D2.2: Spreadsheet with LCCs

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

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

CRAVEzero - Grant Agreement No. 741223
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Co-funded by the Horizon 202

Framework Programme of the European Un

D2.2: Spreadsheet with LCCs

A database for benchmarking actual NZEB life-cycle costs of the case studies

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August 2018

FOREWORD

The present report has been developed within Task 2.2, that set-up the basis for the further project developments of Work package 5, dealing with effective nZEB business models and Work Package 6, in which parametric simulations will be carried out.

Task 2.2 aims to collect and to structure the relevant information about Life-Cycle Cost of nZEBs in an easy-to use spreadsheet, adaptable for different contexts and including all the phases of the building life.

The spreadsheet has been tested and implemented on a series of nZEB case studies provided by the industry partners of the project.

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 principles will be significant drivers in the construction sector in the next few years because all new buildings in the EU from 2021 onwards are expected to be nearly zero-energy buildings (nZEB).

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While nZEB realized so far have shown that the nearly-zero energy target can be achieved using existing technologies and practices, most experts agree that a broad-scale shift towards nearly-zero energy buildings requires significant adjustments to current building market structures. The main challenge is the cost-effective integration of efficient solution sets and renewable energy systems, in a form that fits with the development, manufacturing and construction industry processes, as well as with planning, design, and procurement procedures.

CRAVEzero will focus on proven and new approaches to reduce the costs of nZEBs at all stages of the life cycle. The primary goal is to identify and eliminate the extra costs for nZEBs related to processes, technologies, building operation, and to promote innovative business models taking into account the cost-effectiveness for all the stakeholders.

Published by eurac research, Italy

EXECUTIVE SUMMARY

The EPBD recast (EPBD recast - European Commission, 2010) established that all new buildings have to reach by the end of 2020 the nZEB target set by the Member States (MS). In order to reach the nZEB targets while keeping investments sustainable, it is strategic to focus more on the operational phase (Moran, Goggins, and Hajdukiewicz (2017)).

The scope of this report is to provide a CRAVEzero cost spreadsheet, implementing a comprehensive and structured methodology in order to evaluate the LCC with a particular focus on nZEBs.

METHODOLOGY ADOPTED

The first part of this report describes the approach adopted for collecting the information and the methodology for evaluating the Life Cycle Cost implemented in the CRAVEzero spreadsheet and for the evaluation of the case studies

A data collection template for the evaluation of the nZEB life-cycle costs has been developed as a starting point for the upcoming CRAVEzero LCC tool. The template is structured according to the approach provided by two main sources:

1. the Standard ISO 15686 (Buildings and constructed assets - Service life planning - Part 5: Life cycle costing)
2. the European Code of Measurement, elaborated by the European Committee of the Construction Economists (CEEC, n.d.)

The tool PHPP (Feist et al., 2012) has been used for the energy performance analysis. The tool summarises all the information dealing with the energy-related features of the building components and services and provides a comprehensive overview of the technologies installed.

In addition, a data collection template for the evaluation of the nZEB life-cycle costs has been developed as a starting point for the upcoming CRAVEzero LCC tool. The template is structured according to the approach provided by two main sources:

1. the Standard ISO 15686 (Buildings and constructed assets - Service life planning - Part 5: Life cycle costing)
2. the European Code of Measurement, elaborated by the European Committee of the Construction Economists (CEEC, n.d.)

The first reference provides the main principles and features of an LCC calculation, while the second one describes an EU-harmonised structure for the breakdown of the building elements, services, and processes, in order to enable a comprehensive evaluation of the building life costs.

Following the ISO 15686, the analysis can include different phases of the life cycle, as summarised in Table 1.

			LIFE CYCLE PROCESSES	INCLUDED COSTS
Whole-life cycle costs			1. Political decision and urban design phase	Non-construction cost (cost of land, fees and enabling costs, externalities)
	Life-cycle cost	Initial Investment	2. Building design phase	Building design costs
			3. Construction phase	Construction and building site management costs
			4. Operation phase	Energy and ordinary maintenance costs
			5. Renovation phase	Repair and renovation costs
			6. Recycling, dismantling and reuse phase	Residual value of the elements

Table 1: Phases and costs in WLC and LCC

The data collection for the CRAVEzero spreadsheet is structured in three parts:

1. General project information it includes the main information of a case study and its context
2. Non-construction costs it deals with the preliminary costs for the WLC and the design phase
3. Life Cycle Costs it reports all the costs for building elements and services during construction and operation, including maintenance and energy costs.

Life Cycle cost calculation

According to the ISO 15686-5:2008, the LCC of a building is the Net Present Value (NPV), that is the sum of the discounted costs, revenue streams, and value during the phases of the selected period of the life cycle.

Accordingly, the NPV is calculated as follows:

$$NPV = \sum_{n=0}^{p} \frac{C_n}{(1+d)^n}$$

- C: cost occurred in year n;
- d: expected real discount rate per annum (assumed as 1.5%)
- n: number of years between the base date and the occurrence of the cost;
- p: period of analysis (40 years)

Energy costs

In order to provide a homogeneous and comparable estimation of the energy costs of the case studies, the evaluation is based on the calculated energy demand by using the PHPP evaluation tool (Feist et al., 2012).

In particular, for estimating both the costs and the revenues (due to the renewables installed), we consider the following contributions, in terms of final energy:

- Energy costs:
  - Heating demand [kWh]
  - Energy demand for domestic hot water production [kWh]
  - Cooling demand [kWh]
  - Household electricity [kWh] + electricity demand for auxiliaries [kWh]
- Revenues from renewables
  - Final energy generated by photovoltaic system
  - Final energy generated by the solar thermal system

The energy produced from renewables is considered in the energy balance as a positive contribution to the energy consumption, and the revenues from the renewables have been discounted from the energy costs. As a general assumption, we assumed a rate of increase of the electricity prices in accounting for 1.0% (calculated from Eurostat values in the CRAVEZero countries).

Maintenance costs

The analysis within CRAVEzero is based on standard values from EN 15459:2018 that provides yearly maintenance costs for each element, including operation, repair, and service, as a percentage of the initial construction cost. The standard provides a detailed breakdown of the costs for the HVAC, as reported in Table 2. For the passive building elements, an average yearly value accounting for 0.5% of the construction cost has been assumed for the evaluation. The value has been cross-checked with average values coming from the experience of the industry partners.

Component	Life Span (years)	Annual maintenance (% investment)
	adopted	adopted
Building elements	1.5	40
Air conditioning units	15	4
Control equipment	17	3
Cooling compressors	15	4
Duct system for non-filtered air	30	6
Electric wiring	40	1
Water floor heating	40	2
Heat pumps	17	3
Heat recovery units	15	4
Meters	10	1
Pipes, stainless	30	1
Radiators	35	1,5
Solar collector	20	0,5
Tank storage for DHW	20	1

Table 2. Selected maintenance values for building services from the EN 15459:2018

Normalisation

The analysed case studies are located in different European countries, i.e. Austria, Germany, France, Italy, and Sweden, with specific characteristics in terms of climate conditions, construction, and energy market. Therefore, in order to compare the results of the case studies and to draw a general overview of the costs of the current nZEB practices, a normalization of the collected data is needed. In particular, the construction costs have been normalised considering the data from the ECC (European Construction Costs) that calculated a European construction cost index that quantifies the ratio among the construction costs of EU countries. For the climate conditions, the normalisation has been carried out considering the Heating Degree Days of the building locations. Concerning the energy process, a common value has been adopted, accounting for 0,174 û/kWh
sumed.

PRESENTATION OF THE RESULTS ð CASE STUDIES COMPARATIVE ANALYSIS

The second part reports an overview of the results, with the comparison of relevant indicators, costs, and performances among the case studies considering the effect of local specificities, different context and use of the buildings (in italics normalised results)

DEMO CASE		TYPOLOGY	LOCATION
Bouygues	Green Home	Residential	Nanterre (France)
	Les Héliades	Residential	Angers (France)
	Residence Alizar	Residential	Malaunay (France)
ATP sustain	NH Tirol	Residential	Innsbruck (Austria)
Kohler&Meinzer	Parkcarré	Residential	Eggenstein (Germany
Moretti	More	Residential	Lodi (Italy)
	Isola nel Verde A	Residential	Milan (Italy)
	Isola nel Verde B	Residential	Milan (Italy)
Skanska	Solallén	Residential	Växjö (Sweden)
	Väla Gård	Office	Helsingborg (Sweden
ATP sustain	Aspern	Office	Vienna (Austria)
	I.+R. Schertler	Office	Lauterach (Austria)

Table 3. Case studies analysed

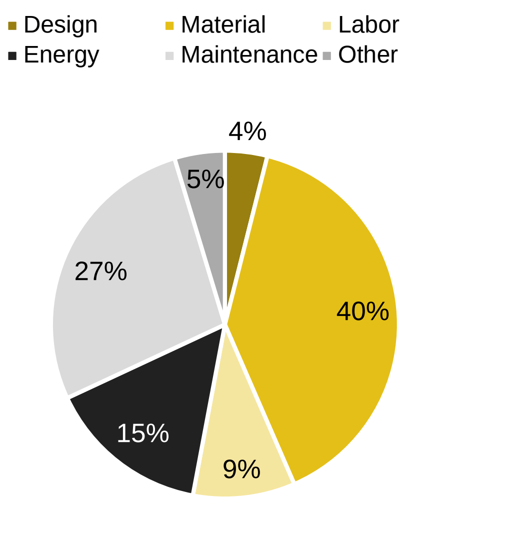


Figure 1: Life-cycle cost breakdown ð average share of the phases

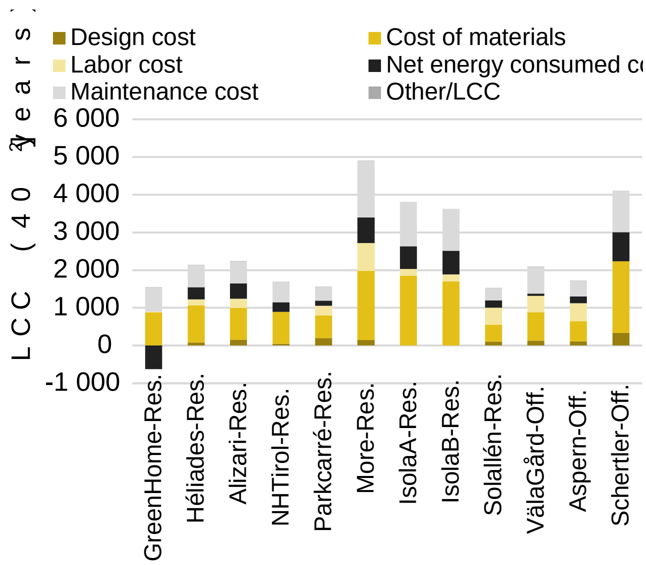


Figure 2 Life-cycle cost breakdown ð normalized values.

Figure 1 shows an overview of the average impact of all the phases on the LCC, the investment costs for design, material labor and other initial expenditures is around 60% of the LCC, while the energy and maintenance account for around 40%.

As it was expected, the energy costs during the life cycle of a nZEB represent a minor contribution to the LCC, with an average of around 15%.

Figure 2 shows the absolute values in €/m² of the LCC. It is important to point out that the contribution from the RES is accounted as a reduction of the energy cost of the overall life cycle (calculated as a balance between energy consumed and produced). In case of Greenhome, the energy reported in the chart assumes a negative value, since the energy produced is higher than the energy consumed, considering the large PV field installed.

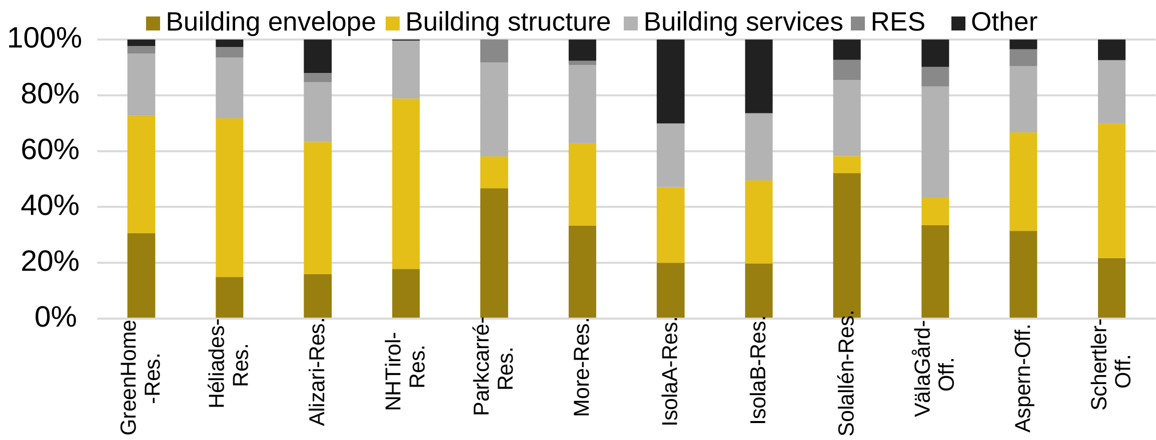


Figure 3. Construction cost breakdow

Figure 3 reports the breakdown of the cost for the building elements, highlighting the impact on the construction costs. It shows that in some cases the structural elements represent a significant contribution to the construction, according to the complexity and the dimension of the building. On the other hand, nZEB related technologies have a small impact on the construction costs, although in comparison to a traditional building the cost for the HVAC system and the integration of renewables is more significant.

CRAVEZERO SPREADSHEETS

The third part of the report presents 12 dedicated technical tables, summarising the main results and indicators calculated with the CRAVEzero spreadsheet (i.e. actual results without normalisation). The unitary costs and energy consumptions are normalised according to the treated floor area (i.e. heated area as inserted in PHPP).

DEMO CASE 9 ðSOLALLÉN ðSKANSKA

GENERAL INFORMATION

Architect: Skanska Teknik

Energy concept Net ZEB

Location: Växjö (Sweden)

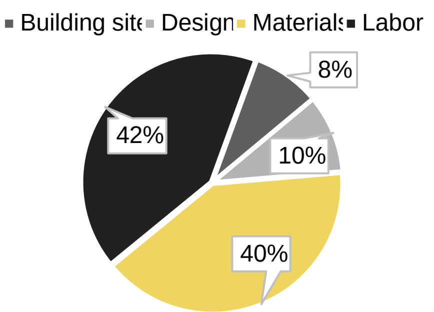
Construction Date: 2015

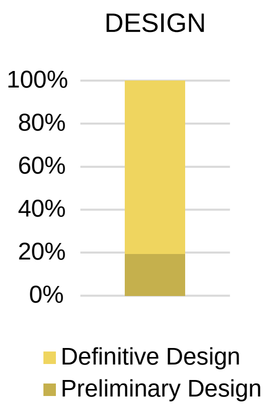
Net floor area 1778 m²

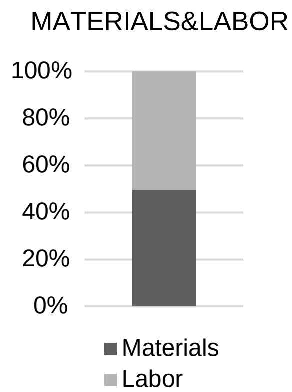
Primary Energy Demand: 109 kWh/(m²a)

Key technologies Well insulated and air tight, Balanced ventilation with heat recovery, Ground source heat pump, Photovoltaic panels

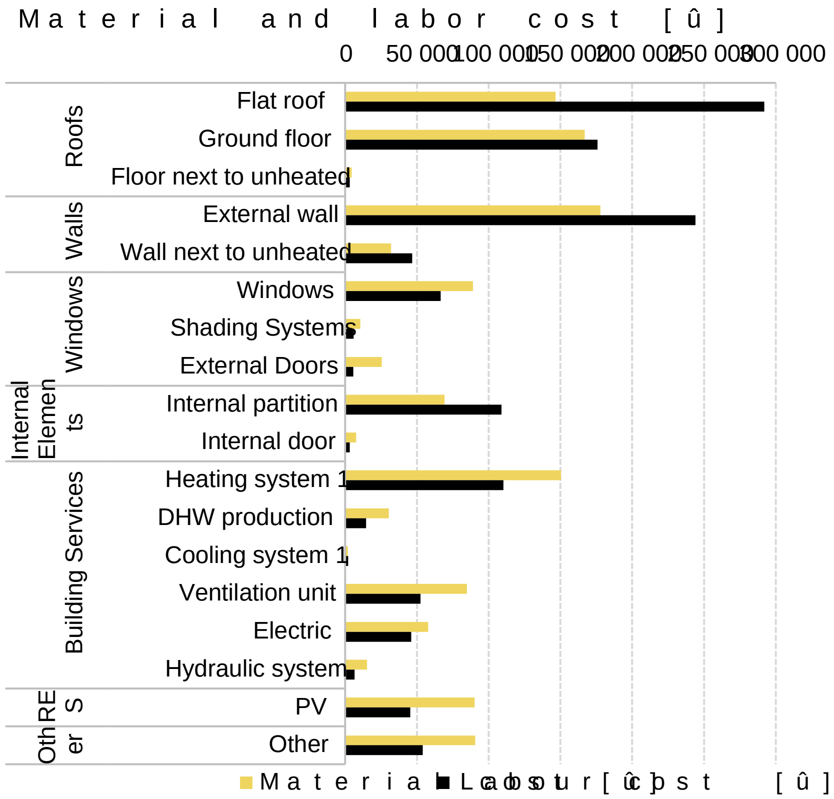
INVESTMENT COSTS







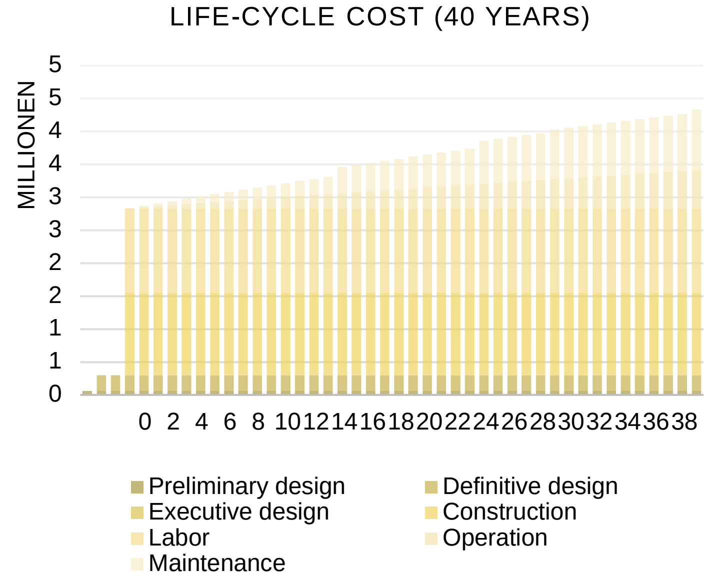
INVESTMENT COSTS	DESIGN COSTS	BUILDING SITE MANAGEMENT	CONSTRUCTION COSTS
3.095.764	300.000 €	260.000 €	2.535.764

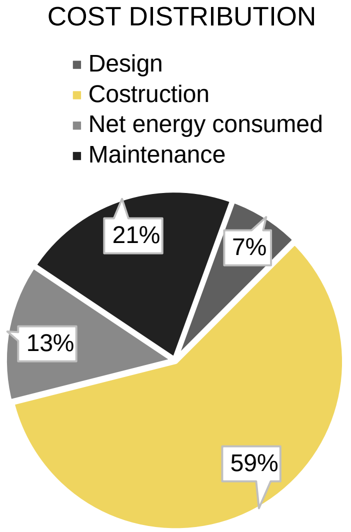


Impact of nZEB technologies on the investment cost	
Construction cost [€]	2.535.764 €
RES	5%
HVAC	18%
DHW	2%
VMC	5%
Heating	10%
Windows	6%

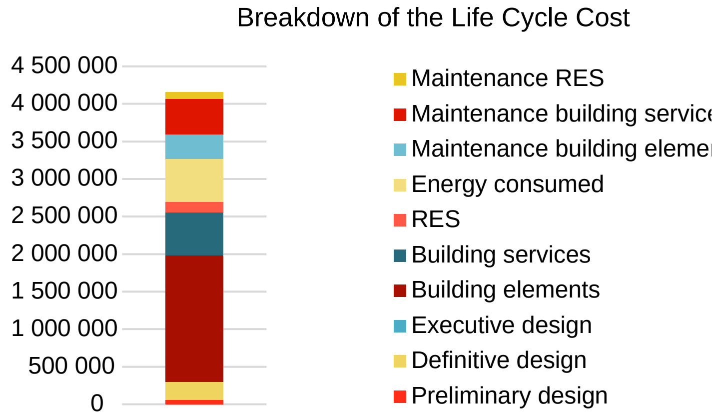
Final Energy Consumption	
Energy demand heating [kWh]	32.688
Energy demand cooling [kWh]	785
Energy demand DHW [kWh]	11.138
Household elt. + aux. [kWh]	47.258
Annual RES generation [kWh]	32.688
Annual CO_2 Emissions [kgCO_2]	48.895

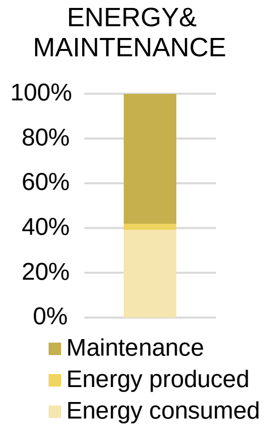
LIFE CYCLE COSTS





WLCC (40)	MAINT .	MAINT./INVES .	LCC (40)	ENERGY (40)	RES/LCC
5.548.872û	916.519û	30%	4.588.972û	576.689û	3%





BREAKDOWN OF THE UNITARY LCC

LCC (40) 2 1 8 5²	Investment 1 4 7 4² û / m	Design 1 4 3 ² û / m	Preliminay	28 û /²m	
			Definitive	1 1 5 ² û / m	
			Executive	- û /²m	
		Construction 1 2 0 8² û / m	Materials 1 5 9 3² û / m	Building Elements	3 4 8 ²û /
				Building Services	1 6 2 ²û /
				RES	4 3 ²û
				Other 4 3 ²û / m	
			Labour 6 1 1 ² û / m		
		Building site management	1 2 4 ² û / m		
	Operation 7 1 1 ² û / m	Energy 2 7 5 ² û / m	Consumed 2 9 6 ² û / m	Heating	1 0 5 ²û /
				Cooling	3 ²û /
				DHW	3 6 û² / m
				H o u s e h o l d	e l ². +
			Produced 2 1 ²û / m		
		Maintenance 4 3 6 ² û / m	Envelope	1 5 6 ² û / m	
			HVAC	2 2 5 ² û / m	
			RES	43 ²û / m	
		Other 1 3 ²û / m			

CONCLUSIONS AND FURTHER DEVELOPMENTS

Deliverable D2.2 describes the approach for the life cycle cost analysis of the CRAVEzero case studies, including the boundary conditions and detailed specificities of the calculation.

The survey of the case studies represents the database of information that will support the further developments of the project, dealing with the identification and the reduction of the extra costs in technologies and processes.

On the one hand, the availability of databases with actual building LCC would help to increase the reliability of the evaluations, providing useful benchmarks and references. On the other hand, one of the future key developments of the CRAVEzero spreadsheet will be the implementation of uncertainty analysis, in order to allow for a probabilistic calculation considering all the factors and boundaries affecting the LCC.

Another future development of the CRAVEzero calculation approach will be the implementation of the co-benefits of nZEBS (e.g. increased comfort, building values, health, etc.) in the economic analysis.

A comprehensive approach for evaluating LCC including uncertainties and co-benefits is strategic to enable the nZEB market uptake and will be developed in the future actions of the project

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1. INTRODUCTION

The EPBD 2020/31/EU [1] established that all new buildings have to reach by the end of 2020 the nZEB target set by the Member States (MS). Nevertheless, there are still many barriers affecting the update process of the construction markets towards nZEB. In fact, even though the MS established minimum nZEB requirements according to the cost-optimal principles indicated by the EPBD, the extra-costs of investment for nZEB technologies is rarely accepted by stakeholders. This is mainly because the investor usually adopts a reduced time horizon for evaluating the cost-optimality of an investment, and this strongly affects the building design and the reachable targets, as stated in [2].

CRAVEzero aims at identifying the extra-costs of nZEB in a life cycle perspective in order to propose solutions for cost reduction or cost shifting.

In fact, in order to reach the nZEB targets while keeping investments sustainable for the user, it is strategic to focus more on the operational phase [3].

In this regard, introducing the Life Cycle Cost (LCC) assessment as a driver in the design phase is one of the key points to foster the nZEB market uptake. A structured methodology for assessing building LCC, with benchmarks, exemplary cases and standard values is needed. D2.2 represents a starting point for developing a structured approach for LCC evaluations, including data collection templates, references and standard costs to be adopted for preliminary evaluations. In fact, one of the main drawbacks of the LCC analysis is the high level of uncertainty affecting the evaluation of the costs during the building life cycle [4]. Collecting a large amount of information on LCC costs of exemplary buildings would allow to reduce uncertainties, provide reliable figures of costs and performances of nZEBs and make more reliable estimates during the design phase.

The scope of this task is to address these drawbacks and barriers, by providing a CRAVEzero cost spreadsheet, implementing a comprehensive and structured methodology in order to evaluate the LCC with a special focus on nZEBs. The spreadsheet has been used for analyzing a set of exemplary nZEBs representing current best practices across Europe. The gathered information was fed into a database on costs and performances. The database forms the basis for the future developments of the project.

The first part of this report describes the approach adopted for collecting the information and the methodology for evaluating the Life Cycle Cost implemented in the CRAVEzero spreadsheet.

This approach was used to collect and analyse data from 12 case studies. The information has been provided by the companies Bouygues, Skanska, Köhler & Meinzer, ATP-sustain, Moretti, that participated as designer, general contractor or technology provider in the building construction process.

The case studies have been analyzed to identify the nZEB related cost of the building elements during the life cycle phases, starting from the design to the construction and operation phase, including energy and maintenance cost.

The second part reports an overview of the results, with the comparison of relevant indicators, costs, and performances among the case studies considering the effect of local specificities, different context and use of the building (i.e. normalised results).

The third part of the report presents 12 dedicated technical tables, summarising the main results and indicators calculated with the CRAVEzero spreadsheet (i.e. actual results).

These technical tables and the database of the case studies represent the basis of the project CRAVEzero. On the one hand, they provide a comprehensive overview of exemplary nZEBs, with a clear methodology to be replicated. On the other hand, they represent the source of data and information for defining the baseline of the current costs and performance of nZEBs, as a base for the further activities of the project.

2. DATA COLLECTION

2.1 STRUCTURE THE INFORMATION

The first step of the analysis was to prepare a data collection template in order to gather all the significant information dealing with the costs and performances of technologies and processes during the building lifecycle of the analyzed case studies. In particular, it has been decided to separate the performance analysis from the cost evaluation. The tool PHPP [5] has been used for the energy performance analysis. This tool summarises all the information dealing with the energy related features of the building components and services and provides a comprehensive overview of the technologies installed.

In addition, a data collection template for the evaluation of the nZEB life-cycle costs has been developed as a starting point for the upcoming CRAVEzero LCC tool. The template is structured according to the approach provided by two main sources:

3. the Standard ISO 15686-5 (Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing)
4. the European Code of Measurement, elaborated by the European Committee of the Construction Economists (CEEC, n.d.) [6].

The first reference provides the main principles and features of an LCC calculation, while the second one describes an EU-harmonised structure for the breakdown of the building elements, services and processes, in order to enable a comprehensive evaluation of the building life costs.

In particular, following the ISO 15686-5, the analysis can include different phases of the life cycle, as summarised in Table 2. Whole Life Costing (WLC) includes the initial phase dealing with political decision-making and urban design, which influence the cost of land, as well as the fees needed for allowing the realisation of the building from the technical and administrative point of view.

The Life Cycle Cost (LCC) index is focused on the design, the construction, and the operation, and includes the costs until the end of life, where the residual values of the elements are taken into account. Within this report and for the case study analysis, also the "Initial investment" is considered, constituted by costs for design and construction of the building.

			LIFE CYCLE PROCESSES	INCLUDED COSTS
Whole-life cycle costs			1. Political decision and urban design phase	Non-construction cost (cost of land, fees and enabling costs, externalities)
	Life-cycle cost	Initial Investment	2. Building design phase	Building design costs
			3. Construction phase	Construction and building site management costs
			4. Operation phase	Energy and ordinary maintenance costs
			5. Renovation phase	Repair and renovation costs
			6. Recycling, dismantling and reuse phase	Residual value of the elements

Table 2: Phases and costs in WLC and LCC

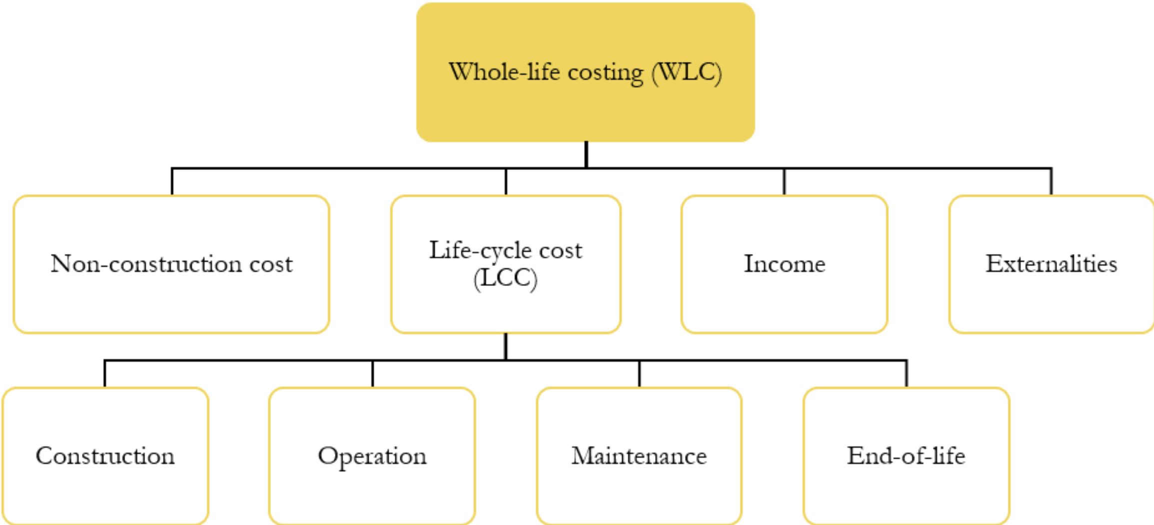

Figure 1 Life-cycle costing according to ISO 15686:2008.

Figure 1 summarizes the definition of whole-life cost (WLC) and life-cycle cost (LCC) according to the norm ISO 15686:2008. The WLC evaluation also includes revenues generated by the building, e.g. rental income, energy produced and delivered to the grid, etc.

At this stage, the end-of-life cost is not included in the evaluation since, like for the most of new and existing buildings, there is no availability of structured and relevant data from the case studies.

The data collection for the CRAVEzero spreadsheet is structured in three parts:

1. General project information: it includes the main information of a case study and its context
2. Non-construction costs: it deals with the preliminary costs for the WLC and the design phase
3. Life Cycle Costs: it reports all the costs for building elements and services during construction and operation

General Project Information / Energy Costs (CRAVEzero cost Spreadsheet based on ISO 15686 and EconCalc - for internal use only)

CELL LEGEND	Cell to be filled-in with input values	Cell to be filled-in with text - comments, references	Automatic calculation (intermediate results)	Automatic calculation (final results)

PROJECT DATA			
Name	Hauptstr. 131 Parkcarré		
Nation/Region/city	Hauptstr. 131 Parkcarré		
Location	Germany Baden-Württemberg		
Author	Gerold Köhler Thomas Stöcker		
Building Use/Typology	Apartment house		
Construction year	2.015		year of the end of the building construction (reference year for the LCC analysis)
BUILDING SURFACES AND VOLUMES			
Gross floor area (GFA)	1.286	m^2	is the total heated floor area of the building measured to the external face of the external walls
Net floor area (NFA)	1.109	m^2	is the floor heated area of the building measured to the internal face of the external walls without lift, columns and ducts.
Gross Volume	3.889	m^3	is the total heated volume of the building measured to the external face of the external walls
Net Volume	3.194	m^3	is the total heated volume of the building measured to the internal face of the external walls without lift, columns and ducts.
UNHEATED AREAS			
Gross floor area (GFA)	225	m^2	is the total unheated floor area of the building measured to the external face of the external walls
Net floor area (NFA)	165	m^2	is the floor unheated area of the building measured to the internal face of the external walls without lift, columns and ducts.
Gross Volume	629	m^3	is the total unheated volume of the building measured to the external face of the external walls
Net Volume	396	m^3	is the total unheated volume of the building measured to the internal face of the external walls without lift, columns and ducts.
OTHER AREAS			
Balconies, Terraces, Winter gardens, porches…	159	m^2	secondary surfaces

Figure 2: Data collection template sheet 1 – Project information

Figure 2 shows a screenshot of the project information – t[…]ct the main information of the building (property, use, year of construction), the geometric data of the building (gross/net, heated/unheated surfaces and volumes), the possible incomes generated by the rent, the energy prices to be adopted for the evaluation and operation costs.

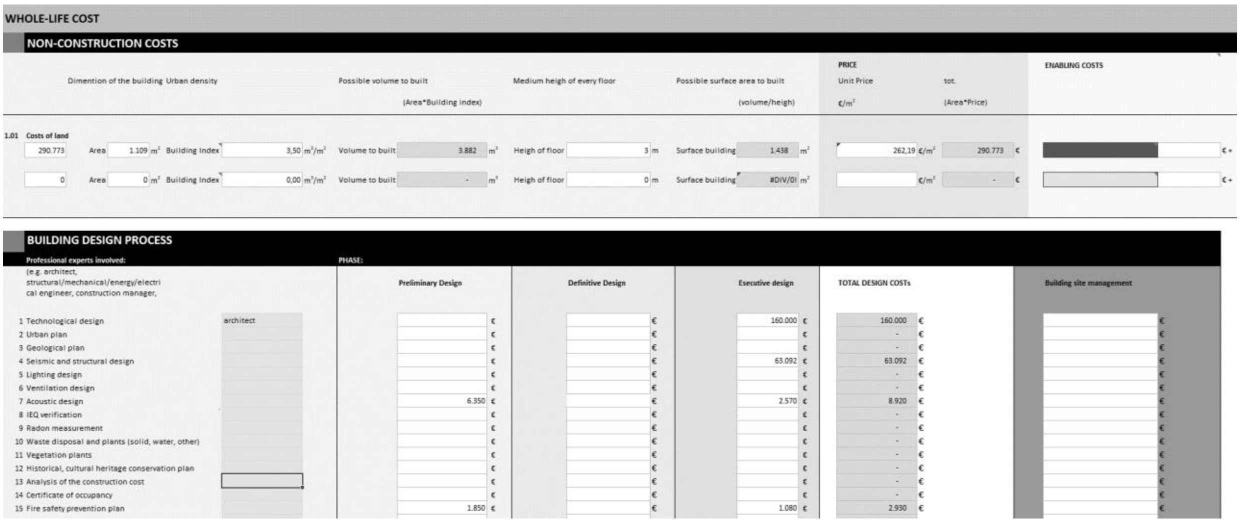

Figure 3: Data collection template sheet 2 – Whole-life cost

Figure 3 displays an overview of the second part of the spreadsheet, where the non-construction costs are collected. In particular, there is a breakdown of the costs dealing with the preliminary phases (i.e. enabling costs and administrative fees), and the cost of land and the finance costs (i.e. the charges needed for the bank loan for the initial investment). Moreover, this sheet includes also the costs for the design process, structured in preliminary, definitive and executive phase and for the management of the construction site.

Figure 4 shows the part of the template to be populated with costs for construction and maintenance of the building elements and services. This part is organized according to the building structure, with the breakdown of the building elements (roofs, walls, windows, floors, etc.), services (heating, cooling, ventilation system, etc.) and renewables installed (photovoltaic, solar thermal, etc.). For each building element, the sheet allows for the collection of the costs for materials and labor during the construction phase, and the maintenance during the operation. Each element can be analyzed with a higher level of detail, separating each layer of the construction and each subsystem of the plant.

Life Cycle Cost		COSTRUCTION COSTS	
CONSTRUCTION COSTS (Based on ISO15686)		MATERIALS	TOT.
		AGGREGATED or DETAILED	€
			Tot.
A1	Roofs		85.508,51 I
A1.01	Flat roof		
A1.02	Pitched roof – Ceiling next to air (outside)		
A2	Ceilings		28.000,00 I
A2.01	Ceiling next to unheated area		
A2.02	Ceiling next to ground (outside)		
A3	Floors		25.000,00 I
A3.01	Floor next to ground (outside)		
A3.02	Floor next to air (outside)		
A3.03	Floor next to unheated area (like garage)		
A4	Walls		116.544,66 I
A4.01	External wall		
A4.02	Wall next to unheated area (garage..)		
A4.03	Wall next to ground (outside)		
A5	Windows		95.491,60 I
A6	Shading Systems		– I
A7	External Doors		– I
A8	Internal elements (next to heated areas)		50.000,00 I
A8.1	Internal partition		
A8.2	Internal floor/ceiling		
A8.3	Internal door		
A9	Structural elements		– I
A9.01	Foundations		
A9.02	Raising structure		
A10	Other elements		36.000,00 I
A10.01	Balcony		
A10.02	Banisters		
A10.03	Chimney		
A10.04	Stair		
A10.05	Lift		
A10.06	Other		
	BUILDING SERVICES		Tot.
B1	Heating System		67.436,00 I
B1.01	Heating system 1		
B1.01	Heating generation	Element n. 17.436 I or (m2 * I/n.) = – I =tot. 17.436 I	
B1.01	Emission system	Element n. 50.000 I or (m2 * I/m2) = – I =tot. 50.000 I	
B1.01	Emission system	Element n. I or (m2 * I/m2) = – I =tot. – I	

Figure 4: Data collection template sheet 3 – Life-cycle cost

3. OVERVIEW OF THE CASE STUDIES:

3.1 DESCRIPTION OF THE CASES

As one of the backbones of the project, 12 case studies have been selected and analyzed in terms of Life Cycle Costs, according to the framework described in this deliverable. In particular, the Industry Partners provided information on 12 existing reference buildings, considered as representative of the current best practices in the construction of new nZEBs with different functions and context. 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 Italy, France, Germany, Sweden and Austria. The following sections report a brief overview of the main features of the case studies.

CASE 1: Green Home – BOUYGUES (GreenHome-Res)

General information

- Owner: Condominium ownership
- Architect: Atelier Zündel Cristea
- Location: Nanterre (France)
- Year of construction: 2016
- Net floor area: 9267 m²

Key technologies

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

Green Home is a plus-energy residential building located in Nanterre, France. The special feature of this building is that it operates without heating and cooling systems. This building has very low energy needs (80% less than a conventional one), thanks to a bioclimatic approach and a well-insulated envelope (external insulation, triple glazing and thermal bridge optimization) close to passive house standard. As a result, a double flux ventilation system with 95% heat recovery is enough to meet almost 100% of the heating needs of the apartments. No heating system has been implemented, except for a small electric resistance in the ventilation system, used when the outside temperature is very low. A centralized heat pump with very high efficiency (performance coefficient equal to 7) uses the heat recovery of grey water to produce domestic hot water. Green Home was designed to consume less than 23 kWh/m² primary energy each year for heating, cooling, ventilation, lighting and domestic hot water, which is almost 3 times less than what is required by the RT2012 (the French thermal regulation for buildings).

CASE 2: Les Héliades – BOUYGUES (Héliades-Res)

General information

- Owner: Podeliha
- Architect: Barré Lambot
- Energy concept: ZEB (heating, cooling, ventilation, lighting and SHW)
- 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

The Héliades residence, where 57 families have been installed since March 2017, is defined as a Positive Energy Building (BEPOS). It was designed by the architect Barré Lambot and Bouygues Bâtiment Grand Ouest, with the goal to combine the comfort of the inhabitants and control of energy. The building with high shape compactness, is connected to the urban heat network powered with biomass for the production of heating and domestic hot water, complemented by solar thermal panels and photovoltaic panels installed on the roof. Solar gains are favoured by largely glazed façade, mainly facing south.

CASE 3: “Residence Alizari” – BOUYGUES (Alizari-Res)

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

Labelled Passivhaus and Promotelec RT 2012 -20%, this residence has 31 apartments and 1 studio. The design of the project was oriented to meet a high standard of energy performance, relying on the compactness of buildings, the control of solar inputs and of the orientation and the management of renewable energies. Electricity generation via photovoltaic panels, heating system with ventilation, with a biomass boiler and reinforced thermal insulation.

Furthermore, a large part of the spaces and services are shared among the different residents (local bicycles and strollers, optical fibre, local compost).

Residential common laundry and a guest bedroom are also integrated into the new building.

CASE 4 : ò-NTHi r ðATPósustain (NHTirol -Res.)

General information

- Owner: Neue Heimat Tirol
- Architect: Architekturwerkstatt DIN A 4
- Energy concept: Cogeneration unit woo solar thermal energy (DHW) and ventilation with heat recovery
- Location: Innsbruck (Austria)
- Year of construction: 2008-2009
- Net floor area: 44959 m^2

Key technologies

- Centralized pellet boiler

This is one of the largest residential complex built according to the passive house approach in Europe. Heating is supplied by a pellet boiler and a gas condensing boiler, whereby approx. 80% of the annual energy requirement (without consideration of the solar system) is covered by the pellet boiler. Due to the low heating demand, only the outer surfaces (edge zones) are heated by means of a floor heating system.

CASE 5 : Parkcarré ó Köhler & Meinzer (Parkcarré-Res.)

General information

- Owner: Owner´s Association
- Architect: Alex Stern/Gerold Köhler
- Energy concept: Contracting model for the quarter energy supply (DHW, heating, and electricity) for all buildings with a local gas boiler and a PV-system
- Location: Eggenstein (Germany)
- Construction date: 2014
- Net floor area: 1109 m^2

Key technologies

- High level of thermal insulation
- Best quality heat bridges optimization and an airtight envelope
- Decentralized ventilation system with heat recovery (2 system/apartment)

The case study is a multi-family home, with 4 floors, 10 dwellings, within a quarter of 6 buildings, each with 4 floors and overall 66 dwellings. This building consumes 40% less than national standards requirements. The envelope is highly insulated and airtight. Decentralised ventilation systems (2 for each dwelling) with heat recovery have been installed. DHW, heating and electric energy of all dwellings are supplied by a gas power and heat plant and a PV system on each building. Moreover, the social and economic sustainability has been taken into account by the project. On the one hand, one of the main objectives in developing this multi-family house was to create a type of building which can meet different demands. On the other hand, the designers focused on the cost-effectiveness of the construction to guarantee affordable costs of the dwellings.

CASE 6 : Moòre ó ðMoretti (More-Res)

General information

- ¶ Owner: Groppi-Tacchinardi
- ¶ Architect: Valentina Moretti
- ¶ Energy concept: Heat pump and condensing boiler, solar heating panel
- ¶ Location: Lodi (Italy)
- ¶ Construction Date: 2014
- ¶ Net floor area: 128 m²

Key technologies

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

Groppi represents one of the typologies of prefabricated single-family house produced by Moretti. The envelope and all the equipment have been designed with the aim to achieve high performances. The thermal equipment consists of an air-water heat pump, distribution through a floor heating system, balanced ventilation with heat recovery, electric system automation. In summer, a natural chimney activates air circulation inside the house, thus ensuring natural ventilation. In addition, the installation of special selective and low emissivity glasses ensures a low cooling demand

CASE 7-8 : ò Isola A+B Nel Verde ó ðMoretti (IsolaA-Res/IsolaB-Res)

General information

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

Key technologies

- ¶ Cogeneration system
- ¶ Geothermal energy
- ¶ Green roof

The complex has two buildings, A and B that are considered separately in the LCC analysis, for the different configuration. The apartments are heated by radiant floor panels, and the conditioning is supplied by a fan coil plant. The buildings of "*Isola nel Verde*" present excellent acoustic and thermal insulation.
Moreover, the insulated green roof reduces the cooling demand. The energy is supplied by a geothermal heat pump for heating and cooling, with the integration of photovoltaic and solar thermal panels.

CASE 9 : S ò l a ð SKANSKA (Solallén-Res.)

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

Well-insulated buildings, using 50% less energy than Swedish code requirements, an energy demand of 30 kWh/m² together with a photovoltaic system and geothermal heating and cooling systems have led to a net zero primary energy balance. During construction, 37% of embodied carbon savings was achieved, using foundation materials efficiently, minimizing construction equipment time on site and sourcing local timber for the structural frames and façades material. Zero hazardous and unsustainable materials were used, all used materials have been approved by Svanen Nordic ecolabel. The buildings use 45% less water than typical newly built Swedish homes and have integrated photovoltaic systems.

CASE 10 : ò V ä l ð SKANSKA (VälaGård-Off.)

General information

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

Key technologies

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

Väla Gård is composed of two buildings used as an office. A prefabricated 120 mm concrete wall with 200 mm graphite EPS is used. Heat and hot tap water are produced using a geothermal heat pump that can also be used for cooling. A demand-controlled ventilation system is used to ensure air quality. The building was constructed with a high level of insulation, and it is equipped with solar cells and ground-source heating. As a consequence of all these green initiatives the building has been certified under Leadership in Energy and Environmental Design (LEED) at the highest level, LEED Platinum.

CASE 11: "Aspern IQ" (ATP sustain/Aspern-Off.)

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
- Small wind turbine

Aspern IQ is located in "Aspern – Vienna's urban lakeside", a developed urban development project and one of the largest in Europe. The building was designed in line with Plus Energy standards and is conceived as a flagship project which shows the approach to create a Plus Energy building adapted to locally available materials and which offers the highest possible level of user comfort while meeting the demands of sustainability. The Technology Centre received a maximum number of points in klima:aktiv declaration and has also been awarded the ÖGNB Building Quality Certificate. The energy demand of the building has actively been lowered by measures in the design of the building form (compactness), orientation and envelope. A balanced glazing percentage, the highly insulated thermal envelope in passive house standard, optimized details for reduced thermal bridges and an airtight envelope (Blower Door Test=0,4 1/h) beating the Austrian building regulation OIB 6 by 55%.

CASE 12: "I.+R. Schertler" (ATP sustain/Schertler-Off.)

General information

- Owner: I.+R. Schertler Alge GmbH
- Architect: Dietrich Untertrifaller Architekten
- Location: Lauterach (Austria)
- Year of construction: 2012-2013
- Net floor area: 2759 m²

Key technologies

- Reversible geothermal heat pump

The new corporate headquarters of the i+R Group were designed with a focus on the aspects of greater comfort, natural materials, and renewable energy. The building has been designed to obtain the LEED Certification. The building 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 the use of timber as a natural material.

3.2 DATA COMPLETION

The collection of the information of the case studies has been carried out through the template described in Section 2. It was filled out by the CRAVEZero industry partners with the support of the research partners. Since the industry partners dealt with different phases of the Life Cycle of the analyzed case studies (e.g. design, construction, etc.), the availability of data was not in compliance with the most detailed level requested by the template for all the phases. Therefore, the template also allows for including the aggregated costs for each building element. In addition, to check the completion of the costs inserted by the partners for the construction phase, the template includes a consistency check with the actual total construction costs.

Table 3, Table 4, Table 5 and Table 6 summarize the level of completion of the case study in the different sections of the template

CASE STUDIES		PROJECT INFORMATION					
		Project data	Building geometry	Building cost	Income	Viewing perspective	Energy price
Bouygues	Green Home	x	x	x	-	-	-
	Les Héliades	x	x	x	-	-	x
	Residence Alizari	x	x	x	-	-	-
ATP sustain	NH - Tirol	x	x	x	x	-	-
Köhler &Meinzer	Parkcarré	x	x	x	x	x	x
Moretti	More	x	x	x	-	x	x
	Isola Nel Verde A	x	x	x	-	-	-
	Isola Nel Verde B	x	x	x	-	x	-
Skanska	Solallén	x	x	x	-	-	-
	Väla Gård	x	x	x	-	-	-
ATP sustain	Aspern	x	x	x	-	-	x
	I.+R. Schertler	x	x	x	-	-	x

Table 3: Project information available for the case studies

In particular, Table 3 reports the overview of the project information sheet, which collects general data, such as building surface and volume, overall building costs, revenues and energy prices. It is possible to point out a significant lack of data about income sources (only two cases have available info). This will not permit to carry out general considerations about the revenue streams in the life-cycle of the building (Section 5.2 reports an example of analysis including revenues and incomes in the building LCC for Parkcarré). Moreover, most of the partners did not fill in the energy prices (since they are not dealing with the building operation and are not aware of the energy costs). Missing energy prices have been taken from the Eurostat database. Table 4 reports the information included in the second sheet of the template “WLC” that colle life costs, such as non-construction costs, design and building site management costs. Concerning the design cost, the availability of data is quite good while there is no detailed information for each level of design (i.e. preliminary, definitive, executive). The cost of this phase is always available except for the cases Isola nel Verde and Green Home. On the other hand, only 27% of the requested data have been included in non-construction costs, and none of the partners reported on finance costs.

CASE STUDIES	DESIGN COSTS			BSM	NON -CONSTRUCTION COSTS					
	PD	DD	ED		Cost of Land	Price	Enabling costs	Planning fees	User support costs	Finance costs
Green Home	-	-	-	x	-	-	-	-	-	-
Les Héliades	x	x	x	x	-	-	-	-	x	-
Residence Alizari	x	x	x	x	-	-	x	-	-	-
Aspern	x	-	-	-	x	x	x	x	-	-
I.+R. Schertler	x	x	x	x	-	-	x	-	-	x
NH - Tirol	-	x	-	x	x	-	-	-	-	-
Parkcarré	x	-	x	-	x	x	-	x	-	-
More	-	x	x	-	-	-	-	x	-	-
Isola Nel Verde A	-	-	-	-	-	-	x	-	-	-
Isola Nel Verde B	-	-	-	-	-	-	-	-	-	-
Solallén	x	x	-	x	x	x	x	x	-	-
Väla Gård	x	x	-	x	x	-	x	x	-	-

Table 4: Whole-life cycle costs (design, building site management, and non-construction costs) available for the case studies.

Table 5 is the third sheet, “LCC construction and labor costs for the demo cases. In particular, the template was created for collecting both material and labor costs. Considering the availability of the information for the case studies, when the breakdown of labor cost was not available, the partners included the overall values in the construction costs data sheet.

It showed that constructions costs related to building elements are widely available, whereas those related to building services present a more significant lack of data. The cost categories are indicated with letters, from A1 to E. Those correspond respectively to costs of roofs (A1), ceilings (A2), floors (A3), walls (A4), windows (A5), shading systems (A6), external doors (A7), internal elements (A8), structural elements (A9), other elements (A10), heating system (B1), domestic hot water production (B2), cooling system (B3), mechanical ventilation system (B4), electric (B5), hydraulic system (B6), renewable energy sources (C), other installations and equipment (D) and site and external works (E).

	COSTRUCTION COSTS																		
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	B1	B2	B3	B4	B5	B6	C	D	E
Green Home	x	-	-	x	x	x	-	x	x	x	-	x	-	x	x	x	x	x	x
Les Héliades	x	-	x	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x
Residence Alizari	x	-	-	x	x	x	-	x	x	x	x	-	-	x	x	x	x	-	x
Aspern	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	x	x	-
I.+R. Schertler	x	-	-	x	x	x	x	x	x	x	x	x	-	-	x	-	-	x	x
NH - Tirol	x	-	-	x	x	x	-	x	x	x	x	-	-	-	x	x	-	-	x
Parkcarré	x	x	x	x	x	-	-	x	-	x	x	x	-	-	x	x	-	-	-
More	x	-	x	x	x	x	-	x	x	x	x	-	-	x	x	x	x	-	x
Isola Nel Verde A	x	-	x	x	x	x	x	x	x	x	x	-	-	-	x	-	-	-	x
Isola Nel Verde B	x	-	x	x	x	x	x	x	x	x	x	-	-	-	x	-	-	-	x
Solallén	x	-	x	x	x	x	x	x	-	-	x	x	x	x	x	x	x	x	-
Väla Gård	x	x	x	x	x	x	x	x	-	x	x	x	-	x	x	x	x	x	-

Table 5: Construction costs available for the case studies

Table 6 highlights the availability of information dealing with the labor costs for the installation of the components. As it can be noticed, the comprehensive LCC overview of the case studies is not complete, and only a few cases were described with the full level of detail set-up for the analysis.

CASE STUDIES		LABOR COSTS																		
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	B1	B2	B3	B4	B5	B6	C	D	E
Bouygues	Green Home	-	-	-	-	-	x	-	-	x	-	-	x	-	x	-	-	x	-	-
	Les Héliades	x	-	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-
	Residence Alizari	-	-	-	x	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-
ATP sustain	NH - Tirol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Köhler &Meinzer	Parkcarré	x	x	x	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Moretti	More	x	-	x	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Isola Nel Verde A	x	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Isola Nel Verde B	x	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skanska	Solallén	x	-	x	x	x	x	x	x	-	-	x	x	x	x	x	x	x	x	-
	Väla Gård	x	x	x	x	x	x	x	x	-	x	x	x	-	x	x	x	x	x	-
ATP sustain	Aspern	x	x	x	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	I.+R. Schertler	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6: Labor costs available for the case studies

Finally, after a preliminary round of data collection, the analysis of the maintenance costs has been based on literature information. In fact, since the buildings are quite new, it is not possible to report actual maintenance costs, and the partners have not carried out this evaluation during the design phase. In this regard, it has been decided to include the maintenance costs calculated with a common approach, as indicated in the Standard ISO 15459 that reports the maintenance for each element as a percentage of the construction costs.

In addition to the data collection template about the costs, the partners were requested to prepare a PHPP file that includes all the information dealing with the energy performance of a building. In this case, the data reported by the partners are complete in all the PHPP files.

4. METHODOLOGY FOR DATA ELABORATION

4.1 LIFE CYCLE COST CALCULATION

The following sections describe the procedure followed for the data elaboration and the calculation of the life cycle costs applied in the case studies.

In particular, the approach is based on the standard ISO 15686-5:2008. This standard provides a structured methodology for calculating LCC of buildings, setting the general principles, phases and assumptions of the evaluation.

In addition, we considered the building elements breakdown as indicated in the European Code of Measurement, a document elaborated by the European Committee of the Construction Economists (CEEC, n.d.), which provides a standard for the subdivision of costs, in order to make LCC analyses comparable at EU level.

Following the framework of ISO 15686-5:2008, the first step in the calculation of the LCC is to set the time period, according to the purpose of the analysis. The standard indicates that the largest period to be selected is 100 years. On the one hand, shorter periods allow more reliable assessments, since the time uncertainties are less affecting. On the other hand, longer periods, while having more uncertainties in the results, allow for more comprehensive evaluations, including the maintenance costs for a significant time frame. As stated by Dwaikat and Ali [7] "the International standard ISO 15686-5:2008 recommends that the estimated service life of a building should not be less than its design life". Furthermore, [8] suggested an analysis period between 25 and 40 years, since the present value of future costs, which arise after 40 years, may be not consistent because of a large number of uncertainties. Therefore, for the purposes of the project, a period of 40 years has been selected.

According to the ISO 15686-5:2008, the LCC of a building is the Net Present Value (NPV), that is the sum of the discounted costs, revenue streams and value during the phases of the selected period of the life cycle.

Accordingly, the NPV is calculated as follows:

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

- C: cost occurred in year n;
- d: expected real discount rate per annum;
- n: number of years between the base date and the occurrence of the cost;
- p: a period of analysis.

The discount rate is one of the most significant parameters to be considered in the LCC. Within CRAVEzero, as a general boundary, a common value for all the case studies has been adopted. The selected value is taken from FRED Economic Database (https://fred.stlouisfed.org/), which provides an interest rate of 1.51%.

Moreover, costs are grouped according to the phases of the life cycle: design, construction, building site management, operation, and maintenance. In the case of WLC, also cost of land and the non-construction costs have been included. Concerning design and construction costs, the partners delivered the data and information according to the template described in Section 2. For the estimation of energy and maintenance costs, a set of assumptions have been set-up and described in the following sections.

The following sections report the approach adopted for estimating energy and maintenance costs in the life cycle.

4.2 DETERMINATION OF THE ENERGY COSTS

In order to provide a homogeneous and comparable estimation of the energy costs of the case studies, since the official bills were not available in most of the cases, the evaluation is based on the calculated energy demand. In particular, the energy performance analysis has been carried out by using the PHPP evaluation tool [5]. PHPP tool allows for implementing all the data dealing with the energy behaviour of a building, including the features of the envelope, HVAC system and renewables installed.

In particular, for estimating both the costs and the revenues (due to the renewables installed), we consider the following contributions, in terms of final energy:

¶ Energy costs:
  - o Heating demand [kWh]
  - o Energy demand for domestic hot water production [kWh]
  - o Cooling demand [kWh]
  - o Household electricity [kWh] + electricity demand for auxiliaries [kWh]

¶ Revenues from renewables
  - o Final energy generated by a photovoltaic system
  - o Final energy generated by the solar thermal system

The energy produced from renewables is considered in the energy balance as a positive contribution to the energy consumption, and the revenues from the renewables have been discounted from the energy costs. As highlighted in Section 3.2, the energy prices have been assumed from Eurostat [9], considering the average values from 2010 to 2017 (Table 7). Most of the case studies are supplied by electricity since the most common technology adopted is the heat pump. Nevertheless, for other energy fuels, the same approach for defining the costs has been adopted.

As a general assumption, for the evaluations described in this report, a common value for considering the increase in the energy price has been adopted. According to the data reported in Table 7 (Eurostat), the inflation of electricity prices in CRAVEzero countries from 2010 to 2017 amounts to 1.0%, and this value is used in the LCC evaluation.

YEAR	AUSTRIA		GERMANY		ITALY		FRANCE		SWEDEN		Average CRAVEZero
	c û / Wh	Increase	c û / Wh	Increase	c û / Wh	Increase	c û / Wh	Increase	c û / Wh	Increase	Increase
2010 S1	19.67		23.75		19,65		12,83		18.39		
2010 S2	19.30	-1.9%	24.38	2.7%	19.2	-2.3%	13.5	5.2%	19.58	6.5%	1.8%
2011 S1	19.86	2.9%	25.28	3.7%	19.87	3.5%	13.83	2.4%	20.92	6.8%	4.0%
2011 S2	19.65	-1.1%	25.31	0.1%	20.65	3.9%	14.22	2.8%	20.44	-2.3%	0.5%
2012 S1	19.75	0.5%	25.95	2.5%	21.23	2.8%	13.92	-2.1%	20.27	-0.8%	0.8%
2012 S2	20.24	2.5%	26.76	3.1%	22.97	8.2%	15.01	7.8%	20.83	2.8%	4.6%
2013 S1	20.82	2.9%	29.19	9.1%	22.92	-0.2%	15.24	1.5%	21.01	0.9%	3.2%
2013 S2	20.18	-3.1%	29.21	0.1%	23.23	1.4%	15.96	4.7%	20.46	-2.6%	-0.1%
2014 S1	20.21	0.1%	29.81	2.1%	24.46	5.3%	15.85	-0.7%	19.67	-3.9%	0.9%
2014 S2	19.87	-1.7%	29.74	-0.2%	23.38	-4.4%	17.02	7.4%	18.67	-5.1%	-1.2%
2015 S1	20.09	1.1%	29.51	-0.8%	24.5	4.8%	16.76	-1.5%	18.51	-0.9%	0.6%
2015 S2	19.83	-1.3%	29.46	-0.2%	24.28	-0.9%	16.82	0.4%	18.74	1.2%	-0.2%
2016 S1	20.34	2.6%	29.69	0.8%	24.13	-0.6%	16.85	0.2%	18.94	1.1%	0.8%
2016 S2	20.10	-1.2%	29.77	0.3%	23.4	-3.0%	17.11	1.5%	19.62	3.6%	0.0%
2017 S1	19.50	-3.0%	30.48	2.4%	21.42	-8.5%	16.9	-1.2%	19.36	-1.3%	-2.1%
2017 S2			30.48	0.0%					19.93	2.9%	
Average	19.96	0.0%	28.0	1.7%	22.4	0.7%	15.5	2.0%	19.7	0.6%	1.0%

Table 7. Electricity prices for households in the EU union (2010-2017)

4.3 MAINTENANCE COSTS

As a result, from the first round of data collection, we observed that the maintenance costs for the case studies were not fully available with a relevant level of accuracy and detail. In fact, the analysed buildings have been built between 2009-2020 and 2016, and only minor maintenance had already taken place. Moreover, following the general current design and construction practice, there are no relevant preliminary evaluations of the impact of maintenance costs during the building life cycle.

Therefore, the analysis within CRAVEzero is based on standard values from the literature.
In particular, the standard EN 15459:2017 (Energy performance of buildings - Economic evaluation procedure for energy systems in buildings) provides yearly maintenance cost for each element, including operation, repair and service, as a percentage of the initial construction cost. The standard provides a detailed breakdown of the costs for the HVAC as reported in Table 8. For the passive building elements, an average yearly value accounting for 1.5% of the construction cost has been assumed for the evaluation. The value has been cross-checked with average values coming from the experience of the industry partners. Accordingly, the yearly maintenance costs for each building element are evaluated and actualized as described in Section 4.1.

COMPONENT	LIFESPAN (YEARS)			ANNUAL MAINTENANCE (% OF INITIAL INVESTMENT)		
	min	max	adopted	min	max	adopted
Building elements	1	2	1.5	-	-	40
Air conditioning units	15	15	15	4	4	4
Control equipment	15	20	17	2	4	3
Cooling compressors	15	15	15	4	4	4
Duct system for non-filtered air	30	30	30	6	6	6
Electric wiring	25	50	40	0,5	1	1
Water floor heating	50	50	40	2	2	2
Heat pumps	15	20	17	2	4	3
Heat recovery units	15	15	15	4	4	4
Meters	10	10	10	1	1	1
Pipes, stainless	30	30	30	1	1	1
Radiators	30	40	35	1	2	1,5
Solar collector	15	25	20	0,5	0,5	0,5
Tank storage for DHW	20	20	20	1	1	1

Table 8: Selected maintenance values for building services from the EN 15459:2018.

4.4 NORMALIZATION

The analysed case studies are located in different European countries, i.e. Austria, Germany, France, Italy and Sweden. Each country presents specific characteristics in terms of climate conditions, construction, and energy market. Therefore, in order to compare the results of the case studies and to draw a general overview of the costs of the current nZEB practices, a normalization of the collected data is needed. In this regard, the following sections present an overview of the normalization factors adopted for comparing the data of the case studies for construction, energy prices and climate conditions. It is important to point out that the normalisation is applied for analysing the results in Section 5.1, while the separate spreadsheets report the actual costs provided by the partners.

4.4.1 CONSTRUCTION COST

The impact of the construction costs on the life cycle is affected by several country-related factors. In fact, the price of the materials can be influenced by several national and international economic factors, as well as the costs of transports, strongly affected by the fuel costs, and the labor cost. In order to reduce the perturbations of the results caused by these national specificities and to compare the case studies, it is important to find a common factor to normalize the construction costs.
The ECC (European Construction Costs) has calculated a comprehensive European construction cost index that quantifies the ratio among the construction costs of EU countries, considering the above mentioned factors [9]. The normalization of the construction costs within CRAVEzero is carried out with the values reported in Table 9.

CONSTRUCTION COST INDEX				
France	Austria	Germany	Italy	Sweden
103.87%	100.67%	96.62%	93.63%	134.19%

Table 9: Construction cost index for CRAVEzero countries

4.4.2 YEAR OF CONSTRUCTION

Another factor influencing the costs of investment and operation is the adopted reference year for the actualization, usually the year of construction. For this analysis, considering that 10 out of 12 demo cases (Table 10) have been constructed between 2012 and 2015, in order to simplify the evaluation process, the normalization of the year of construction has been neglected.

DEMO CASES YEAR OF CONSTRUCTION

Green Home	2016	Isola Nel Verde A	2012
Les Héliades	2015	Isola Nel Verde B	2012
Residence Alizari	2015	Solallén	2015
NH - Tirol	2008-2009	Väla Gård	2012
Parkcarré	2014	Aspern	2012
More	2014	I.+R. Schertler	2011-2013

Table 10 Demo cases year of construction.

4.4.3 CLIMATE

The energy cost of a building is determined by both energy prices and consumption. In order to neglect the effect of the climate conditions on the energy consumption, it is important to normalize the energy costs according to the climate condition of the building location. The most relevant contribution to the energy consumption of the case studies is the heating demand; thus, we focused the normalization on that index. In this regard, we assumed the heating degree days (HDD) as a normalization factor. The values are assumed from the report by Ecofys "U-value and better energy performance" [11], which provides the HDD for a set of reference cities of the EU countries. The HDD is calculated as the sum, over the year, of the difference between the reference temperature (i.e. 20°C) and the average daily temperature of the day (T_m), when it is lower than 15°C

$$HDD = \sum (20\,°C - T_m), \text{ when } T_m < 15\,°C$$

The HDD adopted for the case studies are summarized in Table 11.

REFERENCE HEATING DEGREE DAYS (HDD)

Green Home	2702	Isola Nel Verde A	2616
Les Héliades	2377	Isola Nel Verde B	2616
Residence Alizari	2702	Solallén	4010
NH - Tirol	4256	Väla Gård	3720
Parkcarré	3730	Aspern	2844
More	2616	I.+R. Schertler	3413

Table 11: Heating degree days for the locations of the demo cases (Source: Ecofys).

4.4.4 ENERGY PRICES

Finally, in order to compare the energy costs, a normalization, which considers differences in energy prices among countries, is done. The average value calculated accounts for 0,174 û /kWh, that is adopted for the normalization of the energy supply and for calculating the results compared in Section 5.1. This value has been calculated considering the average price for each fuel/energy vector adopted by the case studies.

For heating and domestic hot water preparation mainly three technologies have been implemented in the demo cases (heat pump, district heating and pellet boiler). Table 12 reports the value of the energy price adopted for each case study. The energy price for district heating reported in Table 11 has been taken from Eurostat, since in most cases it is not available.

CASE STUDY	HEATING		DHW	
	Technology	Energy price [û / kW	Technology	Energy price [û / kW
Green Home	Direct elt.	0.155	Heat Pump	0.155
Les Héliades	District heating	0.10	District heating	0.10
Residence Alizar	Pellet Boiler	0.046	HP	0.146
NH - Tirol	District heating	0.10	District heating	0.10
Parkcarré	District heating	0.10	District heating	0.10
More	Heat Pump	0.21	Boiler	0.21
Isolanel Verde A	Heat Pump	0.21	Heat Pump	0.21
Isolanel Verde B	Heat Pump	0.21	Heat Pump	0.21
Solallén	Heat Pump	0.187	Heat Pump	0.187
Väla Gård	Heat Pump	0.12	Heat Pump	0.12
Aspern	District heating	0.10	District heating	0.10
I.+R. Schertler	HeatPump	0.10	Heat Pump	0.10

Table 12 Energy prices for the demo cases for heating and domestic hot water

4.5 KEY PERFORMANCE INDICATORS

To display the results of the data analysis of each case study, a set of key performance indicators have been proposed. In particular, a list of all performance indicators has been provided to the project partners. These have rated the performance indicators (3ð very interesting; 2ð interesting; 1ð not interesting) and with this rating the most relevant ones have been selected. Table 13 presents the indicators that obtained an average rating higher than 2. These performance indicators will be used to assess the performances of each building, to draw a comparison among the case studies and to set up the nZEB spreadsheets.

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 CO2 emissions	2,2	Final energy consumption
2,5	Life-cycle CO2 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 (lighting, appliances)
2,4	Heating demand for heating	2	Energy demand for ventilation

Table 13 Rated key performance indicators.

5. RESULTS

5.1 PRESENTATION OF THE OVERALL LCC RESULTS

This section reports a general overview of the calculation for the case studies, with the comparison of the costs and the impact of the different phases on the overall LCC. It is important to point out that the results are normalized according to the criteria illustrated in paragraph 4.4.

DEMO CASE		NAME/CODE	TYPOLOGY	LOCATION
Bouygues	Green Home	Case 1	Residential	Nanterre (France)
	Les Héliades	Case 2	Residential	Angers (France)
	Residence Alizar	Case 3	Residential	Malaunay (France)
ATP sustain	NH Tirol	Case 4	Residential	Innsbruck (Austria)
Kohler&Meinzer	Parkcarré	Case 5	Residential	Eggenstein (German
Moretti	More	Case 6	Residential	Lodi (Italy)
	Isola nel Verde A	Case 7	Residential	Milan (Italy)
	Isola nel Verde B	Case 8	Residential	Milan (Italy)
Skanska	Solallén	Case 9	Residential	Växjö (Sweden)
	Väla Gård	Case 10	Office	Helsingborg (Sweden
ATP sustain	Aspern	Case 11	Office	Vienna (Austria)
	I.+R. Schertler	Case 12	Office	Lauterach (Austria)

Table 14 Case studies analysed

Figure 5 and Figure 6 show the overview of LCC calculated considering a period of 40 years for the 12 case studies, with a breakdown of the cost for each phase. In particular, Figure 5 reports the percentage value of the impact of each phase on the LCC, considering design, construction, labor, maintenance and other costs (including the building site management). The cost of materials ranges from around 30% (for the case study Solallèn) to 48% (i.e. Green Home and Isola Verde), while the impact of the labor varies from around 2% towards 26%, where the lowest value occurs for Green home and the highest for Solallèn. In this regards, it is important to point out that the detailed breakdown of the labor and the material costs is not always available, in fact, the cases Isola nel Verde A and B and Schertler does not include this information. On the other hand, it occurs that the labor is particularly low because the breakdown between materials and labor is not complete for all the building elements, but the construction costs are reported as a whole. Therefore, the most significant information for all the cases is the sum of materials and labor (i.e. construction costs), that ranges for all the cases from around 41% to 61%.

Figure 6 shows the absolute val ^{2} of the LCC. It is important to point out that the contribution from the RES is accounted as a reduction of the energy cost of the overall life cycle (calculated as a balance between energy consumed and produced). In case of Greenhome, the energy reported in the chart assumes a negative value, since the energy produced is higher than the energy consumed, considering the large PV field installed.

Figure 7 shows an overview of the average impact of all the phases on the LCC, the investment costs for design, material labor and other initial expenditures is around 60% of the LCC, while the energy and maintenance account for around 40%.

As it was expected, the energy costs during the life cycle of a nZEB represent a minor contribution to the LCC, with an average of around 15%.

Figure 8 shows the overview of the design costs, reported as a percentage of the overall LCC and in absolute value (cost per unit surface). It is possible to point out that the design cost has a reduced impact on the LCC, ranging from 2% (Case NH Tirol) to 8% (Parkcarré). One of the possible causes of the different impact, a part of the general complexity of the building design, could be the higher design costs for the integration of the RES. In fact, in Parkcarré the 41% of the energy is supplied by a photovoltaic system (30 W/m² installed).

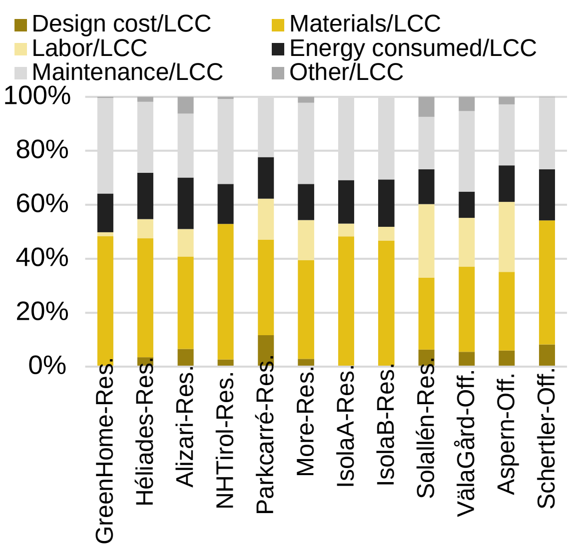

Figure 5: Life-cycle cost breakdown – share of the phases

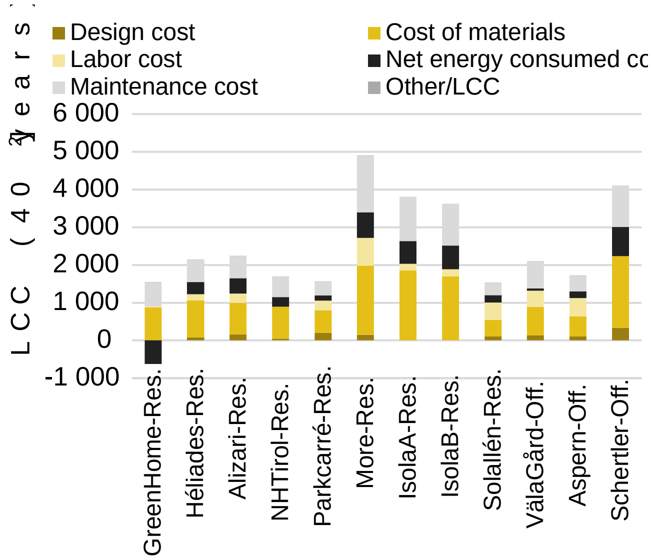

Figure 6: Life-cycle cost breakdown – normalized values.

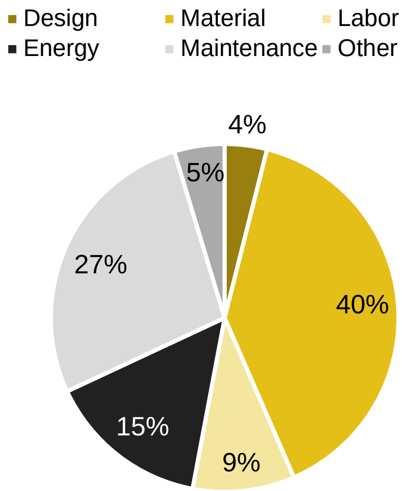

Figure 7: Life-cycle cost breakdown – average.

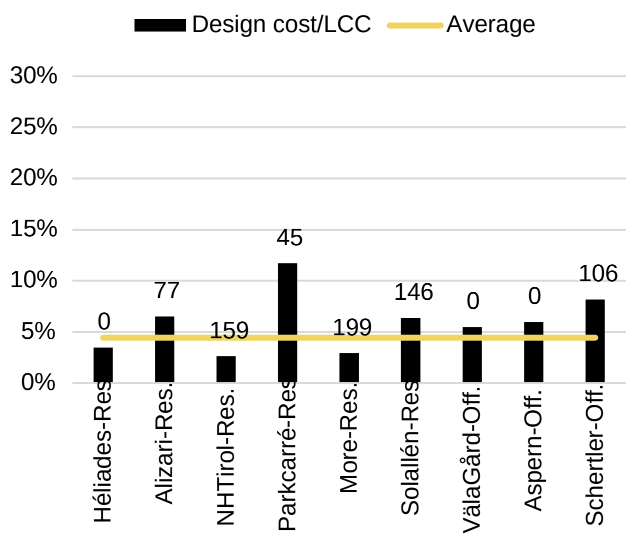

Figure 8: Design cost / LCC