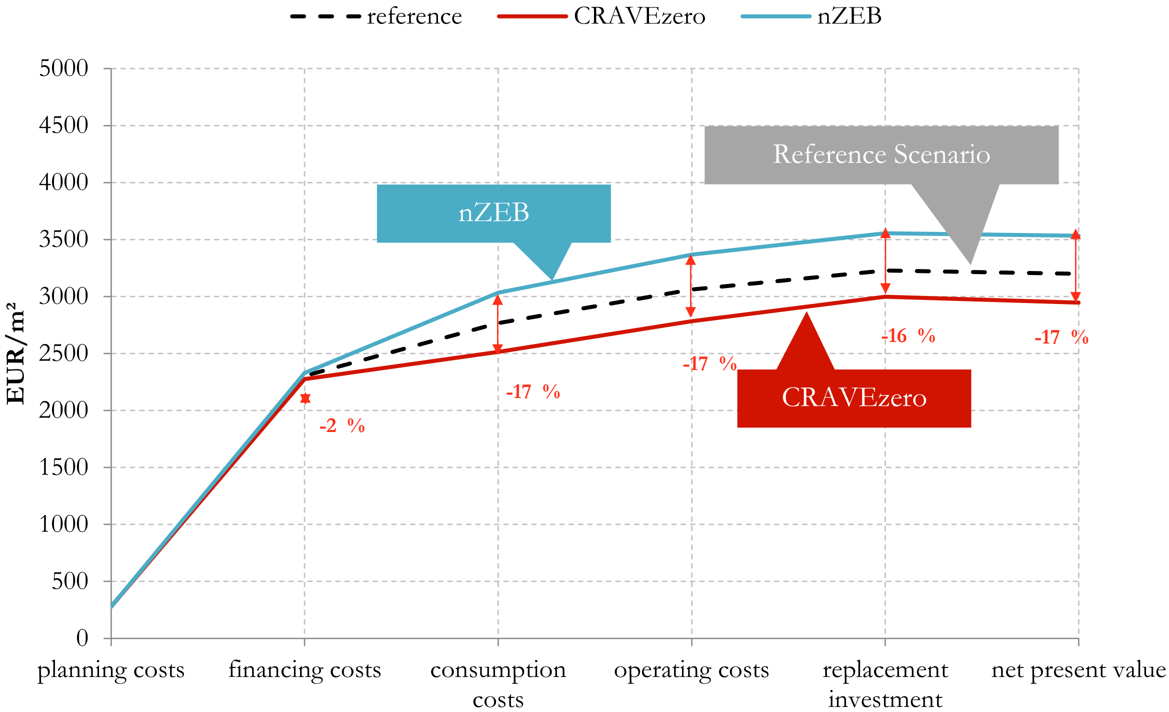


Figure 62: iR-headquarters cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the reference scenario.

		Envelope Quality		Cooling		Shading (fixed elements on south)		PV		User behaviour	
	Reference	nZEB	Passive house	Com-pressor	Ground Water	1.5 m overhang	2.5 m overhang	245 kWp	491 kWp	Not efficient	Standard
Investment Costs [€/m²]	2149	2%	4%	3%	2%	0%	0%	3%	6%	0%	0%
Life Cycle Costs [€/m²]	2897	2%	4%	6%	3%	0%	0%	-3%	-4%	1%	0%
CO2 Emissions [kg/m²]	48	-2%	-5%	-7%	-7%	1%	2%	-19%	-20%	6%	-4%
PE Demand [kWh/m²a]	182	-3%	-5%	-9%	-9%	1%	2%	-24%	-25%	7%	-5%

Figure 63: Heat map of iR-headquarters compared to the reference scenario

Green Home Nanterre

General information

- Owner: Condominium ownership
- Architect: Atelier Zündel Cristea
- Location: Nanterre (France)
- Year of construction: 2019
- Net floor area: 9267 m²

Key technologies

- Triple-glazed windows
- Decentralized ventilation with 96 % heat recovery
- Heat recovery on greywater (with a water-to-water heat pump)

Table 25: Investigated parameters and levels of the case study Green Home Nanterre

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3
Credit period	10 a	20 a	30 a
Interest on credit	0.9 %	1.1 %	1.3 %
Equity ratio	10 %	15 %	20 %
Energy prices	Current energy prices	Current energy prices + 50 %	Current energy prices + 100 %
CO_2-follow-up costs	0 EUR/t_{CO2} a	40 EUR/t_{CO2} a	80 EUR/t_{CO2} a
Energy price increase	2 %/a	4 %/a	6 %/a
Location	Northern Europe	Central Europe	Southern Europe
Technology combination of building envelope and heating	National standard envelope + natural gas heating	As-built	
PV	No PV	133 kWp	

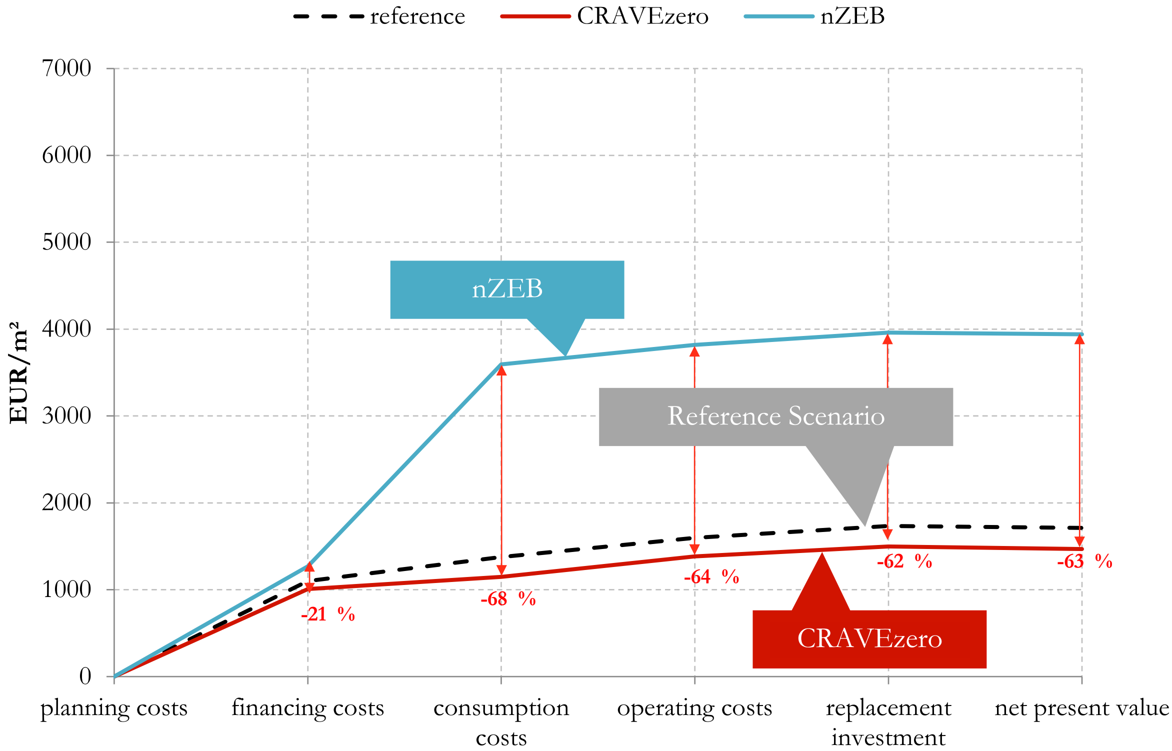


Figure 64: Green Home Nanterre cost performance (EUR/m²) over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the reference scenario.

		Location		Techn. Combination	PV	Credit period		Interest on credit		Equity ratio		Energy price increase	
	Reference	Northern Europe	Southern Europe	as-built	133 kWp	10 a	30 a	0.9 %	1.3 %	10%	20%	4 %/a	6 %/a
Investment Costs [€/m²]	1100	3%	1%	4%	2%	8%	-7%	-2%	2%	2%	-2%	0%	0%
Life Cycle Costs [€/m²]	1712	17%	1%	-5%	0%	5%	-4%	-1%	1%	2%	-2%	7%	20%
CO2 Emissions [kg/m²]	28	25%	2%	-27%	-12%	0%	0%	0%	0%	0%	0%	0%	0%
PE Demand [kWh/m²a]	131	24%	2%	-24%	-12%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 65: Green Home Nanterre heat map compared to the reference scenario.

5.3. OVERALL RESULTS

The parametric calculations include the investigation of ten case studies and more than 360,000 variants in total. Figure 66 shows a summary the average costs of all ten case studies over the different phases of the life cycle.

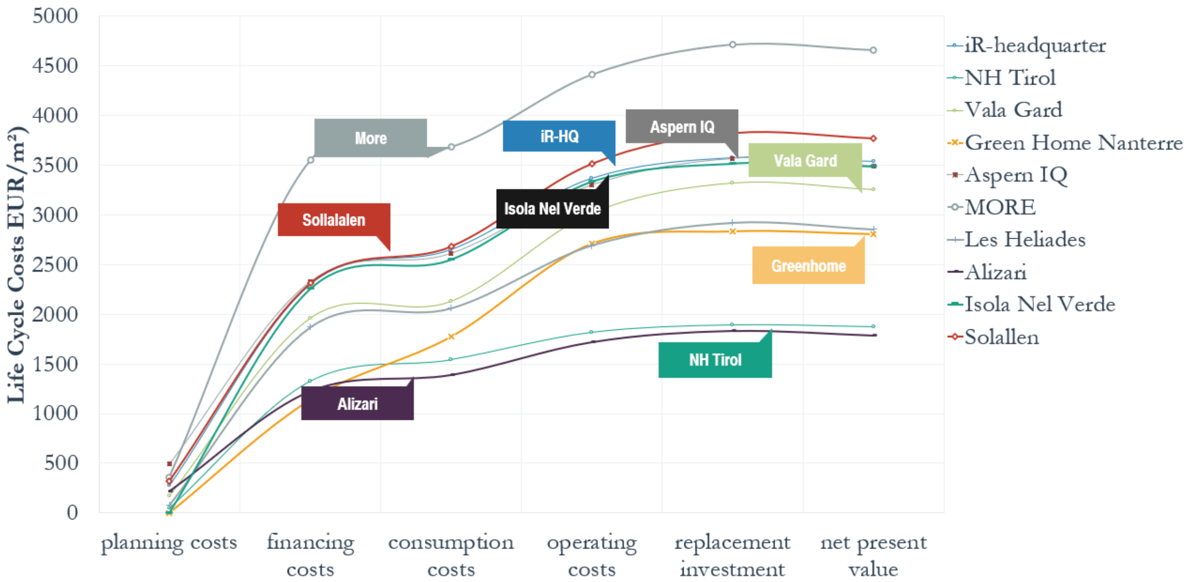


Figure 66: Average specific costs (EUR/m²) in the different phases of all case studies that were investigated within the CRAVEzero project.

The overview on the next page shows the comparison of all case studies with the life cycle costs on the y-axis and the balanced CO_2 emissions on the x-axis.

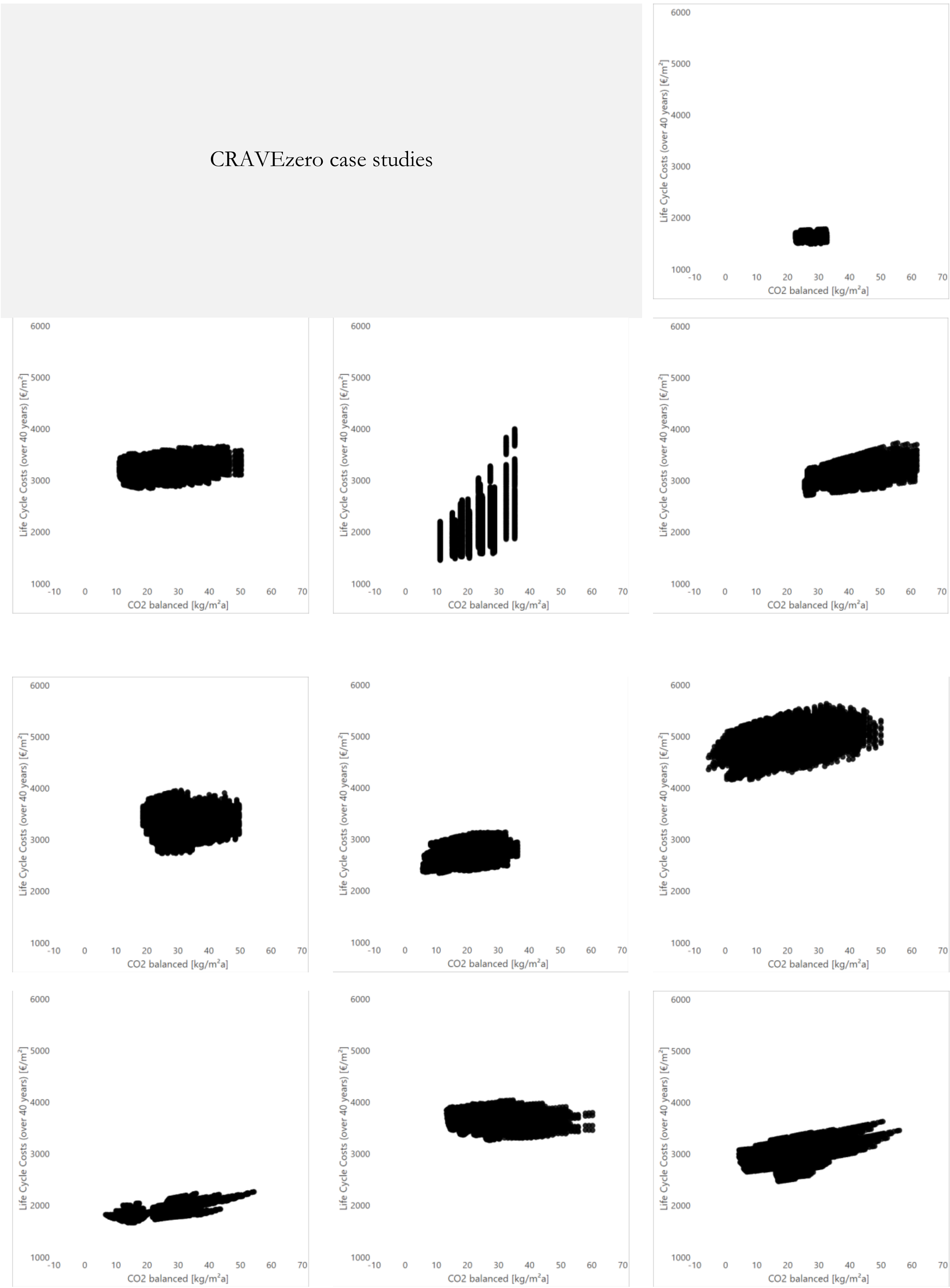


Figure 67: Analysis of the balanced CO_2 emissions related to the LCC for different technology combinations of the case studies.

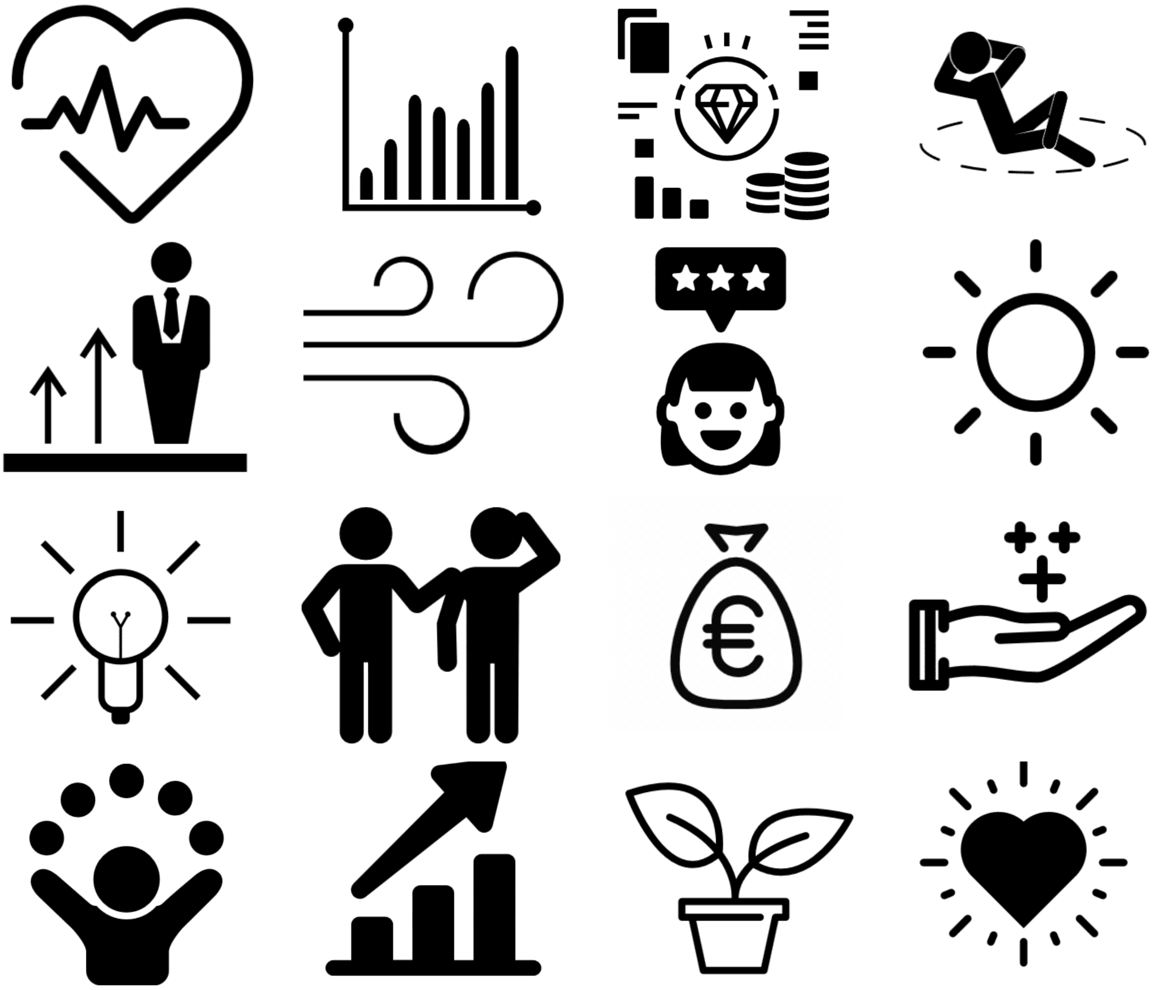
5.4. FINDINGS

Based on the performed parametric calculations, the following conclusions can be drawn:

- nZEB measures only have a small percentage of influence on construction costs, but can reduce CO_2 emissions multiple times.
- The cost reduction potentials for nZEB technologies until 2050 vary from approximately 1% to 65%. Stationary batteries have the highest potential with 65%, followed by decentralized ventilation, PV, and centralized ventilation with 52%, 49%, 46% and 38% respectively. Oil and gas boilers have the lowest potential (less than 10%).
- In many cases, the return of investment in energy efficiency measures to reach the nZEB target is around 25-40 years if calculated only in terms of energy cost-saving. Nevertheless, the cost-effectiveness of nZEB construction becomes more apparent if the co-benefits are included in the analysis.
- The cost optimum of primary energy demand and CO_2 emissions is in the range of nZEBs and passive housing.
- Highly insulated envelopes and highly efficient windows are usually economical even without subsidies. This is due to the long service life of these components compared to HVAC systems.
- The cost-optimum curve, concerning, CO_2 emissions is very flat. nZEBs may therefore be achieved with different energy concepts as long as the envelope is very efficient. This means architectural and conceptual freedom.

CHAPTER 6

nZEB related co-benefits



6. nZEB RELATED CO-BENEFITS

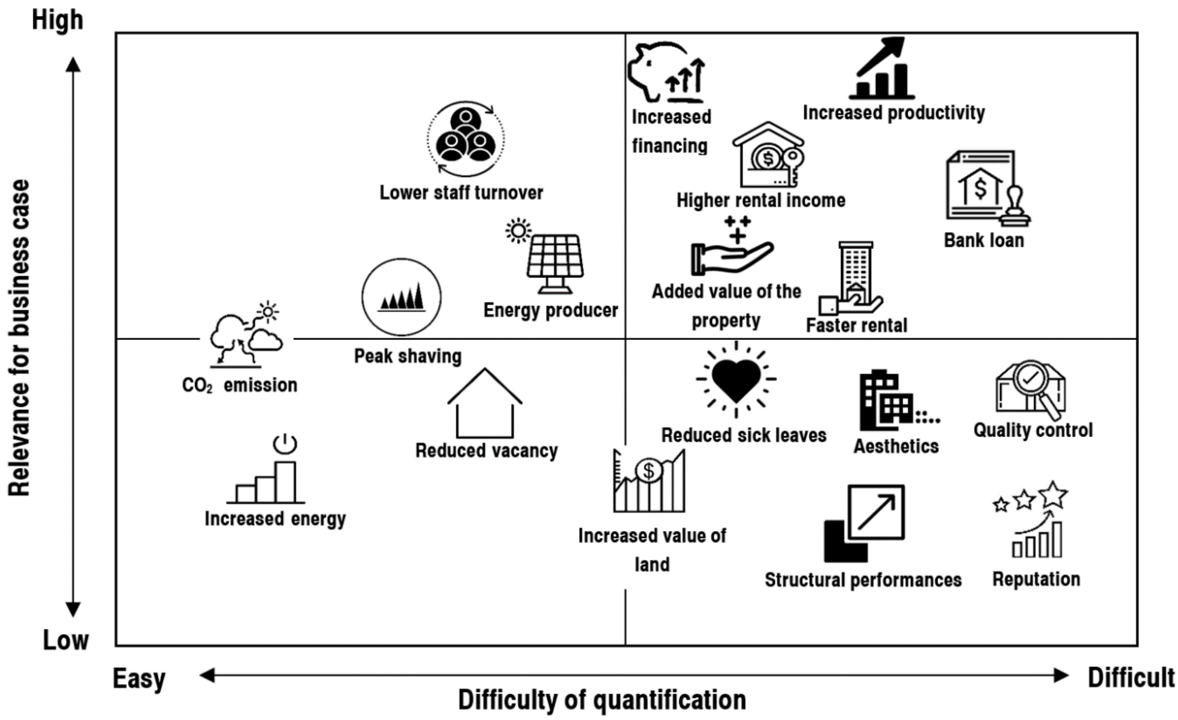


Figure 68: Co-benefits structured in terms of relevance for the business case and difficulty of quantification.

Specific additional incentives for nZEBs, the "co-benefits" are often forgotten. Co-benefits are the added benefits that can be achieved above and beyond the direct benefits of energy savings, climate protection, and lower operational costs. They are also referred to as "multiple benefits" or "synergies." These relate primarily to occupants who are in the buildings every day. They have a financial impact on nZEB office buildings as well. To show the relevance of all co-benefits, the following,
Figure 68 shows how they are structured in terms of relevance for business cases and difficulty of quantification.

- Health benefits
- Increased productivity
- Lower staff turnover
- Reduced sick leaves
- Employment creation
- Market potential
- Owner as energy producer
- Added value for a nZEB property
- Integration of RES
- CO_2 emission savings
- Increased energy security
- Aesthetics and architectural integration
- Increased value of land/context
- Increased reputation and good publicity
- More press releases
- Reduced vacancy due to nZEB
- Faster rental of the building
- Higher rental income
- Increased financing by lower interest rate
- Increased bank loan financing
- Prefabricated building – quality control
- Prefabrication – cost and time efficiency and control
- Prefabricated building – on-site work
- Prefabricated building – façade integration

The advantages of these co-benefits can be very complex because the research is in its early stages. It is often difficult to find statistically sound robust values that allow individual co-benefits to be quantified. However, some studies do serve as a basis for such quantifications. Recent papers address employee turnover and satisfaction (Miller et al. 2009), productivity (Hedge, Miller, and Dorsey, 2014; Thatcher and Milner, 2014), and absenteeism Singh et al. (2010) provide estimations for the implementation of co-benefit evaluation.

Studies show that employees in nZEBs perceive positive effects from their working environment and productivity (Thatcher, 2014; Singh, 2010). In one case, a 10,000 m² office building, a 0.3 % increase in productivity of was reported, equivalent to 8 €/m²a. Another study has noted a decline in absenteeism in nZEBs (Thatcher, 2014).

An American study showed that around 20-25 % of 534 companies reported higher employee morale, easier recruitment of staff, and more effective customer meetings (Miller et al. 2009). 19 % reported lower employee turnover.

In addition to well-being and productivity, higher revenues from rent or sales may be expected from nZEBs (Bleyl., 2017) reviewed previous studies and concluded that higher rent income might range roughly between 5% and 20 %. Furthermore, higher market valuations may range from under 10 % up to 30 %.

Social factors surrounding green buildings and productivity and wellbeing may have a more significant impact in monetary terms, than environmental factors (Hugh, 2016).

The value of positive news articles about a specific building or project is comparable to advertising costs for the specific source in which the article is published (Berggren, 2017).

In order to obtain a targeted overview of the users' understanding of co-benefits, a survey was launched as part of the 2020 EU Horizon project CoNZEBs (2017-2019). The focus was placed on indoor air quality, comfort, building location, and low energy costs (Zavrl et al., 2019).

Interests, target criteria, and co-benefits vary significantly depending on stakeholder perspectives. Figure 68). To achieve low heating costs, for example, the tenant is interested in low rental and operating costs and therefore a good energy standard. As a general rule, the building contractor aims to keep his construction costs low. For properties used by the owner, both cost components are essential – the initial investment and the operating costs. For public owners and users, the total life cycle costs and effects (e.g., CO_2 emissions) are of interest.

☐ Indirect relationship

☑ Direct relationship

	Benefits					Co-benefits						
Stakeholders	Marketability	Lettability	Value development	Rental income	Comfort	Durability	Arch. quality	Image	Energy Savings	User satisfaction	Climate protection	Energy autonomy
Tenant / user		☐			☑	☐	☑	☑	☑	☑	☐	☐
Real estate agents	☑	☑	☑	☑	☐		☐	☑	☐	☐		
Builder/ construction company						☑	☐			☐		
Planner		☐	☐		☑	☑	☑	☑	☑	☑		
Property management		☑	☑			☑			☑	☑		
Investor	☑	☑	☑	☑			☐	☐				
Building owner / landlord	☑	☑	☑	☑	☑	☑	☐	☑	☑	☑		☐
Building owner (public)	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Society	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

Figure 69: Stakeholder related benefits and co-benefits of nZEBs.

To assess the direct monetary value of a building, there are various co-benefits for the individual stakeholders, which often cannot be assessed directly in monetary terms and therefore do not appear in the life cycle cost analysis. These concern marketability, rentability, value development, and comfort as well as image, climate protection or regional goals such as energy autonomy. As far as possible, these advantages and additional benefits should be taken into account by the various stakeholders in the relevant decision-making process. These additional criteria can often overlap with the main criteria. An example is the use of an air-source heat pump in a very noise-sensitive environment. It may perform relatively well in terms of energy and life cycle costs, but it can cause problems due to increased noise pollution on the property and adjacent land. For this reason, it is crucial to quantify the added value of nZEBs in monetary terms by communicating and presenting business opportunities in a way that potential investors may weigh the pros and cons (Bleyl, 2016).

6.1. METHODOLOGY

This chapter deals with the co-benefits associated with nZEBs and their (presently) underestimated positive effects on the payback time of nZEB investments and improved occupant satisfaction.
Two CRAVEzero case studies assess various co-benefits (e.g., increased productivity, improved health, advertising value) to show their individual benefits on payback time in particular.

Cost-benefit analysis of nZEBs for project developers

Using the calculation of Berggren, Wall, and Togerö (2017), effects of various co-benefits on the life cycle costs of nZEB were quantified. The following formula explains the procedure of these calculations.
The value of reduced energy consumption and exported energy described in the first formula summarizes the reduced energy costs (REC). For this purpose, the profitability of the increased costs associated with increased energy efficiency and the environmental values of the building were evaluated. In addition, investment costs were compared with energy efficiency and other sustainable values. Maintenance and renewal costs are not included in this formula.

$$REC = \sum \frac{EI \cdot \alpha + EE \cdot \beta}{\left(1 + \frac{r - i - \gamma}{1 + i + \gamma}\right)^t}$$

Where: EI is reduced imported energy, EE is increased exported energy, α is energy tariff of EI, β is energy tariff of EE, r is the nominal discount rate, i is the inflation rate, and γ is increased in energy tariffs.

Sensitivity analysis

Within CRAVEzero, a sensitivity analysis (SA) was performed for the investigated case studies, to identify which input parameters affect the LCC the most. This includes the implications of uncertainty related to assumptions on input parameters and boundary conditions. The same methodology has been adopted in this deliverable to offer better insight into the co-benefit analysis developed within the CRAVEzero framework and to determine the impact of the co-benefits on the value of a nZEB.
The procedure for quantifying the co-benefits analysis was used to perform the SA of one office building, Aspern IQ in Vienna,, Austria., Among the quantified parameters, not all of the baseline values from literature could be found. For this reason, only a minor fraction of the listed co-benefits could be investigated with the SA.

The SA workflow was designed as follows:

1. Input values and variation ranges must be selected. Since literature data on this subject is scarce/difficult to rely on, input parameters have been varied over a predefined range; in this case, +-10%.
2. SA requires selecting an output in order to measure its value when the input varies. The tool calculates the savings generated by the positive action of the co-benefits on the business value. These savings are used to calculate the time needed to pay back the additional investment for the nZEB. The accumulated total savings after 30 years have been chosen as output for the SA.
3. The analysis was performed applying two methodologies (see D6.1 and D6.2). The first one consists of a *differential sensitivity analysis,* the simplest screening technique. In the second step, the *elementary effects* (EE) method was implemented.

Differential sensitivity analysis

This method belongs to the class of the One Factor At a Time (OAT) screening techniques. In differential analyses, all parameters are set equal to their baseline value. The impact on the LCC is then investigated one parameter at a time, keeping the other parameters fixed. The sensitivity index (s%) is calculated as follows:

$$s\% = \frac{\frac{\Delta \mathrm{O}}{\mathrm{O_{un}}}}{\frac{\Delta \mathrm{I}}{\mathrm{I_{un}}}}$$

Where: ΔO is the output variation, O_{un} is the output baseline value, ΔI is the input variation and I_{un} is the input baseline value.

Elementary effects method

The EE method proved to be a very good compromise between accuracy and efficiency (Campolongo, Cariboni, & Saltelli, 2007), since it ensures a decent exploration of the design space with a reduced number of simulations. SA can be carried out for different combinations of input values.

An elementary effect is defined as a change of the output caused by a change in a single input parameter while keeping all other model parameters fixed. As pointed out in Hedge, Miller, and Dorsey (2014), to obtain robust sensitivity measures, more elementary effects per parameter have to be computed, varying directions of change and base values. Nevertheless, only a reduced part of the possible elementary effects can be analysed; therefore, a Design of Experiment (DoE) has to be generated to carefully select the combinations. The mean elementary effect associated with a factor i is then given by the average of the single elementary effect (EE) associated with that factor:

$$\mu_i^* = EE_i = \frac{1}{r}\sum_{j=1}^{r}\left|EE_i^j\right|$$

$$\sigma_i^2 = \frac{1}{r-1} = \frac{1}{r}\sum_{j=1}^{r}\left(EE_i^j - \mu_i\right)^2$$

Where μ_i* is the absolute mean of the single elementary effects associated with factor i, and σ_i^2 is the variance of the elementary effects associated with factor i.

The main limitation is that, while the impact of a given variable is investigated, the other parameters remain unchanged. Even if the interactions of the parameters cannot be investigated from a global perspective, this characteristic can determine which parameter causes the greatest effect.

6.2. CASE STUDIES

The industry partners of the CRAVEzero consortium provided information on 12 existing reference buildings considered representative of the current best practices in the construction of new nZEBs with different functions and contexts. The industry partners participated in the design and/or the construction or operational phase of the buildings, and thus have access to detailed relevant data. These case studies include both residential, and office buildings and are located in the CRAVEzero countries: Austria, France, Germany, Italy and Sweden. Two of these case studies were used for the co-benefit analyses.

Aspern IQ

Figure 70: Aspern IQ

General information

- Owner: City of Vienna
- Architect: ATP Wien
- Energy concept: Renewable power, environmental heat, and waste heat
- Location: Vienna (Austria)
- Year of construction: 2012
- Net floor area: 8817 m²

Key technologies

- Groundwater heat pump
- Photovoltaics

Aspern IQ is located in Vienna's newly developed urban lakeside area "Aspern" - Austria's largest urban development project and also one of the largest in Europe. The building was designed in line with Plus Energy standards. It was conceived as a flagship project to showcase the approach to creating a plus energy building which is adapted to locally available materials and offers the highest possible level of user comfort while meeting the demands of sustainability.

In the Aspern IQ reference building, to filter out the influences of the individual co-benefits, the economic and energetic building data were used to map the influences as accurately as possible. A parametric cost-benefit analysis (with changing individual parameters of the co-benefits) was performed to see how the added values affected the project (see Table 14). The assumed property value was determined using a comparative value method with comparable buildings in Austria.

Table 26: Data of the reference building

FINANCIAL

Residential/non residential	Non-residential	
Saleable / rentable area	6,600.00	m²
Expected sales year of property	30	years
Assumed property value	3,914.00	€/m²
Rents for tenants	144.00	€/m²a
Expected yield	10	%
Rental or owner-occupation	Rental	
Estimated vacancy rates	6	%
Number of employees	250.00	employees

ENERGY		
Treated floor area	6,633.00	m²
Heating demand	50.00	kWh/m²a
Cooling demand	10.00	kWh/m²a
Electricity demand	40.00	kWh/m²a

Because this is a nZEB, there are economic aspects (e.g. additional costs and energy targets) which cannot be ignored under any circumstances.

Table 27: Aspects based on high-quality nZEBs

FINANCIAL		
Additional nZEB costs	171.60	€/m²
ENERGY		
Heating demand	21.00	kWh/m²a
Cooling demand	2.00	kWh/m²a
Electricity demand	18.00	kWh/m²a
PV yield	14.55	kWh/m²a
PV yield: self-consumption	10.00	kWh/m²a

Based on this building data, the different co-benefits were considered in Aspern IQ. Calculation results with and without the consideration of co-benefits clearly show the influence of the individual parameters on the overall cost curve over 30 years – especially the breakeven of the additional nZEB investments, as can be seen in Figure 71. The following list shows the applied co-benefits.

- Yield reduction due to high quality nZEB
- Reduced vacancy
- Higher rent
- Faster rental of the building
- Reduced maintenance costs
- Amount of press
- Increased productivity
- Lower staff turnover
- Reduced sick leaves

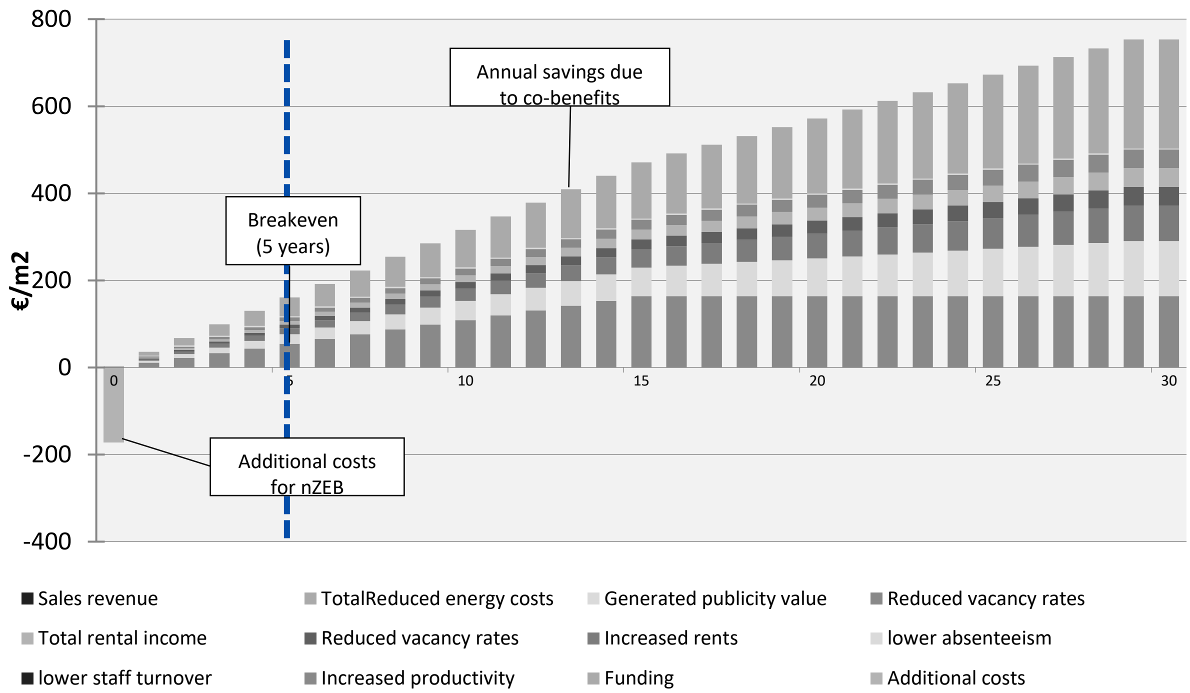


Figure 71: Payback time and breakeven point under consideration of co-benefits over 30 years.

Results

SA was performed first with the DSA method and then the EE method. For each, the two approaches for the baseline values previously illustrated, are displayed. Moreover, the discount rate has been inserted as a variable parameter to add the effect of its variation. DSA calculated the sensitivity index for three scenarios: discount rates 1, 2, and 3 %. In the EE method, the discount rate was added to the investigated parameters.

In the first approach, where real values for the baselines are adopted, the three most influencing co-benefits are "higher rent," "yield reduction due to a high quality nZEB," and "reduced vacancy". However, very different outcomes are obtained if the second approach is considered: the most influencing values by far are "yield reduction due to hq nZEB" and "increased productivity."

Figure 72: Sensitivity index related to real values baseline – discount rates 1, 2 and 3%.

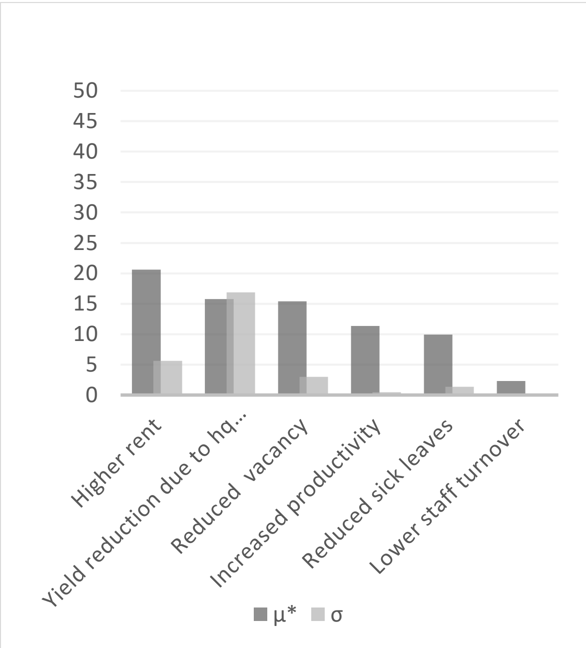


Figure 73: μ* and σ related to real values baseline.

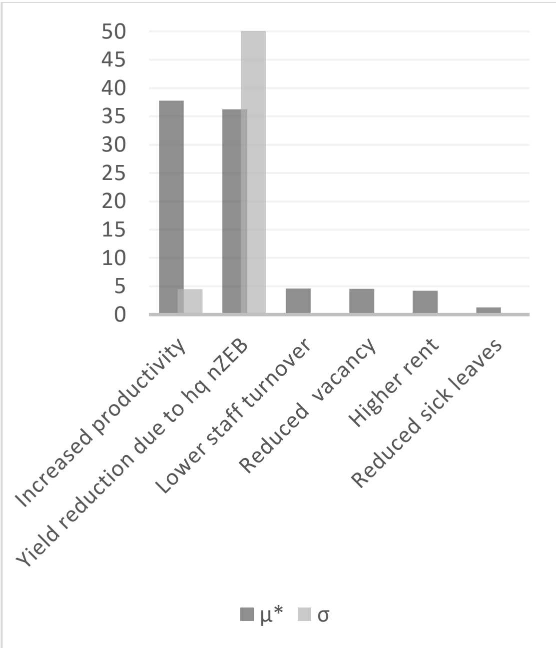


Figure 74: μ* and σ related to common baseline 1%.

In Berggren et al. (2018), increased productivity is indicated as the co-benefit with the largest relative impact. This statement is confirmed by results obtained in the second approach, which applies a fixed variation of 1 % equal to all co-benefits. A productivity increase of 1 % corresponds to 22 €/(m²a) of labour cost savings, assuming an average monthly salary per employee of 3,000 € and employer & social costs (excl. holiday allowance) equal to 60 %.

Nevertheless, the questions that should be further investigated are "How much can the productivity actually increase vary?" and "Is a productivity increase of 1 % plausible? 2 %?"

Bleyl et al. (2017) state that in some cases a rent increase related to a green building can range from below 4 % to 21 %. For this analysis, a 5 % rent increase has been conservatively selected for the approach using baseline values from the literature. Nevertheless, in this case, this co-benefit showed the highest sensitivity index and μ*.

Väla Gård

Figure 75: Väla Gård

General information

- Owner: Skanska
- Architect: Tengbom
- Energy concept: Passive house design with PV-panels and ground source heat pump
- Location: Helsingborg (Sweden)
- Year of construction: 2012
- Net floor area: 1 800 m²

Key technologies

- Passive house design
- Ground source heat pump
- Photovoltaics
- Presence controlled

There is a prefabricated 120 mm concrete wall with 200 mm graphite EPS. Heat and hot tap water are produced using a geothermal heat pump; the geothermal solution can also be used for cooling. Demand controlled ventilation system is used to ensure air quality with sustained energy performance.

Based on the equations presented in section 1316.1, the following parameters were investigated:

- Reduced energy costs (due to decreased energy demand)
- Increased rental income (due to lower vacancy rates)
- Publicity value (based on number of press clippings)
- Increased productivity
- Lower staff turnover
- Lower sick leaves

To investigate the effect of the co-benefits listed above, a reference building is compared to Väla Gård. The reference building and boundary conditions are described in Table 28. Input data for the investigated parameters are described in Table 29. Initially, each parameter is investigated, followed by a combination of all parameters. SA is included with a variation of each parameter by ±25 % when all parameters are combined.

Table 28: Summary of reference building and boundary conditions

Financial info – reference building	
Type of building	Non-residential
Saleable/rentable area	1 600 m²
Rent to tenants	70 €/m²a
Vacancy rate	15 %
Employees	70 persons
Energy – reference building	
Treated floor area	1 670 m²
Heating energy (electricity)	22 kWh/m²a
Cooling energy (electricity)	5 kWh/m²a
Electricity, excluding heating and cooling	65 kWh/m²a
Boundary conditions	
Nominal discount rate	7 %
Inflation	2 %
Tariff for imported energy	0.12 €/kWh
Tariff for exported energy	0.10 €/kWh
Annual energy tariff increase	2 %
Average salary costs	6 350 €/employee
Average employee turnover, SwedenEs ist eine ungültige Quelle angegeben.	4 %
Average sick leave	6 days/year
Value for publicity	3 500 €/article

Table 29: Input data for investigated parameters

Reduced energy costs	
Heating energy	4
Cooling energy	1
Electricity, excluding heating and cooling	35
Increased rental income	
Vacancy rate	5 %
Publicity value	
articles	10
Increased productivity	0.5 %
Lower staff turnover	0.5 %
Lower sick leaves	10%

Results

Figure 76, includes all the co-benefits investigated above. A base case (BC) is presented with a worst-case and an optimal case. In the BC, all co-benefits are included with the additional costs, and the cost reductions received during the project. In the worst case, the additional costs have been increased by 25% and the business benefits have been reduced by 25%. In the optimal case, the changes are the opposite. In the BC, the cumulative savings exceed the additional costs after roughly four years. In the optimal and worst cases, the cumulative savings exceed the additional cost after roughly three and eight years, respectively.

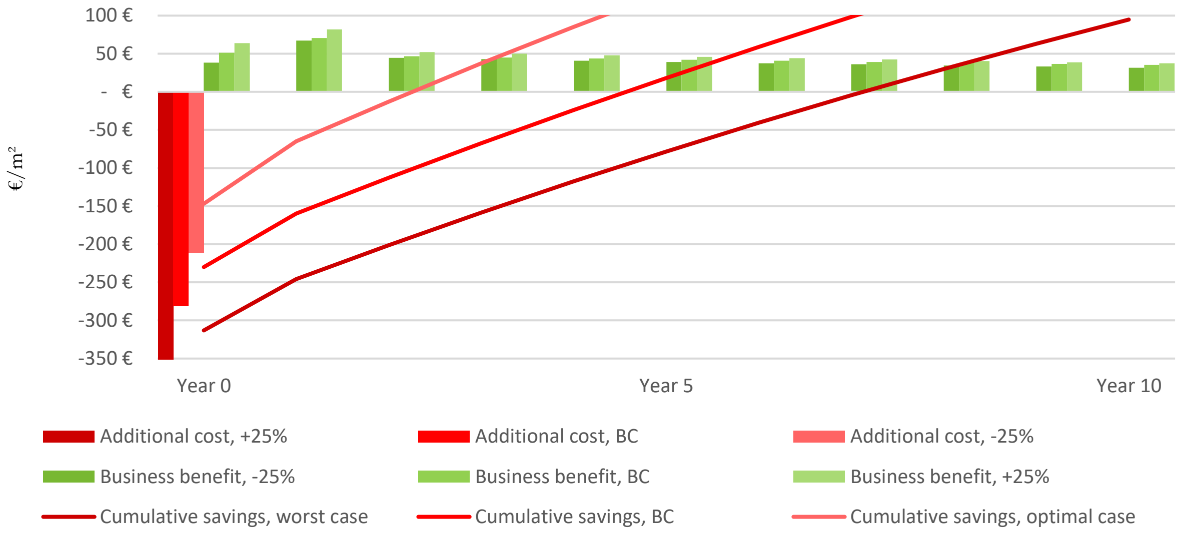


Figure 76: LCC-analysis for Väla Gård.

6.3. CONCLUSION

The co-benefits have been analysed in particular with regard to their influence on the payback time and profit over a period of 30 years for the Aspern IQ and Väla Gard case studies. Increased productivity of the employees due to higher building quality and comfort (and possibly a higher rental income due to a better building standard) are the most important factors with regard to the payback time and profit. Even influences which are usually not considered and are harder to quantify (e.g., the productivity of employees, reduced sick leaves or vacancies) can significantly influence the economic success of a nZEB.

The case studies show that it may be hard to find it profitable to build a nZEB if one only accounts for improved energy performance or a *single* co-benefit. Profitability is significantly affected by more values than energy savings (that cannot balance the initial extra investment to reach the target nZEB if a short time perspective for evaluating profit is applied). However, the studies show that it may be very profitable to build nZEBs if one accounts for *several* green values.

CHAPTER 7
Business models

7. BUSINESS MODELS

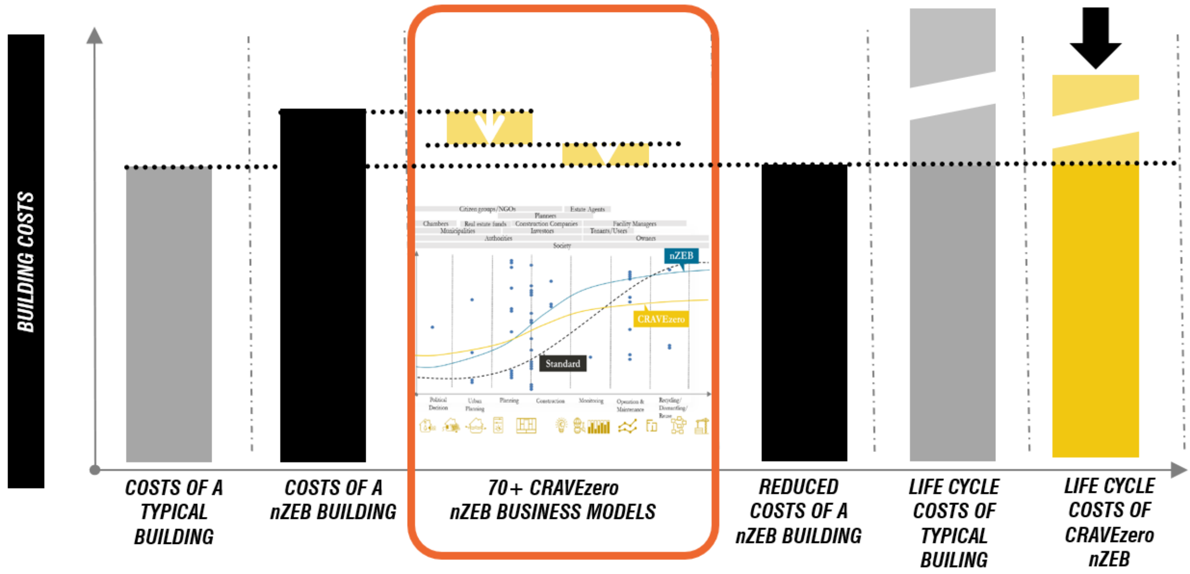


Figure 77: CRAVEzero business models as an important factor to reduce nZEB costs.

The project proposed a holistic evaluation method for business models. The requirements for a successful business model (BM) have been identified. Applying the Osterwalder Business Model Canvas, it was shown that BMs mature at different stages. Some models are already well established and are in use during daily business. Others are in a phase where cost and revenue structures are under development. Depending on the maturity of the BM, adaptations can be established to improve it.

An overview of different stakeholder perspectives and approaches was collected for the different nZEB BMs provided by CRAVEzero industry partners, to capture value during nZEBs' life cycles. In analysing the BMs, common strengths and key factors were identified. The stakeholder perspectives and activities demonstrably affect the structure of BMs more than geographic clusters.

The results were used to enhance existing BMs and develop new BMs related to nZEBs. The whole workflow around BM generation and development can be used with the CRAVEzero-produced documents and interactive tools. It facilitates the market uptake and should motivate increased activity to realize nZEBs. The approach is not limited to new buildings; it is also useful for renovation projects and all building types. During the work, all project partners learned how to use BM development so it should be quite feasible for the related stakeholders to follow for their own purposes. Useful feedback was gained via several workshops, web meetings, and webinars. It was then integrated into the work, as project partners had a common understanding of the importance to satisfy the clients' and customers' needs in formulating real value.

7.1. THE TYPOLOGY OF BUSINESS MODELS

A method to analyse BMs related to nZEBs was developed within the project. The project partners used this method to validate their own BMs. A challenge for all partners was the description of revenue streams and costs. One lesson was that the BMs for low-LCC nZEBs are often embedded in the "normal" business approach and it seems difficult to separate that from the nZEB business approach, especially regarding costs and revenues.

However, the portfolio attractiveness tool (http://www.cravezero.eu/wp-content/uploads/2018/12/CRAVEzero_D51_Typ ology-canvas-BMs.pdf) also makes it possible to assess BMs.

The Business Model Canvas shows that BMs have different stakeholder perspectives, namely:

- real estate developers,
- planners,
- general contractors,
- engineers and constructors,
- facility managers/building operators, and
- urban planners.

With the applied method, critical success factors (strengths and key factors) for nZEB-related business models were identified (see Figure 78 and Figure 79). Key strengths are the "Guarantee on Comfort and Performance," "Valuable Project Management," "Cost Reduction/Guarantee of Costs," and "Human Expertise and Experience." "Competence / Know-how / Experience" was identified as the key factor for cost-efficient nZEBs.

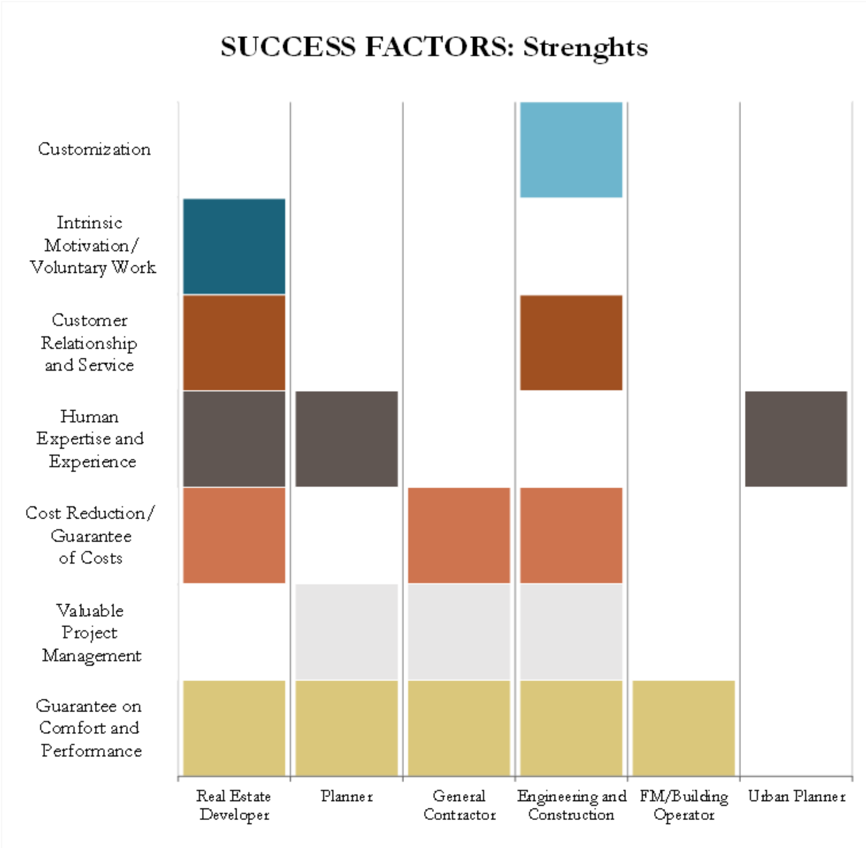


Figure 78: Cross-analysis of BMs' strengths.

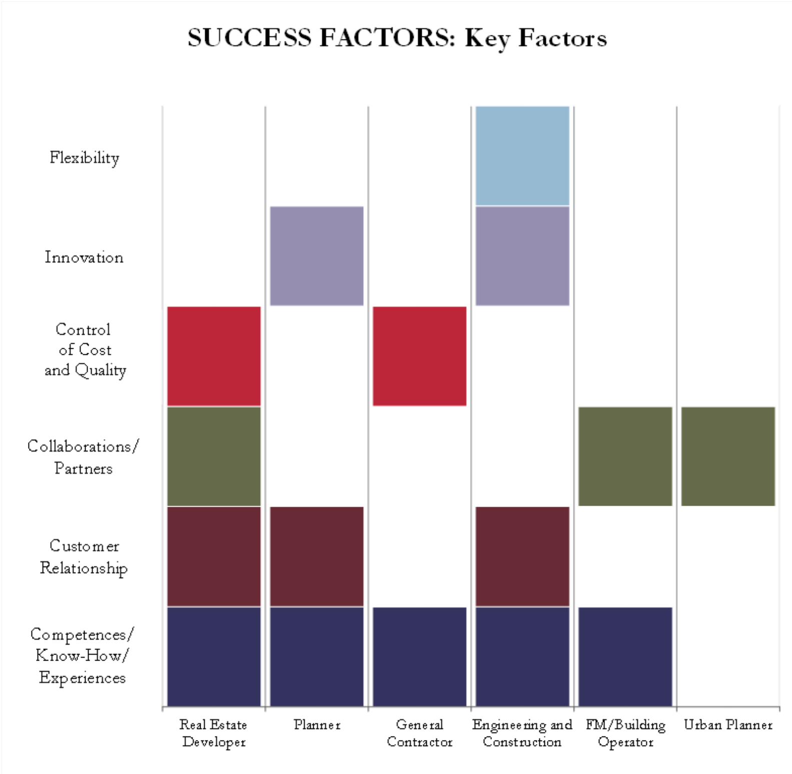


Figure 79: Cross-analysis of key BM factors.

7.2. SCREENING THE EU MARKET

The project describes around 60 existing BMs found in the major European markets. Some of the analysed models were provided by the CRAVEzero partners. Collected profiles have shown BMs belonging to all life-cycle phases of nZEBs. The comparative analysis between these BMs has shed light on the different parameters mentioned and how they vary depending on the stakeholder perspectives. It was also shown that the different stages of maturity of business models can be found within this broad range.
The results were helpful to enhance existing business models and to develop new business models related to nZEBs, and provided fruitful input for the project pinboard.

The use and provision of data through CRAVEzero, reporting features and descriptions of business models, have contributed to the market acceleration of nZEBs. During workshops and feedback within the project's dissemination activities, it was stated that there are only some minor adaptations necessary to implement the models everywhere in the EU. The BMs are presented as profiles (see https://cravezero.eu/businessmodels/) considering the following parameters:

- value proposition,
- customer segment,
- customer relationship,
- activities and capabilities,
- revenues,
- costs,
- strengths and key factors,
- maturity, and
- placement along the value chain of nZEBs.

Other business models were described by the partners on the basis of the information found on the respective companies' websites. However, it is not guaranteed that all information was profiled correctly and holistically.

CRAVEzero

CONSTRUCTION COMPANY: PREFABRICATED HOUSES

VALUE PROPOSITION:
The company offers prefabricated houses with very high energetic standards such as efficiency houses (40+, 40, 55), Plus-energy houses and passive houses such as single or multiply family homes, bungalows and double houses. The offer includes a carefree support starting with informing and advising customers to the actual building and (optionally) renovating processes of a building. With a high level of customization as well as cost and planning security the customer's wishes are met. Moreover, the company promises stable building value and a secure, healthy and sustainable building process, fair cost effectiveness and a transparent communication of costs.

CUSTOMER RELATIONSHIPS:
In order to get in touch with customers the company provides "Building information days", brochures and a detailed website. References of previous projects as well as guarantees of prices and various certificates and awards shown on the website are used to build trust. Personal assistance, a customer service reachable via telephone hotline as well as internet and the offer of renovation services helps building a long-term customer relationship.

CUSTOMER SEGMENT:
The offer is directed at families wishing to build their own home as well as private and public investors building single and multiply family houses all of which emphasize on sustainable and energy efficient buildings.

ACTIVITIES AND CAPABILITIES:
The service portfolio includes providing the necessary information for customers, consultancy, intermediation of architects, construction and its supervision as well as optional financing services, renovation and customer support. Additionally, the company benefits from having their own production sites for building parts, parks with show houses, kitchen studios, design joineries and finance services spread across Germany.

Screenshot: https://www.schwoererhaus.com/en-gb/

REVENUES:
Revenues are made depending on the relevant contract. The company offers various different contracts depending on the construction stages included. Furthermore, costs depend on the customers' wishes such as type of building, architectural style, technical equipment etc. Moreover, additional revenue streams for financial consultancy, interior furnishing or renovating tasks are possible.

COSTS:
The company produces their building materials and prefab parts itself which is likely to be the most expensive expenditure (resources) followed by personnel expenditures for the construction phase, consultancy and customer support.

STRENGTHS AND KEY FACTORS
- Prefab buildings for faster construction
- Easy coordination (most services inhouse)
- Own manufacturing facilities, finance service, kitchen center and show house parks
- Life-long customer support for lock-in

MATURITY:
The company has a long construction history and can provide clients with technical data from older buildings. These data can be used for e.g. future energy efficiency upgrades and design changes.

PLACEMENT ALONG VALUE CHAIN OF NZEBS

Placement of nZEB business models along the value chain

CRAVEzero

BM 1: GENERAL CONTRACTOR AND REAL ESTATE DEVELOPER: HOUSING ASSOCIATION

https://www.koehler-und-meinzer.de

PROPOSITION:
tional and regionally established compa-ns a broad portfolio as a real estate de-nd general contractor. The customer turnkey, energy efficient, ecological and ized property. Both owners and investors om the expertise of various specialist s and quality assurance measures during planning, building and operational pro-energy standard of the building meets t guidelines and funding possibilities in Different offers from architecture ser-ding renovation, municipal and commer-ngs up to the maintenance/ administra-al estate services are available.

MER RELATIONSHIPS:
tablished brand, the company benefits egional presence and public perception. n to common advertising strategies and mouth propaganda, the focus lies on al relationship, personal support and . The company therefore provides an resence which is linked to the current nd sales offers. A lot of references of projects as well as the guarantees and e shown on the website. Contact via or personal contact is available.

MER SEGMENT:
is widely spread: from owners and inves-gle and multi- family houses/apartments ers of industry or municipality buildings. l estate agency service other customer (seller, buyer and tenant of objects) are

TIES AND CAPABILITIES:
olio includes a widely diversified spec-ervices around the topic of planning, construction and maintenance of buildings. The aim is to exceed current energy standards and find innovative, cost-effective solutions for owners that optimize the operating costs. Additionally, the company benefits from long-term relationships with several specialists and consultants and established regional craft businesses.

REVENUES:
Revenues are made by selling apartments or turnkey houses. Additional income will be provided through a wide range of services around the topics of planning, building, building management and brokerage.

COSTS:
The main costs (next to administrative costs of the company itself) in the field of real estate developer and general contractor are the construction costs of the individual trades, the production costs and the remuneration of engineers

STRENGTHS AND KEY FACTORS:
- Reliable regional partner with a good reputation
- individual customer service
- flexible contract design
- individual, high quality and sustainable solutions for the customers needs
- long-term relationship with suppliers, skilled craftsmen, professional engineers

MATURITY:
The company has a long planning and construction experience. In the last decades, many reference projects and buildings have been created. Through a continuous adjustment and improvement process, the buildings are adapted to the respective (also energetic) state of the art and the growing demands of the customers.

PLACEMENT ALONG THE VALUE CHAIN OF NZEBS

Placement of nZEB business models along the value chain

Figure 80: Layout of the prepared BM profiles.

The BMs apply to different stakeholders along a building's life cycle. The key findings for each parameter were filtered by a comparative analysis. It sheds light on the characteristics that make BMs successful, differences, maturity stages of the existing business models, etc. It can indicate when new BMs will make sense in the life cycle/contribute to a diverse market, thus creating a win-win situation for all cooperating stakeholders.

Some features are common to all BMs (e.g., sustainability and energy efficiency).

In most cases, a strong relationship with the client (through customer service and communication) is strategically valuable – to build trust in the face of the expenses that will be incurred.

Besides this, the most essential activity for all stakeholders is the design/engineering and development of projects.

The main revenue is the sale of the asset, while the main costs incurred are related to the ever-present personnel expenditures. Most of the BMs present a relevant cost structure for running the day-to-day activities, with a focus on personnel costs. Such costs are mostly ascribed to work related to technical tasks, while administrative costs seem less relevant. The adoption of systemic approaches in the design and construction phases (e.g., prefabrication of building components, design for assembly) could improve cost structures by reducing personnel costs.

The most frequently recurring strengths and success factors are broad competence, know-how, innovation and sustainability as well as guaranteed prices/performances.

In terms of specific services offered to clients, dismantling, reuse and renovation, facility management, certification, prefabrication of building parts and grid services are not very widespread. Indeed, they could represent a valuable boost in competitiveness for players that are able to offer a set of integrated services covering the whole value chain and optimizing resource use all along the life cycle. These additional services could be proposed on the project pinboard to customize pre-defined BMs and evaluate extra market opportunities in the direction of a "smart" and "flexible" approach to building design and construction.

Most of the BMs collected are connected to the building development phase, leaving out the end-of-life of the building. However, some real-estate developers and building product vendors are already focusing their activity on building recycling. As the consortium gathered BMs along the whole nZEB value chain, it is worth noting that even stakeholders acting at a higher level of the policy making or planning phase often ignore the end-of-life planning in their value proposition. Including this late phase in the value proposition to the final client could boost business opportunities and reduce hidden costs related to building dismantling and recycling.

Larger companies have observably covered more phases and certification bodies along the value chain. Conversely, specialized service providers are more focused on one part of the construction process.

The BM analysis has shown that most companies acting in the field do not consider having a mature BM a priority for their activity; this can be linked to the distributed trades approach to construction adopted by several small and medium-size companies (it has the advantage of being very flexible). Insights from the BM analysis can be used on the project pinboard to propose cross-fertilisation of BMs (from a set of similar stakeholders) to provide clients with an extended range of services.

7.3. CREATE NEW BUSINESS MODELS

The project partners determined that there is more than one method to find new BMs. Existing gaps in one's business could cause the need to search for a new or upgraded BM to fix failures and prevent errors. Other methods include advantage comparison, literature review, new value propositions, better customer relations, new customers and activities, nightmare competitors, or adapting from other sectors using a combination of different BMs from the CRAVEzero BM web tool or any other canvas. Also combining the methods can be beneficial. By varying methods, some additional BMs were described for a sum total of 70 existing or newly found BM descriptions. One of the conclusions is that it is quite important to know which customer segment to address during the preparation of a new BM to bring a solution to solve their problems and excite the market with a new business opportunity. Another conclusion is to focus on a clear and sound value proposition. Estimating revenue remains a problem with the new BMs since revenue is implemented as part of the overall business of a company. However, estimating the costs is easier for both existing and the new BMs since expenses, inputs, and contracts can be seen from a firm's budget.

Most BMs are in use without being created from a dedicated process. Often, companies start with by "doing" something to create value and generate cash flow. To handle the business in a more structured way, knowledge of BM creation is crucial. In practice, it is helpful to organize a small team within a company or institution to discuss all aspects of the group and gain valuable feedback. They can give indications on how to start, define, describe, cluster, and validate business models in the nZEB sector.

Methods to upgrade BMs:

- **Advantage comparison.** This method is about analysing the advantages of and gaps of existing BMs and focusing on improving the latter.
- **Literature review of creation methods.** Reviewing the literature for methods of creating new BMs could be used to develop a completely new idea.
- **New value propositions**
- **Better/new customer relationships**

- **Gain new customers.** For the stakeholders who want to launch a new company or for the existing companies who would like to extend the range of customer segments they address.
- **Find new activities**
- **Improve key strengths**
- **Nightmare Competitor.** "Define your nightmare competitor"- is to a method to learn from that BM and add/replace elements of your own BM.
- **Combine methods**
- **Adapt from other sectors.** Models from outside the building sector (e.g., transportation, energy services, or trading sectors, could be a useful).

The newly identified models are described in the descriptive format as a report on the project website (http://www.cravezero.eu/wp-content/uploads/2020/05/CRAVEzero_D53_Database_of_all_found_services_and_BMs.pdf).
The BM tool comes with a handbook and a webinar for efficient use and can be consulted here: https://www.cravezero.eu/pboard/Canvas/BM_CanvasInfo.htm

"BM 67: Easy Communication Online" (https://www.cravezero.eu/pboard/BM_Canvas/BM_Canvas.htm) was inspired by shipment companies that provide a tracking number for their customers. In this way, customers can easily track their package whenever they want and plan their days accordingly. It is even possible for some shipment companies to send alerts via e-mail or text message about the processes for which the customer requested information. When it is not possible to reach the customer, the company can leave a notice with the times when they are available for the customer to contact them. Both money and time can be saved for the customer and the company.
In the new BM that was developed for the nZEB sector, the customer can follow the main processes of the building design, construction, operation, renovation, and monitoring phases. The purpose of this BM is to automate the process of following an order from a company. Therefore, automated services (notifications, emails) are an option for customer relationships, as are self-service and personal assistance.
The benefits of this new BM are:

- One single solution for complex requirements
- Easy coordination and communication with the tracking app
- Decreasing staff costs which may otherwise be used for communication purposes instead of tracking

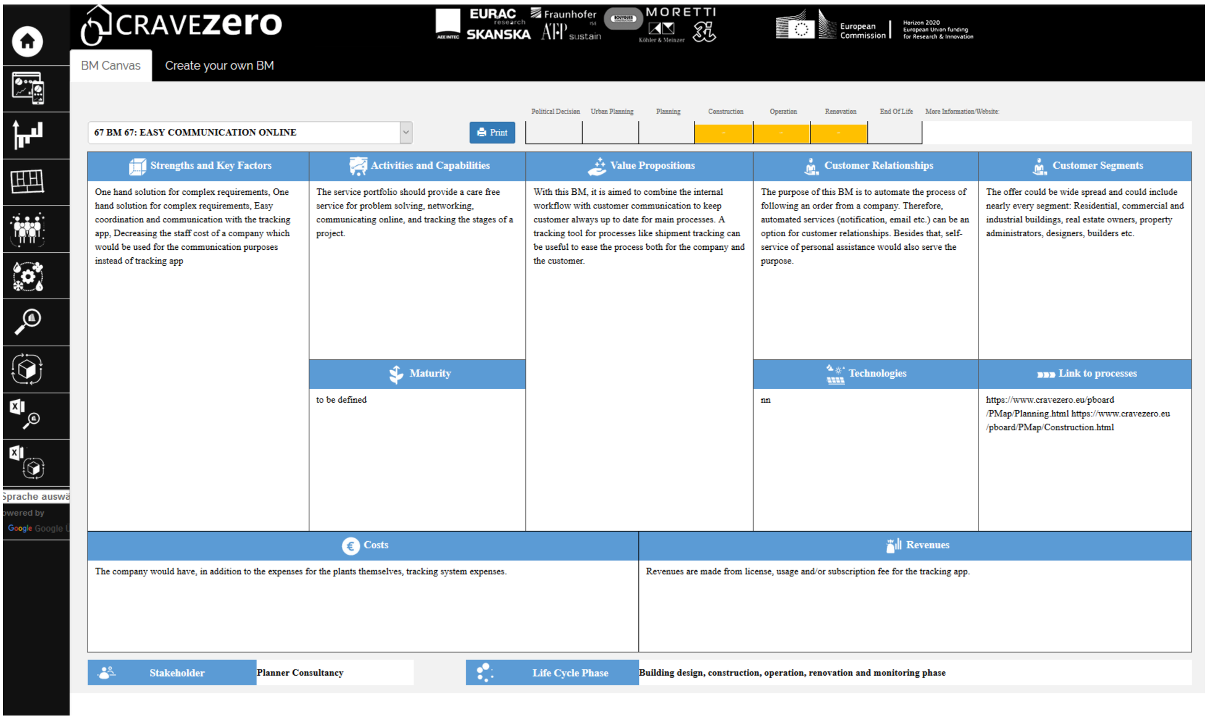


Figure 81: Online business model creator. https://www.cravezero.eu/pboard/BM_Canvas/BM_Canvas.htm

7.4. Transfer LESSONS LEARNED TO THE MARKET

Via the Guideline III on nZEB Business Models, (https://cravezero.eu/reports/) the CRAVEzero project created the necessary knowledge to disseminate findings to stakeholders and users.

The project gives suggestions for business model innovation. It is a summary and a guide to the reports and resources available on the pinboard. All the business models are classified according to their stakeholder perspectives to make it easier for different stakeholders to find existing models and to unite similar stakeholders. Besides that, it illustrates some good business model practices from some of the CRAVEzero project partners.

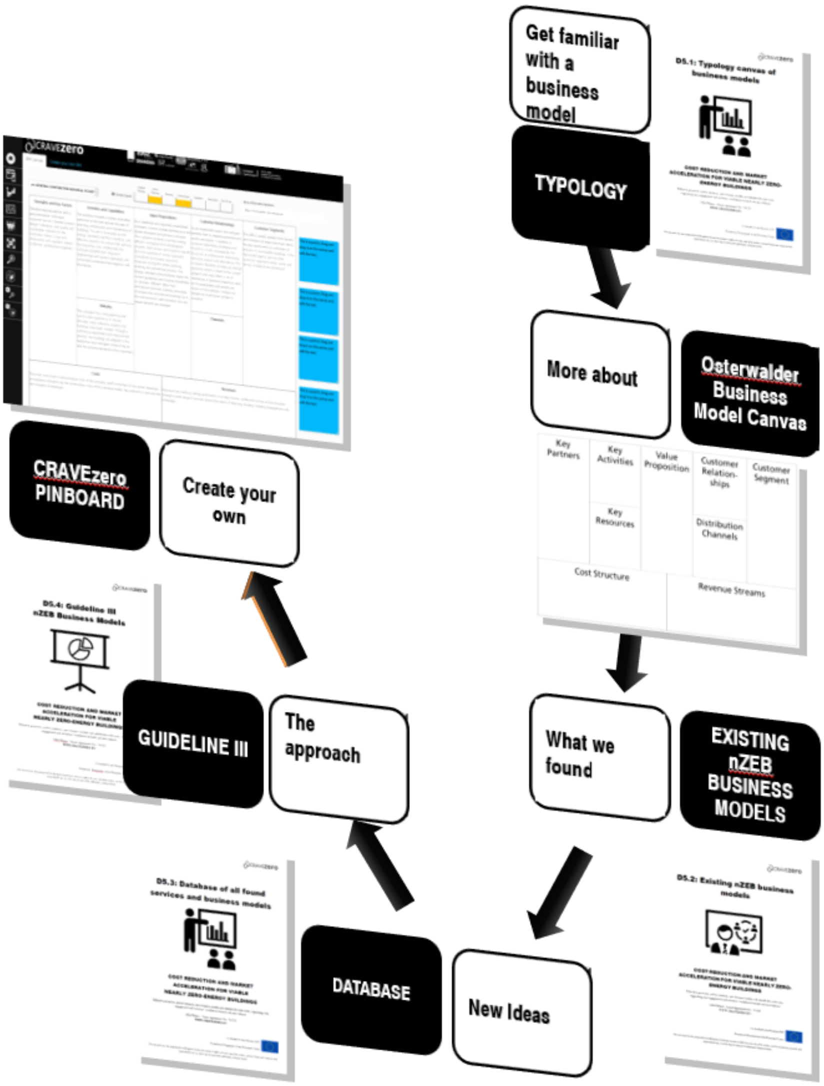


Figure 82: Overview of CRAVEzero nZEB Business Models approach.

The CRAVEzero project provides a clear business model creation approach. By following the different steps and the detailed related documents, a company representative can strengthen the approach for use in his own company.

The business model canvas is a valuable tool to understand a BM in straightforward, structured way. However, the present canvases cannot represent the whole complexity of a BM and is limited to summarizing descriptions.

- It can be a starting point for internal discussions and the detailed development of a new BM as well as understanding the current one in a company.
- For whatever reason the canvas is used, the different elements have to be specified.
- It is important to note that using the canvas in the pinboard does not deliver a ready-to-use BM but is a starting point for the development!

During the development of the approach, weak points of the current nZEB market were identified. Barriers that slow down the market acceleration and actions to promote the market uptake of nZEBs were examined. It was understood that bureaucratic barriers must be reduced to reach the energy transformation goals of the European Union. All in all, successful business model innovation is a must to provide value for customers and accelerate the nZEB market.

8. PROTOTYPICAL IMPLEMENTATION

All the methodologies and approaches developed within the project were collected and tested in six case studies/ongoing project developments provided by the project partners ATP sustain, Bouygues, Skanska, Moretti, 3i and Köhler & Meinzer.

In this section, the results of the application of the design process of two case studies called "prototypical implementations" are presented, with direct feedback on the applicability of the developed methodologies, a validation of the approach, and an assessment of the impact of the approach on the design and results.

Project partners (in this first part, Moretti and 3i) applied a set of tools and methodologies to two case studies as "prototypical implementations," These particular cases do not represent specific projects but are general building models: for 3i, the case is a novel flexible living building model called "DoppioUno" while in the case of Moretti, it is a prefabricated house that can be easily replicated by the company.

DoppioUno - 3i

Figure 83. "DoppioUno" case study.

The selected structure is a residential tower with seven stories and a basement. The main feature of this building is its flexible design. In fact, each floor can adopt different interior layouts according to the evolution of the user needs – from a studio flat to a four-room apartment. DoppioUno is a new construction, designed by different engineering and architecture sectors of the 3i group. The aim is to compare the life cycle costs of a nZEB with a standard building in the current real estate stock of northern Italy to carry out a preliminary quantitative analysis of the DoppioUno BM.

Targeted building performances are the reduction of energy cost influence for the user of DoppioUno, high renewable energy production, low purchase costs for the buyer, and economic sustainability for the company.

Buildings constructed at the current standard, besides a lower envelope quality, only have a limited production of renewable energy whereas a solar system and a PV system supplying a high amount of energy needs are installed on the roof of the DoppioUno building. Compared to the standard building, DoppioUno integrates an advanced control and automation system for all the installed services.

The performed calculation, considering a life span of 40 years, shows an LCC of the DoppioUno nZEB of 8,107,555 €, which is 14 % higher than the standard building. However, the initial investment costs for the nZEB were 33 % higher than the standard building. During the life cycle, the cost gap decreased due to reduced energy consumption, despite the higher maintenance costs.

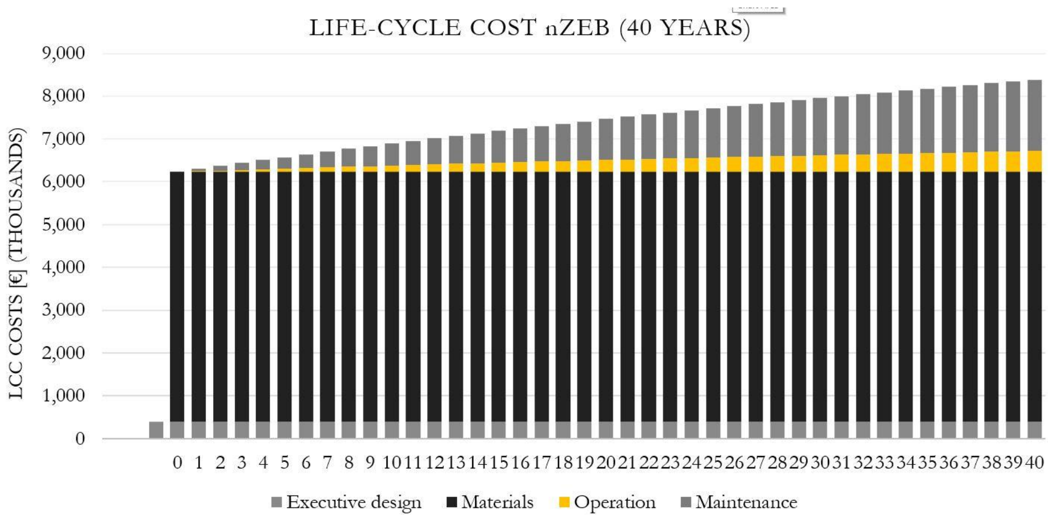


Figure 84. Life cycle cost calculation of the nZEB DoppioUno without PV.

The LCC implementation was the first fundamental step for the quantitative analysis of the feasibility of the DoppioUno BM. The main advantages of applying this methodology are:

- Availability in a single instrument - all costs that must be incurred to design, build and operate a building.
- Possibility to compare the incidence of each cost item at the end of life, and consequently carry out design adjustments for their reduction.
- Possibility to compare different design choices from an economic point of view throughout the life cycle.
- Mapping all costs for the design and construction of a building (nothing is left out from the building's economic evaluation).

The implementation of the methodology requires a relevant time expenditure during the design phase; however, this cost will be transformed into a future added value.

The main objective achieved through the application of the methodology was the qualitative and quantitative definition of the key points, costs, and revenues for the new business model. Furthermore, the database analysis of existing BMs is useful to compare the new model to current market proposals.

Casa More Franchino – Moretti

Figure 85. "Casa More" case study.

The second case study is the model of a prefabricated house in northern Italy developed by Moretti called "Casa More."

A single-family house of one storey was analysed, with prefabricated concrete panels and a wooden roof, which combine structural and thermal performance. For this prototypical implementation, two methodologies were selected: LCC analysis and process map. The objective was to define a standard methodology to be integrated into the company's workflow for future projects.

Having completed the construction phase of the building, a comparison was carried out, using the LCC tool, between two variants, keeping the same characteristics for the building envelope:

- Variant A: the HVAC system configuration as planned in the design phase,
- Variant B: the HVAC system implemented in the construction phase.

Both cases have similar initial investment costs (due to the construction cost, which represents the largest cost share). However, the operating costs in variant B are higher due to the demand for primary energy. Another interesting result is the different impact of the maintenance phase. The same amount is reached at the end of the considered period, but it is clear that the maintenance costs grow much faster in variant B. This difference is due to the number of systems selected and the simplified HVAC solution installed. Based on these results, the LCC tool proves it is a very useful application for companies to evaluate with a client the best building configuration (over a large time frame). In fact, one of the main advantages is being able to analyse in the preliminary stage, how different solutions can affect the costs during and after the construction. In this way, the company has reliable arguments to lead the client to choose the best solution for his/her needs from the whole life cycle of the building, not just the early investment.

Moreover, Moretti is involved in the planning and construction phases with an in-house approach that guides all stakeholders. The company's process map is structured in eight steps, and each phase identifies the activities to carry out with the main actors as per the RACI scheme (Responsible, Accountable, Consulted, Informed). The scheduled time to complete the activities is also indicated. Although Moretti's process map is tested and useful for involved stakeholders, it is not aimed at new nZEBs; therefore, it may be interesting to integrate the CRAVEzero process map into Moretti's workflow.

The Industry Partners, ATP sustain, Köhler & Meinzer, Bouygues and Skanska applied a set of tools and methodologies to four case studies. These buildings are different from those presented in the previous paragraph. They are nZEB frontrunner projects that were either in the planning phase or already under construction.

Case Study 4 - ATP Sustain

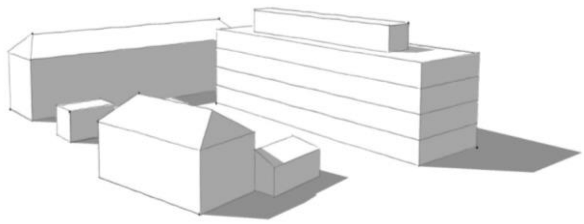


Figure 86: Case Study 4

The building is a compact office building, 18 m deep, 130 m long and 14 m high, with four floors and an underground car park, planned as a timber construction. The proposed building services will have either a balanced mechanical ventilation system - for approx. 50 % of the areas, such as meeting rooms, restrooms, and other internal rooms (KfW55[3] standard) or a supply and exhaust air system for 100 % of the areas (passive house standard), depending on the final building standard selected. Within the framework of the preliminary design, two building standards - the passive house and the KfW55 house - should be compared by the planning team. The focus lies in reducing life cycle costs and optimizing thermal comfort.
To do so, LCC comparison of variants methodology has been applied. No comprehensive LCC analysis was carried out in this process, but a differential cost analysis of the relevant sub-areas was conducted.

Variant 1: The architects planned a building for the client with the necessary insulation thickness for the building standard "KfW55" (and in this context estimated costs for the building). In this first variant, a supply and exhaust air system for approx. 50 % of the areas (meeting rooms. sanitary rooms and other internal rooms) was considered.
Variant 2: The owner wanted to examine resulting differences in the calculation if a complete supply and exhaust ventilation system (passive house standard) with air humidification were considered.
Variant 3: The third building variant took into account a building envelope similar to the passive house quality but with a ventilation system similar to the first calculation.

Results: The calculation results show that the passive house with only a large PV system and without air humidification pays out the additional investment compared to a KfW55 house over the life cycle. Due to the changed view of a building - towards a life cycle approach - a building project is no longer measured solely by its investment but also by its life cycle performance. As a result, more expensive investments become cheaper over the life cycle.
After the LCC variants comparison, a CO_2 emission analysis was carried out to further expand the understanding of the implication of the selected design choices.
Calculation 3, as already determined for the LCC analysis, is a good compromise between life cycle costs and CO_2 emissions.

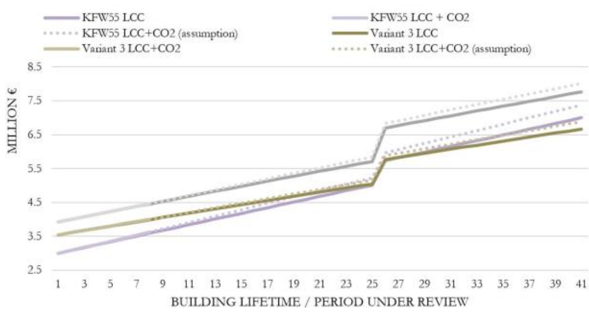


Figure 87. Life cycle costs of the building variants (including and excluding CO_2 costs over 40 years).

[3] KfW is a German Efficiency House Standard (new construction and refurbishment). A KfW Efficiency House 100 meets the requirements of the Energy Saving Ordinance (EnEV). The EnEV sets out specifications that calculate the transmission heat loss and annual primary energy demand of the "reference building" for each construction or renovation project.

Luisengarten Ambiente – Köhler & Meinzer

Figure 88. "Luisengarten Ambiente" case study.

"Luisengarten Ambiente" consists of two residential complexes built in 2019 with 10 units each, a 2,060 m² net floor area, a gas-fired CHP for heating, the owner community as the operator of the PV, battery storage, KfW55 standard. Two buildings are considered one unit. They share the underground parking, a CHP-plant for energy production, the DHW system, and a PV system with battery storage. The main goals of the project are a high-quality building and a low energy consumption level. The owner community becomes an operator and benefits from the profits generated thanks to a new billing model for electricity generation by CHP and PV, which constitutes a new BM.

BM analysis: By participating in the CRAVEzero project, Köhler & Meinzer had the opportunity to view its activities from a different perspective. The intuitive approach to choose the BM was shifted to a more rational and theoretical one.

The main findings which helped to develop the BM are:

- Focus on building and using on-site renewable energy based on a well insulated building envelope and efficient building services rather than theoretically saving on expensive measures for insulating the buildings beyond nZEB level.
- The concentration of subsidies on the energetic improvement of existing buildings.
- Greater focus on efficiency potential in terms of hot water and electricity consumption.

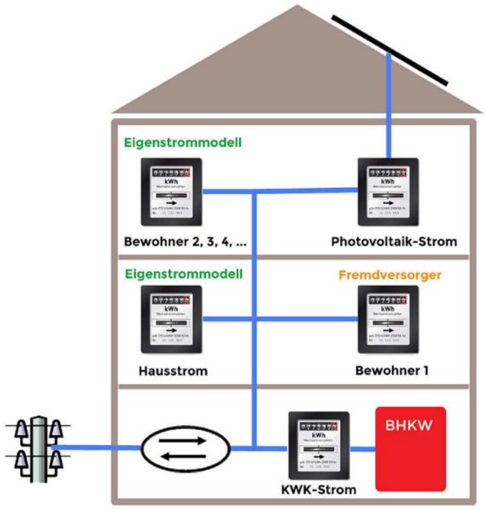


Figure 89. Tenant electricity model (Source: Energiekonzept Ortenau GmbH).

Several key activities, value propositions, and effects for the customer relationship have been identified and integrated in the new BM:

- *Customer satisfaction* versus how it is possible to influence customer behaviour (in the sense of economical use of energy).
- *Prosumer:* change from a classical understanding of being a "patronized consumer" to a producer of energy.
- Win-win-situation for clients when the customer pays more but receives an added value that is worthwhile for him/her in an overheated real estate market.
- Increasing acceptance of nZEBs and technologies if the customer is involved in energy issues.
- Economical one-stop solution with manageable effort for the client and property management.
- Meeting national requirements in terms of ecological and economic regulations.

La Distillerie – Bouygues

Figure 90. "La Distillerie" case study.

The project consists of a new mixed usage sustainable district with a net floor area of 62,000 m². The municipality wanted to redevelop an existing contaminated land into an urban land with an equivalent area of agriculture using green roofs and a landscaping arrangement. The project will include several typologies of buildings: commercial, offices, private and social dwellings, hotels, a kindergarten, and a farm.

The main priorities of the design are the energy autonomy and no consumption or usage of the agricultural field – privileging urban farming. The CRAVEzero process map was used for this prototypical implementation to demonstrate that a structured process can offer opportunities – either to build at a lower cost for the same performance or to enhanced performance at the same cost.

For this reason, the methodology related to optimized nZEB processes will be used during the political decisions and urban planning phases. In fact, a series of actions should be taken with the support of the process map at the indicated timing in order to minimize the cost of the whole project. Some examples of the actions investigated in a preliminary design stage are:

- Action 101: Definition of political and legal framework for nZEBs
- Action 107: Funding schemes for nZEBs
- Action 115: Assessment of the potential for decentralized renewable power generation
- Action 116: Consideration of thermal/electrical micro-grids on district level
- Action 114: Assessment of energy efficiency and renewable energy potentials
- Action 118: Preparation of renewables budget and estimate return on investment/LCC
- Action 113: Definition of basic envelope attributes and energy targets
- Action 109: Requirements analysis

Regarding the planning phase, some of the analysed actions are the following (Figure 91):

- Action 216: Definition of allowed thermal comfort ranges
- Action 206: Flexibility and adaptability
- Action 202: Improve window to wall ratio
- Action 218: Mechanical ventilation
- Action 222: Renewable energy - Photovoltaics
- Action 217: Natural ventilation
- Action 207: Improve daylight factor
- Action 205: Efficient space design
- Action 215: Energy performance calculation
- Action 209: Plug loads and internal gains
- Action 208: Domestic hot water
- Action 224: Storage facilities

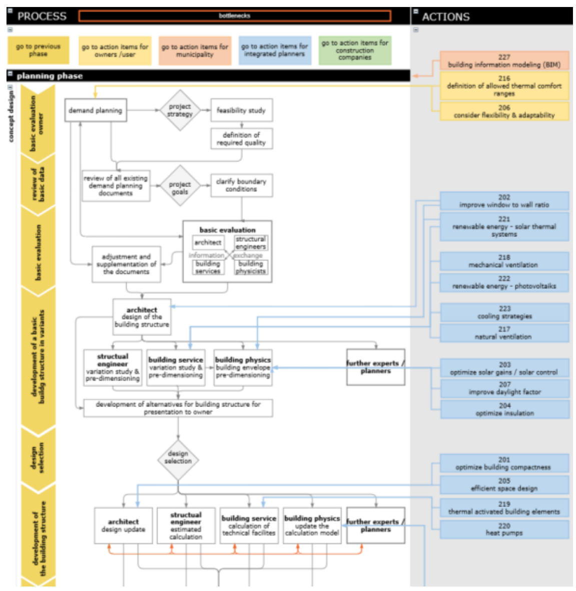


Figure 91. Process map of the planning phase with the overview of actions including numbering.

The main goal of this application is to reduce cost and time due to incorrect or late decisions made to meet the nZEB target.

Ön – Skanska

Figure 92. "Ön" case study.

Skanska's prototypical implementation is a project named Ön. It is a well insulated and airtight building with balanced ventilation, heat recovery, ground source heat pump, wastewater heat exchanger, and photovoltaic panels. Goals are net ZEB and Skanska Deep Green standards, low CO_2-emissions from the construction phase, good comfort, and indoor environmental quality. The process described in this report therefore largely follows a regular project process as it appears in Skanska's ordinary workflow.

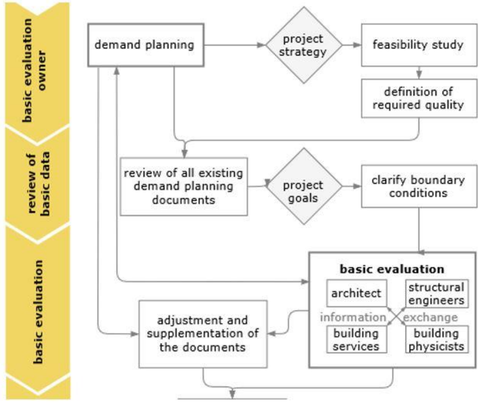


Figure 93. Part of CRAVEzero planning process equivalent to Skanska's Phase: Idea phase.

This methodology presents many similarities to the CRAVEzero approach and tools (e.g., the process map, life cycle tracker, and process management tool, which complement the Skanska Deep Green pre-study templates very well). All these tools collect detailed and tailored actions for nZEB planning. They could be used, among other sources, by Skanska's green development division to refine and create new tools and information leaflets regarding design and construction of energy efficient Deep Green NZEBs.

9. RESULTS AND DISCUSSION

Several results were achieved within the CRAVEzero project: life cycle cost reductions of nZEBs, measurable improvements of the energy balance, enhanced use of renewables, improved processes, and greater economic value.

Cost reduction

CRAVEzero defined an integrated approach for planning and constructing a new nZEB that is able to reduce the design phase up to 20%. In particular, the process map allows a comprehensive overview of the phases and activities as well as of the actors involved during the life cycle of a nZEB, identifying the possible pitfalls and bottlenecks and the relative countermeasures (Chapter 3).

Moreover, the conception of the optimal nZEB solution sets (thanks to the parametric simulation approach) has been strongly improved (Chapter 6).

Thanks to an optimised nZEB design with the CRAVEzero parametric method (Chapter 5), it was shown that it is possible to save up to 16% of the financing costs, 23-29% of operational costs and up to 30% of replacement and investment costs. This has been demonstrated by evaluating the minimum and maximum NPV during all phases of the building life cycle (combining different building, HVAC, and renewable configurations). Considering only the solutions leading to the nZEB target, the range between the minimum and maximum accounts for 7-10% in line with the current extra-cost of nZEBs identified at the beginning of the project (+171€/m² from the project ZEBRA2020).

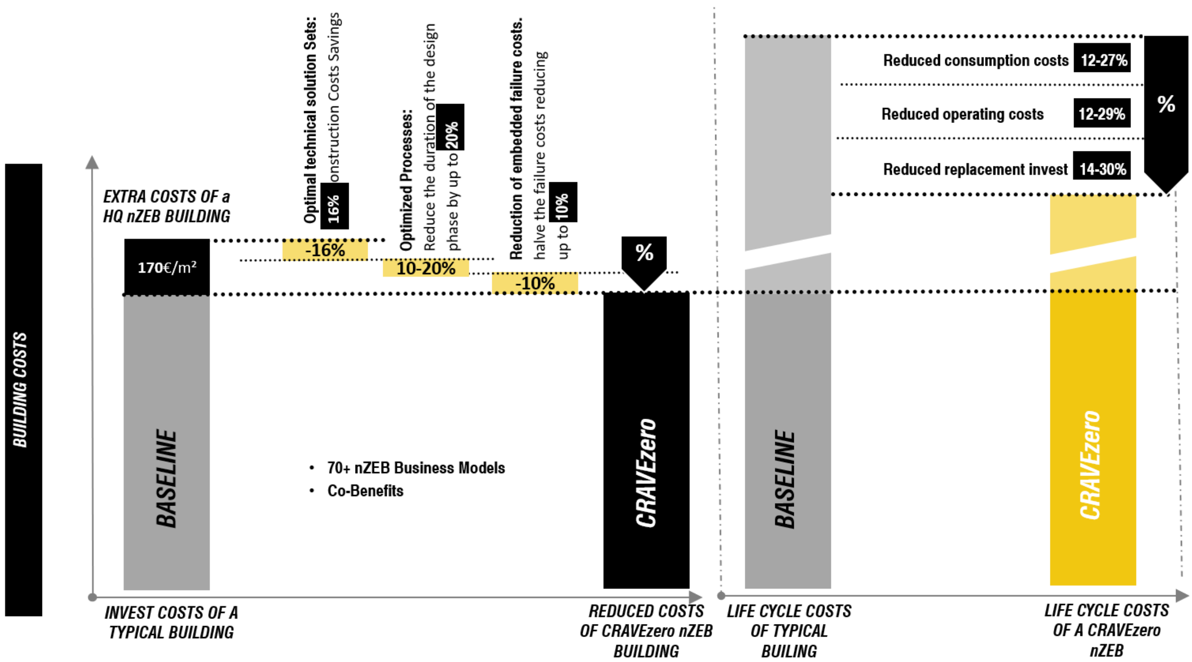


Figure 94. Impact and cost saving potential.

Reference schemes for nZEB urban planning and building design process

A framework for the development of an effective overall process that covers all stages of the life cycle has been finalized and the first version was published in Deliverables 3.1 and 3.2. It provides professionals with a series of useful information, so a developer can have a clear estimation of the preparation, costs, and actions to reach the nZEB standard. The website for the reference scheme/process map is nearly finalized.

The "Interactive Life Cycle Process Map" (LCPM) connects all phases for the entire project lifecycle. It also comes with a downloadable "life cycle tracker tool," an easy-to-use Excel file with VBA macros that combines project roles, actions, and design responsibility matrices. It is based on the experience of the whole consortium in the area of holistic project management with a focus on integral building planning of nZEBs. It supports how key performance parameters to achieve successful nZEBs should be prioritized and can be tracked along the whole life cycle process. It can be downloaded here:

Pinboard: pinboard.cravezero.eu
Process Map: http://www.cravezero.eu/pinboard/PMap/ProcessMap.htm

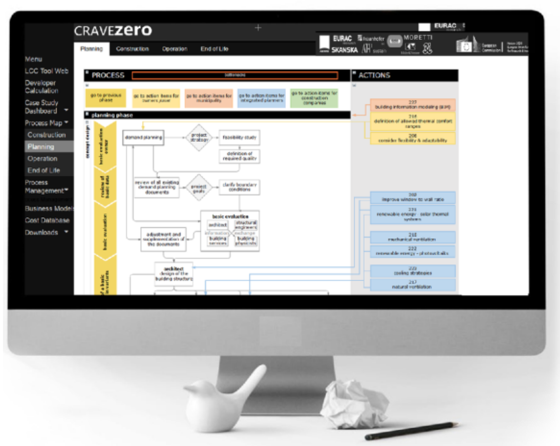


Figure 95: Interactive life cycle process map.

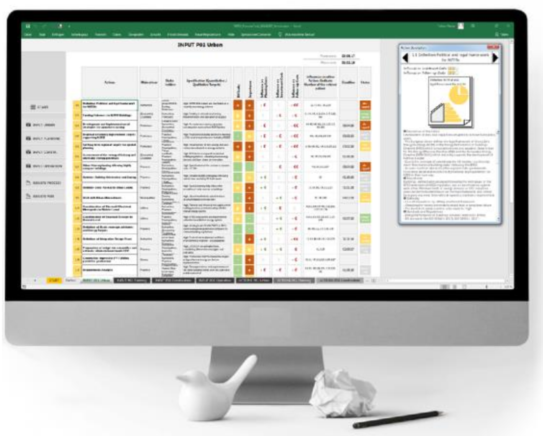


Figure 96: Life cycle tracker tool.

Actions, stakeholder-relations, pitfalls and bottlenecks, as well as the required goals, are pointed out in detail. Considering the importance and the complexity of reaching nZEB-standard in a cost optimal way for all the different stakeholders, multiple actions are required. These are, however missing from the standard planning process. This report provides a practical methodology to achieve the best conditions towards cost optimal nZEBs in the whole planning, construction and operation process considering all relevant decisions, co-benefits, involved players, and cost reduction potentials.

The main additional advantages of integrating the "CRAVEzero process" into standardized building processes are listed as follows:

(1) Reduce risks
(2) Speed-up construction and delivery
(3) Control costs and energy performance
(4) Foster integrative design and make optimal use of team members' expertise
(5) Establish measurable success criteria.

Structured methodological approach for optimising integration of renewables and nZEB technologies

Materials and information to define effective low-cost technology solution sets for new nZEBs has been documented in a database. The main sources adopted were the project case studies, literature, and previous projects/data from the practices of the Industry Partners.

Detailed building simulations showed the potentials of passive approaches to lower the energy demand and LCC of nZEBs. An optimization of passive approaches and the building design are the basis to design low-LCC nZEBs. Efficient and renewable technology buildings can be realised, and low-tech concepts are the most promising.

An operative methodology to achieve the best conditions towards optimal cost nZEBs has been set-up (see CRAVEzero Deliverables 4.1, 4.2, 4.3, 5.1, 5.2, 5.3, and 5.4 for more details).

Comprehensive solution sets and respective investment costs (including expected costs and market developments for the major technologies) based on key industrialized components have been collected.

Cost reduction potentials for technologies cover the aspects of energy production, efficiency and use for heating, cooling, and electricity. They are largely based on implementing passive systems for the building envelope, aperture, and glazing not to mention the thermal mass requirements (see CRAVEzero Deliverables 4.1 and 4.2 for more details). The results are also integrated in a cost database in the CRAVEzero pinboard.

Existing and new KPIs were used to analyse the energy flexibility and grid interaction of CRAVEzero buildings. Renewable energies and higher-level grids were also introduced.

The assessed KPIs are:
(1) Self-consumption,
(2) Autarky rate,
(3) Grid-supportiveness coefficient (GSC), and
(4) Smart readiness indicator (SRI).

In order to quantify the effect of different technology sets on the quantitative KPIs, the two case studies “Brussels” (Germany) and “Moretti More” (Italy) were analysed in detail. The smart readiness of the CRAVEzero buildings was based on the European SRI methodology updated fall 2019.

As the building management models mainly address the operational phase of a building, possible cost savings in this phase of the life cycle were the focus in CRAVEzero. A detailed assessment of the investment and life cycle costs of different technology sets for building to grid interaction is described in the publications of Work Package WP04.

The identification of suitable methods for the energetic-economic optimization of highly efficient buildings in all life cycle phases is a prerequisite for broad market implementation.

In Deliverable D6.1/ D6.2 “Parametric models for buildings and building clusters,” the method was applied to the CRAVEzero case studies to perform multi-objective energy and cost analysis over the life cycle of the buildings. In total, more than 230,000 variants were calculated and analysed with KPIs: financing costs, net present value, balanced primary energy demand, and balanced CO_2 emission. The calculation results are also available on the pinboard.

RELIABLE LIFE-CYCLE-COST MODELS FOR nZEBs

12 existing reference buildings provided by CRAVEzero industry partners considered representative of nZEBs with different functions (both residential and non-residential buildings) have been analysed.

The examined case studies have been scanned to identify the nZEB-related cost for the structure, the design, and the construction process. They will support a baseline of the current costs and performance of nZEBs.

All the different costs of the 12 case studies over the given study period (as adjusted to reflect the time-value of money) have been addressed. This method complied with the one described in ISO 15686-5 and the cost optimal method recently defined by the EU based on EN 15459. The comparative methodology framework accounted for usage patterns, outdoor climate conditions, investment costs, building categories, maintenance and operating costs (including energy costs and savings) and earnings from produced energy.

In order to evaluate and compare different configurations a performance-based characterisation of nZEBs and their implementation at European level was analysed.

In the section where the nZEB requirements for different countries were compared, a few key performance indicators (KPI) were defined to draw comparisons among different requirements. It later became relevant to define a full set of KPIs to summarise and display the results collected from the case studies.

This document describes the procedure followed to define the KPIs as well as the set of benchmarks (the main results are summarized in D2.4: KPIs for performance-based characterisation of nZEBs). All relevant KPIs were evaluated for both the front-runner buildings and the prototypical implementations and are included in the cost database developed in the project (D7.4).

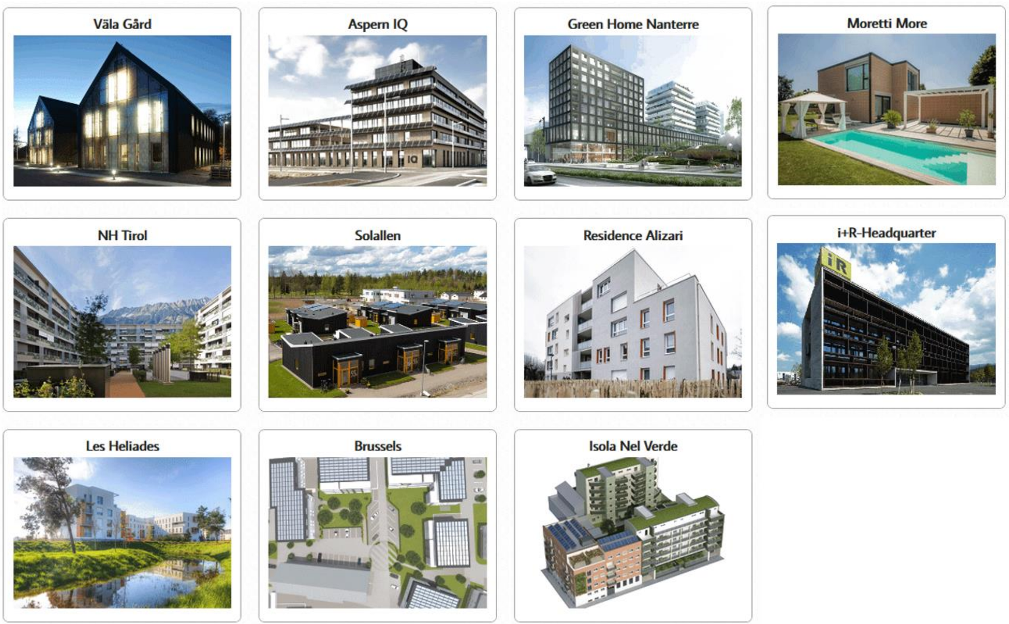


Figure 97: 11 analysed CRAVEzero case studies

Table 30: KPIs assessed for the case studies

Cases	Design	Construction	Investment	Maintenance	Energy cost	Cost of RES	Energy demand heating	Energy demand for DHW	Energy produced from RES	Annual CO_2 Emissions	U-opaque	U-glazing
	€/m²	€/m²	€/m²	€/m²	€/m²	€/m²	kWh/m²	kWh/m²	kWh/m²	$kgCO_2$/m²	W/(m² K)	W/(m² K)
GreenHome	-	1051.98	1051.98	748.55	-749.87	28.51	6.45	5.80	185.89	22.13	0.12	0.83
Les Héliades	91.11	1158.59	1249.71	691.41	355.37	43.88	22.56	18.88	12.00	11.60	0.22	1.51
Residence Alizari	161.38	852.99	1014.37	589.13	417.40	28.78	12.77	34.16	10.52	22.00	0.17	0.97
NH Tirol	52.10	994.92	1047.02	625.06	268.88	-	12.13	19.03	-	16.42	0.15	0.73
Parkcarré	230.42	697.11	927.53	439.60	142.73	53.33	23.27	14.82	25.94	10.59	0.27	0.85
More	201.14	2771.67	2972.82	2073.85	444.21	38.69	19.49	12.13	-	29.34	0.20	1.20
IsolaVerdeA	-	2249.89	2249.89	1370.61	644.71	-	30.03	23.53	2.88	46.00	0.25	1.18
IsolaVerdeB	-	2072.63	2072.63	1292.11	665.05	-	30.45	23.34	2.32	45.91	0.28	1.20
Solallén	125.74	1062.84	1188.58	384.15	216.51	56.80	18.38	6.26	4.44	27.49	0.07	0.92
Väla Gård	142.35	1291.63	1433.98	774.42	95.22	71.38	15.64	1.35	34.01	25.37	0.07	0.87
Aspern	131.82	844.76	976.58	497.95	178.22	39.44	16.78	7.15	14.55	13.32	0.10	0.92
I.+R. Headquarters	393.13	2215.74	2608.86	1283.76	499.64	-	17.42	0.20	-	83.78	0.21	0.75

The detailed data for the analysed buildings represent a starting point for the definition of benchmarks in terms of cost and energy performances for new nZEBs. The definition of reliable benchmarks representative of different European countries as well as normalized values valuable for all Europe represent an important reference for the definition of performance-based tenders for new constructions.

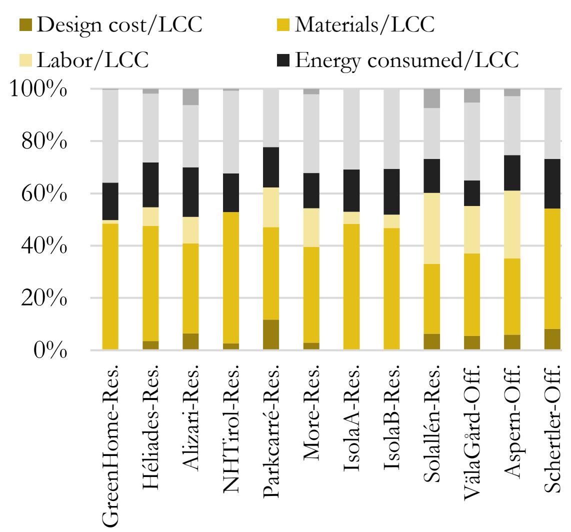


Figure 98: Life-cycle cost breakdown – share of the phases.

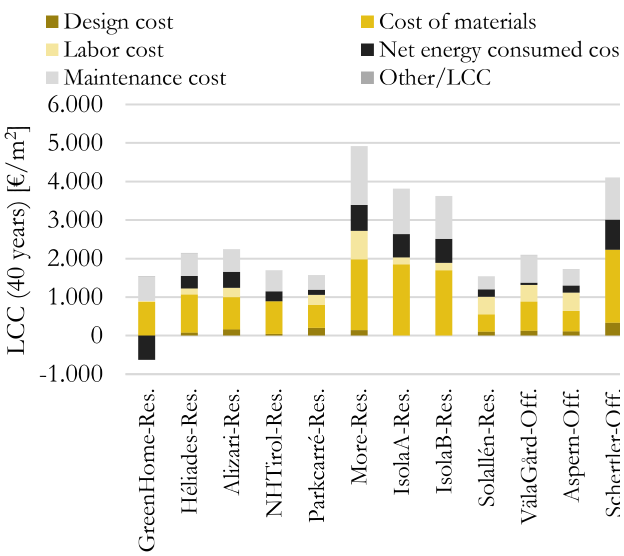


Figure 99: Life-cycle cost breakdown – normalized values.

- An extensive assessment of the cost-effectiveness of the 11 CRAVEzero - nZEB case studies as defined by the EU KPIs and existing literature, taking into account the energy and economic balance, Indoor Environmental Quality, functionality, and real estate value (see Deliverable 2.2).
- The list of KPIs for assessing the performances of nZEBs and to define reliable benchmarks (see Deliverable 2.4).

- A database for benchmarking actual NZEB life cycle costs (LCC) including urban and building planning, construction, commissioning, operation, maintenance, management, and end-of-life, has been developed (see Deliverable 2.2).
- Inventory of different existing business models, considering: i) the CRAVEzero case studies, ii) the approach in the participating countries, and iii) examples of successful case stories have been finalised (see Deliverable 5.1).
- Existing and new examples for innovative nZEB business models have been collected showing advantages to different types of stakeholders while positively contributing to the environment and society (see Deliverable 5.1/ 5.2).
- Available tools from the pinboard: LCC calculator in the simplified on-line version and in the detailed downloadable one.
- nZEB revenue stream tool available from the pinboard for evaluating the impact of co-benefits in the life-cycle cash flow of a NZEB.

Demonstration of co-benefits: optimal architecture and building configuration for high quality living and/or working environment and real estate value (Chapter 6):

In the course of the CRAVEzero project, over 30 possible co-benefits/ added values for high quality nZEBs an interactive tool was developed for the pinboard (http://www.cravezero.eu/pinboard/Developer/Developercalc.htm), which shows the influences of the various co-benefits with regard to project costs in both residential and non-residential buildings. In order to determine the added value of these co-benefits, this tool enables the different parameters of a project to be examined more closely with regard to payback time in order to filter out decisive factors that are of particular importance with regard to nZEBs.

With the help of this tool it is possible to set individual parameters to zero in order to be able to present the individual influences of the co-benefits in a comprehensible way.

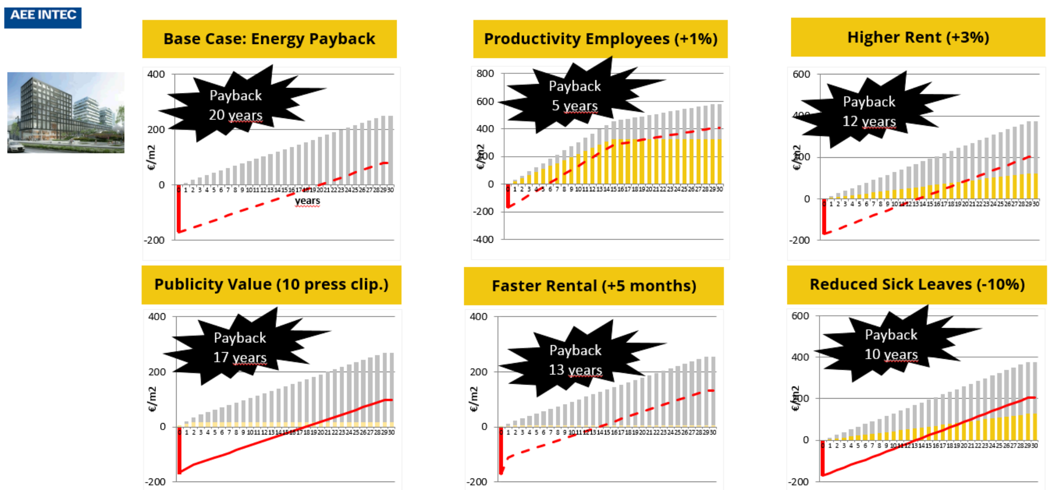


Figure 100: CRAVEzero – Co-benefits evaluation of a CRAVEzero case study (with focus on monetary and environmental values)

Benefit	Energy-related savings	Resource efficiency – "Lean is Green", circular economy	Land access/ Business opportunities	Healthy indoor environment	Improved financial terms (better bank loans etc)
Features	• Energy efficient technology (Building envelope, installations) • On-site RE-generation • Energy storage (building related, eg using electricity when the tariff is low, or using the structure to store heat)	• No waste to landfill (100 % recycling) • Design to cost (and design to fit)-methods that save material, fuel, transports etc	• Promise of green performance to get land for building purposes or cheaper price for the land • Earning credibility and long-term trust from officials at for example municipalities, or customers • Opening door to co-operations with common (green) goals	• More and better daylight • Improved ventilation • Lower noice-level • Avoidance of hazardous chemicals, VOC and moisture/mould damages • More greenery indoor and outdoor • Thermal comfort	• Lower rate (e.g. 0,25%) on bank loans for (certified) green buildings (often residential) • Possibility to receive external funding • Green bonds • Better terms for insurances
Direct value	• Lower operational costs • Lower CO2-emissions • Energy security	• Lower costs during production, thus better profit for contractor • Lower CO2-emissions	• Better margins (profit)	• Higher work productivity (office buildings, hospitals, schools) • Reduced employee turnover • Reduced sick-leave • Lower rental vacancies	• Better margins (profit) • Lower economical risks
Indirect value	• Increased property value • Possibility to get a bigger loan for the investment • Positive publicity and image, market differentiation • Lower risk for future price increases • Driving / pushing innovations, which in turn promotes startups/SME's etc	• More green values, like saving natural resources • Market differentiation	• New business opportunities and co-operations • Market differentiation • Engagement from many more than "green" people – "green halo effect"	• Increased property value • Engagement from many more than "green" people • Market differentiation – "green halo effect"	• Engagement from many more than "green" people – "green halo effect"

Figure 101: Exemplary co-benefits analysed within the project (with focus on monetary and environmental values) by SKANSKA

60+ low-LCC nZEB business models (Chapter 7)

To promote the nZEB market and to create win-win situations for the stakeholders, we allocated business models in each life cycle phase. Within the project, stakeholders have been invited to round table discussions and asked their preferred business ideas and the relevant framework conditions. CRAVEzero evaluated over 60 existing business models in several EU countries (from the biggest markets, taking into account regional particularities). Some 16 new created business model ideas have been created based on the findings and discussions of the project. All stakeholders were considered, ranging from municipalities to end-users and building occupants. Each group of stakeholders is empowered to define (or be aware of) BMs for low-LCC nZEBs that offer them profitable situations and benefits.

A broad range of business models developed in CRAVEzero consider technologies as well as planning and construction process, thus affecting certain requirements. The BMs create answers to the key questions: *Who are our customers? What are their needs? What do we offer?* Value propositions to serve customer problems and satisfy customer needs (in terms of performance, customization, speed, comfort, design, and price) have been defined.

The BMs do not solely consider economic aspects but take into account energy, environmental, and social aspects arranged along the value and life-cycle chain.

On the CRAVEzero website and pinboard, interested nZEB stakeholders can find inspiration and facts about what makes these business models successful. Business models can be adjusted (or new ones can be created). This interactive tool gives also deeper insights with links to the related technology sets or processes to give more value to the BM. All BMs can be found in the deliverables documents or can be directly printed out from the interactive web tool.

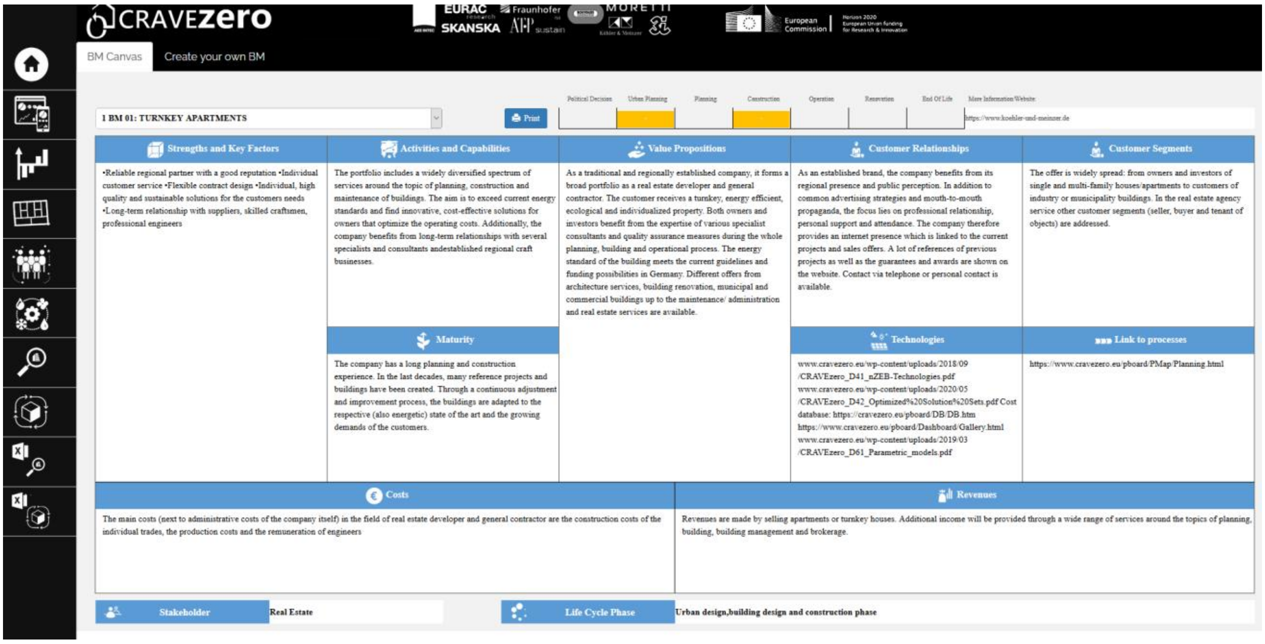


Figure 102: Business model canvas creator and database of over 60 nZEB business models (Deliverable 5.4) https://www.cravezero.eu/pboard/BM_Canvas/BM_Canvas.htm

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CRAVEzero pinboard

All the results reported above have been included in the *CRAVEzero pinboard*, an interactive support web tool for most of the involved stakeholders (developers, design team, advisors, general contractors, suppliers/subcontractors, investors, and financers). The base structure for the CRAVEzero pinboard is a web-based framework supporting low-LCC nZEB BMs and enabling the organization of data and information in a practical and comprehensible way.

The pinboard can be accessed via pinboard.cravezero.eu or http://www.cravezero.eu/thepinboard/

The first version of the pinboard has been online since August 2019 and there are already webinars on the Build Up-platform and national implementation working groups. The Industry Partners used the tools of the pinboard within prototypical implementation in order to assess their usability and provide feedback for the final fine-tuning of the general set-up. The final release of the pinboard was finalised in February 2020. For each tool of the pinboard, a user manual is available as well as a video tutorial with the main features and indications for using the tool. The pinboard was presented during the CRAVEzero webinar held on June 24th for approximately 100 participants.

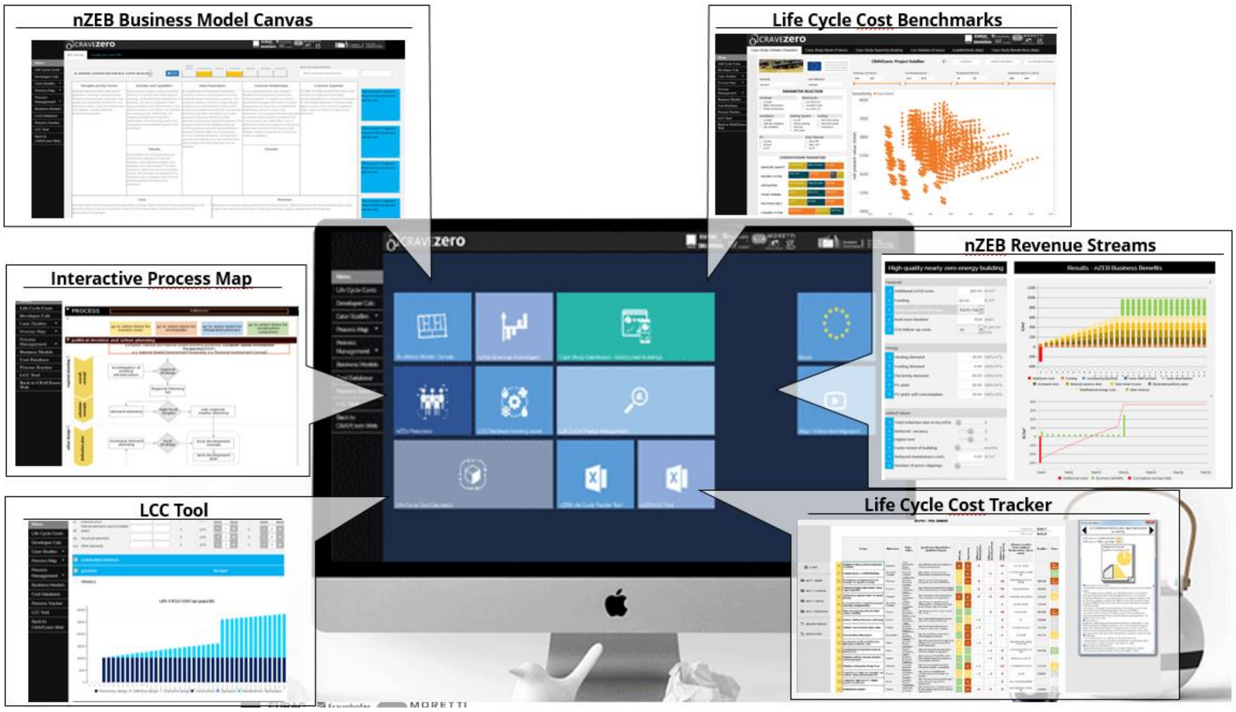

Figure 103: CRAVEzero pinboard – Overview.

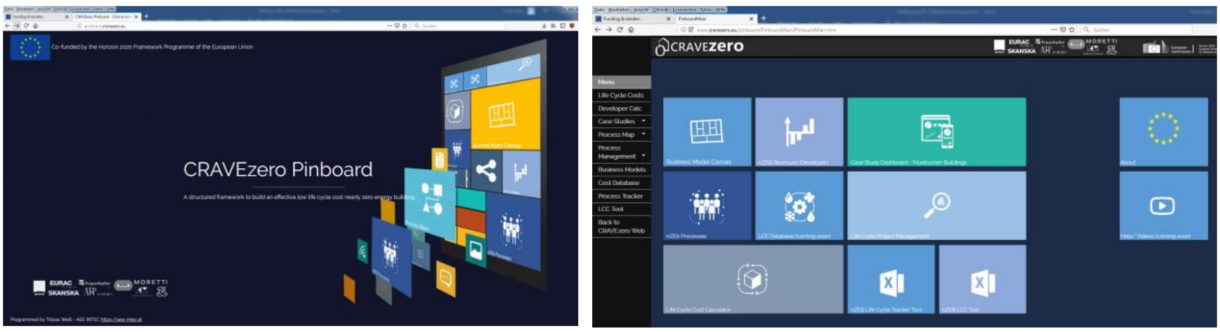

Figure 104: CRAVEzero pinboard GUI.

Market penetration of effective, robust and cost-effective nZEBs

nZEBs are usually designed and constructed in order to minimize operational energy consumption while exploiting the renewable energy available on site. Nevertheless, the added value of real estate regarding low energy consumption and high-performance technologies is almost negligible, and the foreseen energy performance of the building represents an important aspect for purchasing a new house to only 13% of the users. The price of the house and its location represent the main criteria for the choice of the property. Therefore, the market uptake of nZEB needs a more attractive business model. CRAVEzero reduces the price of new nZEBs around 7% – permitting the increase of the yearly market from 385,370 dwellings (at present) to 448,624. Purchasing a CRAVEzero nZEB will become more affordable when considering the operational costs. Figure 105 shows the global cost of a building (the initial investment, the operational costs for energy supply, and the periodic maintenance costs) after 20- and 40-years' interventions on the heating system and a 30-year intervention on the building envelope). The evaluation has been carried out considering an average dwelling in three cases: a new nZEB, a

CRAVEzero nZEB, and the average value between the two. Thanks to CRAVEzero, it is possible to achieve a significant cost reduction, considering the building life cycle, after 40 years of up to 9% in comparison to a traditional nZEB. In addition, the initial cost for a CRAVEzero nZEB is lower than for a new building and this would boost the nZEB market. Moreover, the confidence in the CRAVEzero technology, processes, tools generated via the measured actual benefits, and communication to the different stakeholders will increase penetration of the design and construction nZEB solutions into the EU and global markets.

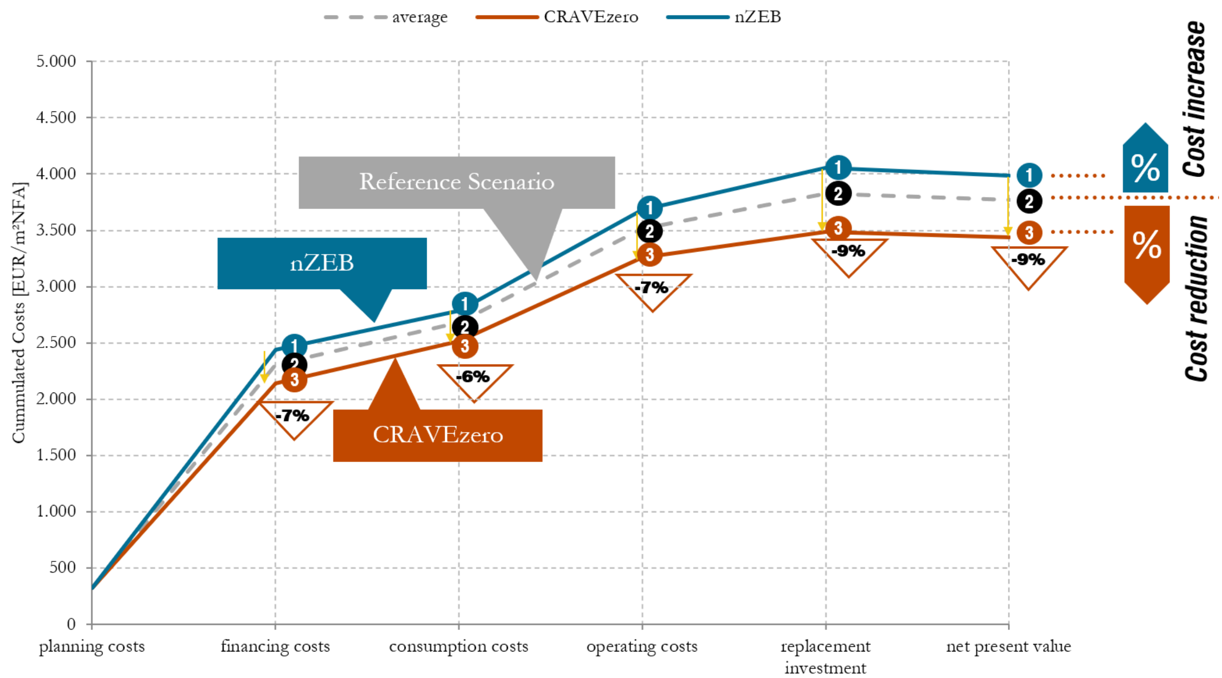

Figure 105: Lifetime global costs for buildings: construction, operation, and maintenance.

With the collaboration of the Industry Partners, the approach defined within CRAVEzero has been applied to six prototypical LCC nZEBs. In particular, each case study implemented the methodology as defined by the project and, when possible, adopted one or more of CRAVEzero tools included in the pinboard. The implementation showed the potential benefits of each project approach while highlighting the improvements compared to the traditional process. In particular, Deliverable 7.2 analysed one nZEB model (DoppioUno by 3i) with the implementation of the LCC calculation and the business model canvas. It also assessed a replicable prefabricated single family house (Casa More – Franchino) where a process map and LCC were implemented.

The other case studies are analysed in Deliverable 7.3. Furthermore, the project partners already have several projects under development and construction, and the Industry Partners continue to implement the tools and approaches as developed within CRAVEzero, further demonstrating the replicability of the method.

Table 31: Upcoming nZEB projects by CRAVEzero partners

Partner	Project	Location	Building use/Typology	Client
Moretti	Casa More Zanetti	Italy	Residential Single-family house	Zanetti Manuel
Moretti	Casa More Costa	Italy	Residential Single-family house	Costa Giorgio
Moretti	Casa More Scaratti	Italy	Residential Single-family house	Scaratti Francesca
Moretti	Casa More Zanini	Italy	Residential Single-family house	Zanini Tommaso
Moretti	Casa More Brambilla	Italy	Residential Single-family house	Sig. Brambilla
Moretti	Casa More Boldrini	Italy	Residential Single-family house	Boldrini Marco
3i	Villaggio Alessandria	Italy	Residential – Block of flats	Owners
3i	Tortona 1	Italy	Residential - Block of flats	Owners
3i	Tortona 2	Italy	Residential - Block of flats	Owners
3i	Via Napoli	Italy	Residential - Block of flats	Owners
3i	Voghera 1	Italy	Residential - Block of flats	Owners
3i	AMAG2020	Italy	Office building	Multi-utility Company
ATP	DRV Karlsruhe	Germany	Office	Deutsche Rentenversicherung
ATP	Bauamt Weilheim	Germany	Office	Staatliches Hochbauamt Weilheim
ATP	Ceratizit	Germany	Office & Production Building	Ceratizit Logistik GmbH
ATP	Kathlisches Siedlungswerk	Germany	Housing	Katholische Siedlungswerk München GmbH
ATP	Magdas Großküche	Austria	Industrial kitchen	Caritas Wien
ATP	Aspern TZ2	Austria	Office	WWFF Business Service Center GmbH
ATP	DOC Zagreb	Croatia	Outlet Center	Designer Outlet Croatia d.o.o (UJEA Centntres)
K&M	Luisengarten, Erna-Hötzel-Str. 1-3	Germany	Multi-storey apartment building	Community of real estate owners
K&M	Luisengarten, Erna-Hötzel-Str. 5-7	Germany	Multi-storey apartment building	Real estate owner community
K&M	Luisengarten, Erna-Hötzel-Str. 9-13	Germany	Multi-storey apartment building	Real estate owners
K&M	Luisengarten, Erna-Hötzel-Str. 8-12	Germany	Multi-storey apartment building	Real estate owners
K&M	Weissachrün	Germany	District with apartment building (63 apartments)	Real estate owners, property owner
K&M	Multiple single-family houses, semi-detached house.	Germany	Single-family houses	Owner
K&M	Luisenstraße 2	Germany	Apartment building	Property owner
Bouygues	Les Tanneries	France	Residential, hotel, retirement community	Private and public
Bouygues	Les Fabriques	France	Residential, offices, commercial, hotel, public realm, apparthotel	Private and public
Bouygues	La chocolaterie à Noisiel	France	Housing, chocolate museum	Private and public
Bouygues	O'Mathurins	France	Housing and offices	Private
Bouygues	Quartier Flaubert	France	Housing, kindergarten, elderly housing and offices	Private
Skanska	Gottorps hage, Etapp 1	Residential project development	Single family houses	
Skanska	Solträket och Havsbrynet		Apartment buildings	14,894
Skanska	Sjömarkenskolan idrottshall		Other	796
Skanska	Villa Kviberg	Commercial	Retirement home	5,406
Skanska	Tolered	Residential	Apartment buildings	
Skanska	Maltren	Commercial	Retirement home	3,618
Skanska	Östermalm	Commercial	Office building	3,500
Skanska	Skärgårdskyrka	Commercial	Retirement home	
Skanska	Överbyggnaden E45	Commercial	Office building	
Skanska	Fader Berström	Residential		
Skanska	Villabacken etapp 2	Residential		
Skanska	Bunkeflo etapp 2	Residential	Apartment buildings	
Skanska	Hjärup Västerstad	Residential	Apartment buildings	
Skanska	Ön	Residential	Apartment buildings	7,000
Skanska	Äppelgården	Commercial	Retirement home	5,100
Skanska	Borstahusen	Residential	Single family houses	5,200
Skanska	Täbz park	Residential	Apartment buildings	13,000
Skanska	Rotorfabriken	Residential	Apartment buildings	

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11. CRAVEZERO - TERMINOLOGY

Life Cycle Phase

1) **Political Decision and Urban Planning**
   a) Regional Planning
   b) Urban Design
   c) Preparation and Brief

2) **Planning**
   a) Concept Design
   b) Authorisation Planning
   c) Technical Design

3) **Construction**
   a) Tender/Construction Contracts
   b) Construction
   c) Commissioning/Handover

4) **Operation**
   a) Operation
   b) Monitoring
   c) Maintenance

5) **Renovation**
   a) Small Renovation
   b) Deep Energy Retrofit
   c) End of Life

Categories of Life Cycle Costs (Simplified Cost Breakdown based on ISO 15686-5)

1) **Infrastructure/Urban Planning**
2) **Planning**
3) **Construction**
4) **Operating**
5) **Maintenance/Repair**
6) **Renovation**
7) **Disposal**
8) **Non Construction**
   a) Land and Enabling Works
   b) Finance
   c) Externalities
9) **Income**
   a) Rental Income
   b) Third Party Income

Stakeholders

- Society
- Authority/municipality
- Real estate fund
- Profit developer/investor
- Landlord
- Client/Owner
- Tenant/user
- Masterplanner
- Architect
- Civil and structural engineer
- Building services engineer
- Planning consultant
- Construction company
- Facility manager
- Other additional project role 1
- Other additional project role 2

Co-Benefits

- Image
- Role model/Pioneering role
- Creative quality
- Durability
- User satisfaction
- Resource savings
- Value development
- Lettability
- Rental income
- Comfort

Glossary

ACQUISITION COST
all costs included in acquiring an asset by purchase/lease or construction procurement route, excluding costs during the occupation and use or end-of-life phases of the life cycle

CAPITAL COST
initial construction costs and costs of initial adaptation where these are treated as capital expenditures

DISCOUNTED COST
resulting cost when the real cost is discounted by the real discount rate or when the nominal cost is discounted by the nominal discount rate

DISPOSAL COST
costs associated with disposal at the end of a life cycle

END-OF-LIFE COST
net cost or fee for disposing of a building at the end of its service life or interest period

EXTERNAL COSTS
costs associated with an asset that are not necessarily reflected in the transaction costs between provider and consumer and that are collectively referred to as externalities

MAINTENANCE COST
total of necessarily incurred labour, material, and other related costs to retain a building or its parts in a state in which it can perform its required functions

NOMINAL COST
expected price to be paid when a cost is due, including estimated price changes (e.g., from forecast changes in efficiency, inflation or deflation, technology)

OPERATION COST
costs incurred in running and managing the facility or built environment, including administration support services

REAL COST

cost expressed as a value at the base date (including estimated changes in price due to forecast changes in efficiency and technology) but excluding general price inflation or deflation

NET PRESENT VALUE

sum of the discounted future cash flows

Acronyms

CHP	Combined Heat and Power
CoC	Cost of Capital
COP	Coefficient of performance
DHW	Domestic hot water
DSM	Demand side management
EEX	European Energy Exchange
HVAC	Heating, ventilation, and air conditioning
LCC	Life cycle Costs
LCCA	Life cycle Costs Approach
max	Maximum
min	Minimum
NPV	net present value
nZEB	Nearly zero energy building(s)
NZEB	Net zero energy building(s)
PE	Primary Energy
PHI	Passive House Institute
PV	Photovoltaic
RES	Renewable energy sources
SCOP	Seasonal Coefficient of Performance
WLC	Whole-Life cycle Costs

Normative references

ISO 6707-1, Building and civil engineering works – Vocabulary – Part 1: General terms
ISO/TR 15686-11, Building and constructed assets – Service life planning – Part 11: Terminology
ISO Guide 73, Risk management – Vocabular
ISO 15686-5, Buildings and constructed assets – Service life planning