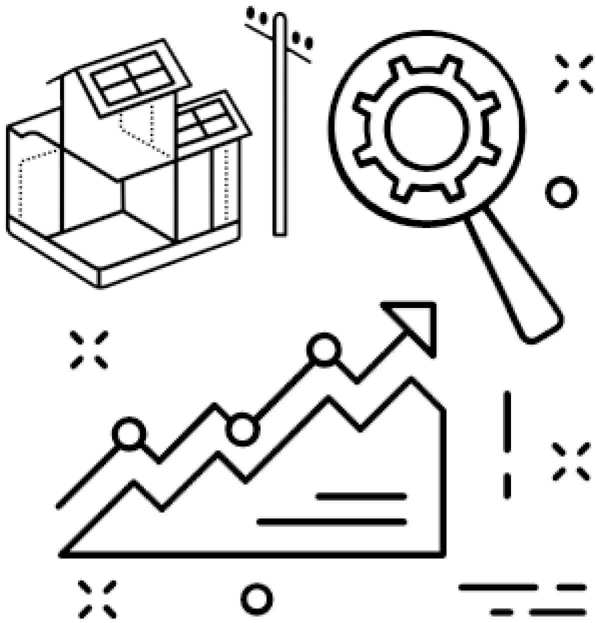
Results of optimised nZEB parametric models



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 and investors' confidence towards net zero balance.

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Results of optimised nZEB parametric models

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FOREWORD

This report was drafted within Work Package 'WP06 – Life cycle cost reduction of new nZEB', part of the Horizon2020 - CRAVEzero 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 will be significant drivers in the construction sector in the next few years because all new buildings in the EU from 2021 onwards have to be nearly zero-energy buildings (nZEBs); public buildings need to achieve the standard already by 2019.
While nZEBs realised 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 nearly zero-energy buildings requires significant adjustments to current building market structures. 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 for nZEBs related to processes, technologies, building operation and to promote innovative business models considering the cost-effectiveness for all stakeholders in the building's life cycle.

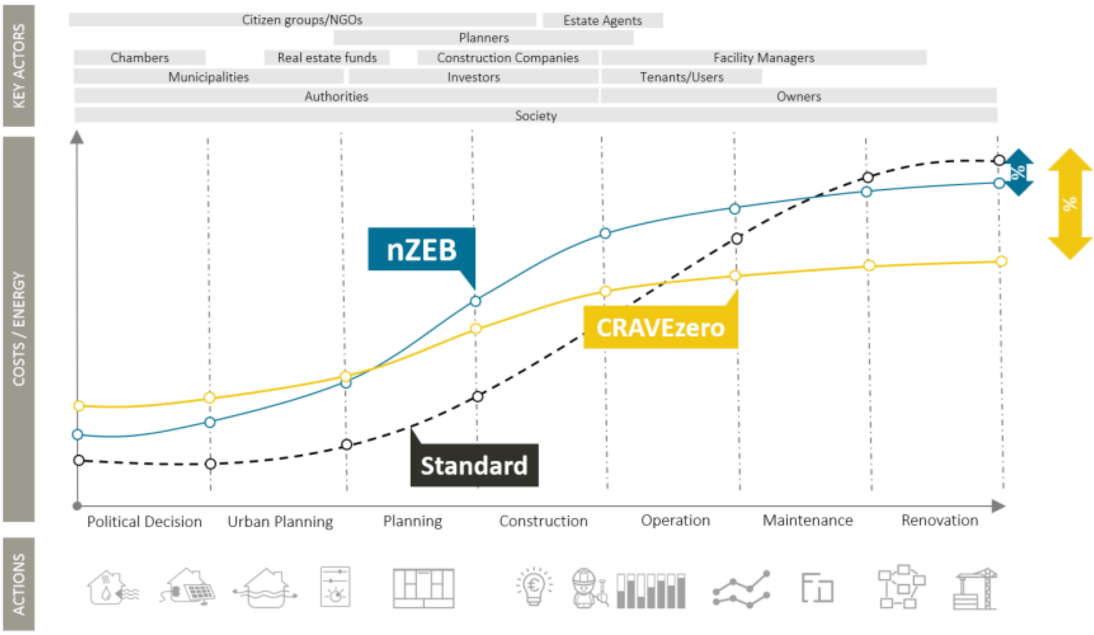

Figure 1: CRAVEzero approach for cost reductions in the life cycle of nZEBs.

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EXECUTIVE SUMMARY

Already today buildings can be realised in the nearly zero and plus energy standard. These buildings achieve extremely low energy demands and low CO_2 emissions and can be operated economically. For this reason, the motivation in the CRAVEzero project is not only based on the energy characteristics of buildings, but also on their life cycle costs. However, the broad market deployment of these buildings is progressing very slowly so far, as methods and processes for the cost-optimal integration of efficiency measures and renewable energies are not yet sufficiently described and therefore not yet familiar. As a consequence - many poorly planned buildings are criticised for the fact that the actual energy consumption of highly efficient buildings is higher than the predicted demand and that high-efficiency standards are expensive and uneconomical. The influence of the user behaviour of such energy-efficient buildings is another aspect, which has to be considered to evaluate the impact on the energy consumption of the building.

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

This method was developed earlier in the CRAVEzero project and documented in Deliverable D6.1 “Parametric models for buildings and building clusters: Building features and boundaries”.

In this Deliverable D6.2, the method was applied to the five CRAVEzero case studies Aspern IQ, Alizari, Isola Nel Verde, Les Heliades and MORE to perform parametric calculations and 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 the key performance indicators: financing costs, net present value, balanced primary energy demand and balanced CO_2 emission. The calculation results can be found in this report as well as on the CRAVEzero pinboard: http://www.cravezero.eu/pinboard/PinboardMain/PinboardMain.htm

Furthermore, the goal of this Deliverable was the extension of the sensitivity analysis to all available CRAVEzero case studies, on the one hand aiming at identifying which input parameters affect the LCC the most and on the other hand aiming at providing this output as a range of values and not as a punctual one. In this way, the implications of uncertainty issues related to the assumptions on input parameters and boundary conditions can be highlighted.

The third part of this Deliverable deals with the investigation of a renovation project and describes the steps from the energy audit to the implementation of energy efficiency improvements.

The following points show an extract from the results and findings:

- Even if the financing costs are very different from case study to case study (range between 1,200 EUR/m² and about 3,500 EUR/m²), the divergence between the highest and lowest financing costs within the individual case studies is nearly the same in all case studies. It´s between 7 % and 16 %.
- The same statement also applies to the results of the net present value calculations. The net present values range between 1,500 EUR/m² as the lowest value and more than 5,600 EUR/m² as the highest value. But within the different case studies, the divergence between the highest and the lowest net present value is about 13 % to 26 %.
- Compared to the costs, the range between the highest and the lowest balanced primary energy demand as well as between the highest and the lowest balanced CO_2 emissions is much higher. For these key performance indicators, possible reductions between 30 % and 85 % are realistic.
- The detailed analysis of the result shows that the most influencing factors (varied parameters) are the heating system, the ventilation system (especially influencing the financing costs and the net present value) as well as the user behaviour (influencing primary energy demand and CO_2 emissions).

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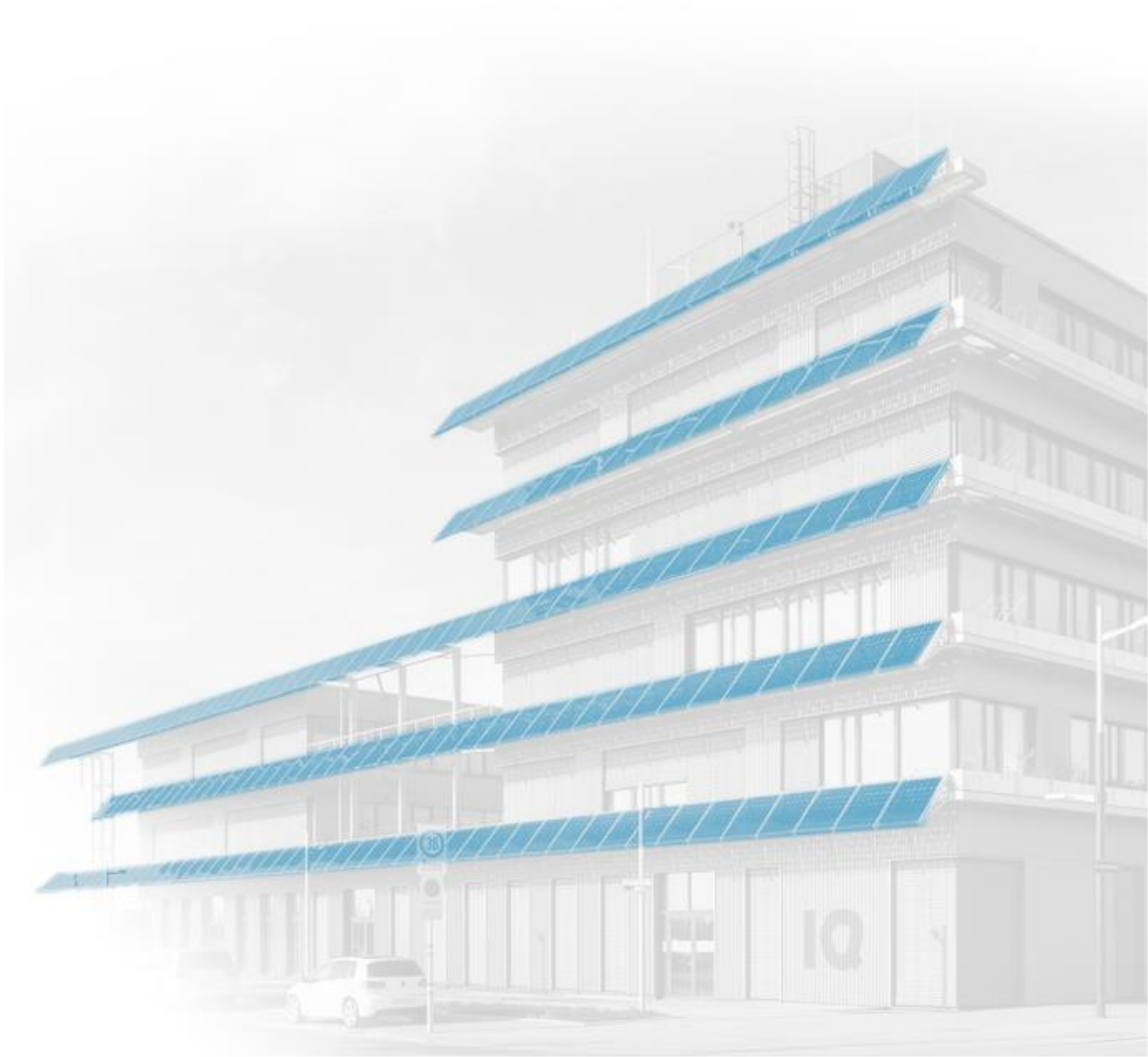


1.INTRODUCTION

1.1. OBJECTIVE

Possible cost saving potentials in planning and construction of high performing nearly zero-energy buildings (nZEBs) with advanced energy standards are often not sufficiently assessed, as only a few, out of numerous possible variants of technology sets are considered in the traditional planning process. Often planning and analysis are not carried out in parallel, and the alternative technical options are 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 where stakeholder interests' conflict with each other. In this report, an exhaustive search method was assessed for five CRAVEzero case studies, which systematically investigates all possible variant combinations. The derived results are applied to multiple objectives and optimisation 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 to find a single optimal solution. On the one hand, a variety of technologies, such as insulation of the building envelope, ventilation or electricity and heat supply, and on the other hand a variation of the boundary conditions (such as user behaviour or CO_2 follow-up costs) was investigated. The results were analysed energetically and economically over the life cycle of the building with the objectives of identifying coherences, deriving trends and optimizations over a time span of 40 years.

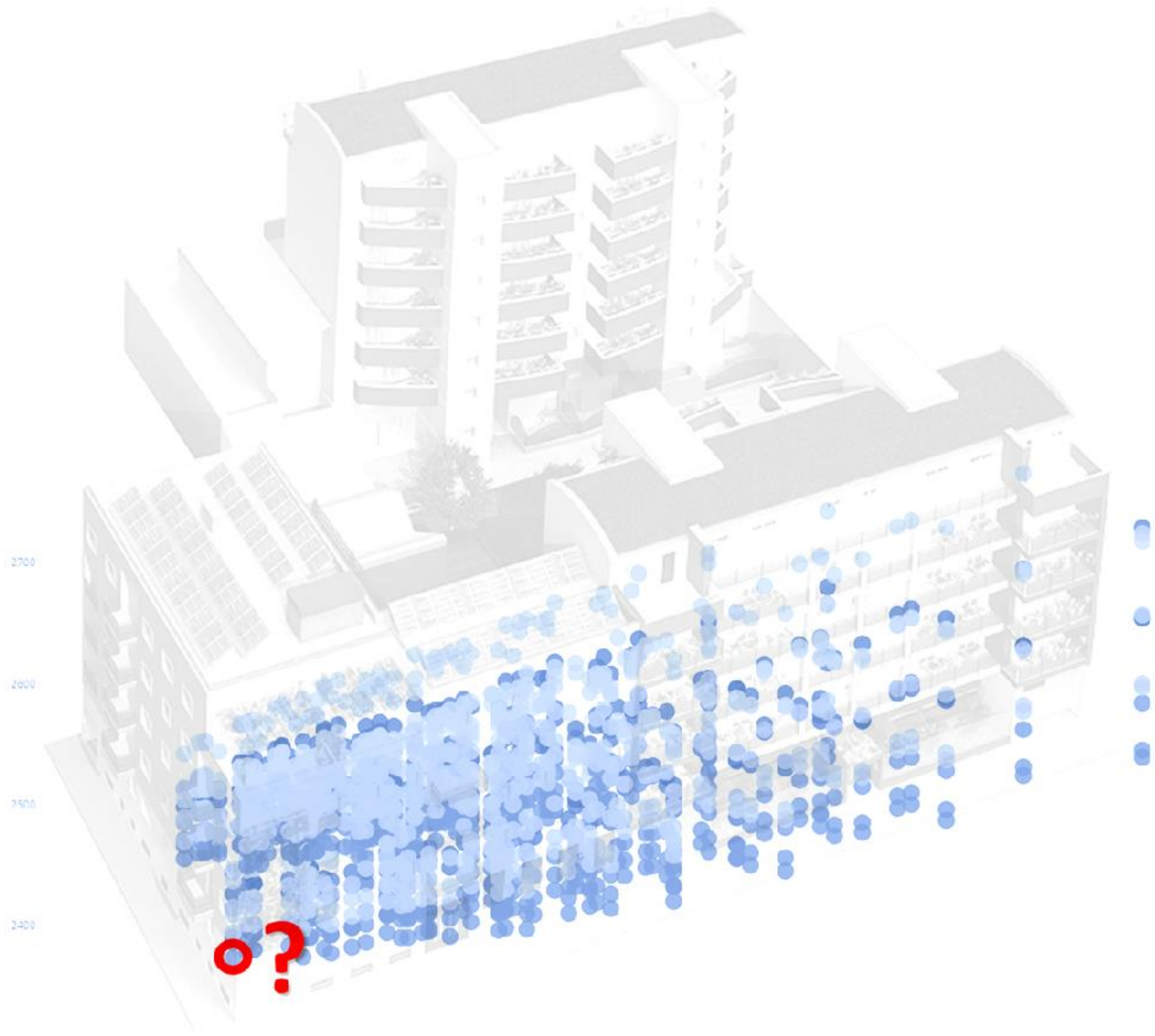
1.2. STATE OF THE ART / PROBLEM DESCRIPTION

Cost optimal and nearly zero-energy performance levels are principles initiated by the European Union's Energy Performance of Buildings Directive, which was recast in 2010 (EU, 2010). Since its introduction as part of the EPBD recast, a vast number of studies of the defined cost-optimal analysis have been carried out.

The implementation of the cost-optimal approach has led to a strong scientific interest in this field, by research institutions and by the EU member states (BPIE, 2010; Kurnitski *et al.*, 2011a, 2011b; Corgnati *et al.*, 2013; Pikas, Thalfeldt and Kurnitski, 2014; D'Agostino and Parker, 2018; Ferrara *et al.*, 2018). In addition to regulative requirements, the term "cost-optimal level" refers to "the energy performance level leading to the lowest total cost over the estimated economic life cycle" (EU, 2010). While nZEBs realised 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 nearly zero-energy buildings requires significant adjustments to current building market structures. Cost-effective integration of efficient solution sets and renewable energy systems are significant challenges (BPIE, 2010). It has to be noted that the total costs, as intended for cost-optimal calculations, only take into account energy-related costs. Therefore, the concept of total costs as foreseen in the revised EBPD is not in line with a full life cycle assessment according to ISO 15686 (BSI ISO 15686-5, 2008). Furthermore, in recent years simulation-based optimization methods for detailed building energy performance and cost assessment have evolved, leading to new research on the cost-optimal design of new buildings from a multiple-objective perspective (Nguyen, Reiter and Rigo, 2014).

CHAPTER 2

PARAMETRIC MULTI-OBJECTIVE ENERGY AND COST ANALYSIS IN THE LIFE CYCLE OF NEARLY ZERO ENERGY BUILDINGS



2.PARAMETRIC MULTI-OBJECTIVE ENERGY AND COST ANALYSIS IN THE LIFE CYCLE OF NEARLY ZERO-ENERGY BUILDINGS – AN EXHAUSTIVE SEARCH APPROACH

2.1. INTRODUCTION

Multi-objective optimization analysis has become popular in recent years. In comprehensive review studies, various multi-objective approaches for building energy design were proposed, as summarized by (Attia *et al.*, 2013; Malatji, Zhang and Xia, 2013; Machairas, Tsangrassoulis and Axarli, 2014; Nguyen, Reiter and Rigo, 2014; Hamdy and Mauro, 2017). The multi-objective approach used in these studies is usually based on the concept of Pareto frontier and genetic algorithms: The basic concept of Genetic Algorithms is designed to simulate processes in the natural system necessary for evolution (Iba and Aranha, 2012). 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 (Nguyen, Reiter and Rigo, 2014).
Genetic algorithms were applied and further optimized within extensive frameworks for cost-optimal and nearly zero-energy building solutions by considering the minimization of energy demand/ CO_2 emissions and investment or life cycle costs as objectives (Fesanghary, Asadi and Geem, 2012; Iba and Aranha, 2012; Hamdy, Hasan and Siren, 2013).
Authors of recent publications have implemented sophisticated sensitivity analysis techniques for nZEB design (Lomas and Eppel, 1992; Lam and Hui, 1996; Heiselberg *et al.*, 2009). Some techniques only interfere with one parameter at a time by keeping the other inputs fixed (Lam and Hui, 1996)or by using sampling procedures (Morris, 1991) , such as Monte Carlo methods (Cervantes, 1972), to interfere with multi-parameter inputs while simulating only some of the total design combinations that may exist. These methods are especially helpful when computing power is limited.
Optimisation using a "parametric optimiser" offers the advantage that the variants are optimised for a specific goal or cost function and can be found depending on the optimisation objective. Results, therefore, are usually based on two optimisation objectives like, for example, cost and energy demand. If this concept is also be applied to three or more optimisation goals, the results are more challenging to analyse. Also, most studies based genetic algorithms do not allow any statement on maxima, minima or statistical distributions of the resulting variants.

2.2. EXHAUSTIVE SEARCH METHOD

The term "parametric analysis" in this report is defined by a brute-force algorithm 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. Brute-force is an exhaustive search method that systematically takes into account all possible variants for a given solution and checking whether each variant satisfies the problem statement (University of Washington, no date). It is based on trial and error where the computer's fast processing power is used to solve a problem, rather than to apply advanced genetic algorithms. Therefore, with the brute-force method, the investigation of all possible variant combinations, all solutions are considered. It offers the advantage that statistical evaluations can be made and distributions can be derived. The most significant benefit is that this concept can also be applied to more than two objectives or optimisation goals. It, therefore, provides a sound basis 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 to find a single optimal solution (Chiandussi *et al.*, 2012).

A big disadvantage is the vast number of variants, by solving the problem by checking all the possible cases which are slow. Tue to its time complexity based on the limited computational power of calculation the possibility of several thousand variants, it also restricts the calculation methods. If, for example, dynamic building simulations are used to analyse a building, where each simulation takes several hours, it is hardly possible to calculate thousands of variants with a manageable amount of computing time.

The difference between a conventional design method and the parametric optimization with an exhaustive search method is shown in following Figure 2.

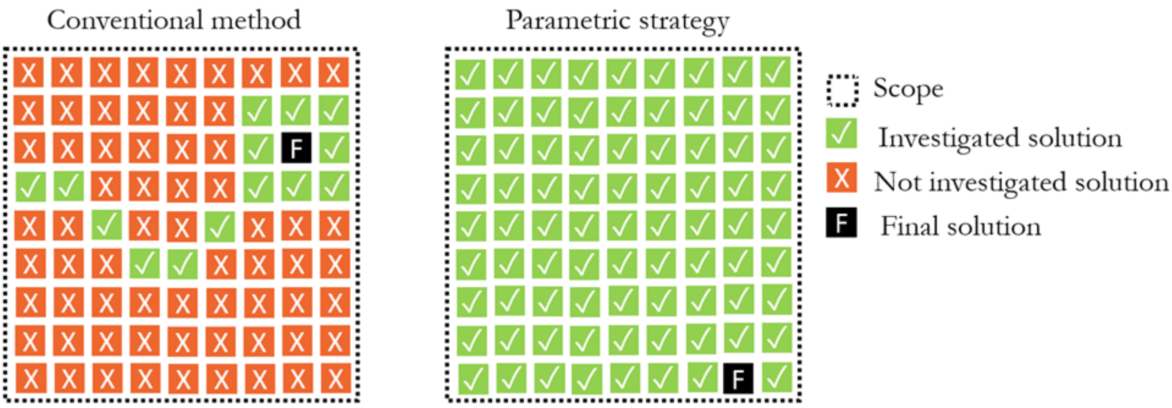


Figure 2: Comparison of conventional optimisation method vs parametric analysis (Hatt et al., 2018)

The advantage of the conventional search of the optima usually lies in the manageable number of variants and thus the reasonable effort. The disadvantage, as shown in Figure 2, is that only a local optimum can be found and not the best global solution or efficient neighbours. For example, it allows finding near-optimal design alternatives, not merely the optimum.

2.3. OPTIMIZATION PROCEDURE

The method of energy-economic analysis is shown in Figure 3.

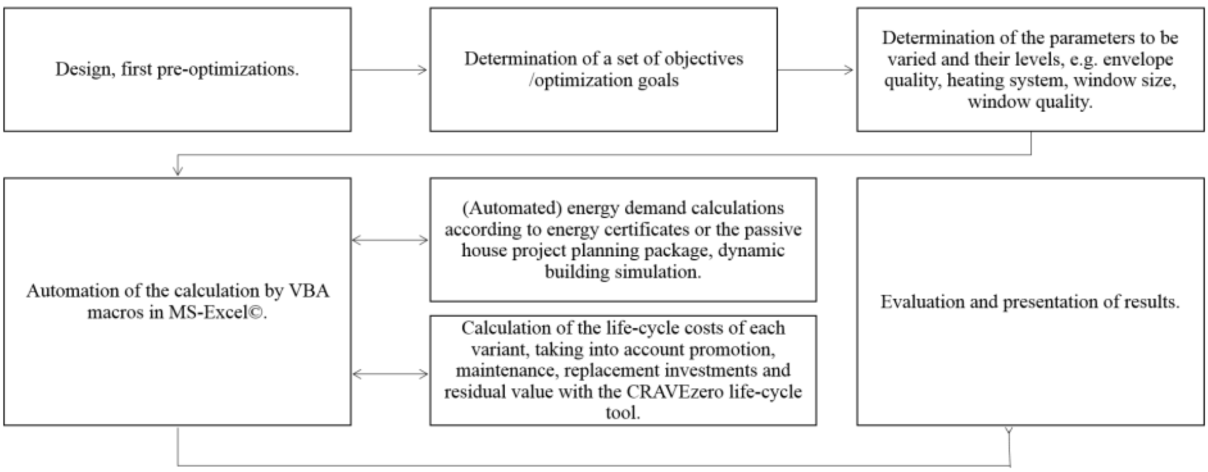


Figure 3: Method of energy-economic analysis - coupling between PHPP and CRAVEzero LCC tool

This method is based on the ISO 15686-5 (BSI ISO 15686-5, 2008) for life cycle cost calculation and the PHPP software (Passive House Institute, 2015) automated by a VBA macro that has been developed by the authors. With this method, several ten thousand different variants per case could be calculated in a manageable amount of time.

The ISO 15686-5 provides the main principles and features of an LCC calculation, while the European Code of Measurement 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 this study.

The software PHPP 9 has been used for 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.

2.4. 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:

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

C: cost occurred 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).

The analysis 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. A detailed overview of the input parameters and boundary conditions can be found in chapter 4.

Table 1: Overview of the included costs of the life cycle cost calculation

			Life cycle phases	**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

In order to provide a homogeneous and comparable estimation of the energy costs, the evaluation is based on the calculated energy demand by using the PHPP evaluation tool (Passive House Institute, 2015).

In particular, for estimating both the costs and the revenues (due to the renewables installed). The energy produced from renewables is considered in the energy balance as a positive contribution to energy consumption, and the revenues from the renewables have been discounted from the energy costs.

CHAPTER 3

DESCRIPTION OF THE CASE STUDIES AND THE INVESTIGATED PARAMETERS

3. DESCRIPTION OF THE CASE STUDIES AND THE INVESTIGATED PARAMETERS

3.1. 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

Aspern IQ is located in Vienna's newly developed urban lakeside area "Aspern" - Austria's largest 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 its klima-aktiv declaration and had also been awarded an 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 quality. 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 guideline 6 by 55 %.

Table 2 gives an overview of the parameters and levels that were investigated for the case study Aspern IQ in this Deliverable. More information on the parameters "envelope quality", "ventilation", "heating", "cooling", "solar thermal", "PV" and "battery storage" is shown in the tables that follow afterwards. Information on the parameters "sensitivity", "CO_2 follow-up costs" and "user behaviour" can be found in chapter 4.

Table 2: 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 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	-

Table 3: investment costs and technical data for the parameter "envelope quality" of the case study Aspern IQ

PARAMETER	**LEVEL 1: NATIONAL STANDARD ◓**	**LEVEL 2: nZEB ◕**	**LEVEL 3: PASSIVE HOUSE ●**
Cost of external wall	13.9 €/m²	40 €/m²	18.8 €/m²
U-value of external wall	0.35 W/m²K	As built	0.15 W/m²K
Cost of floor	10.1 €/m²	12.3 €/m²	20.2 €/m²
U-value of floor	0.40 W/m²K (earth-touched) 0.20 W/m²K (outdoor air)	As built	0.15 W/m²K
Cost of roof	16.7 €/m²	45.0 €/m²	20.2 €/m²
U-value of roof	0.20 W/m²K	As built	0.15 W/m²K
Cost of windows	385 €/m²	316 €/m²	513 €/m²
U and g- value of windows	1.70	0.94	0.8

Table 4: investment costs and technical data for the parameter "ventilation" of the case study Aspern IQ

	LEVEL 1: WINDOW VENTILATION	**LEVEL 2: MECH.VENT. + HR**	**LEVEL 3: EXTRACT AIR UNIT**
Electric efficiency	-	0.153 Wh/m³	0.125 Wh/m³
Cost	-	480,000 €	381,000 €

Table 5: investment costs and technical data for the parameter "heating" of the case study Aspern IQ

	LEVEL 1: GAS CONDENSING BOILER	**LEVEL 2: GROUND SOURCE HP**	**LEVEL 3: AIR SOURCE HP**	**LEVEL 4: DIS-TRICT HEATING**
Cost	257,000 €	206,000 € + 97,000 € water well	192,000 €	187,000 € + 53,000 € connection
Power / COP	396 kW	240 kW / 5.8 COP	205 kW / 4.5 COP	240 kW

Table 6: investment costs for the parameter "cooling" of the case study Aspern IQ

	LEVEL 1: ABSORPTION COOLING	**LEVEL 2: GROUND SOURCE HEAT PUMP COOLING**	**LEVEL 3: AIR SOURCE HEAT PUMP COOLING**
Cost	441,700 €	Included in heating cost	Included in heating cost

Table 7: investment costs for the parameter "solar thermal" of the case study Aspern IQ

	LEVEL 1: NO SOLAR THERMAL	**LEVEL 2: 28 m² FLAT PLATE DHW**	**LEVEL 3: 80 m² FLAT PLATE DHW**
Total costs of collectors	-	370 €/m²	370 €/m²
Other solar thermal costs	-	3,600 €	10,360 €
Cost of water storage	-	13,000 €	37,000 €

Table 8: investment costs for the parameter "PV" of the case study Aspern IQ

	LEVEL 1: NO PV	**LEVEL 2: 74 kWp**	**LEVEL 3: 148 kWp**
Cost of PV modules	-	288,600 €	576,000 €
Cost of PV inverter	-	10,800 €	19,000 €
Additional cost	-	40,400 €	51,800 €

3.2. 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

Groppi represents one of the typologies of the 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.

In this Deliverable different parameters and levels were investigated. Information on these investigated parameters (and levels) of the case study MORE are given in Table 9, the information to the investment costs and the technical data, which were used for the parametric calculations follow in Table 10 to Table 15.

Table 9: 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	-

Table 10: investment costs and technical data for the parameter "envelope quality" of the case study MORE

PARAMETER	LEVEL 1: NATIONAL STANDARD	LEVEL 2: nZEB	LEVEL 3: PASSIVE HOUSE
Cost of external walls	36,591 €	As built	39,051 €
U-value of external walls	0.26 W/m²K	As built	0.15 W/m²K
Cost of floor	8,237 €	As built	9,623 €
U-value of floor	0.26 W/m²K	As built	0.15 W/m²K
Cost of roof	14,295 €	As built	15,354 €
U-value of roof	0.22 W/m²K	As built	0.15 W/m²K
Total envelope costs	59,123 €	As built	64,028 €
Cost of windows	34,200 €	As built	46,800 €
U and g- value of windows	1.4 – 0.35	As built	0.8

Table 11: investment costs and technical data for the parameter „ventilation" of the case study MORE

	LEVEL 1: WINDOW VENTILATION	LEVEL 2: AS BUILT MECH.VENT. + HR	LEVEL 3: EXTRACT AIR UNIT
Electric efficiency	-	0.196 Wh/m³	0.712 Wh/m³
Costs	-	6,000 €	4,000 €

Table 12: investment costs and technical data for the parameter "heating" of the case study MORE

	LEVEL 1: GAS CONDENSING BOILER	LEVEL 2: AIR SOURCE HEAT PUMP + GAS CONDENSING BOILER	LEVEL 3: AIR SOURCE HEAT PUMP	LEVEL 4: DISTRICT HEATING
Cost	3,500 €	HP=5,031 € BOILER=2,122 €	11,000 €	14,000 €
Power / COP	45 kW Eff = 104 %	HP: 15 kW COP 4.2 BOILER: 33.74 kW Eff = 97.3 %	45 kW COP =4.07 EER=3.12	45 kW

Table 13: investment costs for the parameter "cooling" of the case study MORE

	LEVEL 1: COMPRESSOR COOLING	LEVEL 2: NO COOLING	LEVEL 3: AIR SOURCE HEAT PUMP COOLING
Costs	8,000 €	-	11,000 €

Table 14: investment costs for the parameter "solar thermal" of the case study MORE

	LEVEL 1: NO SOLAR THERMAL	LEVEL 2: 5 m² FLAT PLATE DHW	LEVEL 3: 10 m² FLAT PLATE DHW+SH
Total costs of collectors	-	1,266 €	2,532 €
Other solar thermal costs	-	929	2,000 €
Cost of water storage	-	1,497 €	3,000 €

Table 15: investment costs for the parameter „PV" of the case study MORE

	LEVEL 1: NO PV	LEVEL 2: 5 kWp	LEVEL 3: 10 kWp
Cost of PV modules	-	3,800 €	7,600 €
Cost of PV inverter	-	1,500 €	2,200 €
Additional cost	-	2,200 €	3,700 €

3.3. 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

The complex has two buildings, A and B. 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.

For the parametric calculations and analysis in this Deliverable only building A was investigated. Table 16 shows the defined parameters of the case study Isola Nel Verde. Additionally also the three respectively four different levels of each parameter are mentioned. Table 17 to Table 22 give an overview of the investment costs and technical data of each parameter.

Table 16: 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	-

Table 17: investment costs and technical data for the parameter "envelope quality" of the case study Isola Nel Verde

	LEVEL 1: NATIONAL STANDARD	LEVEL 2: nZEB	LEVEL 3: PASSIVE HOUSE
Costs of external walls	166,366 €	As built	173.000 €
U-value of external walls	0.26 W/m²K	As built	0.15 W/m²K
Cost of floor	31,200 €	As built	36,347 €
U-value of floor	0.26 W/m²K	As built	0.15 W/m²K
Cost of roof	55,236 €	As built	58,460 €
U-value of roof	0.22 W/m²K	As built	0.15 W/m²K
Total envelope costs	252,802 €	As built	267,773 €
Cost of windows	119,250 €	As built	172,250 €
U and g- value of windows	1.4 W/m²K – 0.35	As built	0.8 W/m²K

Table 18: investment costs and technical data for the parameter "ventilation" of the case study Isola Nel Verde

	LEVEL 1: WINDOW VENTILATION	LEVEL 2: MECH.VENT. WITH HEAT RECOVERY	LEVEL 3: EXTRACT AIR UNIT
Electric efficiency	-	0.48 Wh/m³	0.178 Wh/m³
Heat recovery rate	-	83 %	-
Costs	-	56,000 €	4,800 €

Table 19: investment costs and technical data for the parameter "heating" of the case study Isola Nel Verde

	LEVEL 1: GAS CONDENSING BOILER	LEVEL 2: GEOTHER-MAL HEAT PUMP + DISTRICT HEATING	LEVEL 3: AIR SOURCE HEAT PUMP	LEVEL 4: DIS-TRICT HEATING
Cost	12,000 €	466,577 €	60,000 €	25,000 €
Power / COP	85 kW Eff =102 %	Heat pump: 86.82 kW COP 4.38	140 kW COP =3,9	Heat Exchanger 85 kW

Table 20: investment costs for the parameter "cooling" of the case study Isola Nel Verde

	LEVEL 1: COMPRESSOR COOLING	LEVEL 2: GEOTHERMAL HEAT PUMP COOLING	LEVEL 3: AIR SOURCE HEAT PUMP COOLING
Cost	42,000 €	50,000 €	60,000 €

Table 21: investment costs for the parameter "solar thermal" of the case study Isola Nel Verde

	LEVEL 1: NO SOLAR THERMAL	LEVEL 2: 36 m² FLAT PLATE DHW	LEVEL 3: 72 m² FLAT PLATE DHW
Total costs of collectors	-	12,500 €	19,000 €
Other solar thermal costs	-	1,200 €	1,800 €
Cost of water storage	-	8,000 €	8,000 €

Table 22: investment costs for the parameter "PV" of the case study Isola Nel Verde

	LEVEL 1: NO PV	LEVEL 2: 7 kWp	LEVEL 3: 14 kWp
Cost of PV modules		5,040 €	9,800 €
Cost of PV inverter		3,150 €	4,000 €
Additional cost		3,850 €	7,000 €

3.4. 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

The Héliades residence, where 57 families have been living since March 2017, is defined as a Positive Energy Building (BEPOS). It was designed by the architect Barré-Lambot and Bouy-gues 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.

In Deliverable 6.2 different parameters and levels were investigated. These are shown in Table 23. Table 24 to Table 28 on the next page show the investment costs and technical data of each investigated parameter.

Table 23: 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	-

Table 24: investment costs and technical data for the parameter "envelope quality" of the case study Les Heliades

PARAMETER	**LEVEL 1: NATIONAL STANDARD**	**LEVEL 2: nZEB**	**LEVEL 3: PASSIVE HOUSE**
Costs of external walls	195 €/m²$_{wall}$	240 €/m²$_{wall}$	247 €/m²$_{wall}$
U-value of external walls		0,233 W/m²K	
Cost of floor	160 €/m²$_{GFA}$	160 €/m²$_{GFA}$	197 €/m²$_{GFA}$
U-value of floor		0,259 W/m²K	
Cost of roof	150 €/m²$_{GFA}$	157 €/m²$_{GFA}$	170 €/m²$_{GFA}$
U-value of roof		0,139 W/m²K	
Cost of windows	550 €/m²$_{Window}$	700 €/m²$_{Window}$	950 €/m²$_{Window}$
Uw and g- value of windows	1.7 W/m²K – 0.7	1,51 W/m²K – 0.62	1,1 W/m²K – 0.5

Table 25: investment costs and technical data for the parameter "ventilation" of the case study Les Heliades

	LEVEL 1: WINDOW VENTILATION	**LEVEL 2: MECHANICAL VENTILATION WITH HEAT RECOVERY**	**LEVEL 3: EXTRACT AIR UNIT**
Electric efficiency	-	0.3 Wh/m³	0.2 Wh/m³
Costs	0,7 € / (m³/hr)	26 € / (m³/hr)	0.5-1 € / (m³/hr)

Table 26: investment costs and technical data for the parameter "heating" of the case study Les Heliades

	LEVEL 1: GAS CONDENSING BOILER	**LEVEL 2: DISTRICT HEATING**	**LEVEL 3: AIR SOURCE HEAT PUMP**
Cost	70 €/m²	0	110 €/m²
Power / COP	220 kW / Eff = 110 %	220 kW / Eff = 100 %	220 kW / COP = 3.5

Table 27: investment costs for the parameter "solar thermal" of the case study Les Heliades

	LEVEL 1: NO SOLAR THERMAL	**LEVEL 2: 42 m² FLAT PLATE DHW**	**LEVEL 3: 110 m² FLAT PLATE DHW**
Total costs of collectors	-	466 €/m²	466 €/m²
Other solar thermal costs	-	300 €/m²	300 €/m²
Cost of water storage	-	1.81 €/litre	1.81 €/litre

Table 28: investment costs for the parameter "PV" of the case study Les Heliades

	LEVEL 1: NO PV	**LEVEL 2: 56 kWp**	**LEVEL 3: 82 kWp**
Cost of PV (modules, inverter and additional costs)	-	2,8 €/Wp	2,8 €/Wp

3.5. 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

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 are the key elements of this building.
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.

Table 29 shows the parameters and levels of the case study Alizari, which were analysed in this Deliverable. The cost and technical data which was necessary for the parametric calculations are shown in Table 30 to Table 33.

Table 29: 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

Table 30: investment costs for the parameter "insulation envelope" of the case study Alizari

	Level 1: 250 mm EXTERNAL	Level 2: 300 mm EXTERNAL	Level 3: 200 mm EXTERNAL + 100 mm INTERNAL
Cost	115.92 €/m²	122.22 €/m²	137,59 €/m²

Table 31: investment costs and technical data for the parameter "heating" of the case study Alizari

	LEVEL 1: ETA BOILER	LEVEL 2: HARGASSNER BOILER	LEVEL 3: ÖKOFEN BOILER	LEVEL 4:CO-GENERATION PLANT
boiler efficiency	0.91	0.94	1.03	1.09
Total cost (supply)	173 €/kW	192 €/kW	238 €/kW	897 €/kW
Labour cost	1,300 €	1,650 €	1,650 €	2,250 €

Table 32: investment costs and technical data for the parameter "ventilation" of the case study Alizari

	LEVEL 1: WINDOW VENTILATION	LEVEL 2: ROTATECH VENTILATION UNIT	LEVEL 3: HELIOS VENTILATION UNIT	LEVEL 4: SWEGON VENTILATION UNIT
Heat recovery efficiency	-	0.68	0.81	0.84
Total cost (supply)	-	7,557 €	8,350 €	15,884 €
Labour cost	-	420 €	420 €	420 €

Table 33: investment costs and technical data for the parameter "PV" of the case study Alizari

	LEVEL 1: NO PV	LEVEL 2: 30 kWp / 15 % EFFFICIENCY	LEVEL 3: 34 kWp / 17 % EFFFICIENCY	LEVEL 4: 41 kWp / 21 % EFFFICIENCY
Power	-	30.01 kW	34.13 kW	40.71 kW
Number of Panels	-	118	118	118
Area	-	192 m²	192 m²	192 m²
PV efficiency	-	0.15	0.17	0.21
Cost	-	54,310 €	62,650 €	77,190 €

CHAPTER 3

ASSUMPTIONS AND BOUNDARY CONDITIONS

4.ASSUMPTIONS AND BOUNDARY CONDITIONS

4.1. BOUNDARY CONDITION FOR ECONOMIC EVALUATION

The construction costs of the buildings (as shown in the previous chapters) were provided by the project partners ATP, Bouygues, Moretti and 3i. All buildings have already been constructed, and therefore real cost data was available. The costs for the varied technologies and building elements were also directly provided by those project partners. If necessary, assumptions were made according to the CRAVEzero database of WP4. All costs are reported as "net costs" (excluding VAT). Land costs and excavation costs were on principle taken into account.

The considered buildings are located in Austria, France and Italy. Therefore climate data files were generated with Meteonorm 7.1.8.29631.

The economic evaluation of the variants is based on an observation period of 40 years (see also Table 34), which was previously defined in D2.2 (Deliverable D2.2: Spreadsheet with LCCs). This observation period was chosen because this duration is feasible for private housing, as well as for property developers. As for the financing scheme, a bank loan was chosen with a credit period time 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 to 2 % and the discount rate of the used capital investment was 3 %. All these values were taken from the CRAVEzero LCC-Tool.

The different technical maintenance costs and lifespans of the different components are taken into account and based on the gathered data in D2.2 and the CRAVEzero database of WP4. Cost drivers can also be determined by evaluating individual parameters in relation to costs. The following cost items are taken into account: total costs, financing costs, energy costs including basic fees, replacement investments, operation costs, maintenance costs, repairs and residual values. The energy costs also take into account the revenues from the grid feed-in of the electricity generated on the building from renewable sources (e.g. PV electricity). No additional follow-up costs such as administration, insurance, cleaning, security services, building services and demolition costs are included in this report. Rental incomes are not taken into account.

All costs are calculated using the "CRAVEzero life cycle cost tool", which was developed in the projects KoPro LZK+ and CRAVEzero.

Table 34: 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
Interest rate bank credit	3 %

4.2. MAINTENANCE COSTS

To consider the costs during the operational phase of the building, life cycle maintenance cost were applied as fraction of the investment costs per year. These maintenance costs were gathered from the LCC-spreadsheets (see D2.2). For the parameters which are not covered in the case study, these factors were conducted from the CRAVEzero database of WP4. The most important building elements are listed in Table 35. 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 manager.

Table 35: Summary of the most important maintenance costs and maintenance intervals

Position	Activity	Interval	Share of Investment costs	Unit
Exterior wall	Maintenance	Annually	1.5 %	€/a
Floor construction	Maintenance	Annually	1.5 %	€/a
Flat roof construction	Maintenance	Annually	1.5 %	€/a
Windows and doors	Maintenance	Annually	1.5 %	€/a
Ventilation system with heat recovery	Maintenance	Annually	4.0 %	€/a
Air distribution system	Cleaning and maintenance	Annually	6.0 %	€/a
District heating transfer station	Maintenance	Annually	3.0 %	€/a
Ground source heat pump	Maintenance	Annually	3.0 %	€/a
Air heat pump	Maintenance	Annually	3.0 %	€/a
Thermal collectors	Maintenance	Annually	1.0 %	€/a
PV system	Maintenance	Annually	1.0 %	€/a

4.3. REPLACEMENT AND RENEWAL

The replacement of the construction components is necessary, especially for active components. 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. Active components of the building equipment are typically renewed several times during the lifetime of the whole building. In this report, an observation period of 40 years is chosen, which is a relatively low expected lifetime for the building envelope. This has to be adjusted if a higher observation period will be chosen. The building elements, with a lifespan lower than the observation period, are reinvested, and the remaining residual value is deducted after the observation period. Table 36 lists the technical lifetime of the building elements, which were gathered from the D2.2 and the CRAVEzero database of WP4.

Table 36: 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

Position	Techn. life-time (years)	Position	Techn. lifetime (years)
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		

4.4. ENERGY PRICES AND PRICE INCREASE

The energy costs were calculated for each investigated variant based on the final energy demand of the variant. If PV was 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 (see Table 37). The electricity price was derived from the LCC tool in WP2 and cross-checked with the values from Eurostat.

Table 37 gives an overview of the used energy prices of the different energy sources in Austria, France and Italy.

Table 37: Energy prices as boundary conditions of the economic efficiency calculation

Energy carriers	AUSTRIA	FRANCE	ITALY	Unit
Natural Gas	0.060	0.086	0.095	€/kWh
Electricity	0.187	0.146	0.216	€/kWh
District heating	0.090	0.033	0.100	€/kWh
PV feed-in tariff	0.048	0.060	0.070	€/kWh

As described in chapter 3 for each case study the energy prices and feed-in tariffs were varied (parameter "sensitivity"). In total four different scenarios were defined and investigated. The assumptions on which the calculations in the respective levels are based are shown in Table 38.

Table 38: 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: PHPP DEFAULT
Energy price increase per year	1.0 %	2.0 %	0.5 %	-
Increase of PV feed-in tariff per year	1.7 %	2.7%	0,7%	-

4.5. ANALYSIS OF THE CO2 FOLLOW-UP COSTS

Besides the variation of the energy price and feed-in tariff increase, a further varied parameter in the economic evaluation was the consideration of CO_2 follow-up costs at different levels. In total four levels were defined, calculated and analysed. These four levels are:

- Low CO_2 follow-up costs: 100 EUR/t_{CO2}.a
- Standard CO_2 follow-up costs: 200 EUR/t_{CO2}.a
- High CO_2 follow-up costs: 300 EUR/t_{CO2}.a
- No CO_2 follow-up costs: 0 EUR/t_{CO2}.a

4.6. ANALYSIS OF THE USER BEHAVIOUR

Additionally also a sensitivity analysis was carried out to investigate the influence of different user behaviours on the results. As already indicated in the description of the investigated parameters of each case study, four different user behaviours, which range from inefficient user behaviour (level 1), over a standard user behaviour (level 2) to efficient user behaviour (level 3). For comparison also the default settings from PHPP were used (level 4).

Table 39 gives an overview of the four different user behaviours and the parameters that were varied.

Table 39: 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)	21 °C	22 °C	23 °C	20 °C
DHW-demand (at 60°C)	29 l/d	33.3 l/d	48.5 l/d	33.3 l/d
Misuse of external blinds during winter time	0 %	+10 %	+20 %	0 %
Electrical loads	20 kWh/m²a	26.6 kWh/m²a	35 kWh/m²a	26.6 kWh/m²a
Additional window ventilation during winter time	0.0 1/h	+0.05 1/h	+0.1 1/h	0.0 1/h

CHAPTER 5

RESULTS OF THE PARAMETRIC ENERGY AND COST CALCULATIONS

5. RESULTS OF THE PARAMETRIC ENERGY AND COST CALCULATIONS

5.1. OVERALL RESULTS

In this Deliverable the four main indicators for the analysis of the calculation results are: the financing costs, net present value over the life cycle of the building, the balanced primary energy demand and the balanced CO_2 emissions.

"Balanced" in this case means that the self-consumption of the PV system was considered, transferred into CO_2 emissions (and in further consequence also into primary energy) by the conversion factors for electricity and then subtracted from the calculated CO_2 emissions (respectively primary energy demand). Written as a formula, the balanced CO_2 emissions were calculated as follows:

$$CO_2 \text{ emissions balanced } [\frac{kg}{m^2a}] =$$
$$CO_2 \text{ emissions } [\frac{kg}{m^2a}] \text{ - self-consumption of PV } [\frac{kWh}{m^2a}] \text{ x conversion factor of electricity } [\frac{kg}{kWh}]$$

Figure 4 shows the comparison of the financing costs and the balanced primary energy demand of the five case studies. The results allow the following analysis:

- The financing costs are very different, and range between about 1,200 EUR/m² and about 3,500 EUR/m². Here the country-specific differences in price levels become evident.
- Within the different specific case study results, the range between the highest financing costs and the lowest financing costs is between 7 % and 16 % divergence. That means, starting from the highest financing costs, the different investigated measure combinations can reduce the financing costs by 7-16 %. Expressed as EUR value the 16 % is about 550 EUR/m² (case study MORE), the 7 % are about 90 EUR/m² (case study Alizari).
- Compared to the financing costs, the range between the highest and the lowest balanced primary energy demand is much more significant. The highest balanced primary energy demand about is 230 kWh/m²a and the lowest value below zero (-22 kWh/m²a). The negative value is achieved by the situation, that in this case the case study is located in Palermo (climate as investigated parameter), which results in a very low heating demand. In combination with a large PV installation and a high share of PV electricity self-consumption the balanced primary energy value can be reduced that far.
- Since the total highest and lowest primary energy demand is achieved in the case study MORE, here the range between the highest and the lowest is the largest. Due to the different measure combinations, the balanced primary energy demand could be reduced by nearly 110 % (starting from the highest value). At the other case studies the range between the highest and the lowest primary energy value lies between 30 % and 85 %.

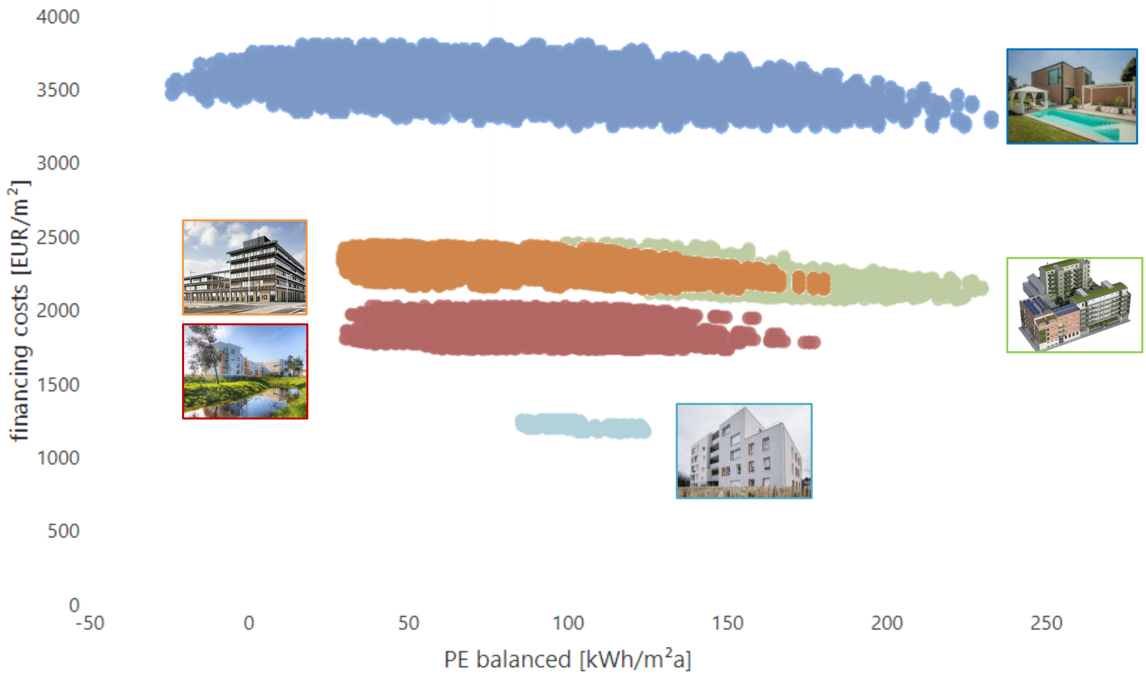


Figure 4: financing costs (EUR/m²) in relation to the balanced primary energy demand (kWh/m²a) of all variants of the five case studies

The visualization of the results in Figure 5 shows similar findings. Here the net present value is compared to the balanced CO_2 emissions:

- The range between the highest and the lowest net present value is about 13-26 % over the five case studies. In comparison to that, the range between the highest and the lowest balanced CO_2 emissions is much higher (30-110 %). Summarized, this means (also with regard to the results in Figure 4), very low primary energy and CO_2 emission values could be achieved with only slightly higher financing and life cycle costs.
- Looking at the net present value in detail the values range between 1,500 EUR/m² as the lowest value (case study Alizari) and more than 5,600 EUR/m² as the highest value (case study MORE). In general, the case study MORE achieves the highest life cycle costs, the case study Alizari the lowest. As already described for the financing costs, the different country-specific economic parameters have a very large influence on the case study-specific results.
- The CO_2 emissions, on the other hand, range between 50 kg_{CO2}/m^2a and -5 kg_{CO2}/m^2a. Both values are achieved in the case study MORE. This means that MORE achieves the total highest and also the total lowest value of all case studies. The negative value is again a result of the investigated measure combination (climate Palermo + large PV installation).

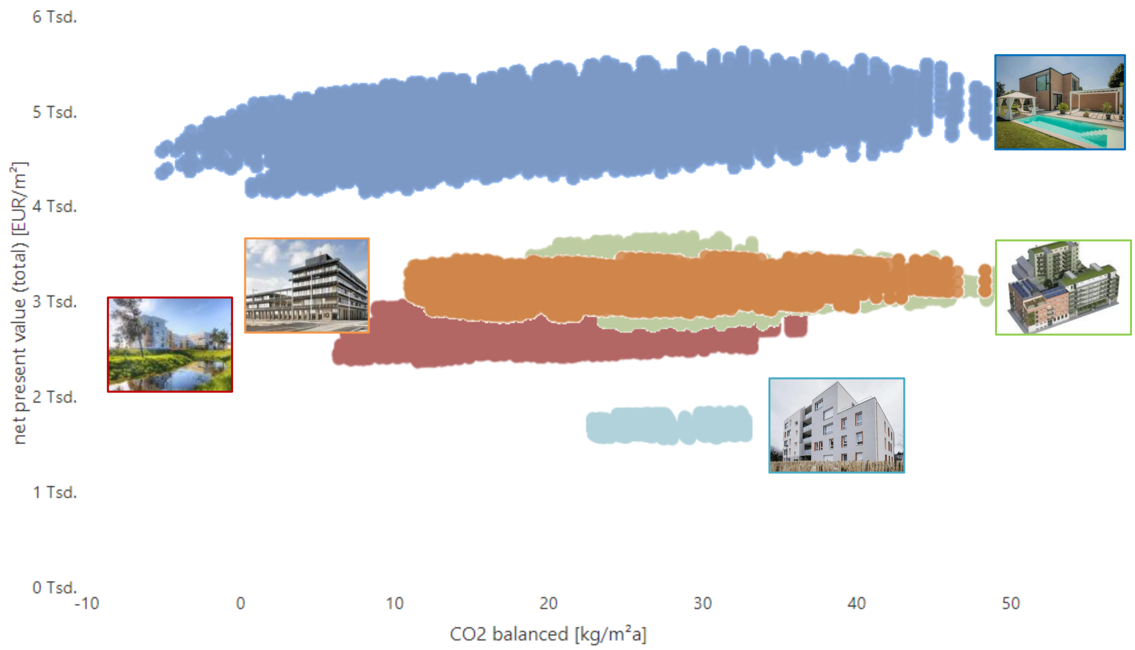


Figure 5: net present value (EUR/m²) in relation to the balanced CO_2 emissions (kg_{CO2}/m²a) of all variants of the five case studies

To give a more detailed overview of the overall calculation results, box plots for financing costs (Figure 6), net present value (Figure 7), balanced primary energy demand (Figure 8) and balanced CO_2 emissions (Figure 9) were produced. With the help of this method, the data can be analysed according to its quartiles. The shown boxes represent in each case the first quartile (splits off the lowest 25 % of data from the highest 75 %), the second quartile (also called median), which cuts the data set in half, and the third quartile (splits off the highest 25 % of data from the lowest 75 %). The lines shown represent the minimum and maximum values.

The analysis of the following box plots is a confirmation of the findings already stated in the analysis of Figure 4 and Figure 5:
For the financing costs and the net present value, the range between the maximum and the minimum is much lower than the range between the maximum and minimum balanced primary energy demand and the maximum and minimum balanced CO_2 emissions.
As the boxplots show, not only the range between the maximum and minimum values is smaller, also the range between the first and the third quartile is much smaller. The box is smaller and more compact. In contrast to that, the range between the minimum and maximum values as well as the range between the first and third quartiles is larger at the balanced primary energy and balanced CO_2 emission results.

In further consequence, this means, that the investigated parameters and levels (and their combinations) have in fact just a small influence on the financing costs and the net present value, but a very high influence on the primary energy demand and the CO_2 emissions. This highlights the importance of in-depth comprehensive analysis in the planning phase, to be able to fully exploit the existing reduction potentials.

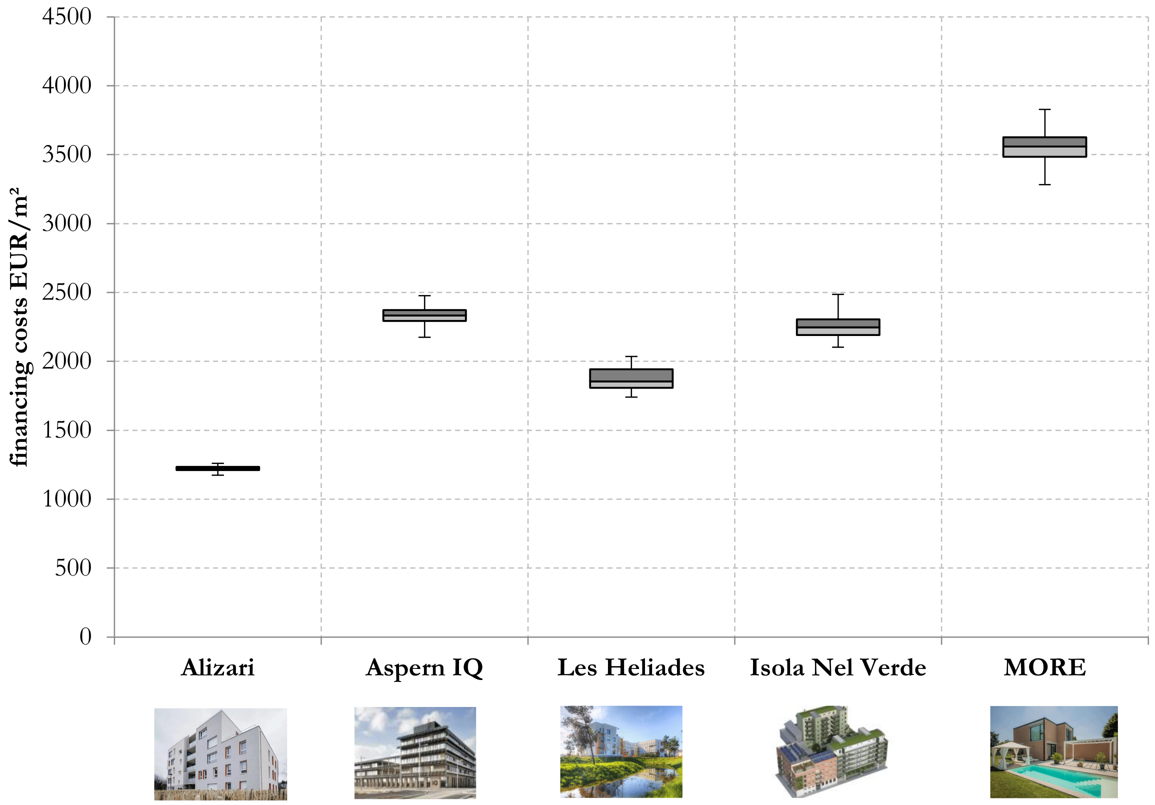


Figure 6: box plot of the financing costs of all five case studies, indicating minimum, maximum and median value as well as the lower and upper quartile

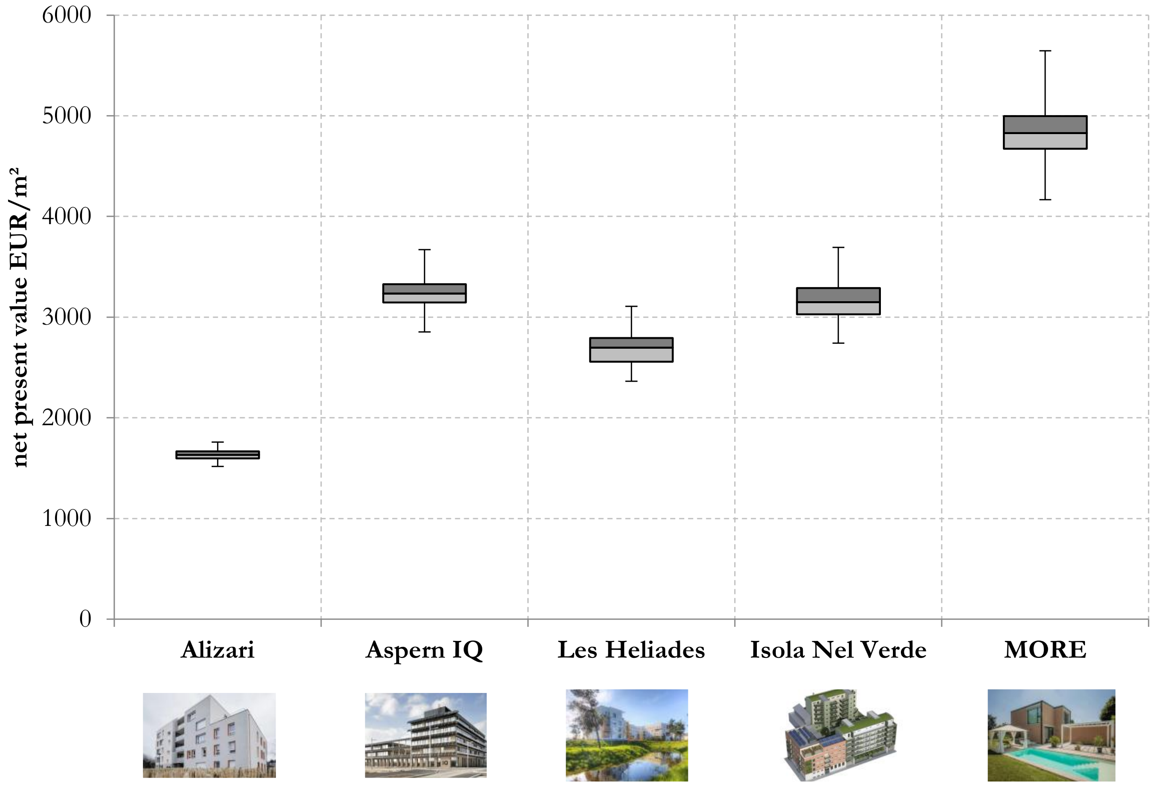


Figure 7: box plot of the net present value of all five case studies, indicating minimum, maximum and median value as well as the lower and upper quartile

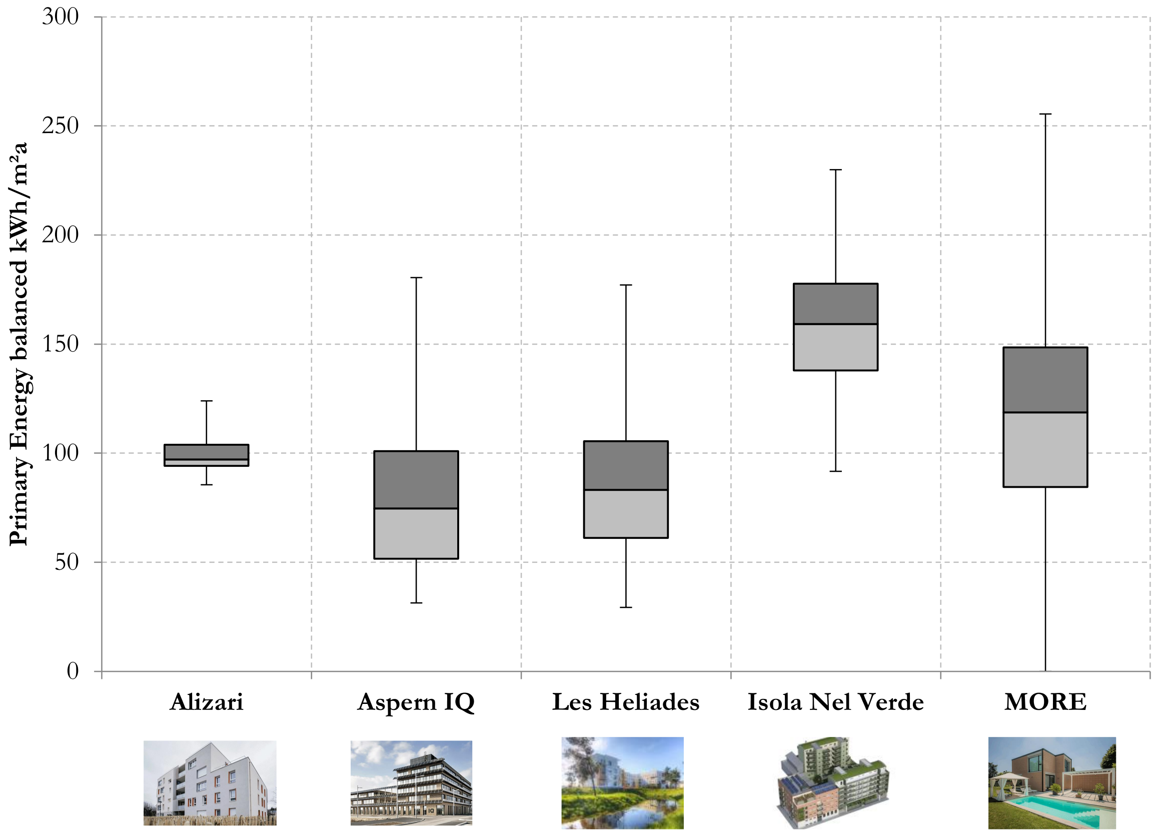


Figure 8: box plot of the balanced primary energy demand of all five case studies, indicating minimum, maximum and median value as well as the lower and upper quartile

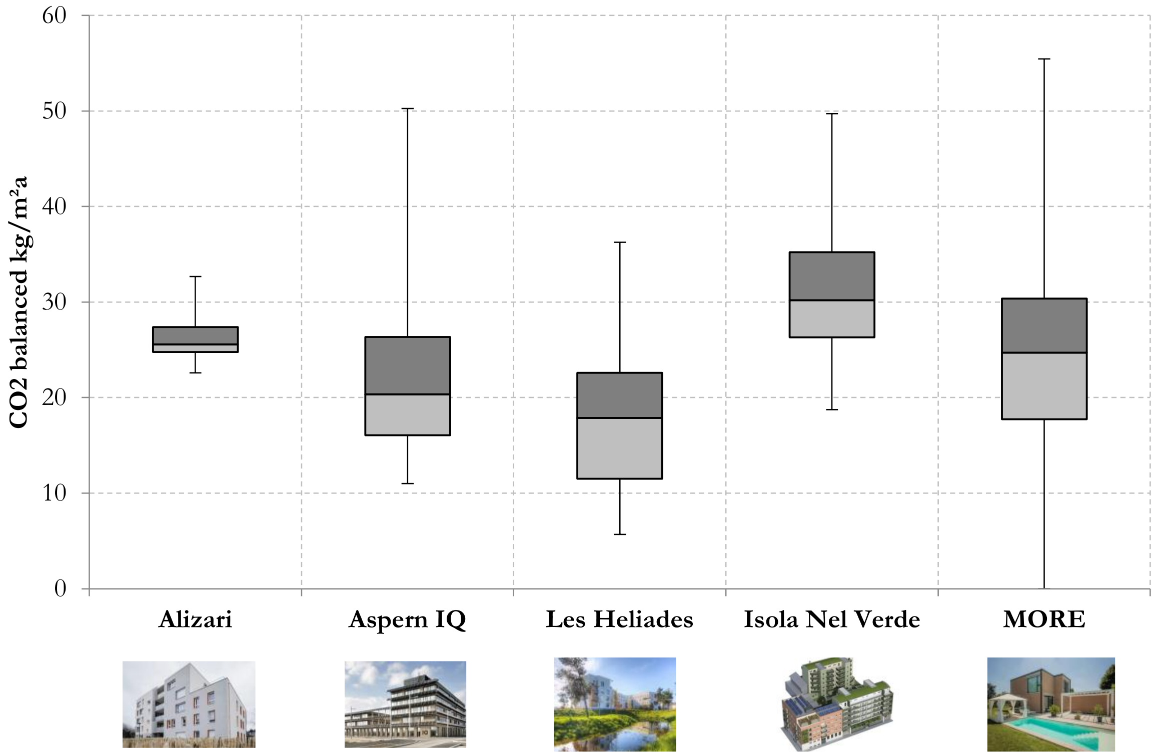


Figure 9: box plot of the balanced CO_2 emissions of all five case studies, indicating minimum, maximum and median value as well as the lower and upper quartile

Further analysis of the overall results is shown in Figure 10. It shows the specific costs in the different phases of the life cycle of the five case studies. The minimum (min) and maximum (max) values indicate the min and max values per phase. In this Deliverable, the following costs were considered:

- Planning costs
- Financing costs
- Consumption costs incl. PV own use and PV feed-in
- Operating costs
- Replacement investment
- Residual value

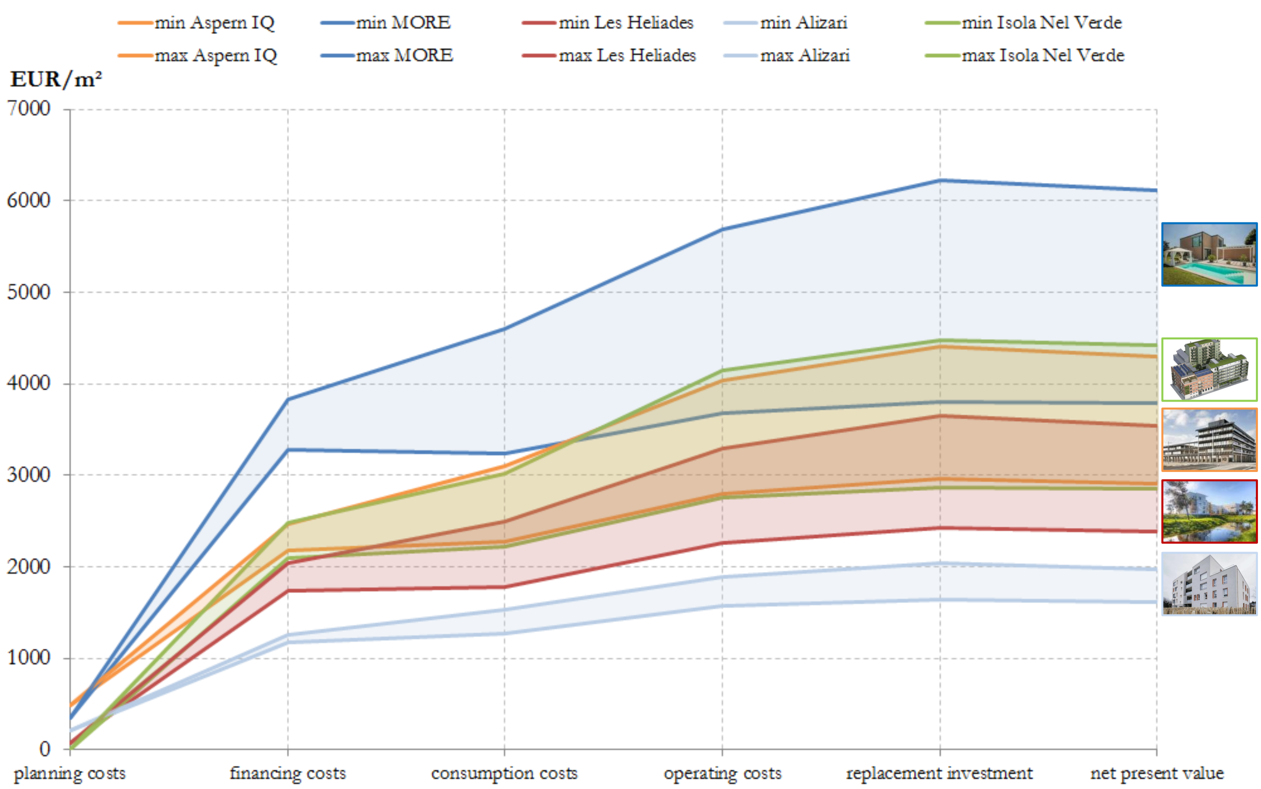


Figure 10: specific costs (EUR/m²) in the different phases of the five case studies over the whole life cycle of the buildings; range between the different parameters indicated as minimum (min) and maximum (max) values; indicated values represent the min and max values per phase

5.2. CASE STUDY SPECIFIC RESULTS

5.2.1. ASPERN IQ

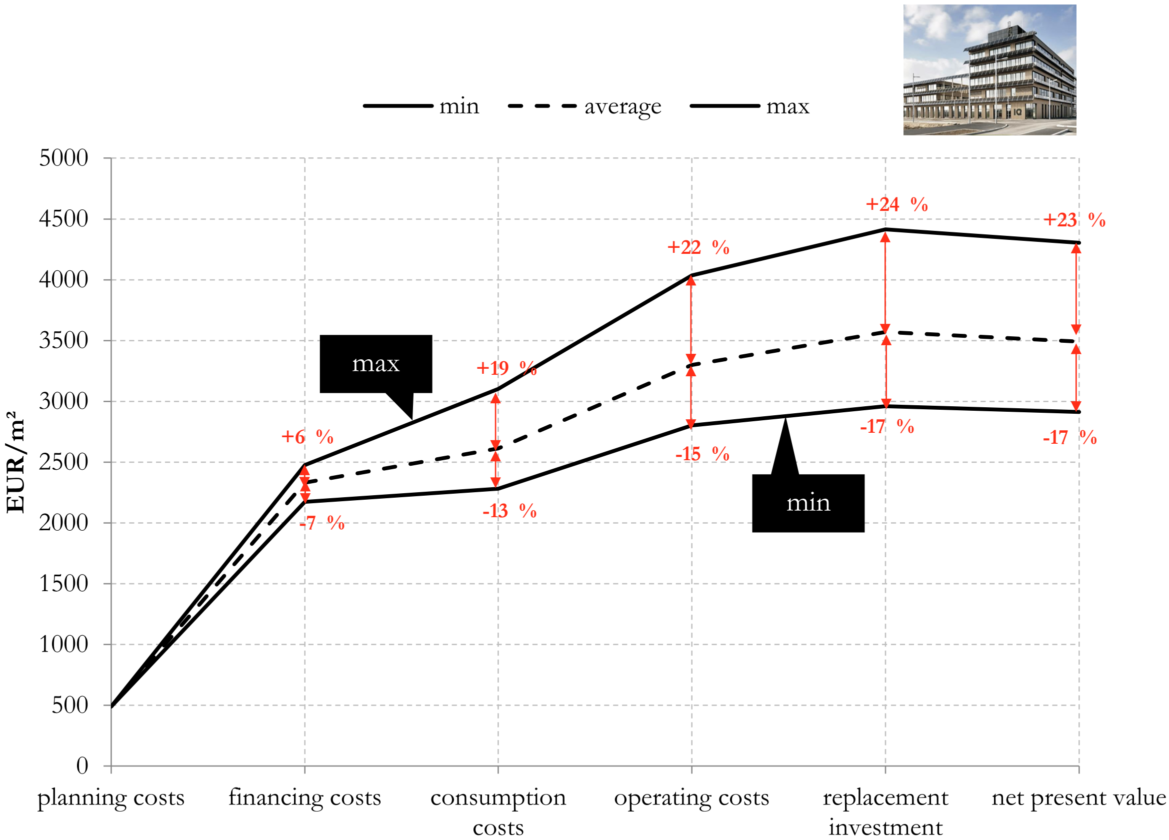


Figure 11: specific costs (EUR/m²) in the different phases of the case study Aspern IQ over the whole life cycle of the building; range between the different parameters indicated as minimum (min), average and maximum (max) values; percentages represent the deviation from the average value

Figure 11 shows the specific costs in the different phases of the case study Aspern IQ. 11,665 different variants were calculated (to simplify the calculation and the analysis the sensitivity and the user behaviour had to be defined as standard and were therefore not varied). The minimum, average and maximum values of all those variants are plotted in Figure 11, indicating the range of the costs in each individual phase of the building life cycle. The indicated numbers are based on the average value and show the deviation upwards and downwards. The decline of the net present value is caused by the residual value of the building components, which did not reach the end of their lifespan after the reinvestment. Their residual values are deducted at the end of the observation period.

Looking at each phase of the building life cycle in detail, the results show that based on the maximum values, reductions between 13 % and 41 % are possible.

Figure 12 shows the cost curve for three different variants of the parametric calculations. For the nearly zero-energy building (nZEB) the variant with the highest net present value was plotted. In comparison to that, the variant with the lowest net present value was selected and illustrated. This variant is called "CRAVEzero". The "average" variant is the median variant, where the net present value is precisely in the middle between the "nZEB" and the "CRAVEzero" variant.

The percentages in the figure represent the possible cost reductions of the CRAVEzero variant in comparison to the nZEB variant. In the case study Aspern IQ, 7 % to 20 % reductions in each phase are possible.

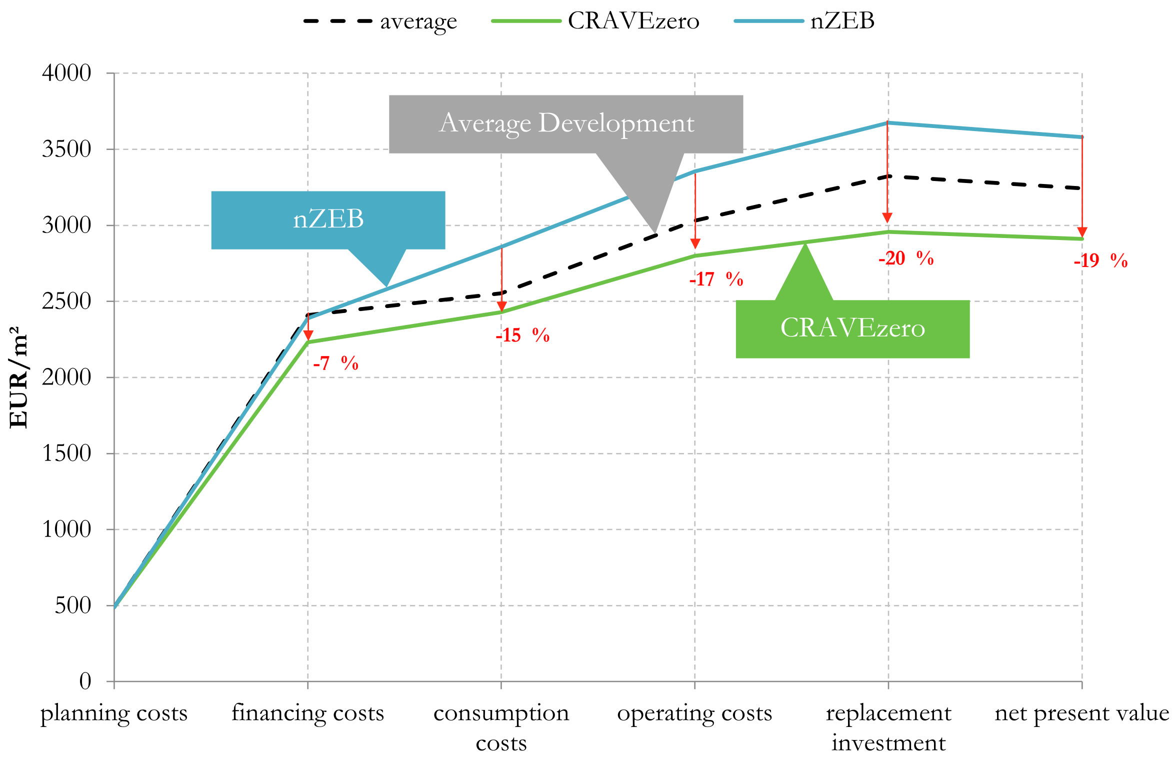


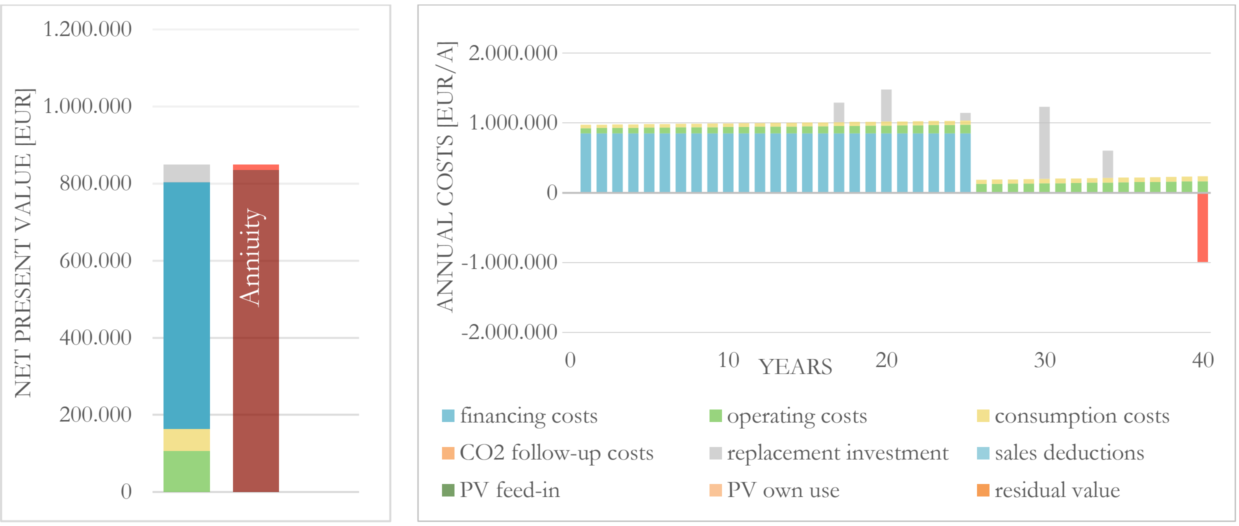
Figure 12: cost performance (EUR/m²) of the case study Aspern IQ over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value

For each of the three variants, which are shown in Figure 12, a detailed economic analysis is available. This analysis is shown in Figure 13 and includes the detailed composition of the net present value (on the left side) and the allocation of the costs of the 40 years period under consideration (on the right side).

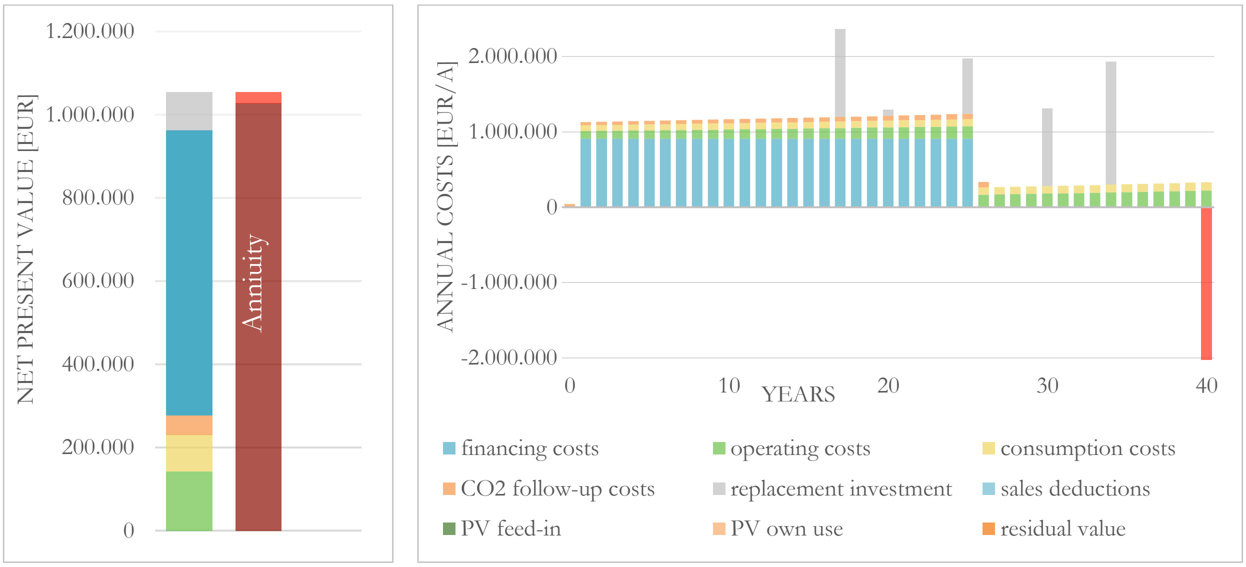
The analysis shows that the financing costs account for the largest share of the costs, followed by the operating costs, the consumption costs and the costs for replacement investment.

All other costs play only a subordinate role and contribute only insignificantly to the overall result over the entire life cycle.

DETAILED LIFE CYCLE COSTS VARIANT "CRAVEzero"



DETAILED LIFE CYCLE COSTS VARIANT "nZEB"



DETAILED LIFE CYCLE COSTS VARIANT "Average Development"

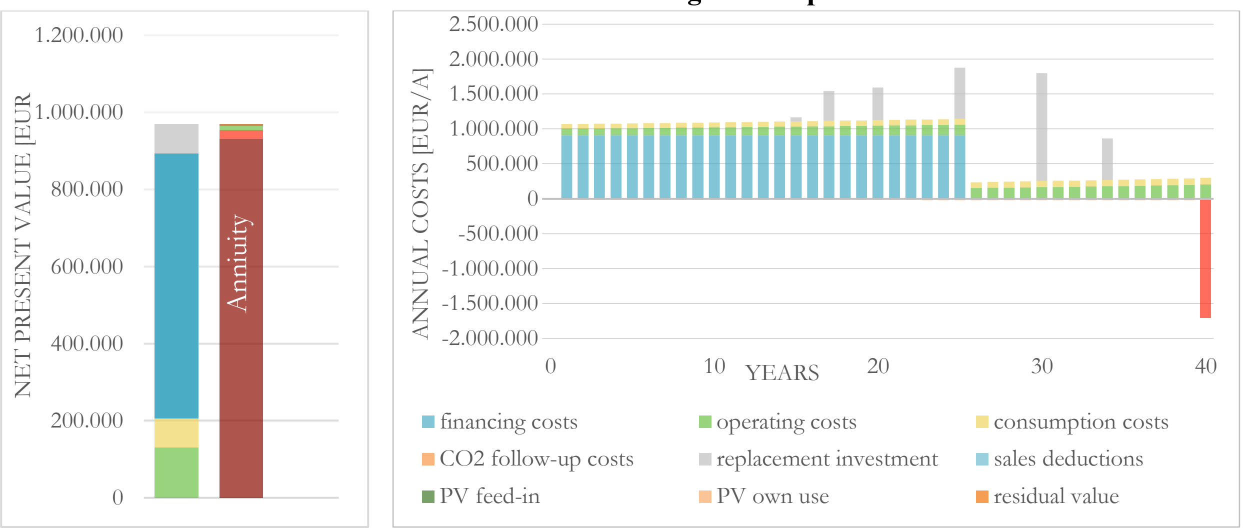


Figure 13: Net present value and life cycle costs of the variants "nZEB", "CRAVEzero" and "Average Development" of Figure 12

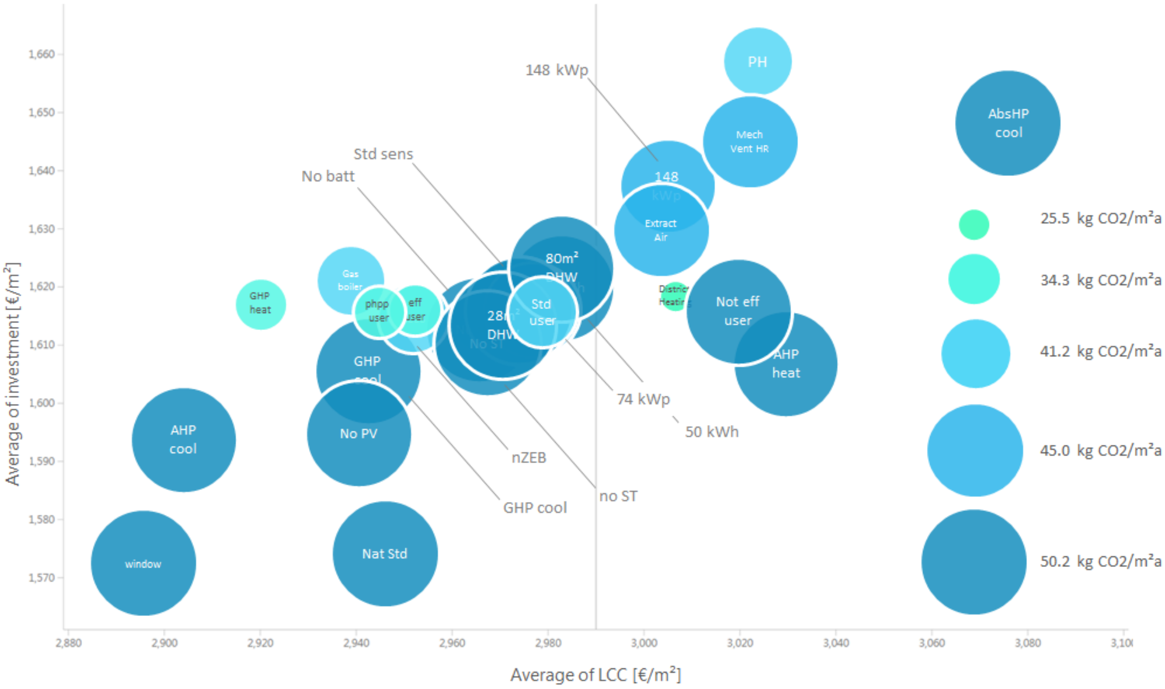


Figure 14: "bubble chart" of the case study Aspern IQ; bubble size indicates the average CO_2 emissions; bubble position is determined by average investment costs and average life cycle costs

Another evaluation of the results was done by creating so-called "bubble charts". The advantage of these bubble charts is the unification of three different results in one chart: investment costs, life cycle costs and CO_2 emissions. Furthermore, all investigated parameters and levels can be plotted at the same time.

The bubble chart for the case study Aspern IQ in Figure 14 shows that the parameters "window ventilation" and "national standard envelope" achieve the lowest average investment costs and also low average life cycle costs, but in fact, have the highest average CO_2 emissions. Similar results are achieved by the parameters "air source heat pump cooling" and "no PV". On the opposite the parameter "passive house envelope" achieves the highest average investment costs but reduces the average CO_2 emissions to a lower average level. The parameter "absorption heat pump cooling" has the highest average life cycle costs. The lowest average CO_2 emissions are achieved by the parameter "district heating", "ground source heat pump heating", "PHPP default user behaviour" and "efficient user behaviour". This allows the conclusion that the most influencing factors on the CO_2 emissions are the heating system and user behaviour.

Based on the average values, that were calculated and also used in Figure 14, the deviation of each individual parameter from the total average value was calculated and is shown in Table 40. The analysis was done for the four performance indicators financing costs, net present value, balanced primary energy and balanced CO_2 emissions. Reductions compared to the average value are highlighted by a green bar; a grey bar indicates an increase. This analysis allows identifying the dependencies of the performance indicators on the different parameters.

For Aspern IQ the ventilation and the envelope quality have the biggest influence on the financing costs, the net present value is influenced by the cooling system, the heating system, the ventilation but also by the CO_2 follow-up costs and the user behaviour. The user behaviour also influences the primary energy demand and CO_2 emissions. But these performance indicators are mostly influenced by the choice of the heating system and by the ventilation, the envelope quality and the installed PV size.

Table 40: deviation of each individual variant from the mean value of the case study Aspern IQ; 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	0,00%	-0,65%	0,00%	0,00%
	Std_CO2	0,00%	0,65%	0,00%	0,00%
	High_CO2	0,00%	1,94%	0,00%	0,00%
	no_CO2	0,00%	-1,94%	0,00%	0,00%
user behavior	Not_eff_user	0,00%	1,80%	20,14%	20,04%
	Std_user	0,00%	0,21%	2,37%	2,35%
	Eff_user	0,00%	-0,85%	-9,47%	-9,42%
	phpp_user	0,00%	-1,17%	-13,05%	-12,97%
battery storage	no_Batt	-0,14%	-0,11%	1,83%	1,83%
	25_kWh	0,01%	0,00%	-0,18%	-0,19%
	50_kWh	0,13%	0,11%	-1,65%	-1,65%
PV	no_PV	-0,91%	-0,01%	12,64%	12,65%
	74_kWp	0,00%	-0,25%	-4,00%	-4,00%
	148_kWp	0,91%	0,25%	-8,64%	-8,65%
solar thermal	no_ST	-0,24%	-0,18%	1,98%	1,54%
	28m2_DHW	-0,07%	-0,08%	0,23%	0,17%
	80m2_DHW	0,31%	0,25%	-2,21%	-1,71%
cooling	AbsHP_cool	1,39%	3,15%	0,00%	0,00%
	GHP_cool	-0,43%	-0,98%	0,00%	0,00%
	AHP_cool	-0,96%	-2,17%	0,00%	0,00%
heating	Gas_Boiler	0,23%	0,00%	29,81%	14,14%
	GHP_heat	0,05%	-2,36%	-20,92%	-20,46%
	AHP_heat	-0,39%	1,99%	33,48%	33,98%
	District_Heating	0,12%	0,38%	-42,37%	-27,67%
ventilation	Window	-1,86%	-2,18%	9,06%	8,98%
	MechVent_HR	1,26%	1,24%	-8,46%	-8,37%
	ExtractAir	0,60%	0,94%	-0,60%	-0,61%
envelope	Nat_Std	-1,79%	-0,58%	14,86%	14,78%
	nZEB	-0,05%	-0,85%	-8,90%	-8,85%
	PH	1,84%	1,43%	-5,96%	-5,93%

In the evaluation process so far, the focus was on the overall results respectively the influence of one single parameter on the results. Figure 15 and Figure 16 now show the results for selected technology combinations. So, a passive house envelope in combination with mechanical ventilation with heat recovery and an 80 m² solar thermal installation is compared to nZEB envelope quality, a ground source heat pump in combination with 148 kWp PV and a national standard envelope with air source heat pump and window ventilation. For these technology combinations the financing costs were compared to the balanced CO_2 emission in Figure 15. Figure 16 shows the comparison of the net present value and the balanced CO_2 emissions.

The results show that two of the three investigated technology combinations can achieve low CO_2 emissions, but with different financing costs and different net present values. Compared to the three selected combinations, the technology combination "national standard envelope quality with air source heat pump and window ventilation" achieves the lowest investment costs, but not the lowest life cycle costs. In addition, the CO_2 emissions are significantly higher than those of the other two variants.

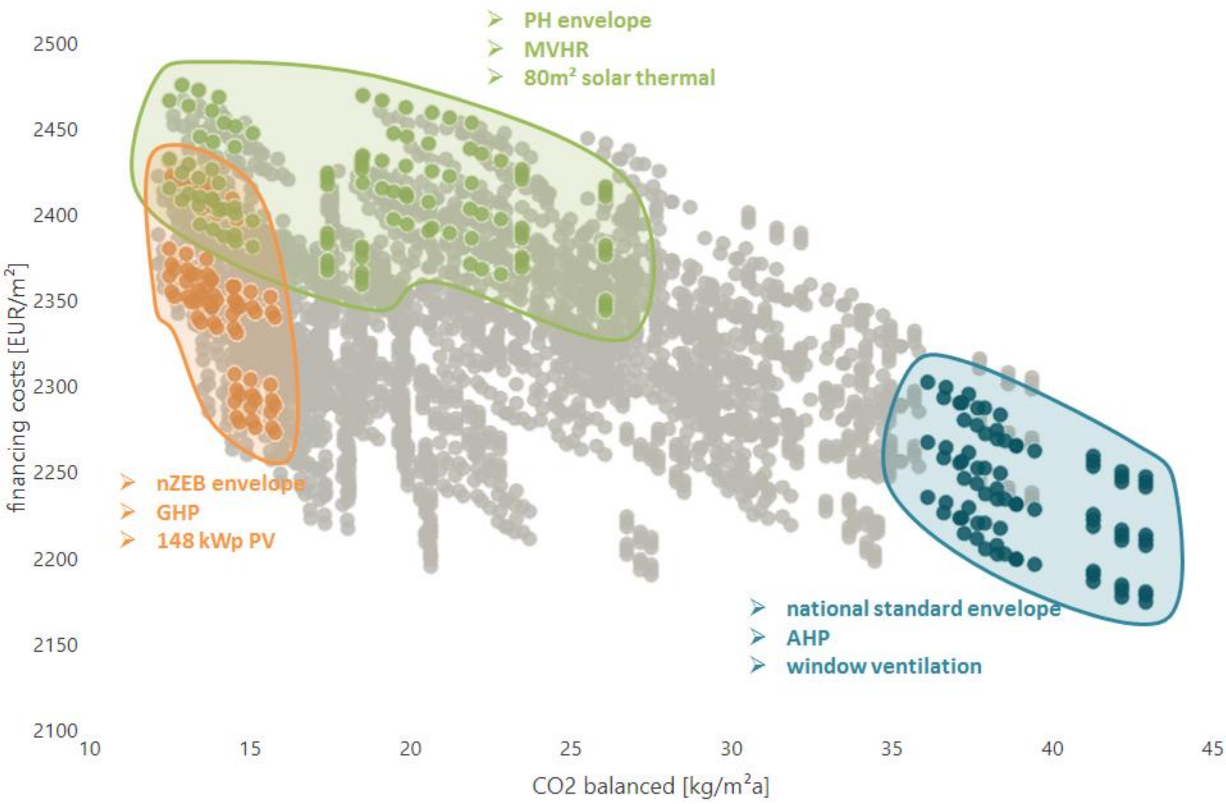


Figure 15: analysis of the balanced CO_2 emissions related to the ***financing costs*** *for different technology combinations of the case study Aspern IQ*

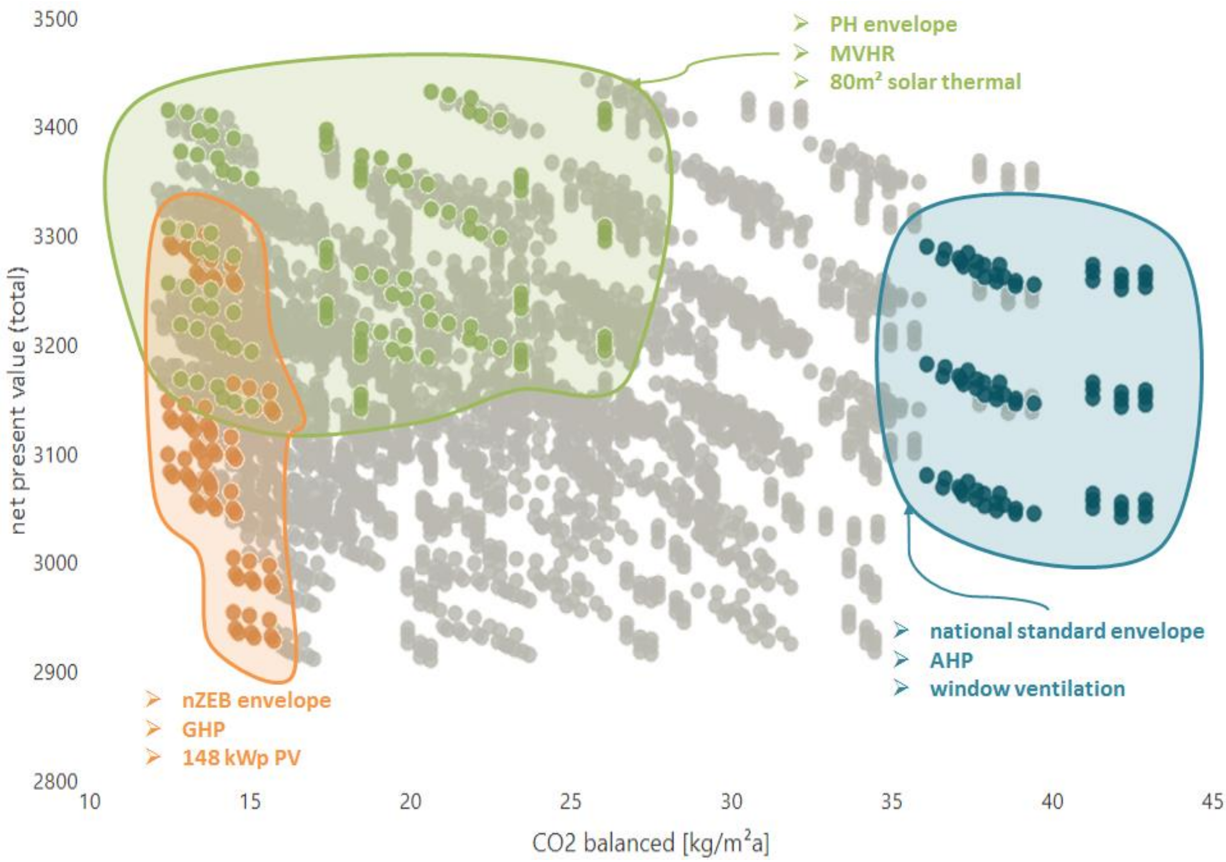


Figure 16: analysis of the balanced CO_2 emissions related to the ***net present value*** *for the same technology combinations as in Figure 15*

5.2.2. MORE

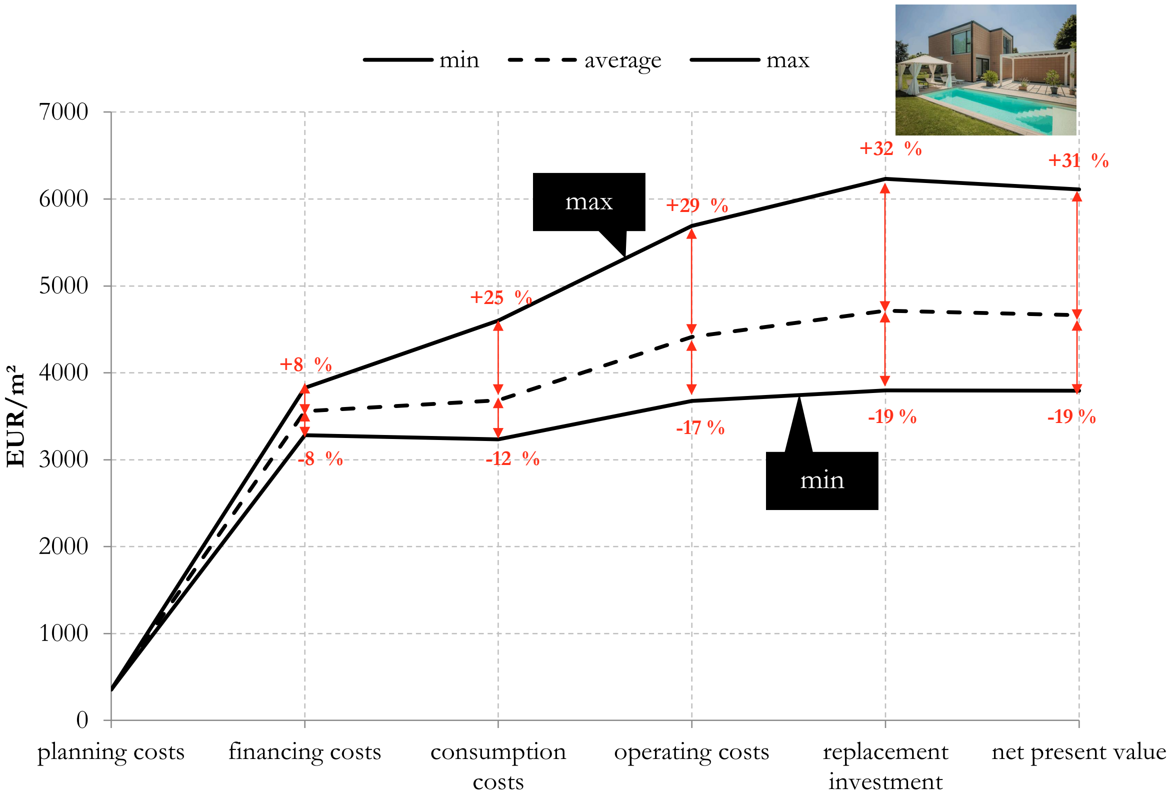


Figure 17: specific costs (EUR/m²) in the different phases of the case study MORE over the whole life cycle of the building; range between the different parameters indicated as minimum (min), average and maximum (max) values; percentages represent the deviation from the average value

Figure 17 shows the specific costs in the different phases of the case study MORE. 3,889 different variants were calculated (to simplify the calculation and the analysis the sensitivity and the user behaviour had to be defined as standard and were therefore not varied). The minimum, average and maximum values of all those variants were plotted in Figure 17, indicating the range of the costs in each individual phase of the building life cycle. The indicated numbers are based on the average value and show the deviation upwards and downwards.

Looking at each phase of the building life cycle in detail, the results show that based on the average value deviations from +8 % to +32 % respectively -8 % to -19 % per phase is possible. In total reductions from 15 % to 52 % per phase can be achieved (reduction from "max" to "min" value).

Figure 18 shows the cost curve for three different variants of the parametric calculations. For the nearly zero-energy building (nZEB) again, the variant with the highest net present value was plotted. In comparison to that, the variant with the lowest net present value was selected and illustrated. This variant is called "CRAVEzero". The "average" variant is the median variant, where the net present value is exactly in the middle between the "nZEB" and the "CRAVEzero" variant.
The percentages in the figure represent the possible cost reductions of the CRAVEzero variant in comparison to the nZEB variant. In the case study MORE, 5 % to 24 % reductions in each phase is possible.

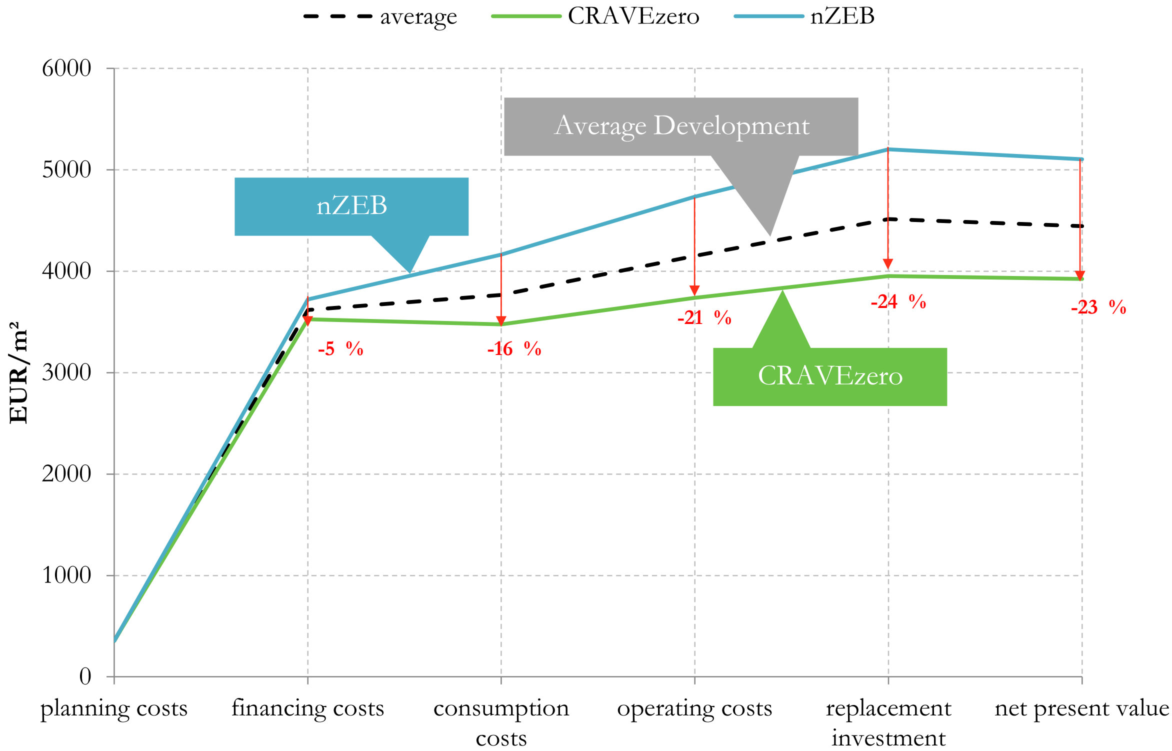


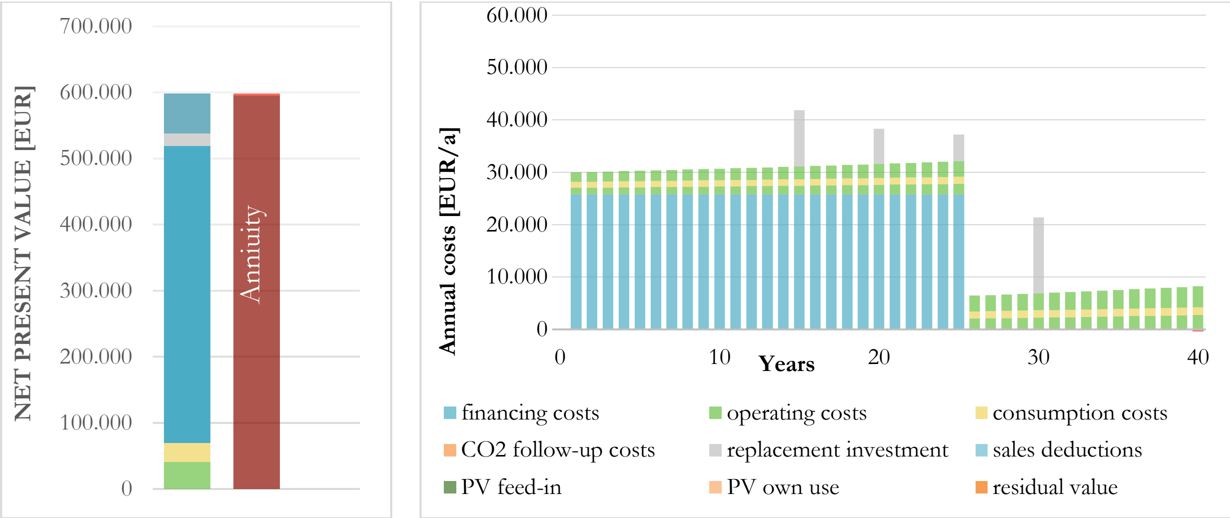
Figure 18: cost performance (EUR/m²) of the case study MORE over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value

Again for each of the three variants, which are shown in Figure 18 a detailed economic analysis is available. This analysis is shown in Figure 19 and includes the detailed composition of the net present value (on the left side) and the allocation of the costs of the 40 years period under consideration (on the right side).

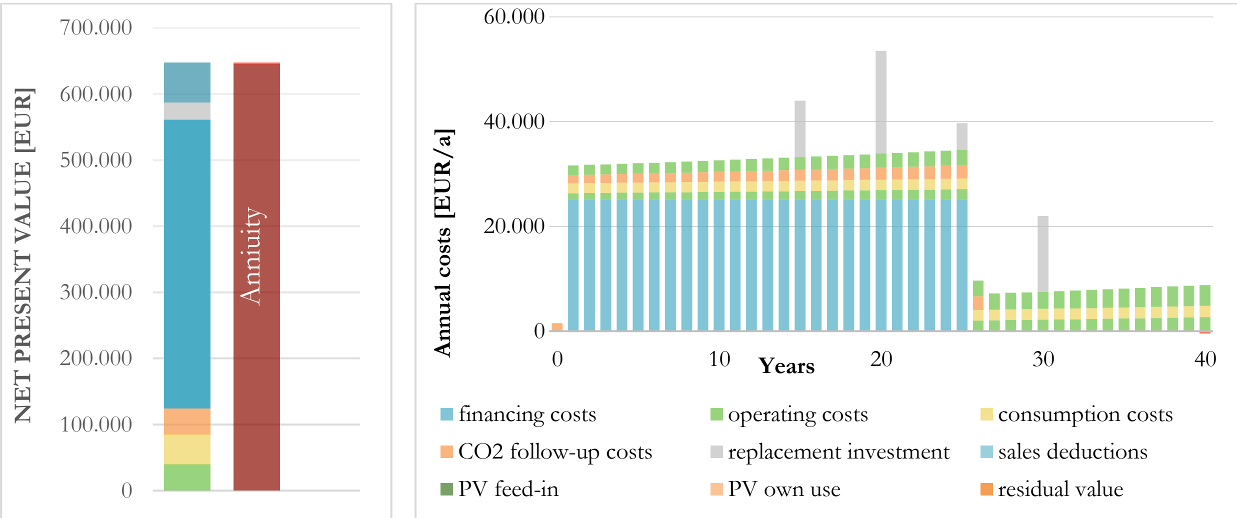
The analysis shows that the financing costs account for the largest share of the costs, followed by the operating costs, the consumption costs and the costs for replacement investment.

All other costs play only a subordinate role and contribute only insignificantly to the overall result over the entire life cycle.

DETAILED LIFE CYCLE COSTS VARIANT “CRAVEzero”



DETAILED LIFE CYCLE COSTS VARIANT “nZEB”



DETAILED LIFE CYCLE COSTS VARIANT “Average Development”

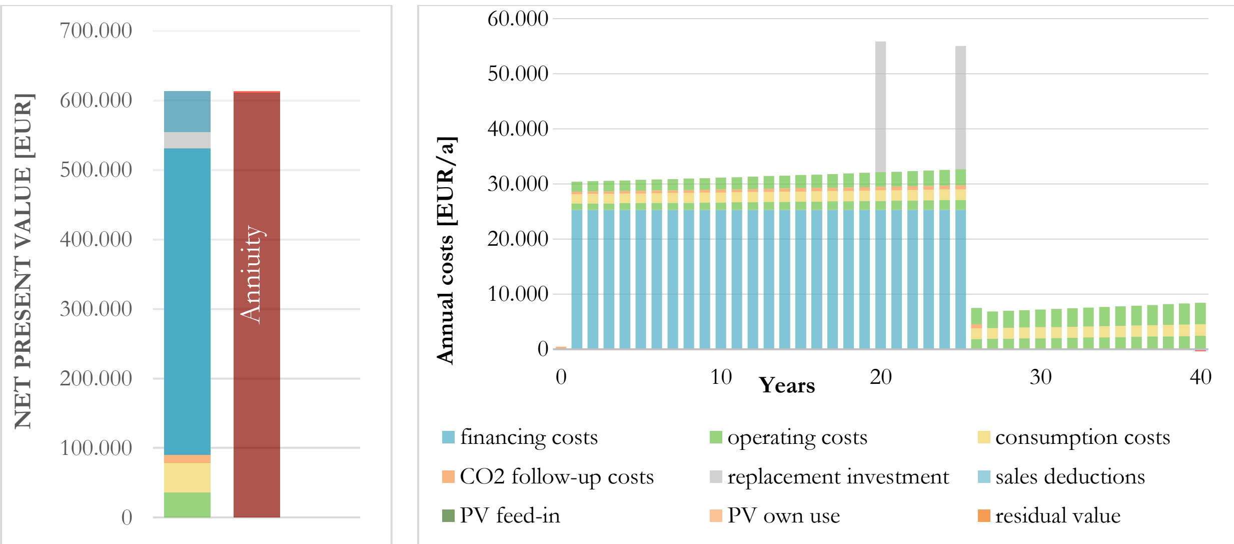


Figure 19: Net present value and life cycle costs of the variants “nZEB”, “CRAVEzero” and “Average Development” of Figure 18

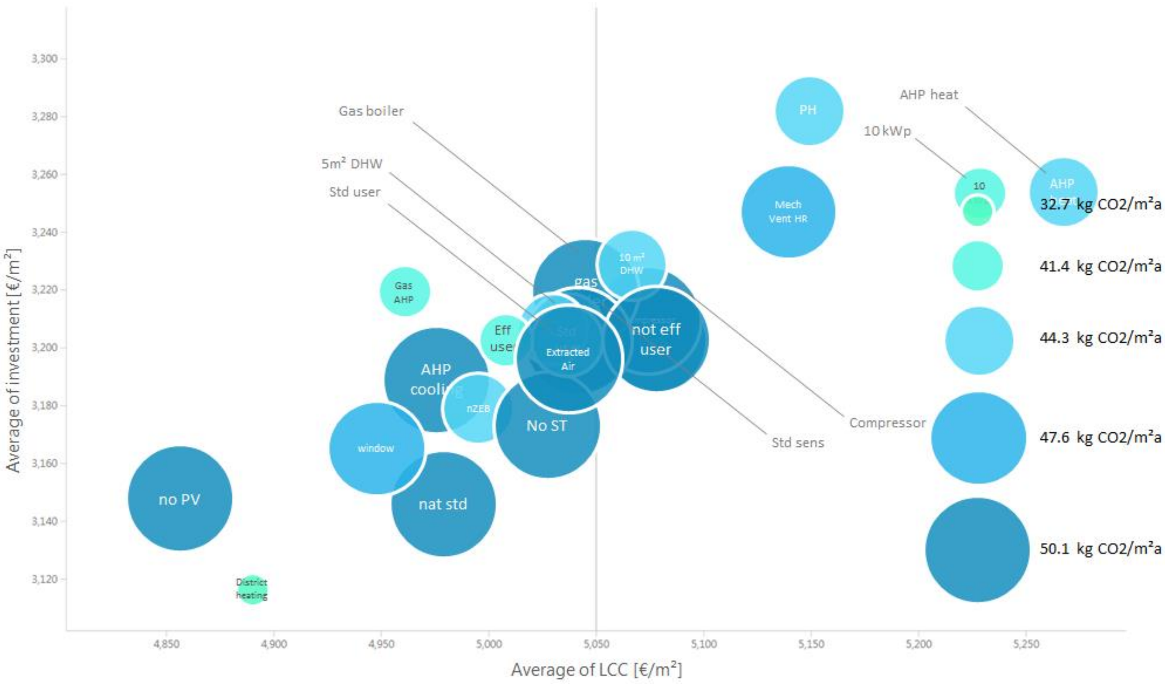


Figure 20: "bubble chart" of the case study MORE; bubble size indicates the average CO_2 emissions; bubble position is determined by average investment costs and average life cycle costs

Figure 20 shows the so-called "bubble chart" of the case study MORE. Again the influencing results for preparing the chart were the average investment costs, the average life cycle costs and the average balanced CO_2 emissions.

The results show that the parameter "no PV" and the parameter "district heating" have similar average investment costs and average life cycle costs, but very different CO_2 emissions. Interesting is also the comparison of the envelope quality. While the national standard envelope ("nat std") has the lowest average investment costs and the lowest average life cycle costs, the parameter "nZEB" achieves a lot less CO_2 emissions, with only slightly higher costs. The third parameter in this comparison, the parameter "passive house envelope" ("PH"), can´t further reduce the average CO_2 emissions but increases the average investment costs and the average life cycle costs.

Based on the average values that were calculated and also used in Figure 20 the deviation of each individual parameter from the total average value was calculated and is shown in Table 41. The analysis was again done for the four performance indicators financing costs, net present value, balanced primary energy and balanced CO_2 emissions. Reductions compared to the average value are highlighted by a green bar; a grey bar indicates an increase. This analysis allows identifying the dependencies of the performance indicators on the different parameters.
For the case study MORE the PV system, the heating system and the envelope quality have the biggest influence on the financing costs, the net present value is also influenced by the heating system but also by the ventilation system, the envelope quality, the PV size and in this case also by the climate. The influence of the climate is also clearly visible in the results of the balanced primary energy and the balanced CO_2 emissions. Both indicators are also influenced by the PV system and the heating system. Also the user behaviour and the solar thermal system have an impact on primary energy and CO_2 emissions. The influence of all other parameters is rather low.

Table 41: deviation of each individual variant from the mean value of the case study MORE; 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	0,00%	-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%

Figure 21 and Figure 22 show the results for selected technology combinations of the case study MORE. A passive house envelope in combination with mechanical ventilation with heat recovery a 10 m² solar thermal and a 10 kWp PV installation is compared to a building with an envelope quality according to the national standard, which is also equipped with an air source heat pump and window ventilation. The third technology combination in this comparison is a building which is equipped with district heating, extract air ventilation and has no PV installed. For these technology combinations, the financing costs were compared to the balanced primary energy demand in Figure 21. Figure 22 shows the comparison of the net present value to the balanced CO_2 emissions.

The technology combination with the passive house envelope (red dots) has the highest financing costs by far, but over the whole life cycle it is competitive with the other technology combinations. The lowest financing costs and also the lowest life cycle costs are achieved from the technology combination which includes district heating and extract air ventilation (green dots). But looking also on the balanced CO_2 emissions and the balanced primary energy demand, it is obvious that this technology combination doesn't achieve the best results. Especially the balanced primary energy demands are among the highest of all calculated.

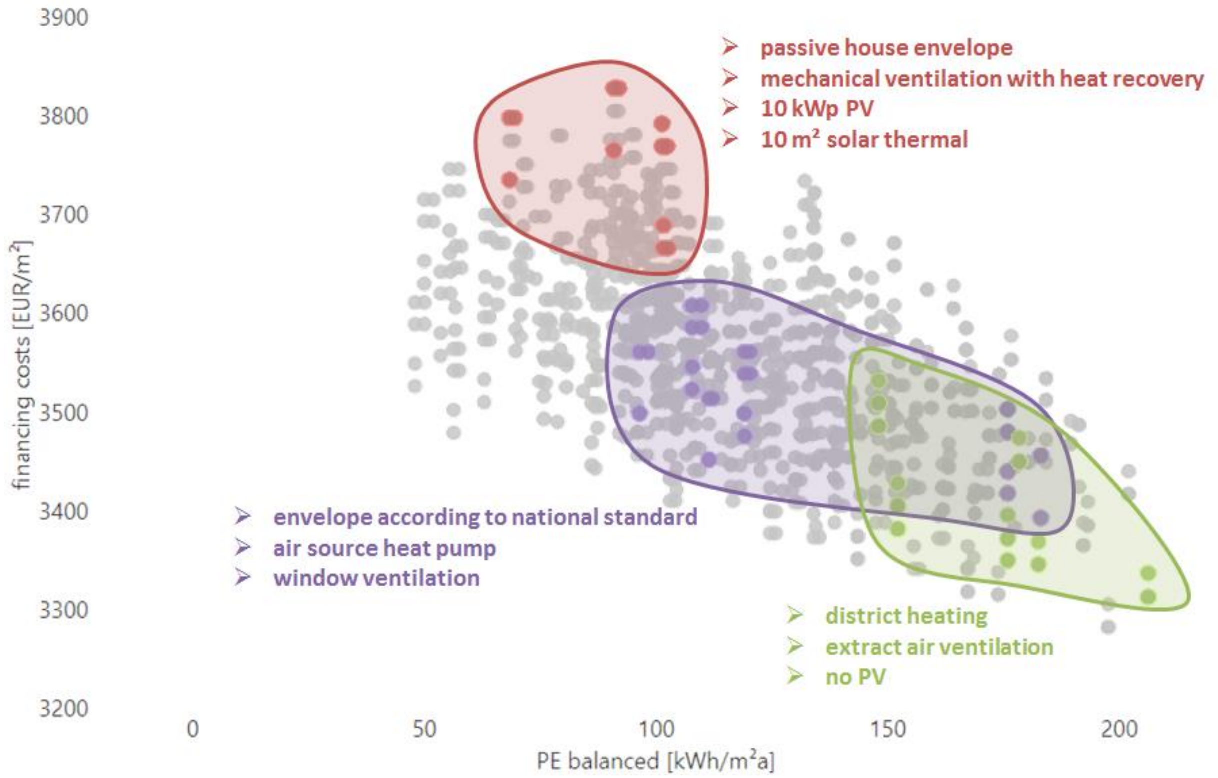


*Figure 21: analysis of the balanced primary energy demand related to the **financing costs** for different technology combinations of the case study MORE*

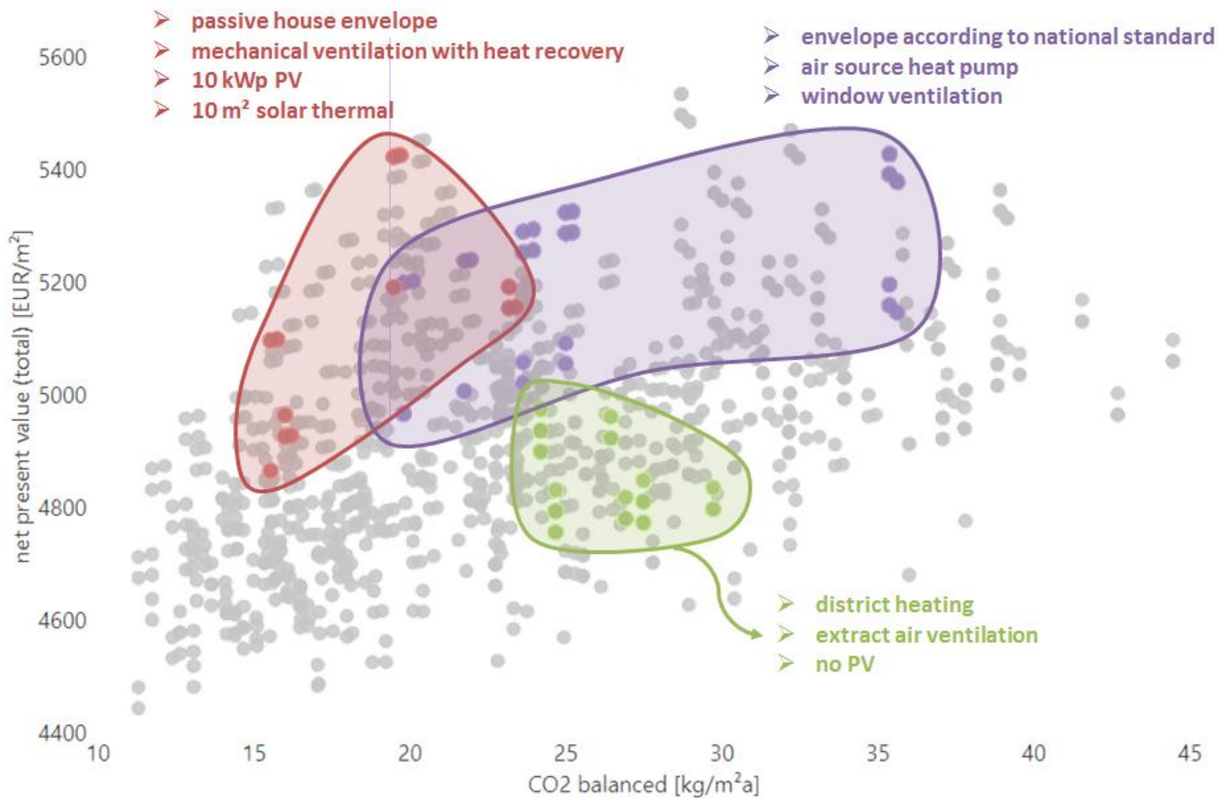


*Figure 22: analysis of the balanced CO_2 emissions related to the **net present value** for the same technology combinations as in Figure 21*

5.2.3. ISOLA NEL VERDE

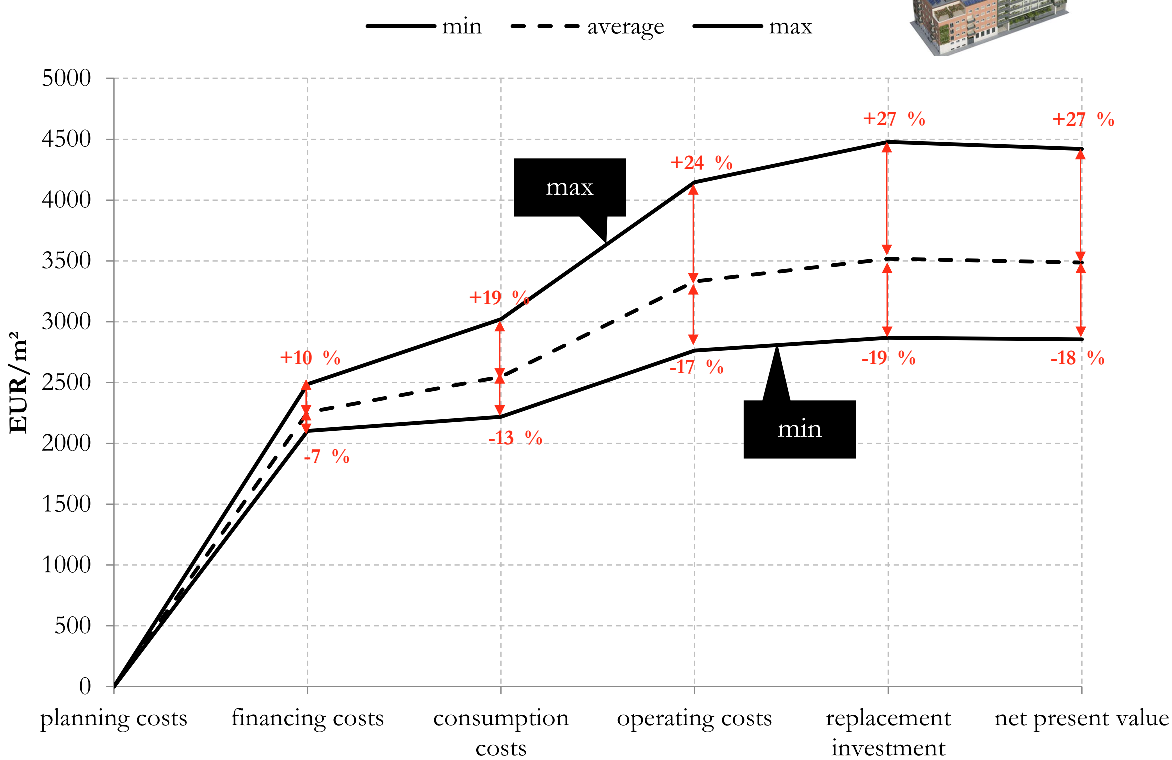


Figure 23: specific costs (EUR/m²) in the different phases of the case study Isola Nel Verde over the whole life cycle of the building; range between the different parameters indicated as minimum (min), average and maximum (max) values; percentages represent the deviation from the average value

Figure 23 shows the specific costs in the different phases of the case study Isola Nel Verde. 3,889 different variants were calculated (to simplify the calculation and the analysis the variation of the CO_2 follow-up costs were excluded, and the user behaviour was defined as standard and was therefore also not varied). The minimum, average and maximum values of all variants are plotted in Figure 23, indicating the range of the costs in each individual phase of the building life cycle. The indicated numbers are based on the average value and show the deviation upwards and downwards.

Looking at each phase of the building life cycle in detail, the results show that based on the average value deviations from +10 % to +27 % respectively -7 % to -19 % per phase is possible. In total reductions from 17 % to 46 % per phase can be achieved.

Figure 24 shows the cost curve for three different variants of the parametric calculations. For the nearly zero-energy building (nZEB) again the variant with the highest net present value was plotted. In comparison to that, the variant with the lowest net present value was selected and illustrated. This variant is called "CRAVEzero". The "average" variant is the median variant, where the net present value is exactly in the middle between the "nZEB" and the "CRAVEzero" variant.

The percentages in the figure represent the possible cost reductions of the CRAVEzero variant in comparison to the nZEB variant. In the case study Isola Nel Verde, 14 % to 25 % reductions in each phase are possible.

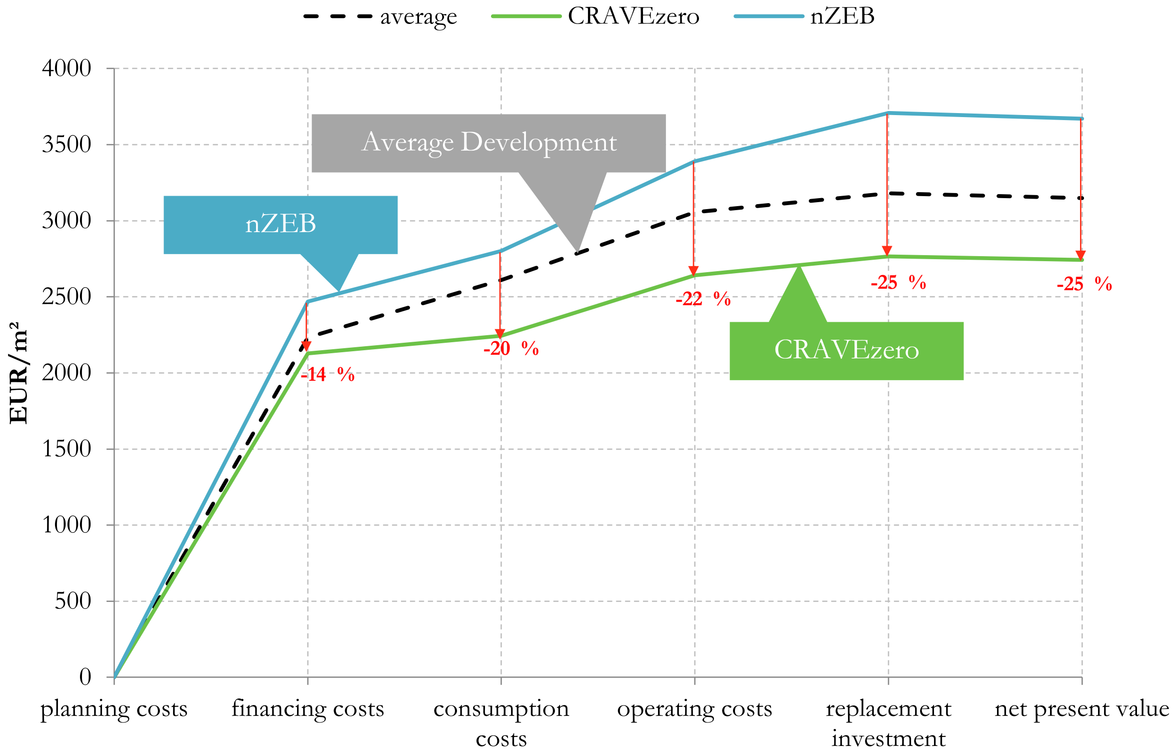
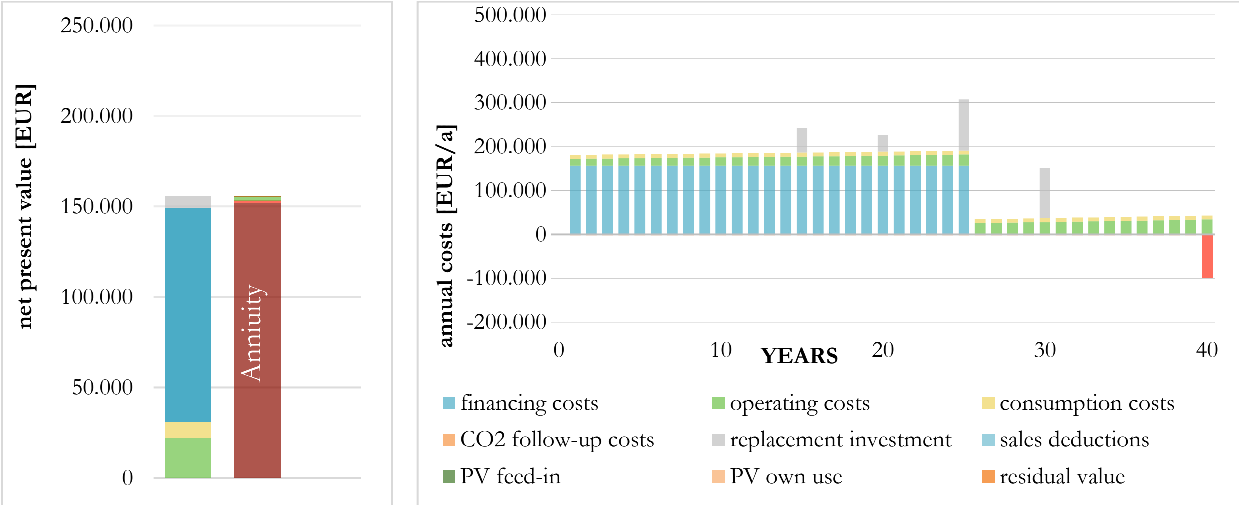


Figure 24: cost performance (EUR/m²) of the case study Isola Nel Verde over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value

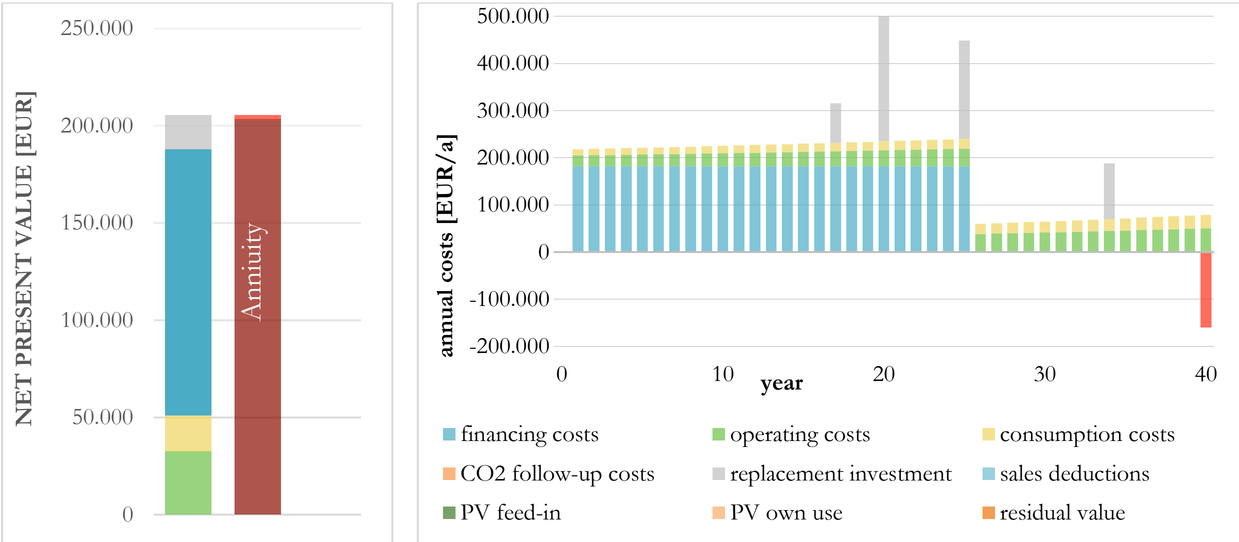
The detailed economic analysis of the three variants, which are shown in Figure 24, are presented in Figure 25 and includes the detailed composition of the net present value (on the left side) and the allocation of the costs of the 40 years period under consideration (on the right side).

Again the analysis shows that the financing costs account for the largest share of the costs, followed by the operating costs, the consumptions costs and the costs for replacement investment.

DETAILED LIFE CYCLE COSTS VARIANT "CRAVEzero"



DETAILED LIFE CYCLE COSTS VARIANT "nZEB"



DETAILED LIFE CYCLE COSTS VARIANT "Average Development"

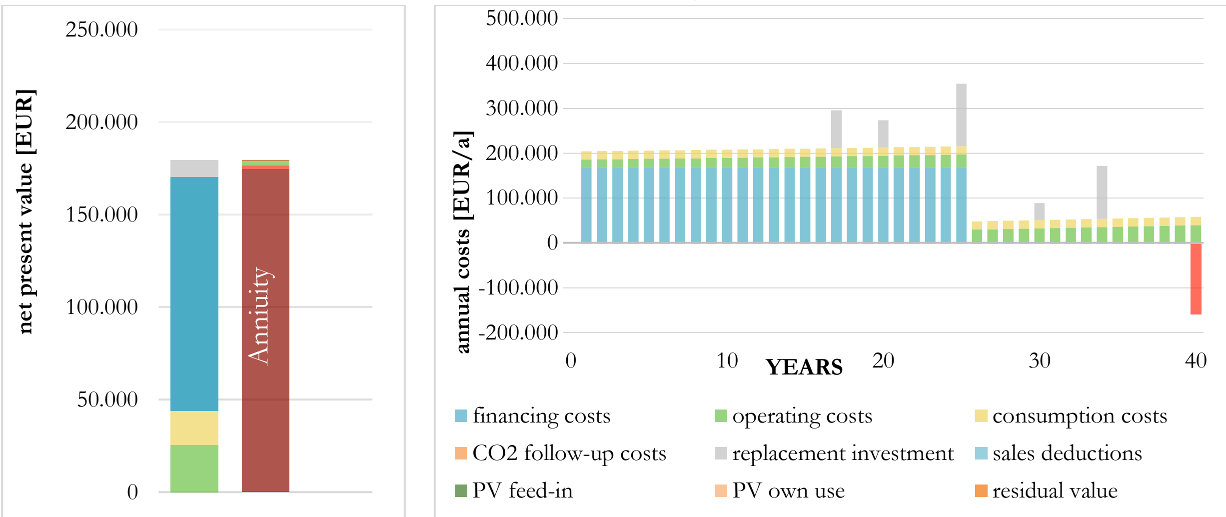


Figure 25: Net present value and life cycle costs of the variants "nZEB", "CRAVEzero" and "Average Development" of Figure 24

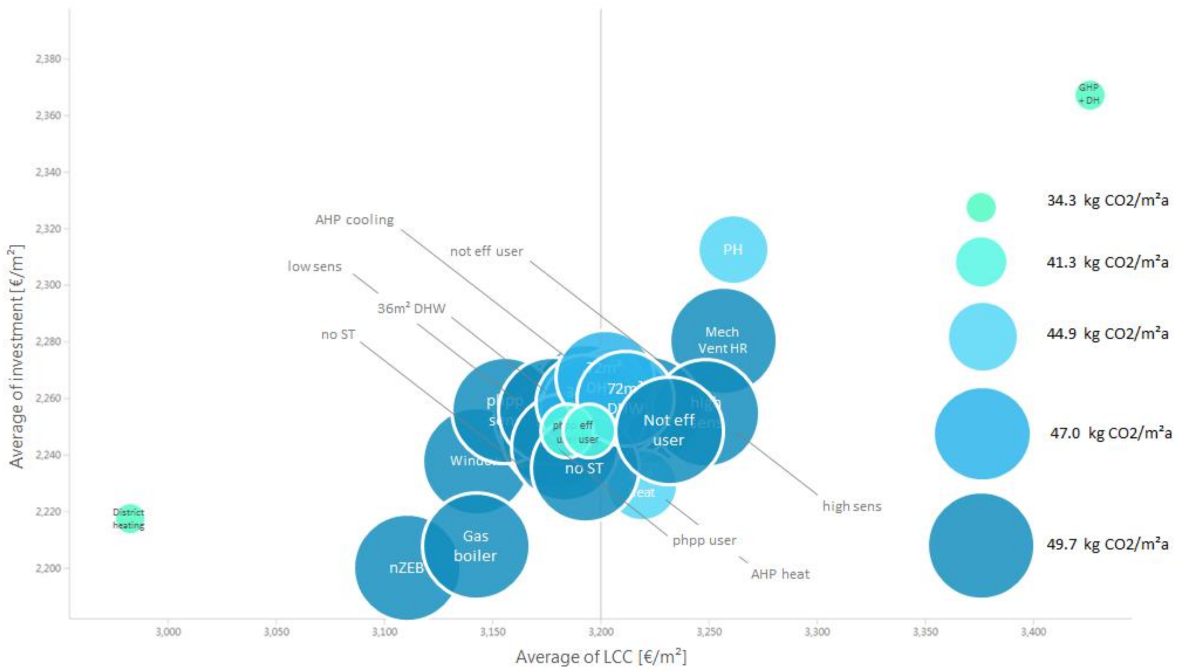


Figure 26: "bubble chart" of the case study Isola Nel Verde; bubble size indicates the average CO_2 emissions; bubble position is determined by average investment costs and average life cycle costs

Figure 26 shows the so-called "bubble chart" of the case study Isola Nel Verde. As already described for the case studies Aspern IQ and MORE, the influencing results for preparing the chart were the average investment costs, the average life cycle costs and the average balanced CO_2 emissions.
Two things become quite clear in the analysis: The parameter "district heating" achieves low average investment costs, the lowest average life cycle costs by far and also the lowest average CO_2 emissions by far. No other analysed parameter comes close to these results.
In fact, all other investigated parameters achieve quite similar investment and life cycle costs. Minor "outliers" are the parameters "nZEB" and "gas boiler" which have lower investment costs than the rest and the parameter "PH" (passive house envelope) with higher average investment costs.

Table 42 shows the deviation of each individual parameter from the total average value for the case study Isola Nel Verde. As before the analysis was done for the four performance indicators financing costs, net present value, balanced primary energy and balanced CO_2 emissions. Reductions compared to the average value are highlighted by a green bar; a grey bar indicates an increase. This analysis allows identifying the dependencies of the performance indicators on the different parameters.

For the case study Isola Nel Verde the heating system has the biggest influence on the financing costs. Influence is also given by the ventilation system and the envelope quality. The same parameters have also the biggest influence on the net present value. The biggest influence on the balanced primary energy demand and the balanced CO_2 emissions has the heating system but also the user behaviour, the PV system, the solar thermal installation and the envelope quality.

Table 42: deviation of each individual variant from the mean value of the case study Isola Nel Verde; 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
user behavior	Not_eff_user	0,00%	0,88%	12,00%	11,25%
	Std_user	0,00%	0,04%	0,56%	0,51%
	Eff_user	0,00%	-0,43%	-5,81%	-5,45%
	phpp_user	0,00%	-0,49%	-6,75%	-6,31%
PV	no_PV	-0,38%	0,51%	8,35%	8,71%
	7_kWp	0,04%	0,00%	-0,60%	-0,63%
	14_kWp	0,34%	-0,52%	-7,75%	-8,08%
solar thermal	no_ST	-0,58%	-0,31%	6,63%	5,06%
	36m2_DHW	0,17%	0,10%	-1,85%	-1,39%
	72m2_DHW	0,41%	0,21%	-4,78%	-3,66%
cooling	Compressor	0,02%	0,43%	0,00%	0,00%
	GHP_cool	-0,14%	-0,51%	0,00%	0,00%
	AHP_cool	0,12%	0,07%	0,00%	0,00%
heating	Gas_Boiler	-2,13%	-1,52%	9,26%	21,76%
	GHP+DH	4,96%	7,32%	-20,73%	-18,94%
	AHP_heat	-1,16%	0,74%	1,65%	7,23%
	District_Heating	-1,68%	-6,54%	9,82%	-10,05%
ventilation	Window	-0,81%	-1,56%	-1,11%	-1,53%
	MechVent_HR	1,13%	2,00%	0,23%	0,69%
	ExtractAir	-0,32%	-0,44%	0,87%	0,84%
envelope	Nat_Std	0,13%	0,46%	4,52%	4,20%
	nZEB	-2,62%	-2,62%	2,21%	2,05%
	PH	2,49%	2,16%	-6,72%	-6,25%

Figure 27 and Figure 28 show the results for selected technology combinations of the case study Isola Nel Verde. So, a passive house envelope in combination with mechanical ventilation with heat recovery and district heating is compared to a building with an envelope quality according to the national standard, which is also equipped with an air source heat pump and window ventilation. The third technology combination in this comparison is a building which is equipped with 14 kWp PV and a 72 m² solar thermal installation. For these technology combinations, the financing costs were compared to the balanced primary energy demand in Figure 27. Figure 28 shows the comparison of the net present value to the balanced primary energy demand.

The technology combination of the building which is equipped with PV and solar thermal (violet dots) has a quite a broad range of financing costs and also of the net present value. That means that these variants achieve the highest but also the lowest costs in this comparison. The deviation of the costs is not so big at the other two investigated technology combinations. The technology combination with PV and solar thermal also achieves the lowest primary energy values.
The second finding is that the combination with the passive house envelope (orange dots) has higher financing costs than the combination using the envelope according to the national standard (green dots), but over the whole life cycle of the building the order changes and the combination which was more expensive before becomes then more favourable.

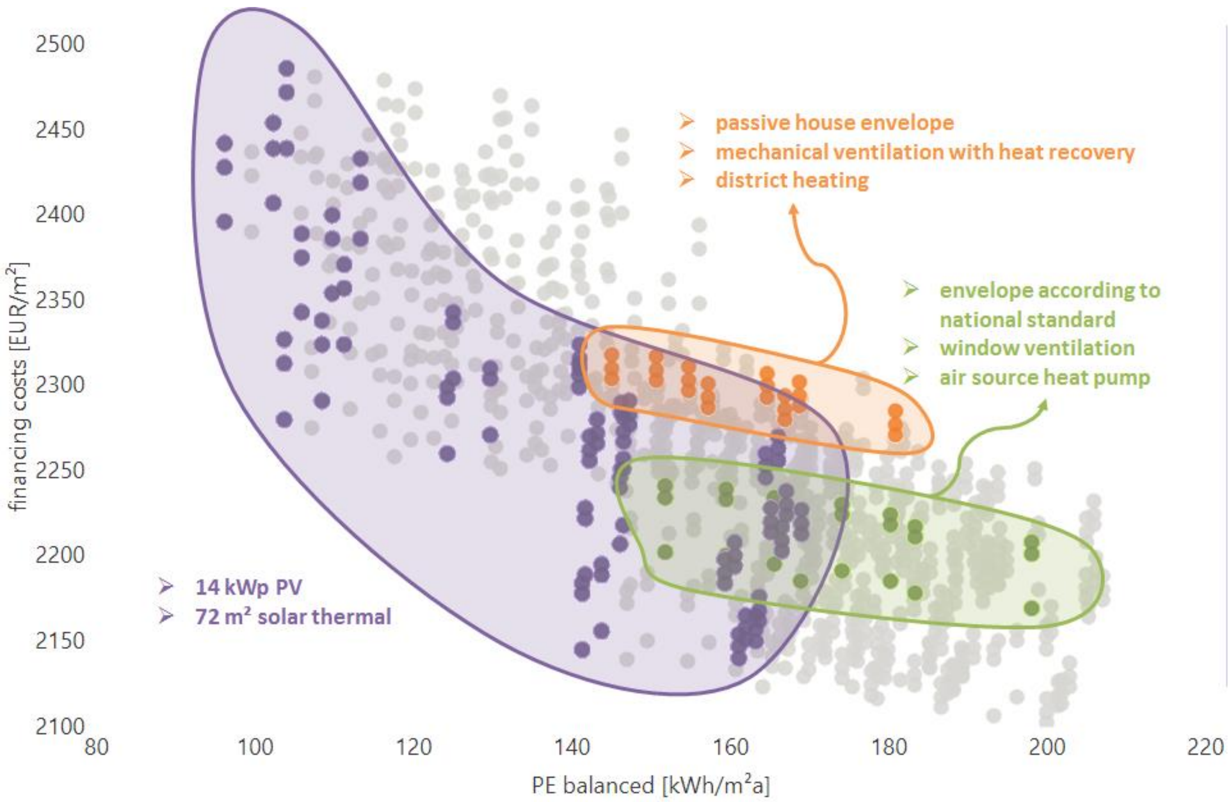


Figure 27: analysis of the balanced primary energy demand related to the ***financing costs*** *for different technology combinations of the case study Isola Nel Verde*

Figure 28: analysis of the balanced primary energy demand related to the ***net present value*** *for the same technology combinations as in Figure 27*

5.2.4. LES HELIADES

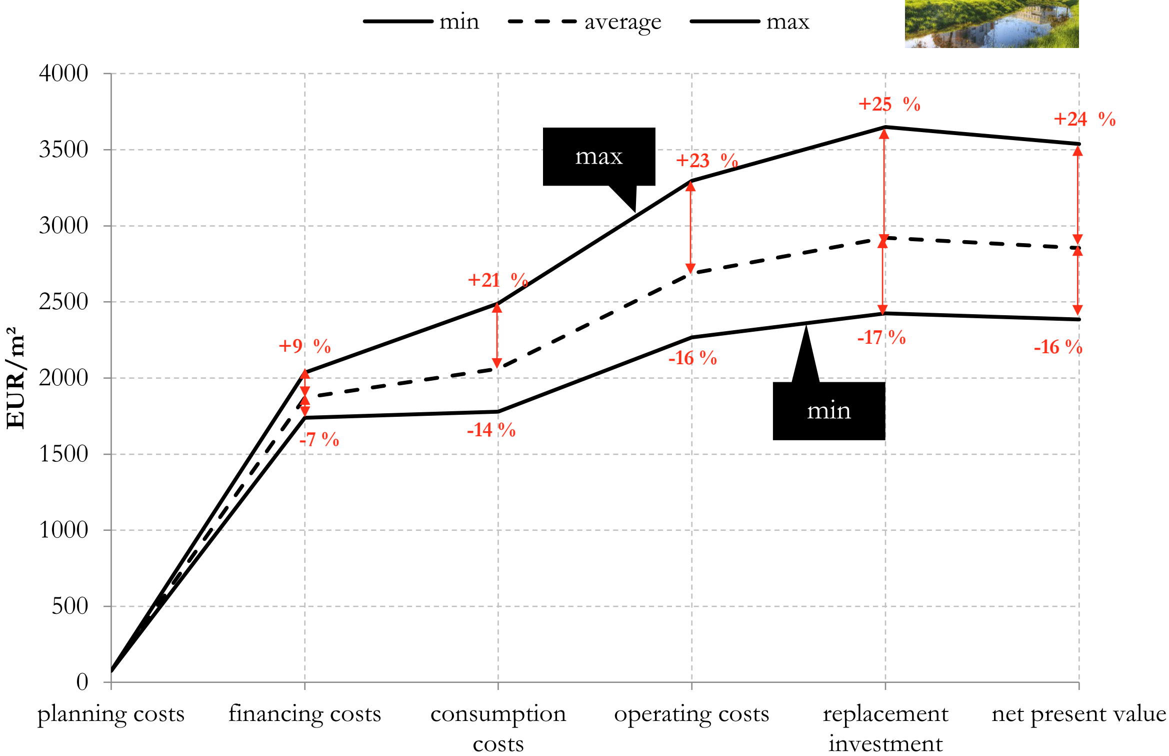


Figure 29: specific costs (EUR/m²) in the different phases of the case study Les Heliades over the whole life cycle of the building; range between the different parameters indicated as minimum (min), average and maximum (max) values; percentages represent the deviation from the average value

The specific costs in the different life cycle phases of the case study Les Heliades are plotted in Figure 29. The chart is based on 3,889 different variants that were calculated (to simplify the calculation and the analysis of the sensitivity and the user behaviour were defined as standard and therefore not varied). The minimum, average and maximum values of all those variants are shown, indicating the range of the costs in each individual phase of the building life cycle.

Looking at each phase of the building life cycle in detail, the results show that based on the average value deviations from +9 % to +25 % respectively -7 % to -17 % per phase are possible. In total reductions from 16 % to 42 % per phase can be achieved.

The results in Figure 29 show similarities to the results in all other case studies in the previous chapters. The smallest spread between the minimum and the maximum, and therefore the lowest reduction potential, is given at the stage of the financing costs. Much more important seem to be the consumption, operation and replacement costs.

Figure 30 shows the cost curve for three different variants of the parametric calculations. For the nearly zero-energy building (nZEB) again the variant with the highest net present value was plotted. In comparison to that, the variant with the lowest net present value was selected and illustrated. This variant is called "CRAVEzero". The "average" variant is the median variant, where the net present value is exactly in the middle between the "nZEB" and the "CRAVEzero" variant.

The percentages in the figure represent the possible cost reductions of the CRAVEzero variant in comparison to the nZEB variant. In the case study Les Heliades, 14 % to 24 % reductions in each phase are possible.

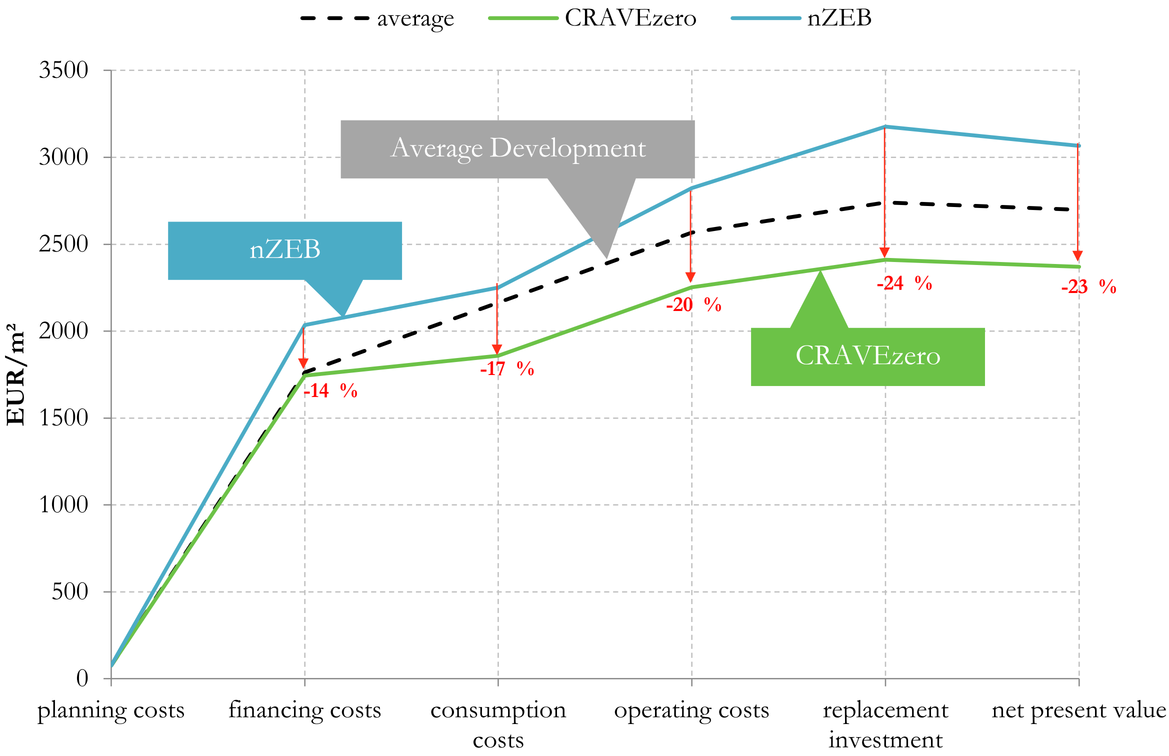
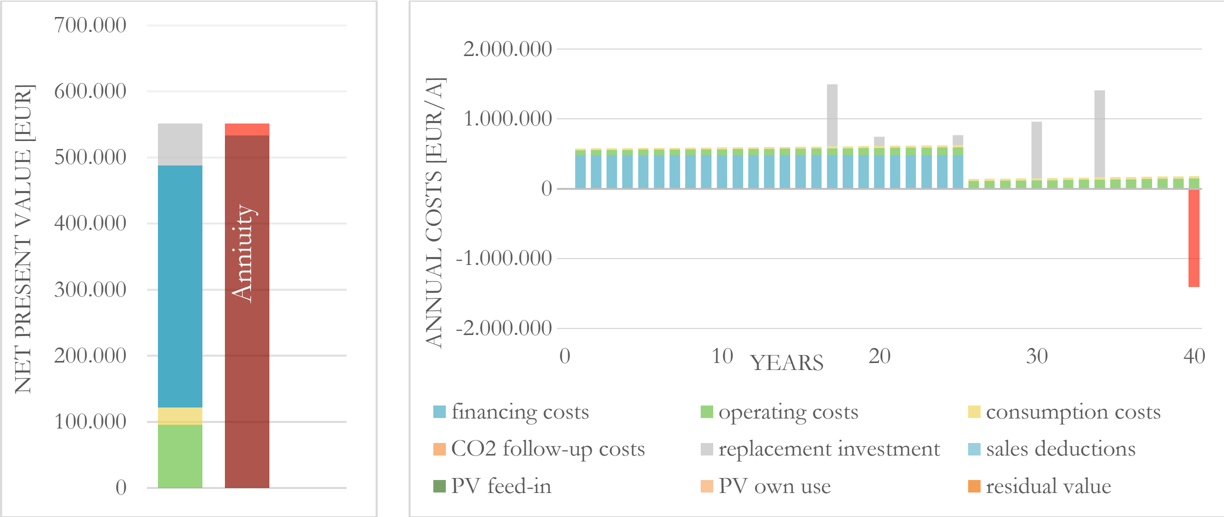


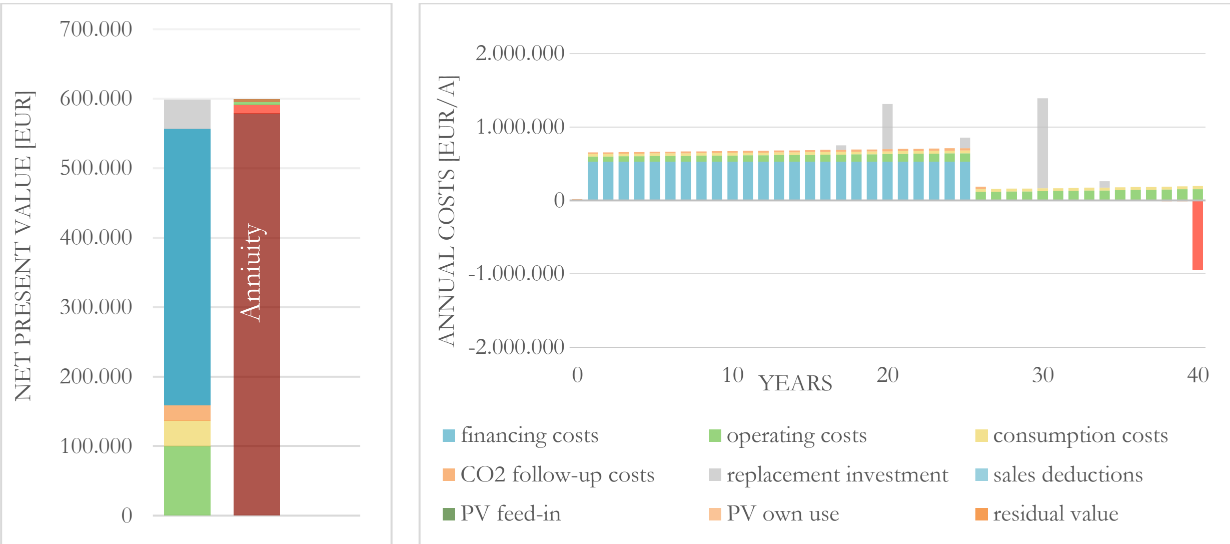
Figure 30: cost performance (EUR/m²) of the case study Les Heliades over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value

The detailed economic analysis of the variants "nZEB", "Average Development" and "CRAVEzero" of the case study Les Heliades are shown in Figure 31. On the left side, the detailed composition of the net present value is shown. The right side shows the allocation of the costs of the period under consideration.

DETAILED LIFE CYCLE COSTS VARIANT "CRAVEzero"



DETAILED LIFE CYCLE COSTS VARIANT "nZEB"



DETAILED LIFE CYCLE COSTS VARIANT "Average Development"

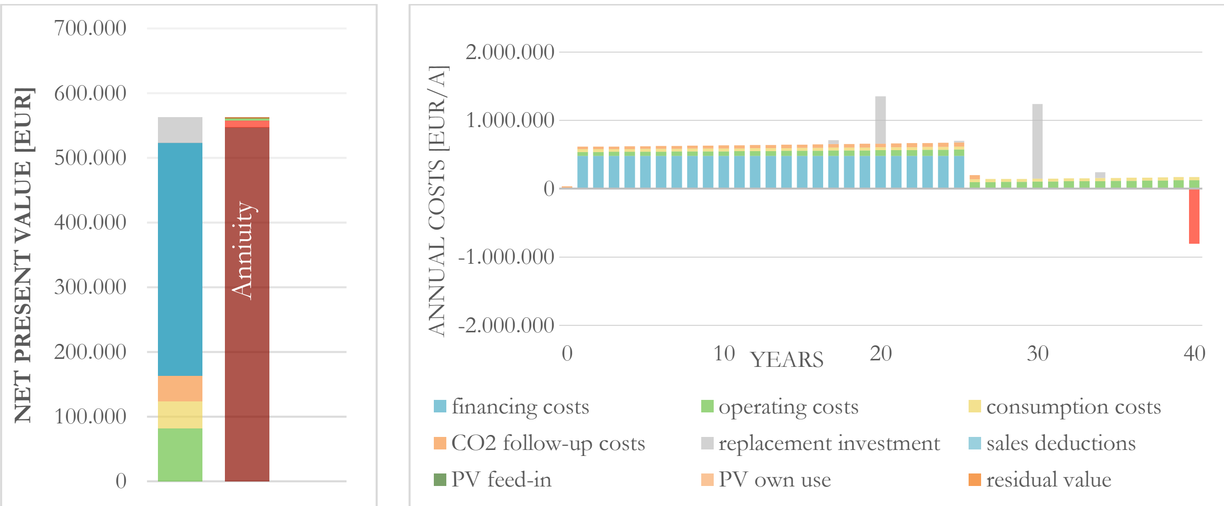


Figure 31: Net present value and life cycle costs of variants "nZEB", "CRAVEzero" and "Average Development" of Figure 30

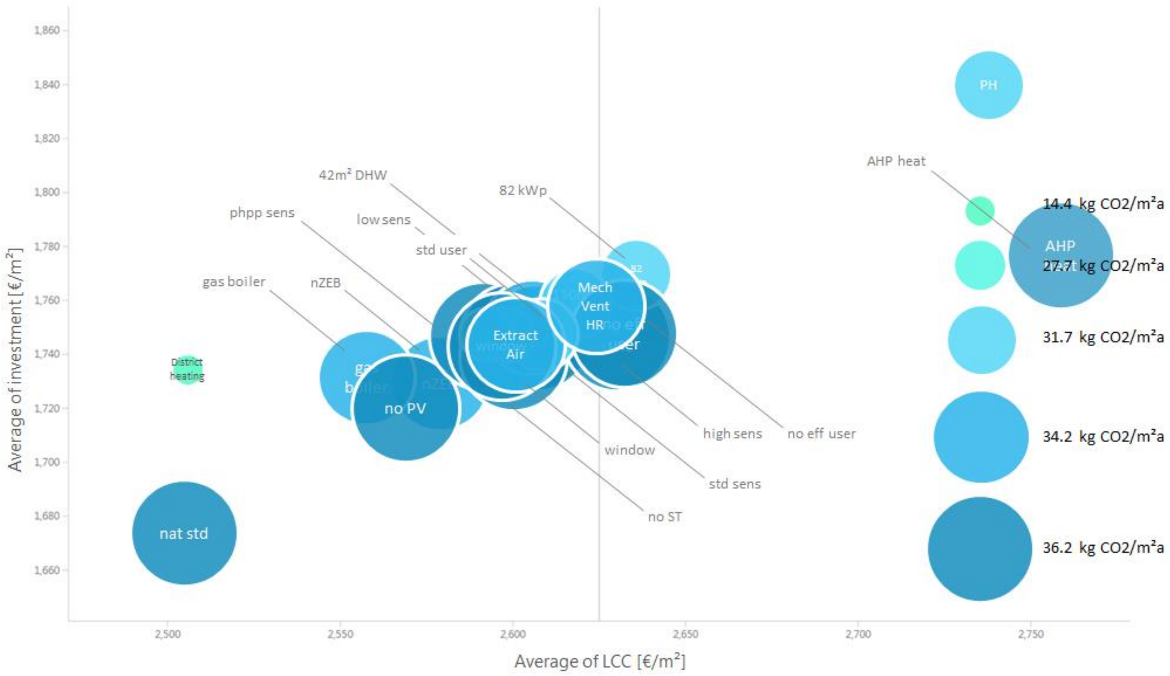


Figure 32: "bubble chart" of the case study Les Heliades; bubble size indicates the average CO_2 emissions; bubble position is determined by average investment costs and average life cycle costs

The "bubble chart" of the case study Les Heliades can be found in Figure 32. Also, this chart shows the average investment costs, the average life cycle costs and the average CO_2 emissions for all investigated parameters of the case study Les Heliades.

The results show clearly that the parameter national standard envelope ("nat std") has the lowest average investment costs and the lowest average life cycle costs but also almost the highest average CO_2 emissions. The parameter "district heating" on the contrary has indeed higher average investment costs as the parameter "nat std" but the average life cycle costs are almost equal and beyond that, the lowest average CO_2 emissions are achieved.

On the opposite side of the chart are also two parameters, which have the highest average investment and life cycle costs. These are the parameter air source heat pump ("AHP") and the passive house envelope ("PH"). Furthermore, the parameter "AHP" also has a very high average of CO_2 emissions.

All other investigated parameters achieve quite similar results of average investment costs and average life cycle costs. The percentage difference between them is only 3-4 %.

Table 43 shows the deviation of each individual parameter from the total average value for the case study Les Heliades. It can be seen that the most influencing factor on the financing costs is the building envelope. Smaller influences also have the PV system and the heating system. The heating system is also the parameter which has the biggest influence on the net present value. But also here the envelope quality, together with the CO_2 follow-up costs, the user behaviour and the climate has an influence.

The largest influence on the balanced primary energy demand and the balanced CO_2 emissions can be found at the heating system and the climate. Due to low heating demand in the climate of southern France, an effect is here recognizable. Further influencing factors on the primary energy and the CO_2 emissions are the user behaviour, the PV system and also a little bit the solar thermal system.

Table 43: deviation of each individual variant from the mean value of the case study Les Heliades; 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	0,00%	-0,69%	0,00%	0,00%
	Std_CO2	0,00%	0,68%	0,00%	0,00%
	High_CO2	0,00%	2,05%	0,00%	0,00%
	no_CO2	0,00%	-2,05%	0,00%	0,00%
user behavior	Not_eff_user	0,00%	1,28%	16,09%	15,88%
	Std_user	0,00%	0,08%	1,13%	1,10%
	Eff_user	0,00%	-0,60%	-7,56%	-7,48%
	phpp_user	0,00%	-0,76%	-9,66%	-9,50%
Climate	Northern_FR	0,00%	1,11%	14,57%	14,06%
	Central_FR	0,00%	0,83%	11,05%	10,77%
	Southern_FR	0,00%	-1,75%	-23,52%	-22,79%
	real_location	0,00%	-0,20%	-2,10%	-2,04%
PV	no_PV	-1,48%	-0,43%	15,19%	15,05%
	56_kWp	0,31%	-0,03%	-5,98%	-5,92%
	82_kWp	1,16%	0,46%	-9,21%	-9,12%
solar thermal	no_ST	-0,48%	-0,14%	6,46%	5,01%
	42m2_DHW	-0,06%	-0,09%	-0,19%	-0,19%
	110m2_DHW	0,54%	0,24%	-6,28%	-4,81%
heating	Gas_Boiler	-0,89%	-0,71%	15,54%	23,73%
	District_Heating	-0,70%	-4,46%	-31,81%	-40,24%
	AHP_heat	1,59%	5,18%	16,27%	16,51%
ventilation	Window	-0,27%	-0,30%	0,99%	0,94%
	MechVent_HR	0,52%	0,49%	-3,69%	-3,60%
	ExtractAir	-0,26%	-0,20%	2,69%	2,65%
envelope	Nat_Std	-3,94%	-3,71%	4,48%	4,40%
	nZEB	-0,98%	-1,07%	-0,72%	-0,71%
	PH	4,92%	4,77%	-3,77%	-3,70%

For the investigation of the technology combinations in Figure 33 and Figure 34 three different combinations were defined. The first one is based on a passive house envelope and district heating (violet dots), the second one is based on an envelope which fulfils the national requirements plus also district heating (red dots) and the third one is based on a nZEB envelope and an air source heat pump (green dots).

Again the financing costs were compared to the balanced CO_2 emissions (Figure 33). In Figure 34 the balanced CO_2 emissions were compared to the net present value.

For the case study Les Heliades the combination using the national standard envelope (red dots) achieves the lowest financing costs, the lowest net present values and also the lowest balanced CO_2 emissions. In this case the more expensive passive house envelope can´t offset this financial disadvantage over the whole life cycle. This means that the net present values of this combination are higher than the net present values of the combination using the national standard envelope.

The technology combination using the nZEB envelope (green dots) is, regarding the financing costs, located between the two other combinations, but over the life cycle of the building it is the most expensive one. Moreover, this combination has also the highest balanced CO_2 emissions, which is a direct result of the use of the air source heat pump.

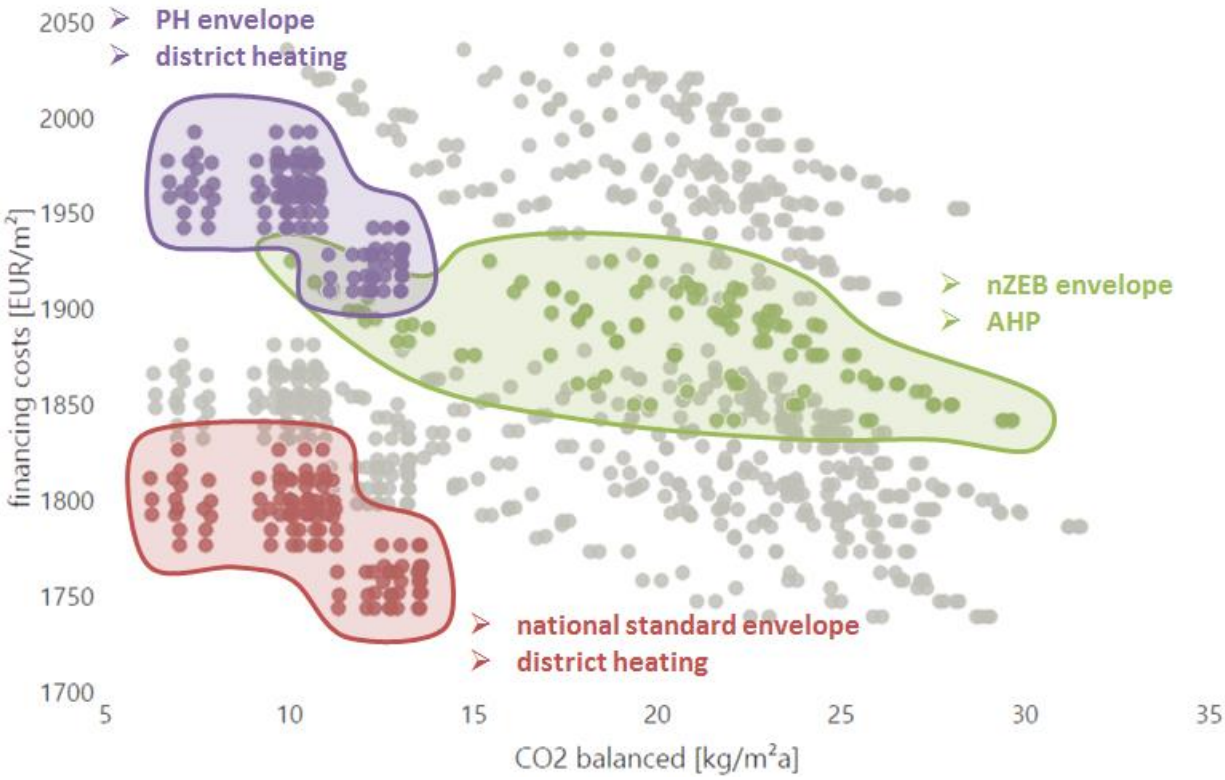


Figure 33: analysis of the balanced CO_2 emissions related to the ***financing costs*** *for different technology combinations of the case study Les Heliades*

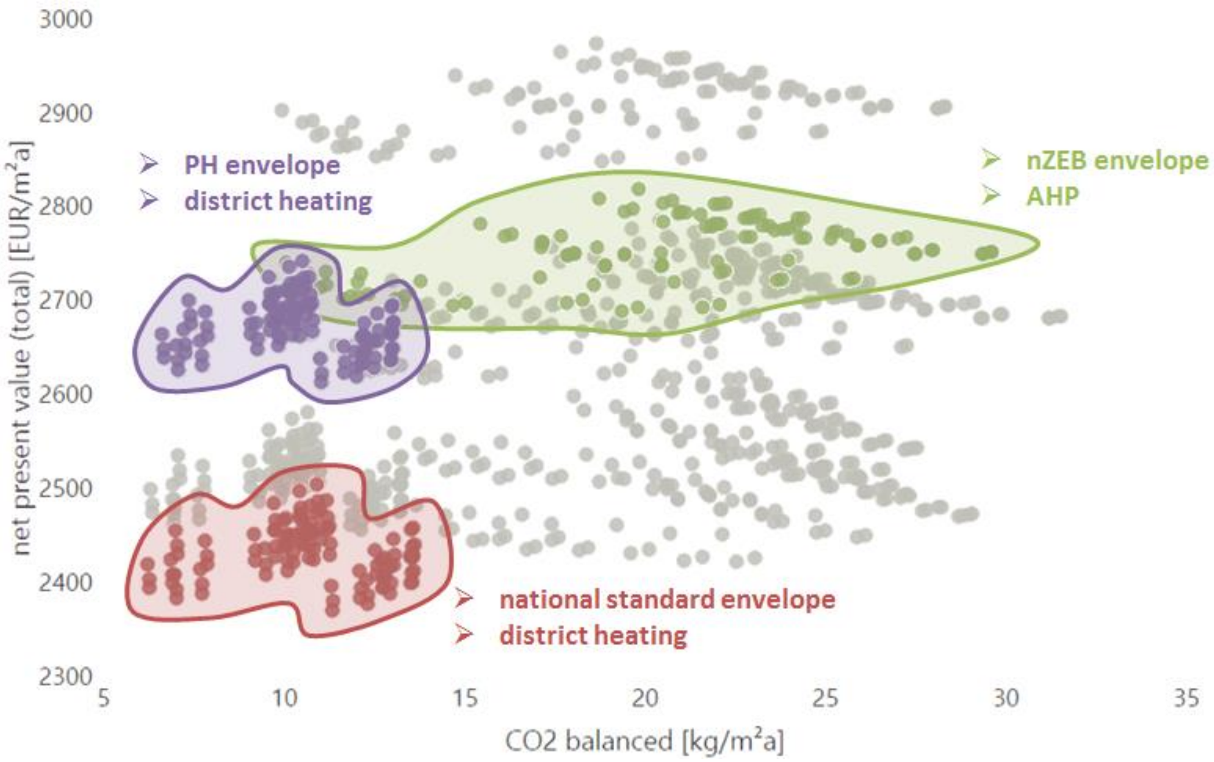


Figure 34: analysis of the balanced CO_2 emissions related to the ***net present value*** *for the same technology combinations as in Figure 33*

5.2.5. ALIZARI

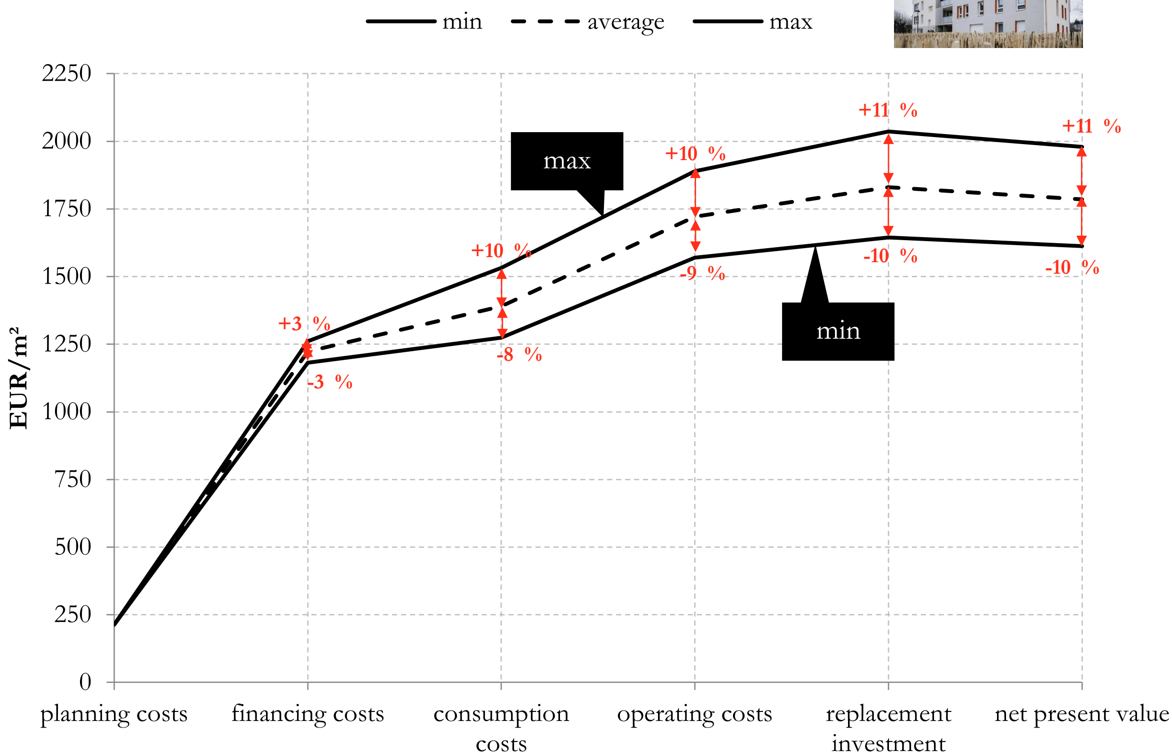


Figure 35: specific costs (EUR/m²) in the different phases of the case study Alizari over the whole life cycle of the building; range between the different parameters indicated as minimum (min), average and maximum (max) values; percentages represent the deviation from the average value

Figure 35 shows the specific costs in the different phases of the case study Alizari. The chart is based on 768 different variants that were calculated. The minimum, average and maximum values of all those variants are shown, indicating the range of the costs in each individual phase of the building life cycle.

Looking at each phase of the building life cycle in detail, the results show that based on the average value deviations from +3 % to +11 % respectively -3 % to -10 % per phase are possible. In total reductions from 6 % to 21 % per phase can be achieved. Compared to the other case studies and the possible reductions that were calculated there, these values are the lowest ones. In general, the costs of the case study Alizari (financing costs and net present value) the lowest by comparison.

But the results in Figure 35 also show similarities to the results in of the other case studies in the previous chapters. The smallest spread between the minimum and the maximum, and therefore the lowest reduction potential, is given at the stage of the financing costs. Much more important seem to be the consumption, operation and replacement costs.

Figure 36 shows the cost curve for three different variants of the parametric calculations. For the nearly zero-energy building (nZEB) again the variant with the highest net present value was plotted. In comparison to that, the variant with the lowest net present value was selected and illustrated. This variant is called "CRAVEzero". The "average" variant is the median variant, where the net present value is exactly in the middle between the "nZEB" and the "CRAVEzero" variant.
The percentages in the figure represent the possible cost reductions of the CRAVEzero variant in comparison to the nZEB variant. In the case study Alizari, 4 % to 14 % reductions in each phase are possible.

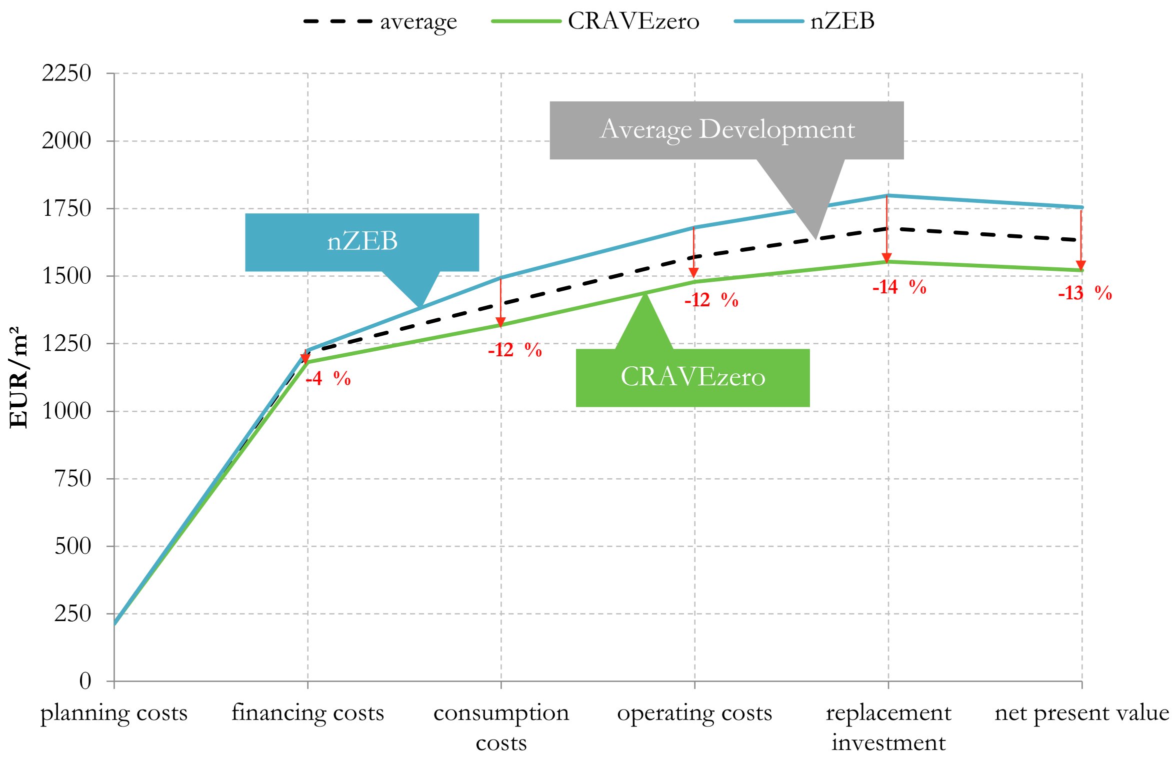
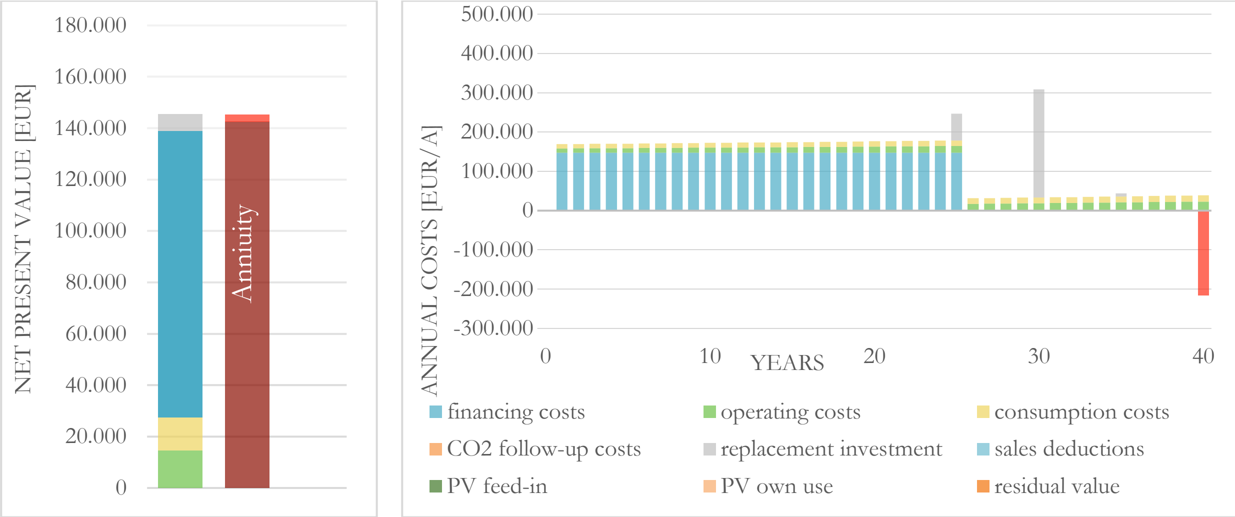


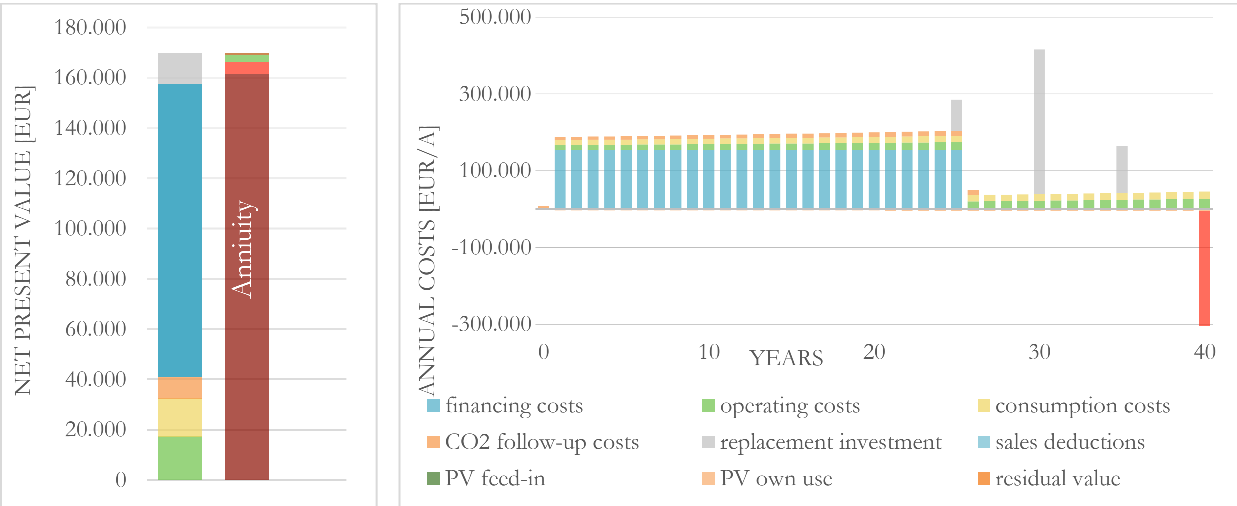
Figure 36: cost performance (EUR/m²) of the case study Alizari over the whole life cycle of the building; comparison of nZEB variant with a building according to the CRAVEzero approach and the average value

The detailed economic analysis of the variants "nZEB", "Average Development" and "CRAVEzero" of the case study Alizari is shown in Figure 37. On the left side the detailed composition of the net present value is shown, the right side shows the allocation of the costs of the period under consideration.

DETAILED LIFE CYCLE COSTS VARIANT "CRAVEzero"



DETAILED LIFE CYCLE COSTS VARIANT "nZEB"



DETAILED LIFE CYCLE COSTS VARIANT "Average Development"

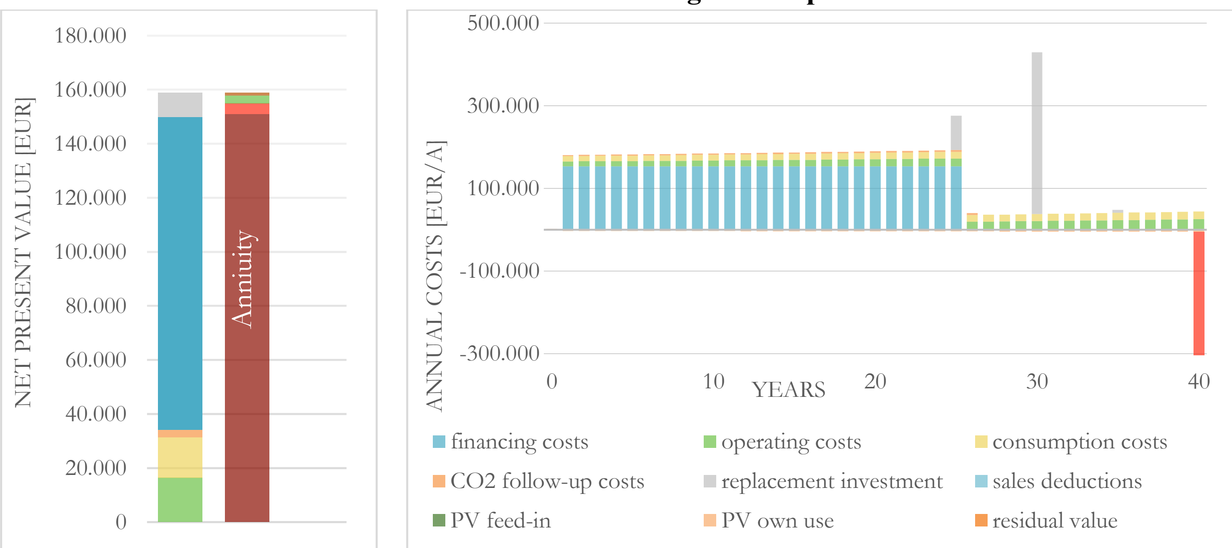


Figure 37: Net present value and life cycle costs of variants "nZEB", "CRAVEzero" and "Average Development" of Figure 36

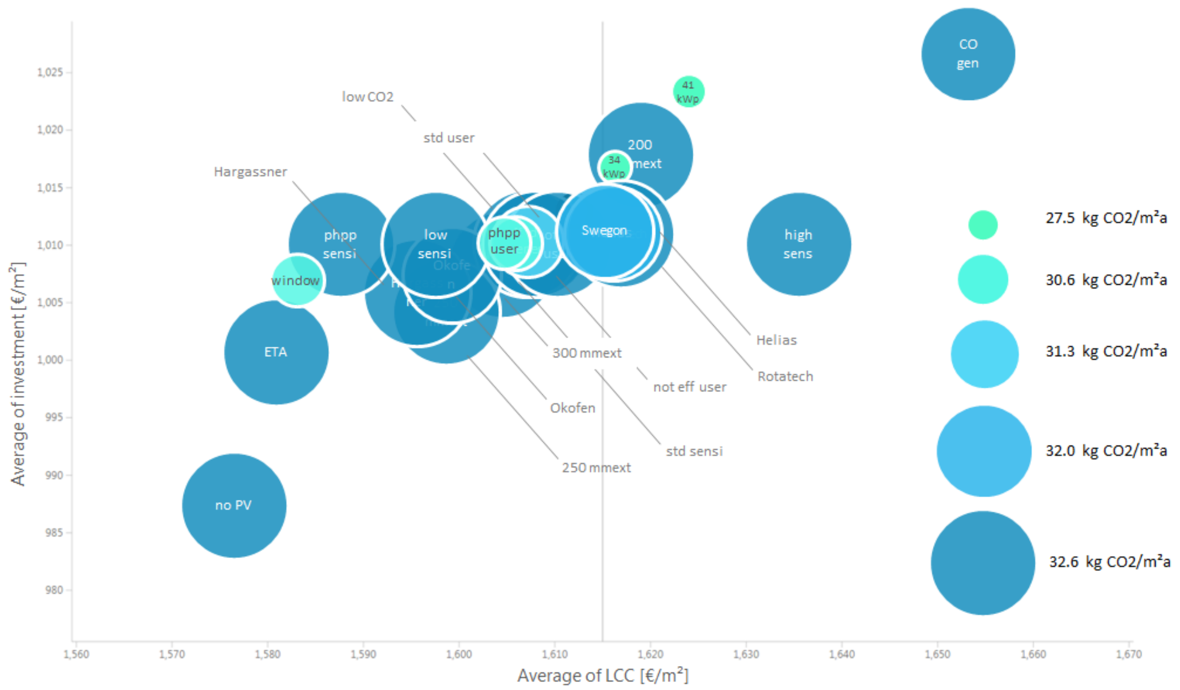


Figure 38: "bubble chart" of the case study Alizari; bubble size indicates the average CO_2 emissions; bubble position is determined by average investment costs and average life cycle costs

The "bubble chart" of the case study Alizari can be found in Figure 38. Also, this chart shows the average investment costs, the average life cycle costs and the average CO_2 emissions for all investigated parameters of the case study Alizari.

Looking at the results, a few insights stand out right away. On the one hand, that the parameter "no PV" has the lowest average investment costs and the lowest average life cycle costs but also among the highest average CO_2 emissions. On the other hand, the parameter "co gen" has the highest average investment costs and also the highest average life cycle costs, but in fact cannot reduce the average CO_2 emissions much.

Another conclusion is that the lowest average CO_2 emissions are achieved by the parameters "PHPP user behaviour", "34 kWp PV", "41 kWp PV" and interestingly also by the parameter "window ventilation".

The deviation of each individual parameter from the total average value for the case study Alizari is shown in Table 44. The analysis shows, that the most influencing factors on the financing costs are the PV system, the heating system and to a lesser extent the envelope quality.

Over the whole life cycle of the building, the PV system has no influence. The net present value is mainly influenced by the CO_2 follow-up costs, the heating and ventilation system and a little bit also by the building envelope.

Looking at the balanced primary energy demand and the balanced CO_2 emissions, it is obvious that the most influencing factor is the PV system, followed by the user behaviour and the ventilation system. All other parameters have no influence little the balanced primary energy demand and balanced CO_2 emissions.

Table 44: 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%

The analysis of two different technology combinations of the case study Alizari is visible in Figure 39 and Figure 40. In Figure 39 the financing costs are compared to the balanced primary energy demand, in Figure 40 the net present value is compared to the balanced CO_2 emissions. In both cases two technology combinations were investigated. The first one is based on 300 mm external insulation of the external wall and a 41 kWp PV system, the second one includes 250 mm external insulation, window ventilation and no PV.

The results show significantly reduced primary energy demand and CO_2 emission values of the combination using the PV system. This reduction is a direct result of the PV system. Furthermore, the results show that the combination with the improved insulation and the additional PV system, has indeed higher financing costs than the other combination, but over the whole life cycle of the building the net present values are almost equal.

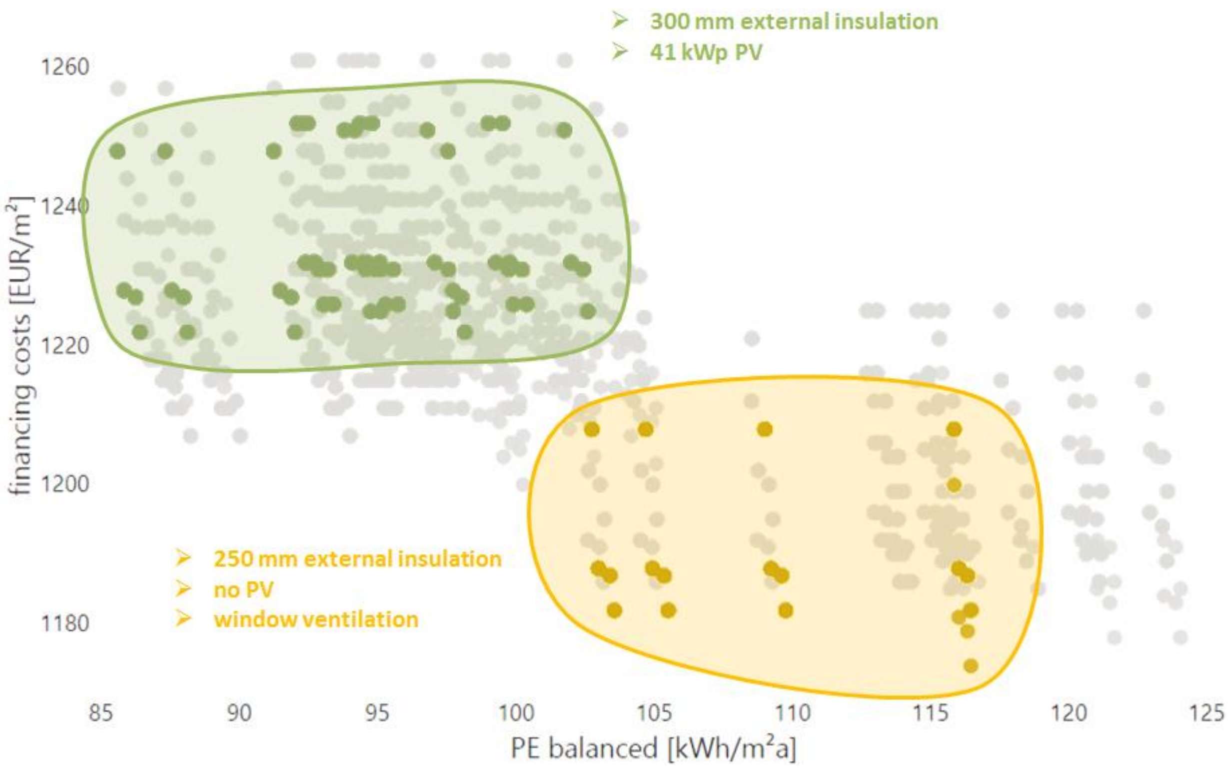


Figure 39: analysis of the balanced primary energy demand related to the ***financing costs*** *for different technology combinations of the case study Alizari*

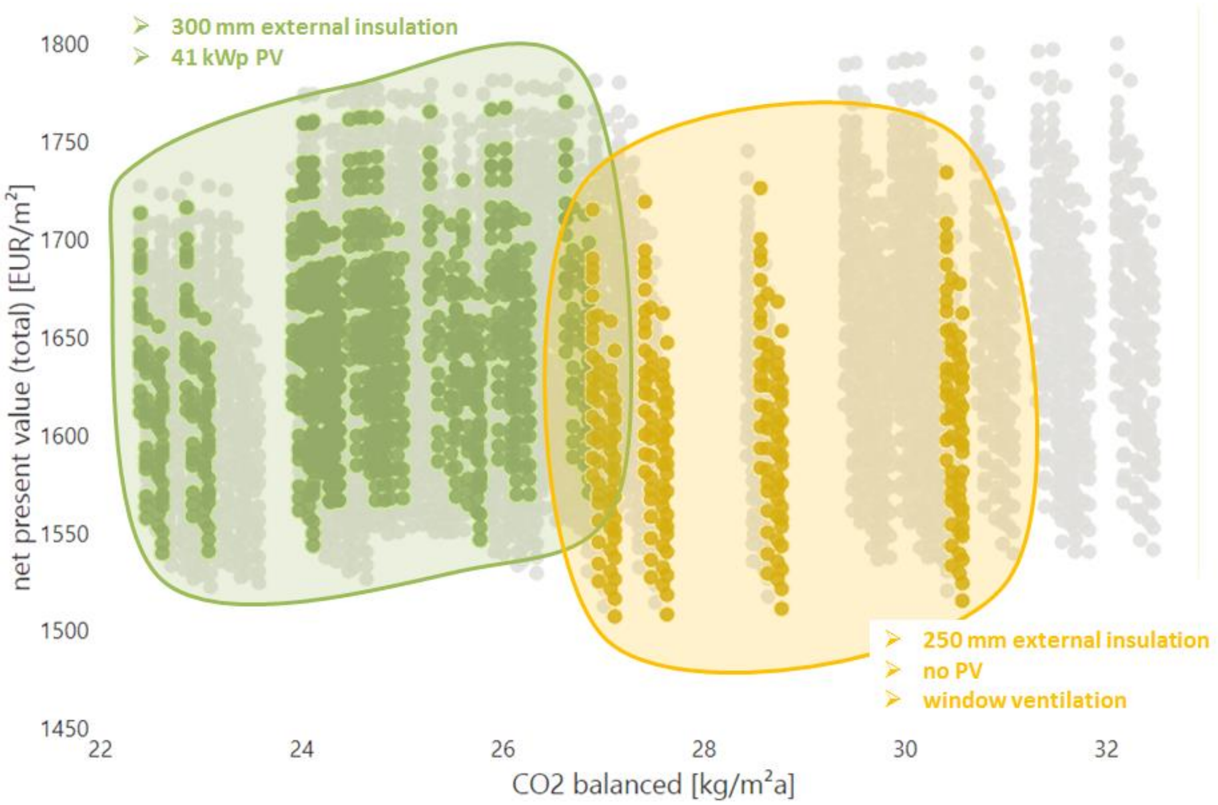


Figure 40: analysis of the balanced CO_2 emissions related to the ***net present value*** *for the same technology combinations as in Figure 39*

CHAPTER 6

INTERACTIVE DASHBOARD AND RESULTS VIEWER

6. INTERACTIVE DASHBOARD AND RESULTS VIEWER

The results of the multi-objective building life cycle cost and performance analysis of the CRAVEzero case studies Solallén, Aspern IQ, Alizari, MORE, Isola Nel Verde and Les Heliades are furthermore integrated into the "CRAVEzero pinboard" as an interactive dashboard. The dashboard allows a further multi-perspective view into the analysis results, with visualisations that represent different findings and insights from the dataset described in this chapter.

The results of the CRAVEzero case studies can be found at the following links:

- **Solallen:** http://www.cravezero.eu/pinboard/Dashboard/Sollalen.html
- **Alizari:** http://www.cravezero.eu/pinboard/Dashboard/Alizari.html
- **Aspern IQ:** http://www.cravezero.eu/pinboard/Dashboard/AspernIQ.html
- **Les Heliades:** http://www.cravezero.eu/pinboard/Dashboard/LesHeliades.html
- **Isola Nel Verde:** http://www.cravezero.eu/pinboard/Dashboard/IsolaNelVerde.html
- **MORE:** http://www.cravezero.eu/pinboard/Dashboard/More.html

Figure 41 shows a screenshot from the web-based interactive dashboard.

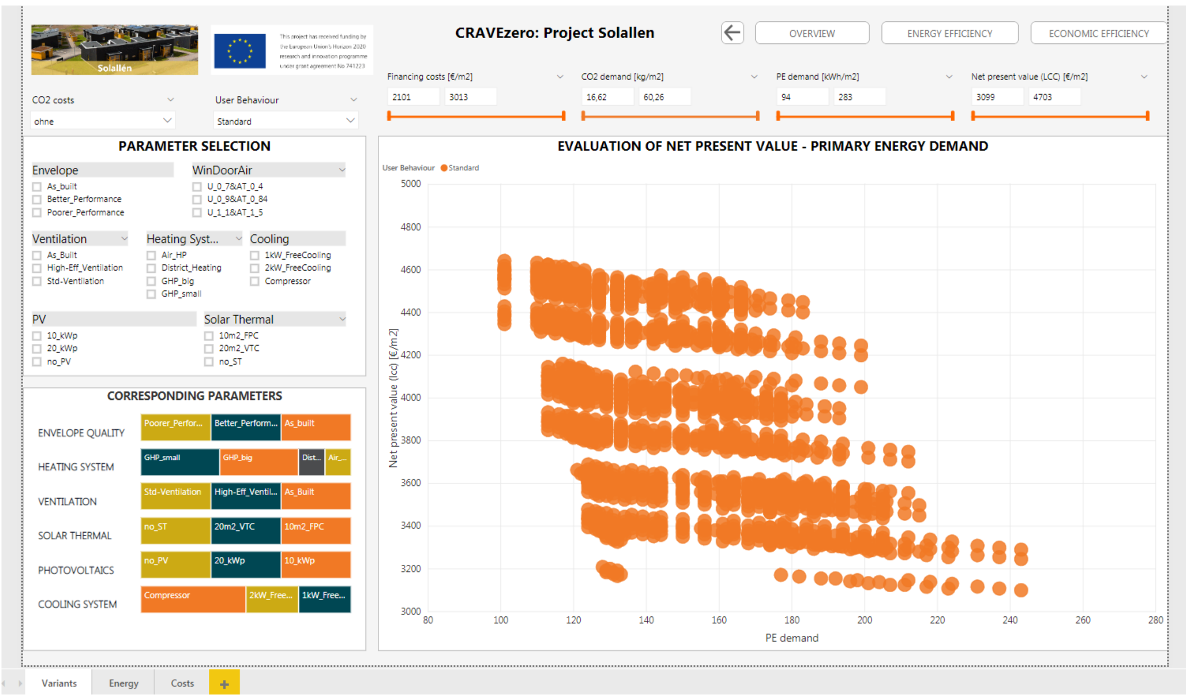


Figure 41: Web-based interactive dashboard of the derived results for the investigated case studies

How to use the interactive dashboard

The dashboard consists of three pages/ tabs as can be seen in Figure 41 where the "variant overview" page is displayed. The visualisations in the interactive dashboard represent a piece of information like for example the life cycle costs or relating CO_2 emissions of selected variants. Within the dashboard, users can add and remove data, change visualisation types, and apply filters. The idea of this interactive dashboard is to allow users of the pinboard to dig into the data and discover insights and look for optimal solutions that can also be applied for their nZEB developments. The web-report is highly interactive and highly customizable, and the visualisations update as the underlying data changes. Buttons at the bottom of a report can be used to navigate between pages. Also reports can be viewed full-screen, and users can save/print a screenshot of the report using the print option.

Interaction with filters

Filters/slicers allow users of the dashboard to narrow the cost and energy-related data that is visualised on a page. Multiple filters, as shown in Figure 42 can be selected to narrow down the dataset. To remove a filter, users can deselect all filtered values. Example: All variations of the life cycle cost and performance optimisation are initially shown for the building. Selecting, for example, a special heating system or filtering a life cycle cost range in the visualisations shows only data for that heating system or life cycle cost range in the visualisations.

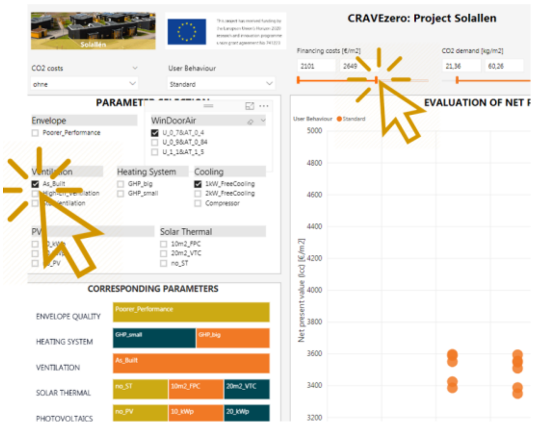


Figure 42: Filters and slicers

Cross-highlighting related visualisations

The visualisations on a single report are "connected" to each other. If one or more values are selected in one visualisation, other visualisations will change based on that selection.

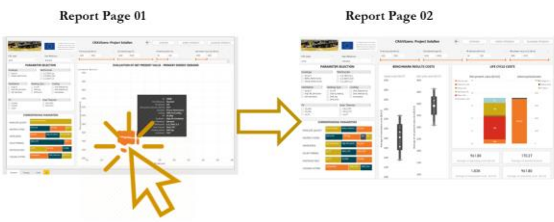


Figure 43: Cross highlighting of different visualisation pages

Hover effects of visuals

If the cursor is placed on a variant, users can find out more about a selected variant. The cursor needs to be placed over any visual element in the dashboard in order to view detailed data.

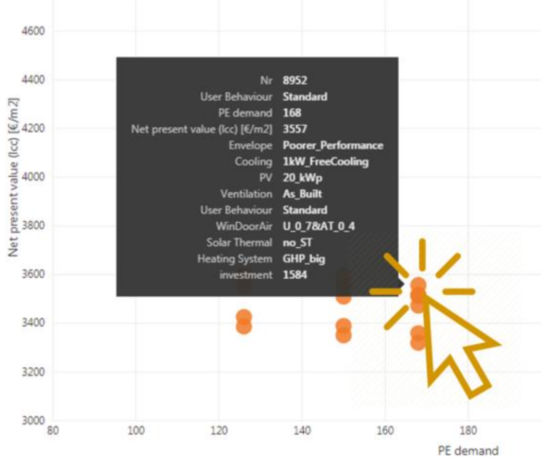


Figure 44: "Mouse over" effect of a selected visual element

Export dashboard data

Data can be exported out of the visual via the **Export data option**. The resulting .csv file will contain all the data presented in a visual and will respect any filters applied to the data.

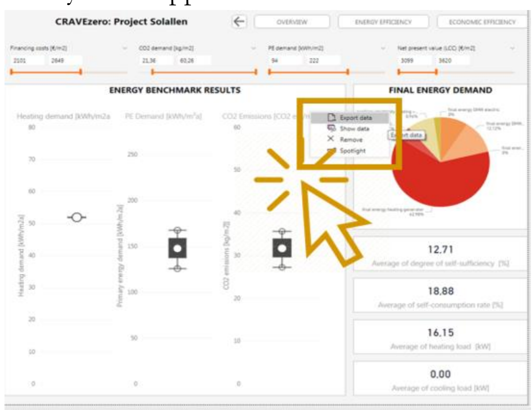
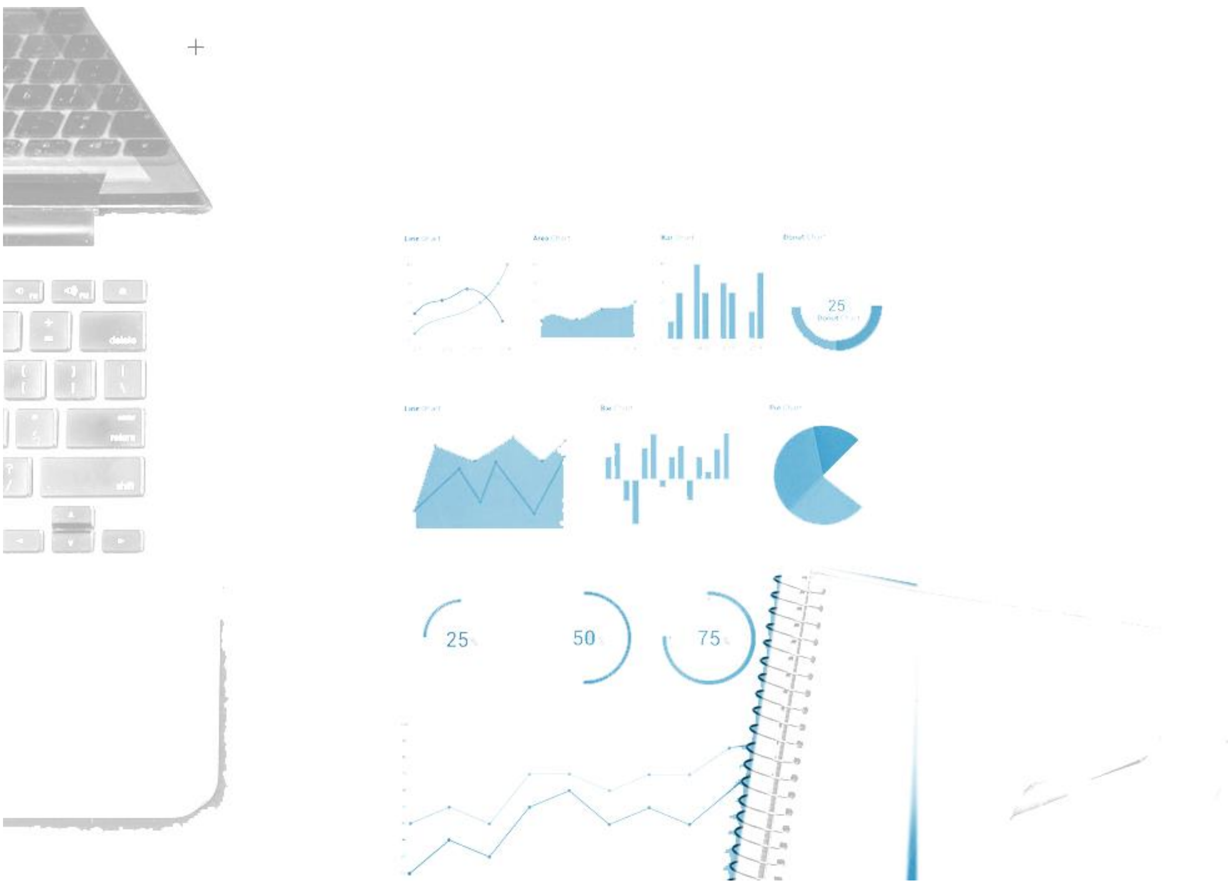


Figure 45: Data export option

CHAPTER 7

LCC SENSITIVITY ANALYSIS OF CRAVEZERO CASE STUDIES



7.LCC SENSITIVITY ANALYSIS OF CRAVEZERO CASE STUDIES

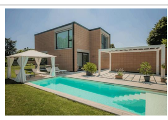
7.1. CASE STUDIES OVERVIEW

In Deliverable 6.1 the sensitivity analysis (SA) was introduced and two case studies were analysed: Résidence Alizari located in France and Solallén located in Sweden. These cases have been chosen to test the methodology of the SA, due to their detailed cost data breakdown.

In this Deliverable, the SA is extended to all available case studies, on the one hand aiming at identifying which input parameters affect the life cycle cost (LCC) the most and on the other hand aiming at providing this output as a range of values and not as a punctual one. In this way, the implications of uncertainty issues related to the assumptions on input parameters and boundary conditions can be highlighted.

Table 45 reports an overview of the investigated case studies, where location, year of construction, main features, net floor area (NFA) and the LCC are indicated. LCC values were calculated within task 2.2. These values are referred to the NFA and have been used as baseline values in the SA.

Table 45: Case studies main features.

Case study		**Location**	**Year**	**Main features**	**NFA [m²]**	**LCC [€/m²]**
Green Home (Residential)		Nanterre (France)	2016	Triple-glazed windows, decentralized ventilation with 96 % of HR, HP on grey water.	9267	1250
Les Héliades (Residential)		Angers (France)	2015	Well insulated and airtight, ventilation with HR, GSHP, PV.	4590	2257
Résidence Alizari (Residential)		Malaunay (France)	2015	Triple glazing, ventilation with HR, centralized wood boiler, PV.	2776	2021
NH – Tirol (Residential)		Innsbruck (Austria)	2008/ 2009	Centralized pellet boiler.	44959	2020
Parkcarré (Residential)		Eggenstein (Germany)	2014	High thermal insulation, heat-bridges optimization, decentralized ventilation with HR.	1109	1490
More (Residential)		Lodi (Italy)	2014	Precast component, flexible and modular	128	5265
Isola Nel Verde A (Residential)		Milan (Italy)	2012	Green roof, CHP, GSHP.	1409	4097
Isola Nel Verde B (Residential)		Milan (Italy)	2012		1745	3880

Case study		Location	Year	Main features	NFA [m²]	LCC [€/m²]
Solallén (Residential)		Växjö (Sweden)	2015	Well insulated and airtight, balanced ventilation with HR, GSHP, PV.	1778	2581
Väla Gård (Office)		Helsingborg (Sweden)	2012	Well insulated and air tight, balanced ventilation with HR, GSHP, PV.	1670	2885
Aspern (Office)		Vienna (Austria)	2012	GSHP, PV, small wind turbine.	8817	1671
I.+R. Schertler (Office)		Lauterach (Austria)	2011/ 2013	Reversible GSHP	2759	4606

The inspected input parameters of the case studies are the same defined in the previous Deliverable. On the one hand boundary conditions are analysed since typically uncertainty affects boundary conditions such as interest rate, energy cost and its inflation rate, maintenance cost (as a % of the construction cost) and operational cost data. On the other hand, key building features are investigated. Table 46 and Table 47 show the selected input parameters.

Input parameters are varied over predefined ranges; these have been determined following two criteria: first, a fixed range of variation, ± 10 %, equal for all parameters, has been defined. In a second step, a variation range coming from real data and literature has been adopted (here called "input real data"). This method was applied only to boundary conditions, whereas building features have been varied ± 10 % since only one value (construction cost) was available from the data collection. Regarding the sources used to determine the baseline values and its variation ranges detailed information can be found in Deliverable 6.1.

Table 46: Boundaries conditions input parameters.

Differential sensitivity analysis	Elementary effects method
Inflation energy cost	Inflation energy cost
Interest Rate	Interest rate
% Maintenance costs - Construction	% Maintenance costs
% Maintenance costs - HVAC	District heating cost
Lifespan Maintenance HVAC	Pellet cost
District heating cost	Elt. cost
Pellet cost	Heating consumption
Elt. cost	DHW consumption
Heating consumption	Cooling consumption
DHW consumption	Household electricity consumption
Cooling consumption	PV Production
Household electricity consumption	
PV Production	

Table 47: Building features input parameters.

Differential sensitivity analysis	Elementary effects method
Structural elements - Foundations	Structural elements
External insulation	External insulation - External walls
Flat roof insulation	Flat roof insulation
Floor next to the ground insulation	Windows
Windows	Insulation of the windows
Site and external work	Site and external work
Heating system	Heating system
DHW production	DHW system
Mechanical ventilation	Mechanical ventilation
Hydraulic system	Hydraulic system
Electric system	Electric system
Shading systems	Shading system
HVAC system	Photovoltaic system
Photovoltaic system	Building automation
Building automation	

7.2. SENSITIVITY ANALYSIS METHODOLOGIES

SA was performed by applying two methodologies. The first one consists of a differential sensitivity analysis. This represents the most straightforward screening technique. In the second step, the elementary effects method was implemented.

7.2.1. 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. Then, the impact on the LCC of one parameter at a time is investigated, keeping the other parameters fixed. 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: Output variation
- O_{un}: Baseline value
- ΔI: Input variation
- I_{un}: Baseline value

7.2.2. ELEMENTARY EFFECTS METHOD

The elementary effects method was proven to be an excellent compromise between accuracy and efficiency (Campolongo et al., 2007), since a good exploration of the design space with a reduced number of simulation can be ensured (CASTAGNA et al.). With this method, SA can be carried out for different combinations of input values, analysing the effects of parameters interactions.
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 Roberti et al. (2015), 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 so-called Design of Experiment (DoE) has to be generated to choose the combinations carefully.
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:

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

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

μ_i^* is the absolute mean of the single elementary effects associated with factor *i*. 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 in a global perspective, this characteristic permits to determine which parameter causes the most significant effect.
Ultimately, this method is useful for identifying critical LCC assumptions, but it has limited effectiveness in providing a sense of overall uncertainty since is not possible to have probabilistic distributions of the input parameters.

7.3. RESULTS

7.3.1. DIFFERENTIAL SENSITIVITY ANALYSIS

Figure 46 and Figure 47 display an average value of the sensitivity index for the input parameters among all case studies. The results of the SA conducted with a 10 % input variation show that the parameter " % maintenance costs" among boundary conditions and the parameter "structural elements" among the building features are the input parameters which variation mainly affects the LCC.
The analysed case studies have been built mainly between 2011 and 2016. Thus no data about maintenance was available. For this reason, yearly maintenance costs have been estimated using a percentage of the construction costs. A change of 10 % of this percentage produces a substantial effect on LCC, since this value acts on recurrent costs along a period of 40 years. Concerning structural elements, these costs own a high share of the total building construction costs. Therefore their variation has an important influence on LCC output.

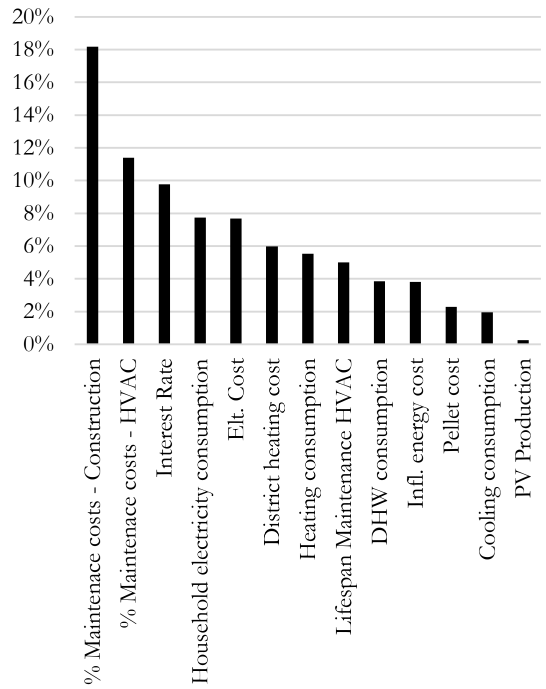


Figure 46: Sensitivity index (s %) of boundary conditions – Input ± 10 %.

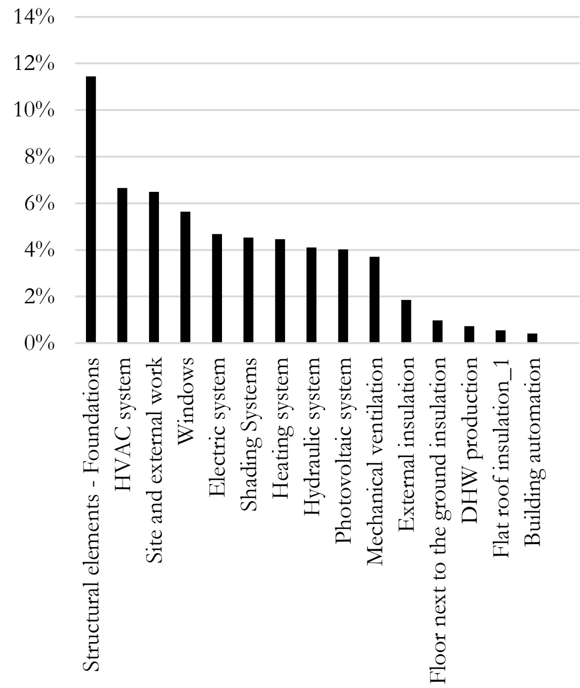


Figure 47: Sensitivity index (s %) of building features – Input ± 10 %.

Figure 48 shows the sensitivity index when the values for the input parameters come from real data, literature and norms. " % maintenance costs", "interest rate" are, like in the previous case the most influencing parameters. However, maintenance costs for the HVAC systems have the highest sensitivity index in this case. Values from the EN 15459:2018 were adopted to determine yearly maintenance costs for HVAC systems, the values indicated in the norm can vary up to ± 50 %.

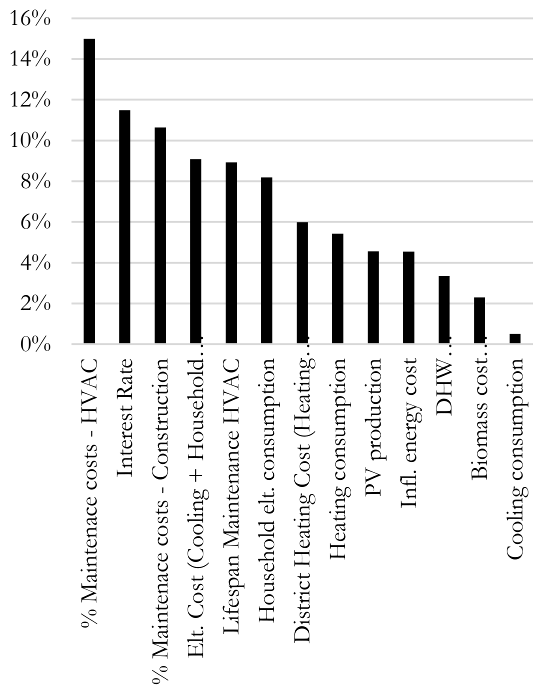


Figure 48: Sensitivity index (s %) of boundary conditions – Input real data.

7.3.2. ELEMENTARY EFFECTS METHOD

The following figures report the results of the elementary effects method. Average values of μ^* and σ among all case studies have been plotted. Figure 49 and Figure 50 are the results related to the fixed input variation, ± 10 %. To some extent, this method leads to similar results to the differential sensitivity analysis, whereas interest rate reaches the first position as the most influencing parameter among boundary conditions. The " % maintenance costs – construction" (maintenance costs for the building elements) and structural elements show, within this analysis, again a leading role as LCC influencing input parameters.

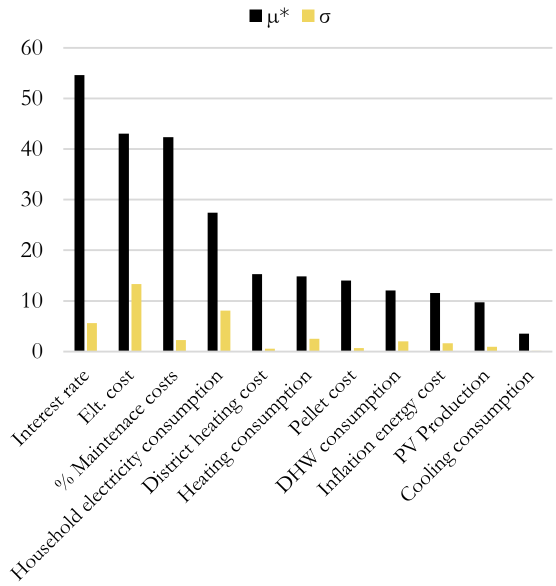


Figure 49: Average μ^* and σ of boundary conditions – Input ± 10 %.

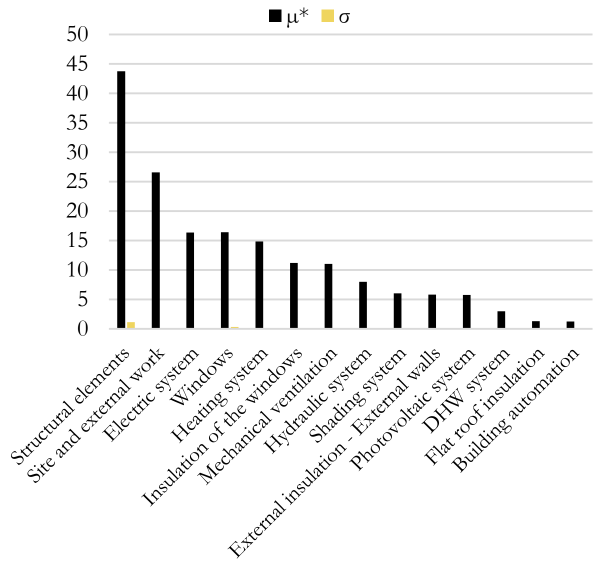


Figure 50: Average μ^* and σ of building features – Input ± 10 %.

Finally, considering the elementary effects method applied to input parameters coming from real data, "interest rate" and "inflation energy cost" play a dominant role. This is the result of combining together the effects of literature values with a wide range of variation. For instance, "inflation energy cost" can vary between -1 % and +6 % and "interest rate" from +0.25 % and +5 %. For this reason, the combined effects of extreme values of interest rate and inflation energy cost cause strong variations in the LCC output.

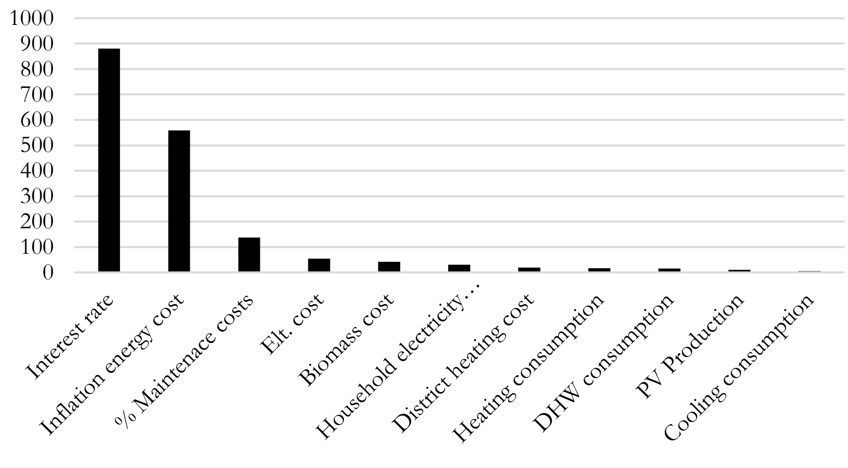


Figure 51: Average μ^* of boundary conditions – Input real data.

Table 48 collects the highest and the lowest LCC value for each case study analysed with the elementary effects method, where input parameters came from real data. It is clear that those extreme values appear when the effects of the highest value of "inflation energy cost" and the lowest of "interest rate" (and vice versa) are combined.

From a macroeconomic point of view, this scenario is confirmed. Interest rate is the amount charged by lender to a borrower. In general, as interest rates are reduced, more money can be borrowed easily. Consequently, the economy grows and inflation increases, because consumers have more money to spend.

Table 48: LCC extreme values and corresponding input parameters.

Case study	LCCmax	Inflation energy cost	Interest rate	LCCmin	Inflation energy cost	Interest rate
Les Héliades	3707	0.50 %	0.25 %	1773	0.50 %	5.00 %
Résidence Alizari	4904	7.80 %	0.25 %	2097	0.50 %	5.00 %
Parkcarré	2299	6.40 %	1.83 %	1077	0.60 %	5.00 %
More	8939	6.80 %	0.25 %	4352	1.27 %	5.00 %
Isola Nel Verde A	9519	6.80 %	0.25 %	3417	-1.50 %	5.00 %
Isola Nel Verde B	8990	6.80 %	0.25 %	3206	-1.50 %	5.00 %
Solallén	3542	3.70 %	0.25 %	2072	-5.90 %	5.00 %
VälaGård	3836	3.70 %	0.25 %	2308	-5.90 %	5.00 %
Aspern	2719	1.20 %	0.25 %	1752	-0.29 %	5.00 %
IR Schertler	6179	2.90 %	0.25 %	3394	-3.10 %	5.00 %

Figure 52 plots the LCC values for every single simulation performed in the elementary effect method with an input variation of ± 10 %. The investigated case studies show similar behaviour, although different average LCC values are present. See Table 45 for the LCC baseline values.

Figure 53 plots the LCC values for each single simulation performed using real data for the input parameters. This visualisation confirms what already displayed in Figure 51 and Table 48, combining together the effects of input parameters which can have wide ranges of variations, produces extreme values in the LCC output.

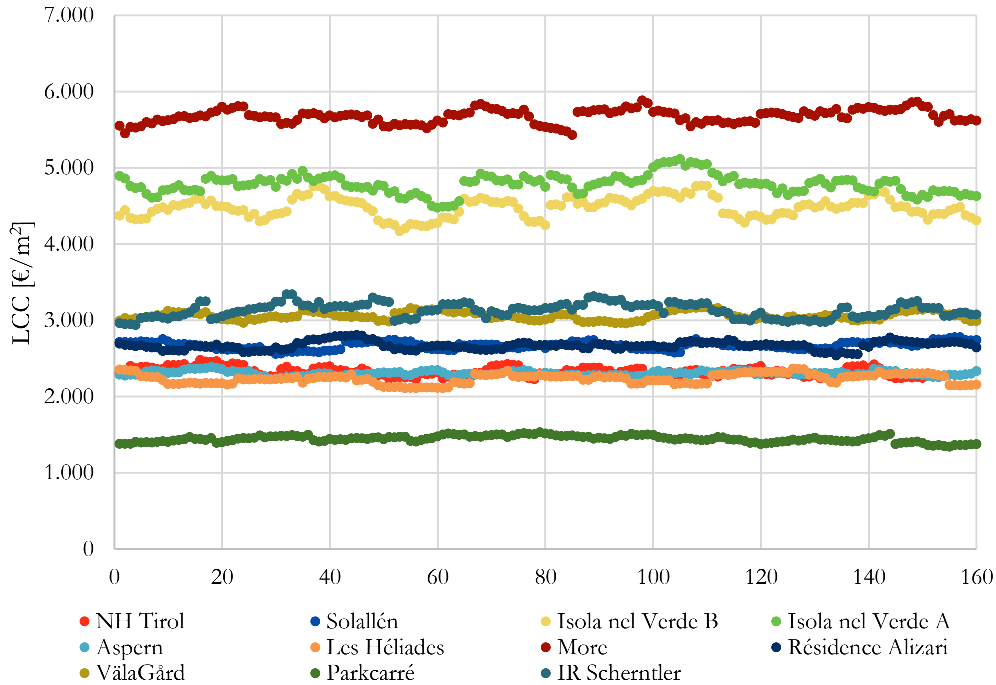


Figure 52: LCC values for simulation of the elementary effect method – input ± 10 %.

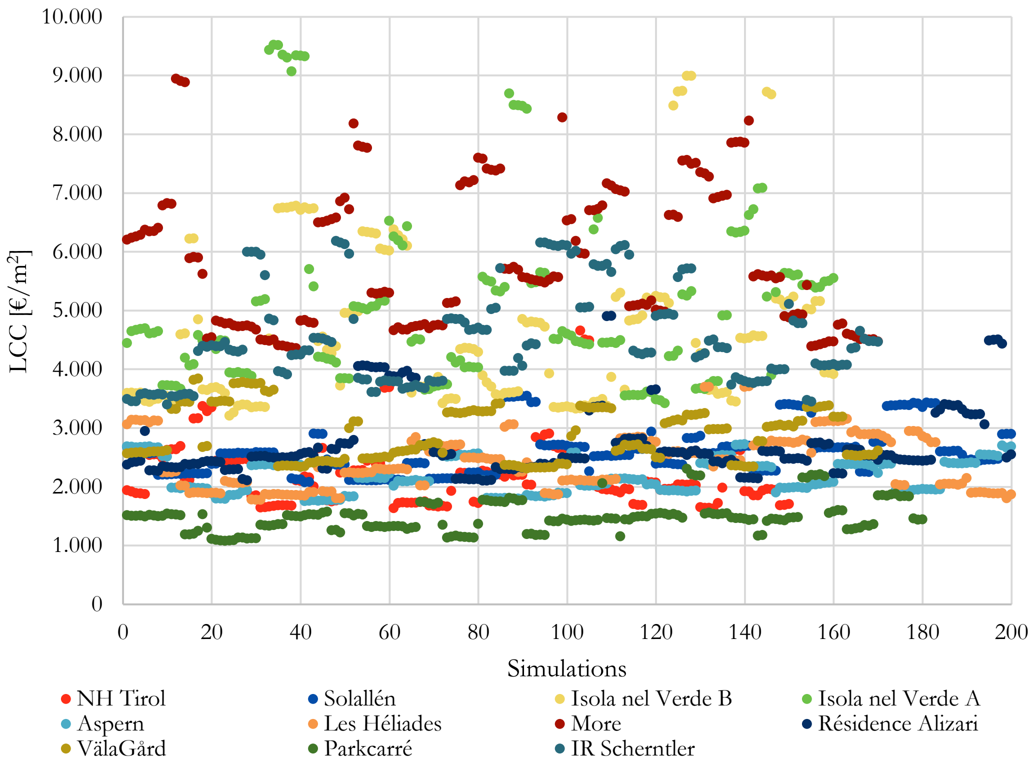


Figure 53: LCC values for simulation of the elementary effect method – Input real data.

Finally, all the LCC values have been analysed, computing those between the 20° and the 80° percentile, where the 50° percentile is the average LCC value. The average deviation of these values with respect to their mean value is displayed in Figure 54 and Figure 55. An average deviation of 2.8 % in the case of input ± 10 % and 11.7 % with real input data were calculated.

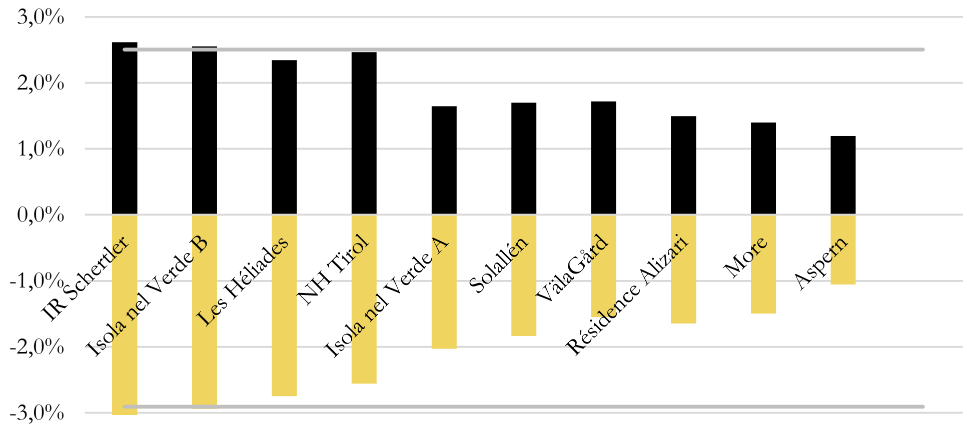


Figure 54: % of LCC values between the 20° and the 80° percentile. 50° percentile is the mean value. Input variation ±10 %.

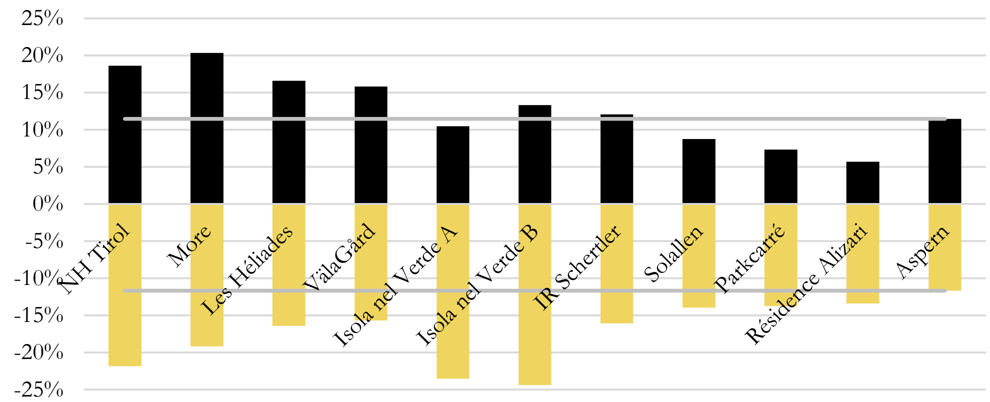


Figure 55: % of LCC values between the 20° and the 80° percentile. 50° percentile is the mean value. Input – real data.

Table 49: LCC values for the two input typologies.

	LCC - INPUT ± 10 %			**LCC - Real input data**		
Case study	20° percentile [€/m²]	Mean [€/m²]	80° percentile [€/m²]	20° percentile [€/m²]	Mean [€/m²]	80° percentile [€/m²]
Les Héliades	2,168	2,229	2,281	2,017	2,414	2,814
Parkcarré	1,400	1,438	1,476	2,361	2,727	2,882
Résidence Alizari	2,617	2,661	2,701	1,725	2,207	2,617
NH Tirol	2,264	2,324	2,381	1,278	1,482	1,591
More	5,586	5,671	5,751	4,725	5,845	7,032
Isola nel Verde A	4,684	4,781	4,860	3,900	5100	5635
Isola nel Verde B	4,345	4,477	4,591	3,490	4,615	5,229
Solallén	2,614	2,663	2,708	2,225	2,587	2,813
VälaGård	3,006	3,053	3,105	2,431	2,884	3,339
Aspern	2,277	2,301	2,328	1,916	2,169	2,417
IR Schertler	3,029	3,124	3,206	3,786	4,511	5,054

CHAPTER 8

NZEB RENOVATION: FROM ENERGY AUDIT TO ENERGY EFFICIENCY IMPROVEMENTS

8.NZEB RENOVATION: FROM ENERGY AUDIT TO ENERGY EFFICIENCY IMPROVEMENTS

8.1. INTRODUCTION

In this chapter 3i Group shows the project of renovation of its offices. The goal that it wanted to achieve was to renovate the building, improve the comfort of workers and customers and to reduce operative costs related to heating, cooling and lighting. It is possible to achieve similar results in almost all similar buildings by performing an energy audit and by identifying energy improvements. This project was financed by European Funds, therefore it was required to write a technical report describing all measures and to implement a monitoring system to prove the energy-saving obtained.
The process followed during the project is shown in the figure below; the main steps were:

- Energy audit and thermal model;
- Energy improvements;
- Decision-making process;
- Cost evaluation and technical design;
- Work planning and monitoring;
- Technical report and project founding
- Construction phase;
- End of works report.

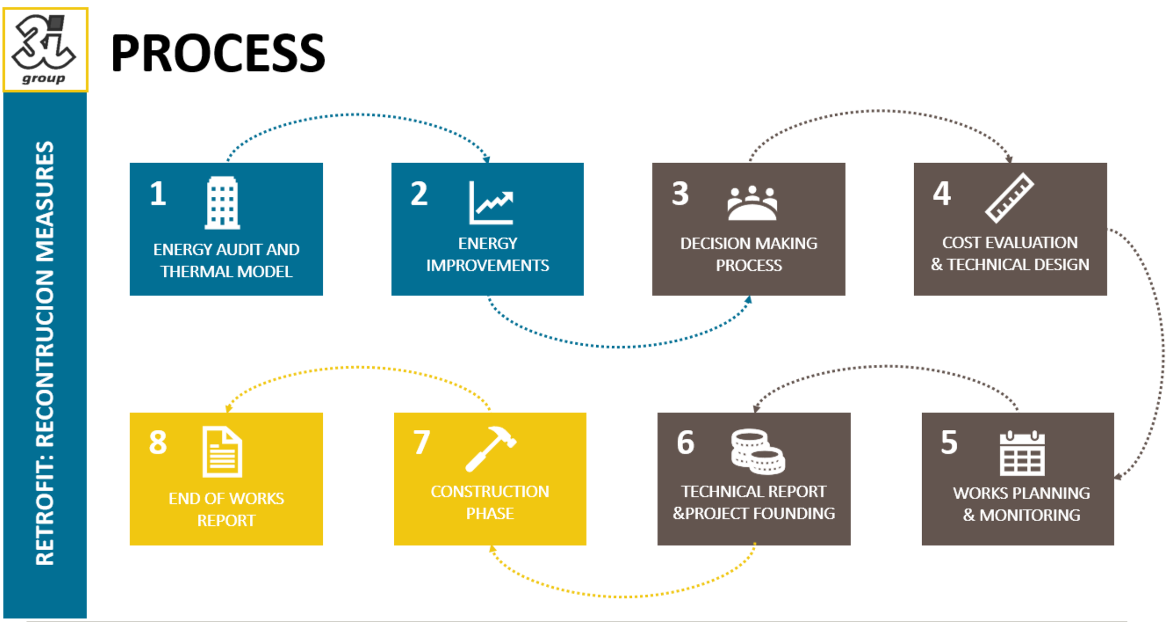


Figure 56: Process followed in the case study

8.2. ENERGY AUDIT OF OFFICES

The procedure followed in this chapter is similar to the structure of an energy audit (according to D.Lgs 102/14), from the description of the building, through the collection of consumption data until the evaluation of energy efficiency improvements. An energy audit is an inspection survey, and an analysis of energy flows for energy conservation. It is a systematic procedure with the purpose of obtaining adequate knowledge of the energy consumption profile of a building, identifying and quantifying cost-effective energy-saving opportunities, and reporting the findings.

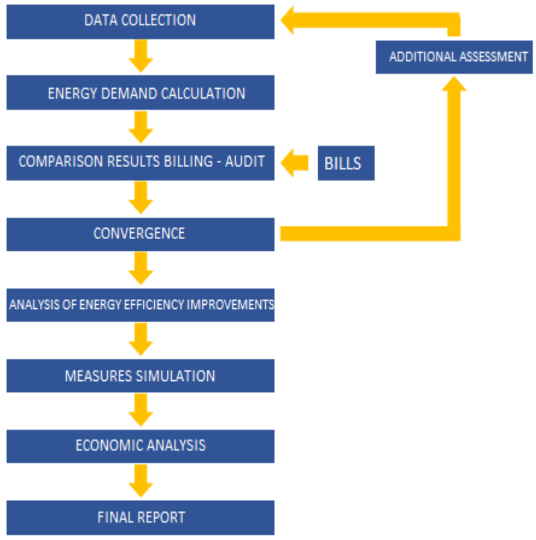


Figure 57: steps of the energy audit

The first step is represented by data collection; the installed equipment, user profile and characteristics of building envelope are identified. Other important points of this analysis are weather conditions, operating schedules and user behaviour. All these data are used to perform the thermal model of the building through specific software. The result of energy demand obtained from the software calculation is compared with bills. Then the convergence of the two results is performed and the model is validated. Otherwise, it is necessary to perform an additional assessment.

In the next step, the analysis of energy efficiency improvements is carried out: all measures are simulated with the software to decide which the optimum solution is, both from a technical and economic point of view. For each energy conservation measure, energy-saving potential, investment cost and simple payback time are calculated. Finally, once defined the life-time of each measure, other economic parameters like Net Present Value, Index of profit and Internal Rate of Return are evaluated.

8.2.1. BUILDING AND HVAC

Figure 58: Picture 3i Group offices

The offices are located in a '80s building in Alessandria (north-west of Italy). In the last ten years an expansion was done and the second floor was built respecting the energy standards of those years. The use of the building is related to office activity held inside eight hours a day in a five-day week. There are 18 offices of different size, orientation and thermal needs.
The building was heated by the heating system with a central gas condensing boiler feeding a series of fan convectors throughout the offices. The cooling was provided by an air-water heat pump. This HVAC system had much room for improvement because in winter the heating was provided by the boiler instead of the high-performance heat pump.

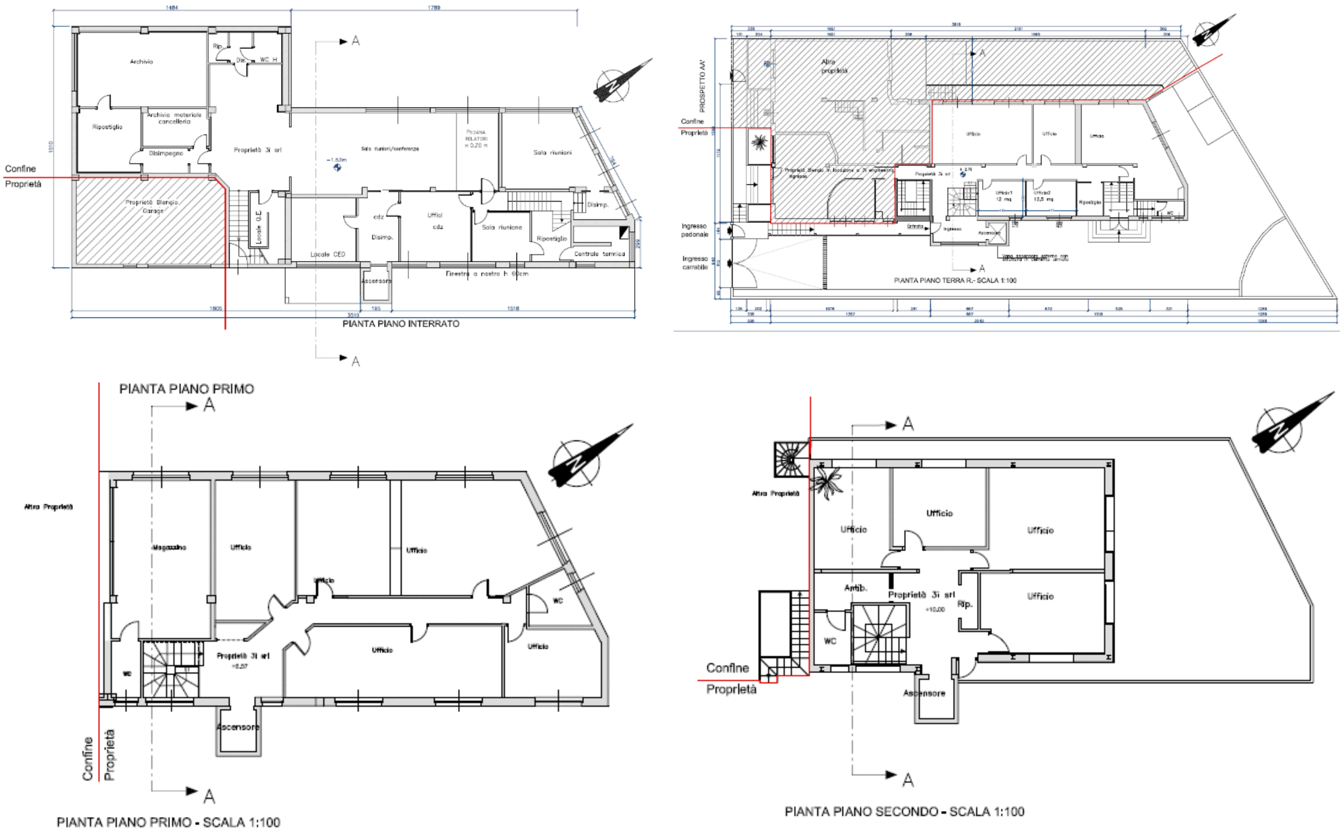


Figure 59: Overview of offices

Table 50: 3i Group offices – area data

TOTAL AREA	**750 m²**
Offices floor 0	158 m²
Offices floor 1	148 m²
Offices floor 2	100 m²
Reception and meeting room	50 m²
Toilets	32 m²
Kitchen	22 m²
CED	18 m²
Archive	50 m²
Education area	172 m²

Table 51: 3i Group Offices - building data and U-value of the envelope

type of building	offices	
net floor area (heated floor area)	750 m^2	
gross volume	3409 m^3	
surface area to volume ratio	0.49	
year of construction	'80s	
relation surface window / outer wall	10.81 %	
quality of wall	U=1.1 W/(m^2K)	
quality of wall (insulated second floor)	U=0.256 W/(m^2K)	
quality of window	Uw=1.6-1.9 W/(m^2K)	double glazing
	g=0.55-1.0	
quality of roof	U=0.478 W/(m^2K)	
thermal bridges	not considered	
air-tightness	not considered	
heating system	gas condensing boiler	
cooling system	air-water HP	
mechanical ventilation	Only in one underground office	

8.2.2. ENERGY CONSUMPTION

Table 52: Total energy consumption of the last three years

ENERGY CONSUMPTION	3 GAS		ELECTRICITY		TOTAL CONSUMPTION
	[Sm^3]	[TOE]	[kWh]	[TOE]	[TOE]
2016	7,217	5.95	64,263	12.02	18
2017	7,162	5.91	62,982	11.78	18
2018	9,482	7.82	64,915	12.14	20

At this step of the analysis, bills of gas and electricity of the last three years were collected to figure out the total energy consumption over the years and monthly load profiles. This made it possible to identify the critical areas, analyse and then subsequently optimize them.

The result obtained is that the primary source of supply was the electricity, its consumption was almost 65,000 kWh, and it represented 60.8 % of the total energy use of the building. The gas consumption stood at 9,500 Sm^3, which was 39.2 % of the total energy consumption.

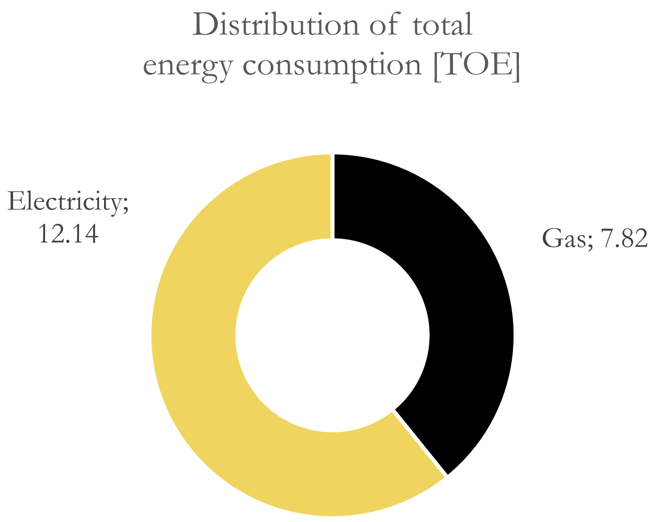


Figure 60: Distribution of total energy consumption [TOE]

8.2.2.1. ELECTRICITY

The average monthly cost for electricity was 0.228 €/kWh. This value is high compared to other similar small-sized users and makes the measures affecting the reduction of electricity consumption more remunerative. The table below shows the energy consumption and energy costs for each month of 2018.

Table 53: Electricity consumption, monthly cost and specific cost in 2018

MONTH (2018)	CONSUMPTION				MONTHLY COST	SPECIFIC COST	TOT
	F1	F2	F3	TOT			
	[kWh]	[kWh]	[kWh]	[kWh]	[€]	[€/kWh]	[TOE]
January	2,004	846	1,281	4,131	941	0.228	1
February	2,133	983	1,496	4,612	1,038	0.225	1
March	2,131	999	1,642	4,772	1,043	0.219	1
April	1,894	759	1,454	4,107	910	0.222	1
May	2,287	1,044	1,759	5,090	1,141	0.224	1
June	2,869	1,216	2,036	6,121	1,348	0.220	1
July	4,410	1,525	2,238	8,173	1,778	0.218	2
August	2,691	1,038	1,964	5,693	1,269	0.223	1
September	2,732	1,068	1,719	5,519	1,250	0.227	1
October	3,677	1,432	2,096	7,205	1,612	0.224	1
November	2,358	951	1,495	4,804	1,071	0.223	1
December	2,155	874	1,659	4,688	1,042	0.222	1
Total year	31,341	12,735	20,839	64,915	14,450	0.223	12

This energy carrier is used mainly for devices like lighting (22 %), cooling (21 %), CED (19 %), computers and printers (18 %). It is evident that it is possible to obtain important results in improving the efficiency of lighting and cooling system, the two most energy-intensive users.

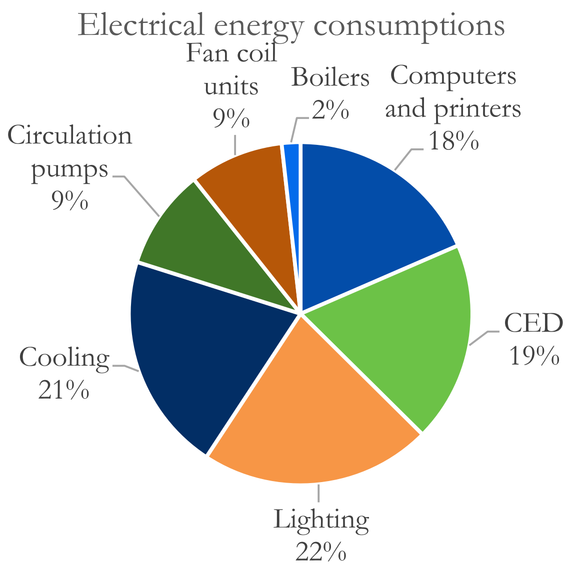


Figure 61: Distribution of electrical energy consumption

8.2.2.2. GAS

The average monthly cost for this energy carrier was 0.553 €/Sm³. In the table below the gas consumption, monthly cost and equivalent primary energy of 2018 are shown.

Table 54: Monthly gas consumption, thermal energy, monthly cost and specific cost in 2018

MONTH (2018)	GAS QUANTITY	THERMAL ENERGY	MONTHLY COST	SPECIFIC COST	TOT
	[Smc]	[kWh]	[€]	[€/Smc]	[TOE]
January	3,087	29,175	2,180	0.443	3
February	1,831	17,308			2
March	1,224	11,569	1,409	0.679	1
April	853	8,063			1
May	0	0	8.97	/	0
June	0	0	8.97	/	0
July	0	0	8.97	/	0
August	0	0	8.97	/	0
September	0	0	8.97	/	0
October	36	342	32,95	0.915	0
November	1,270	12,004	813	0.640	1
December	1,179	11,144	756	0.642	1
Total year	9,482	89,605	5,238	0.553	8

Gas is used for the offices heating through the condensing boiler. The maximum consumption is reached in January (3,087 Smc), while December's consumption is very low because of the office closing days for holidays. Since the gas used in summer months is zero, the DHW is not provided by gas, in fact, it is provided by electric boilers.

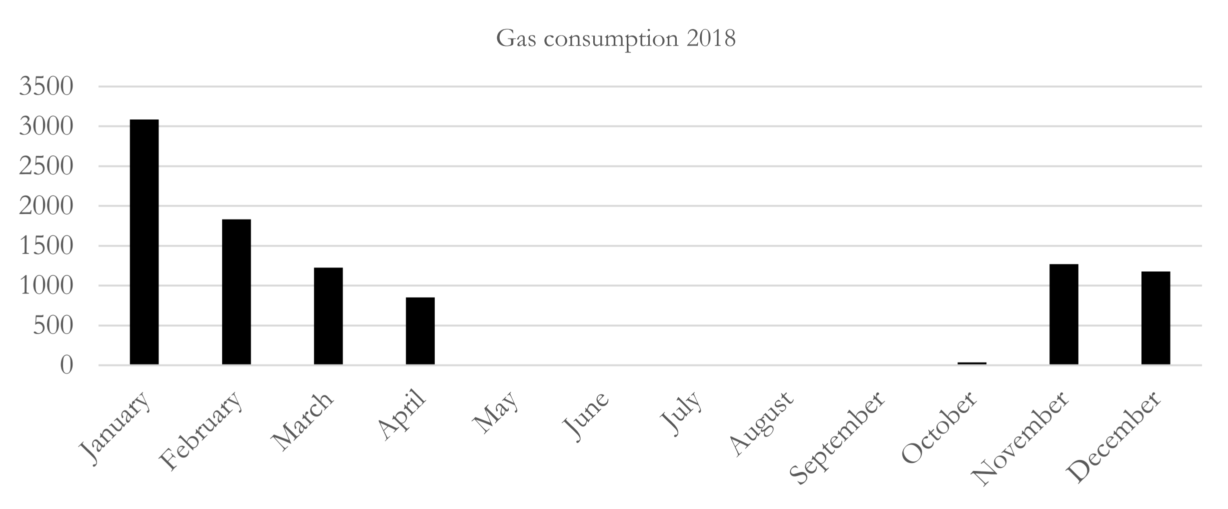


Figure 62: Monthly gas consumption in 2018

8.2.3. ENPI ENERGY PERFORMANCE INDICATORS

Energy Performance Indicator (EnPI) is a measure of energy intensity used to gauge the effectiveness of energy management efforts. It is interesting to compare the building and utility performances over time, in order to identify abnormal situations and to understand the most sensitive zones for improvements.

In this case, the energy consumed is compared with the net floor area. The EnPi for heating was 12.64 Sm^3/m^2a, equivalent to 119.4 kWh/m^2. In the table below, energy performance indicators for the electric consumers are shown (and compared with heating EnPI). The highest indicators were represented by lighting and cooling (18 kWh/m^2a and 17 kWh/m^2a respectively). Therefore, these two consumers were more sensitive to energy efficiency improvements, and it was possible to obtain higher energy savings.

Table 55: Energy consumption of principal utilities and the related energy performance indicators

UTILITY	ENERGY CONSUMPTION		ENPI
	kWh	TOE	kWh/m^2
Computers	6,199	1.16	8.27
Plotter	3,709	0.69	4.95
Printers	1,531	0.29	2.04
TOTAL	**11,439**	**2.14**	**15.25**
Cooling CED 2	7,008	1.31	9.34
CED 1	3,329	0.62	4.44
CED 2	1,390	0.26	1.85
TOTAL	**11,727**	**2.19**	**15.64**
Lighting	13,507	2.53	18.01
Cooling	12,768	2.39	17.02

Circulation pumps	5,843	1.09	7.79
Fan coil units	5,513	1.03	7.35
Boilers	1,095	0.2	1.46
TOTAL	**38,725**	**7.24**	**51.63**

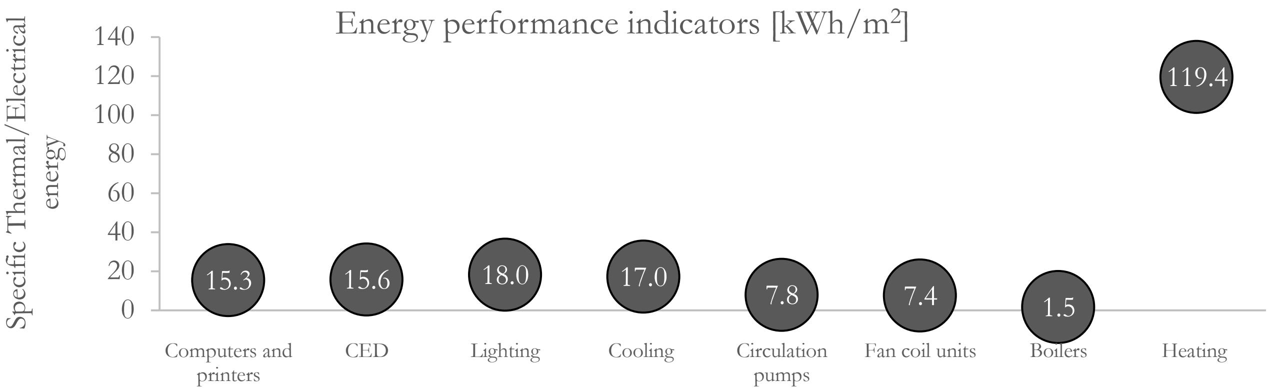


Figure 63: Energy performance indicators for eletric utilities and heating

8.3. ENERGY EFFICIENCY IMPROVEMENTS

Having identified the consumers that require most electricity and gas (highest EnPI), it was clear where it was possible to obtain higher energy savings. Given these considerations, the energy efficiency measures were proposed, they were chosen according to the reduction of consumption and energy costs obtained.
In particular, the most interesting measures in this project were:

- Photovoltaic plant;
- Walls Insulation;
- LED lighting;
- Heat pump control.

8.3.1. PHOTOVOLTAIC

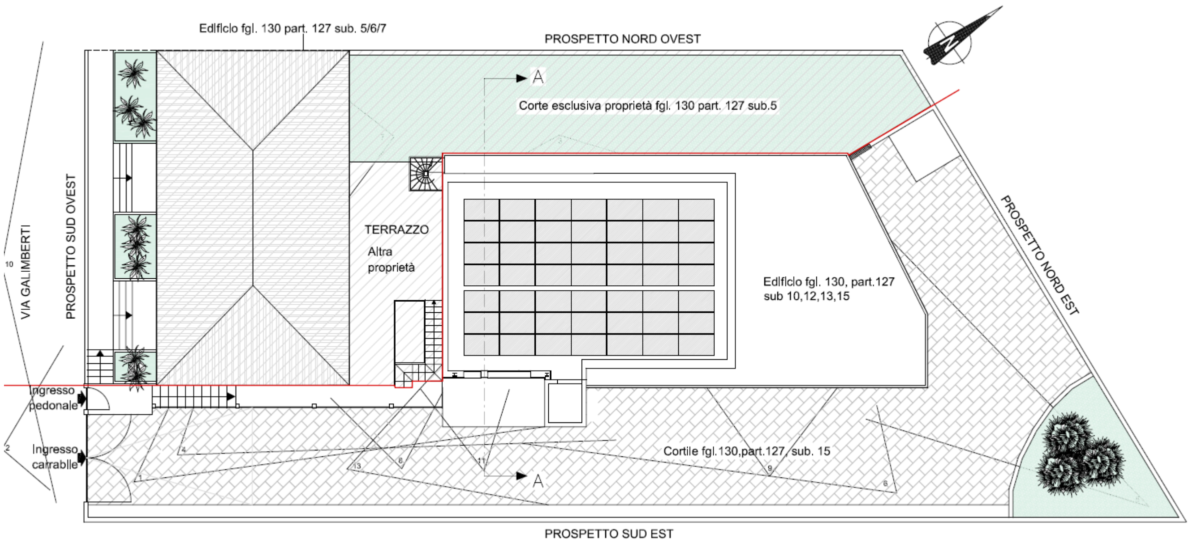


Figure 64: Photovoltaic plant on the roof of the second floor

The first energy measure analysed was the photovoltaic plant on the roof of the offices on the second floor. The two parameters used to evaluate the power of the system were: load curves, to maximize the self-consumed energy, and roof area. After the analysis of both parameters, the most convenient solution from the economic and energetic point of view was to install 13.72 kW, covering all the surface of the roof. The self-consumption rate is about 90 %, and the produced energy reduces the electricity from the grid especially in summer season.

Table 56: Energy efficiency improvements – photovoltaic 13,72 kW data

PHOTOVOLTAIC 13.72 kW	
Specific cost [€/kWp]	1,500
Peak power [kWp]	13.72
Productivity [kWh/kWp]	1,072
Panel power [kWp]	0.28
Number of panels [°n]	49
Tot area [m^2]	78
Self-consumption [%]	90 %
Selling price [c€/kWh]	12
Rate [%]	2.00 %
Energy rate [%]	3.00 %
Efficiency losses [%]	0.35 %
Maintenance rate [%]	2.00 %
Electricity self-consumed [kWh]	13,236
Electricity sold [kWh]	1,471
Saving (first year) [€]	2,956
The investment [€]	20,580
Simple Payback [years]	6.5
Avoided CO_2 emissions [ton/year]	6.37
Net Present Value [€]	57,596
Index of profit [%]	280 %
Internal Rate of Return [%]	16.38 %

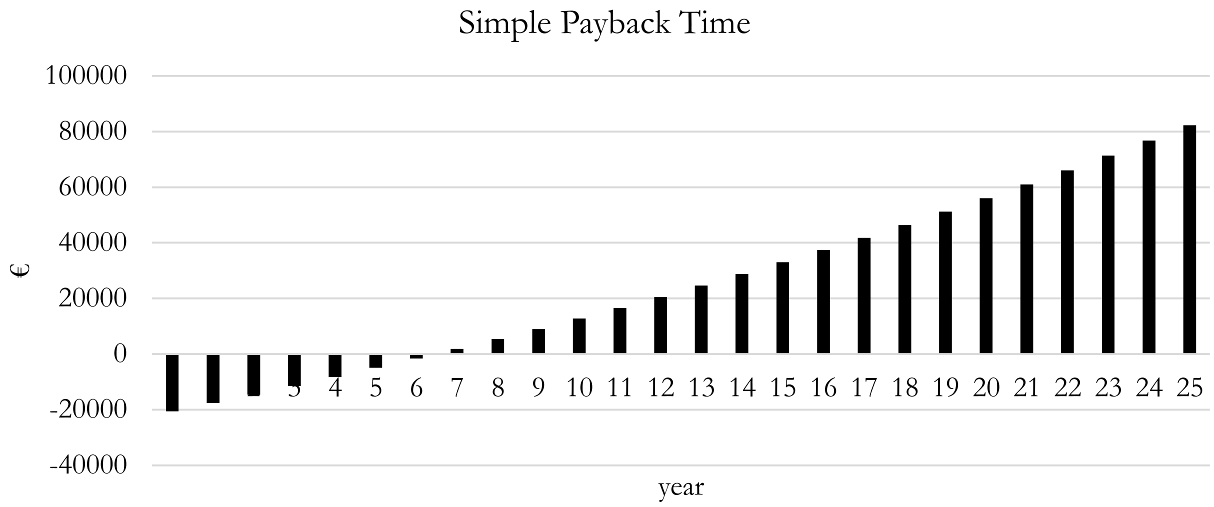


Figure 65: Simple payback time - photovoltaic 13.72 kW

8.3.2. THERMAL INSULATION

It was possible to reduce thermal losses through the walls by insulating them with a thermal insulation wall cladding system. Therefore, 12 cm of insulating material with a thermal conductivity 0.022 W/mK were applied on the existing wall. The interspace between the cladding and the wall is designed to allow the natural flow of air using the chimney effect. The primary energy saving obtained every year is about 4 TOE. Moreover, since the wall is ventilated, there is an additional energy-saving also in summer. The ventilated façade creates a "heat shield" for the envelope of the building, protecting it from heat through a continuous and regular circulation of air at ambient temperature. This ventilation results in a phase shift of the heat wave: the heat penetrates the interior of the envelope less and at times when the ambient temperature is lower.

Table 57: Data of insulated wall

U-VALUE WALL	**0,154**	**W/m2K**
Thickness	513	mm
Outside temperature	-8.0	°C
Permeance	20.855	10-12kg/sm²Pa
Surface mass (with plaster)	326	kg/m²
Surface mass (without plaster)	274	kg/m²

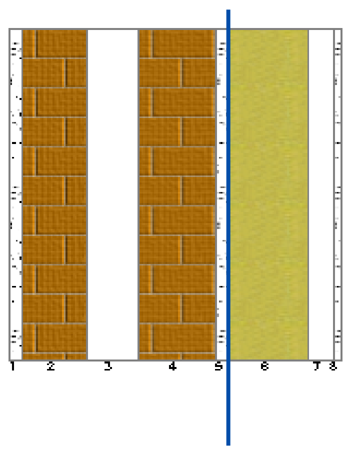


Table 58: Stratigraphy of insulated wall: thickness and thermal data of materials

EXISTING

N.	Description	s	Cond.	R	M.V.	C.T.	R.V.
-	Internal surface resistance	-	-	0.130	-	-	-
1	Gypsum plaster	20.00	0.400	-	1000	1.00	10
2	Perforated brick	100.00	0.370	-	780	0.84	9
3	Unventilated air layer Av<500 mm^2/m	80.00	0.444	-	-	-	-
4	Hollow brick	120.00	0.632	-	1508	0.84	9
5	Lime plaster	20.00	0.800	-	1600	1.00	10
6	Isotec	120.00	0.022	-	38	1.40	60
7	Ventilated air layer Av=1100 mm^2/m	40.00	-	-	-	-	-
8	Elycem panel	12.50	0.174	-	800	1.40	-
-	Exterior surface resistance	-	-	0.059	-	-	-

s	Thickness	mm
Cond.	Thermal conductivity	W/mK
R	Heat resistance	m^2K/W
M.V.	Density	kg/m^3
C.T.	Thermal capacity	kJ/kgK
R.V.	Water vapour diffusion resistance factor	-

Table 59: Energy efficiency improvements: thermal insulation

Specific cost [€/m²]	**190**
Electricity saving [kWh]	3,297
Gas saving [Smc]	4,050
Primary energy saving [TOE]	3.96
Saving (first year) [€]	3,496
Investment [€]	98,938
Simple Payback [years]	21
Avoided emissions [ton/year]	8.96
Net Present Value [€]	-2,360
Index of profit [%]	-2.4 %
Internal Rate of Return [%]	1.8 %

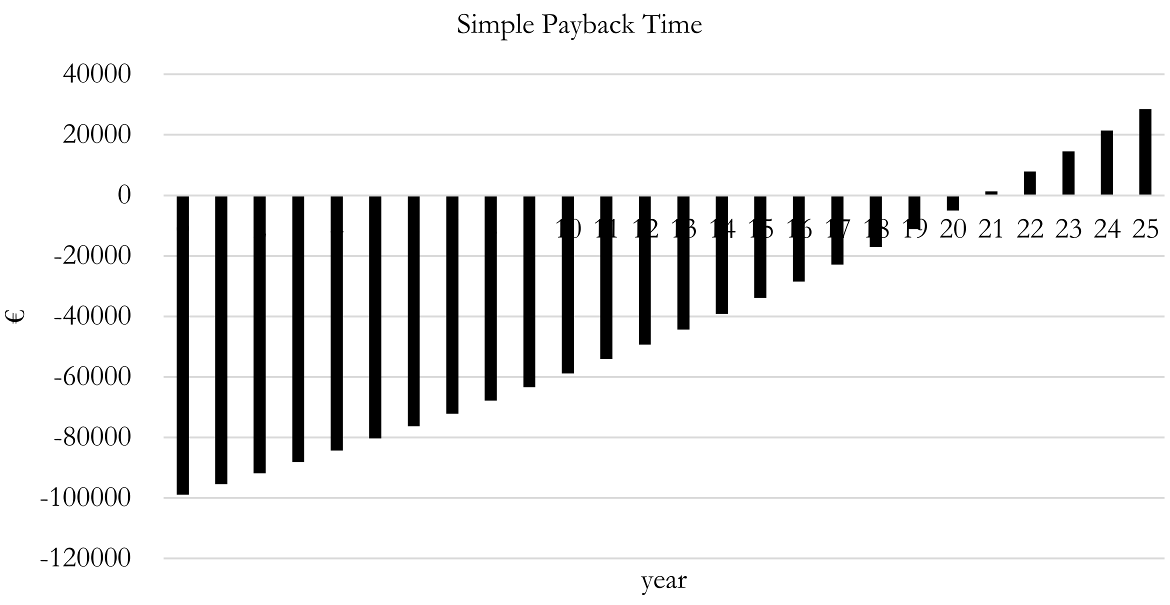


Figure 66: Simple payback time: thermal insulation

8.3.3. LED

The lighting system was represented by fluorescent lamps with high energy consumption. It was possible to achieve a significant quantity of saving by replacing the lighting system with more efficient LED. The resulting energy saving is around 4470 kWh and the simple payback time is 5 years.

Table 60: Energy efficiency improvements: LED

Ante operam energy consumption [kWh]	**10,447**
Ante operam power [kW]	5
Equivalent hours of operation [kWh/kW]	2,000
Post operam consumption [kWh]	5,977
Post operam power [kW]	3
Years of operation [y]	25
Rate [%]	2.00 %
Energy rate [%]	3.00 %
Maintenance rate [%]	2.00 %
Electricity saving [kWh]	4,470
Saving for avoided maintenance [€]	300
Saving (first year) [€]	1,511
Investment [€]	6,400
Simple Payback [years]	5
Avoided CO_2 emissions [ton/year]	1.94
Net Present Value [€]	12,523
Index of profit [%]	196 %
Internal Rate of Return [%]	15 %

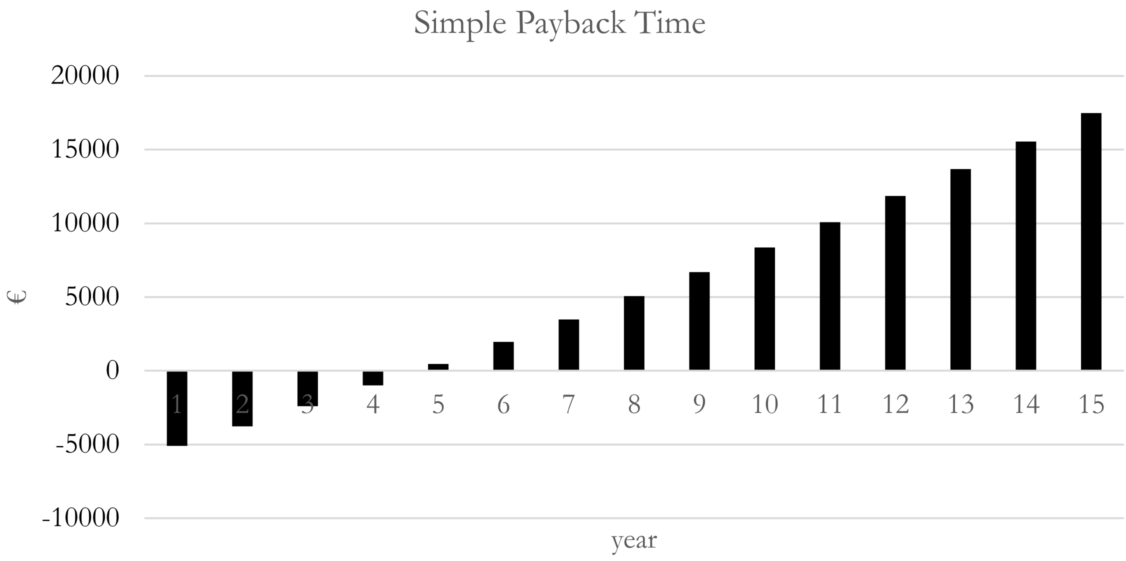


Figure 67: Simple payback time: LED

8.3.4. HEAT PUMP CONTROL

The heating was provided by a gas condensing boiler and cooling by the heat pump. Since in all offices there were fan coil units compatible with low-temperature distribution, it was possible to use the heat pump not only for cooling but also for heating. It was enough to implement small changes to existing equipment so that the heat pump works in all seasons and the condensing boiler is used only to integrate it in coldest days.

Furthermore, thermostats and electric control panels were installed in all offices to guarantee the desired temperature conditions. Sensors were integrated on all windows: when the window is opened the heating/cooling of that office is turned off to save energy.

Therefore, after the adjustments of the heat pump control, it started to work not only for cooling but also for heating. During winter, when the temperature is very low, the heating demand is guaranteed by the condensing boiler; instead, with the increasing of the temperature, the heat pump comes into service with high performance. In the table and graph below the functioning of both technologies is shown.

Table 61: Thermal energy provided by heat pump, condensing boiler and total heat demand

Month	θest	Total Heat Demand	Heat Pump	Condensing Boiler
	[°C]	[kWh]	[kWh]	[kWh]
Jan	1.5	7143	2291	4852
Feb	4.2	3858	2148	1710
Mar	8.4	938	872	66
Apr	11.9	38	38	0
May	17.5	-	-	-
Jun	21.6	-	-	-
Jul	23.5	-	-	-
Aug	22.4	-	-	-
Sep	17.6	-	-	-
Oct	12.5	339	339	0
Nov	6.7	3845	3707	138
Dec	1.1	7742	2175	5567
TOT	-	23903	11570	12332

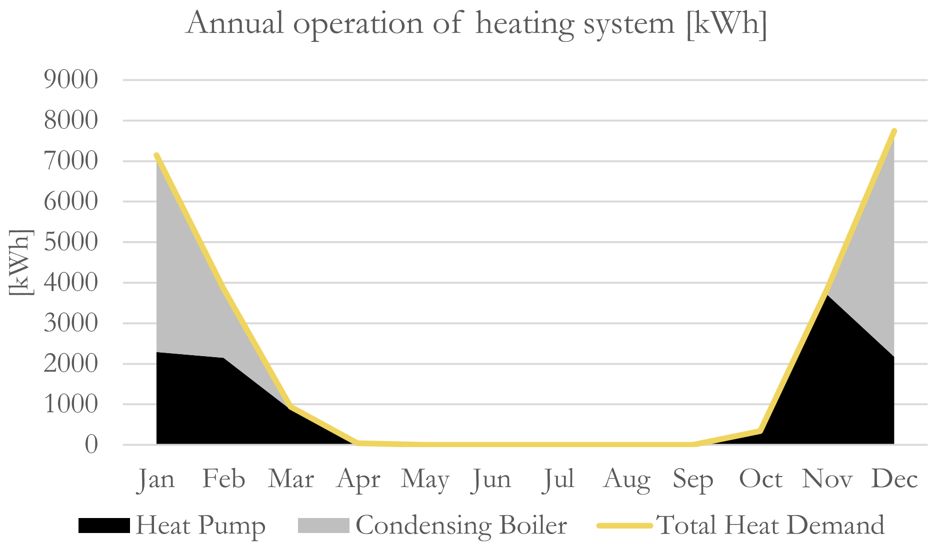


Figure 68: Annual operation of heating system [kWh] after regulation of HP

Table 62: Energy efficiency improvements: heat pump regulation

Gas saving [Smc]	**3,800**
Primary energy saving [TOE]	1.73
Saving (first year) [€]	978
Investment [€]	8,000
Simple Payback [years]	7.5
Avoided CO_2 emissions [ton/year]	3.57
Net Present Value [€]	19,019
Index of profit [%]	238 %
Internal Rate of Return [%]	12.18 %

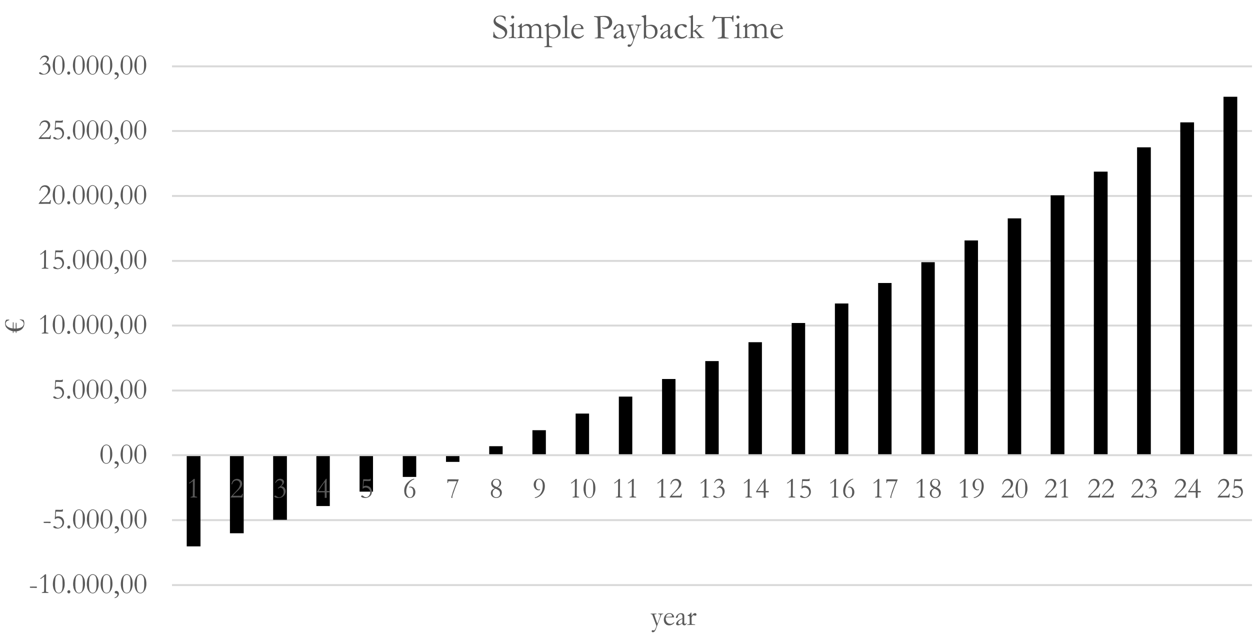


Figure 69: Simple payback time: heat pump regulation

8.3.5. MEASURES RECAP AND RESULTS

In the graph below, it is possible to see the complexity and simple payback time (SPB) of all measures; the size of the bubble indicates the investment cost. The lighting system substitution is the improvement with the lower complexity, cost and simple payback time, on the contrary, the insulation requires a higher investment cost, and it is more complex.

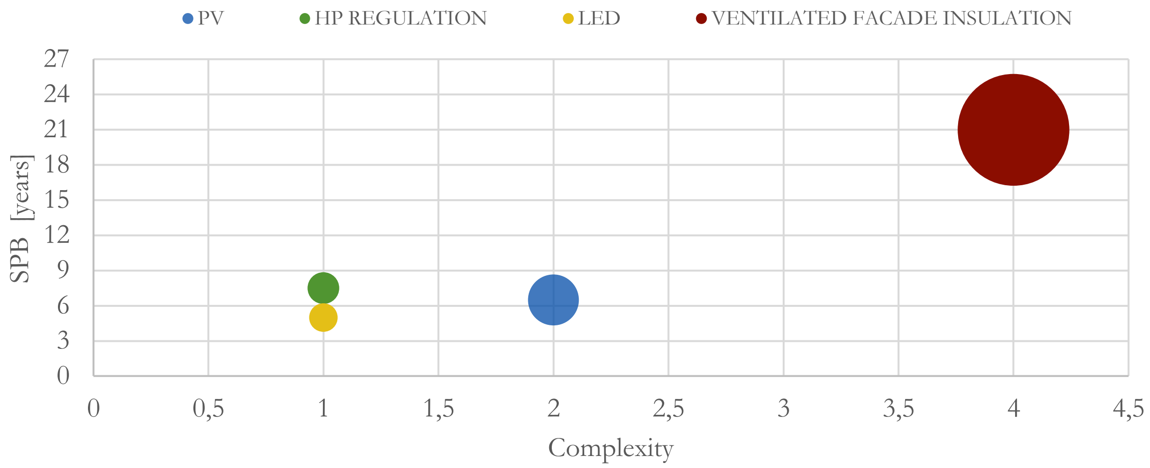


Figure 70: Complexity, simple payback time and investment cost of energy efficiency improvements

In the table below, costs of all considered energy efficiency measures are shown, they are divided into materials, installation, masonry work and technical costs. The main cost is represented by insulation of walls, in particular, by its installation and masonry work, significantly higher than material costs. On the contrary, the photovoltaic plant needs more effort in materials rather than in the other items.
From the point of view of energy, thanks to these improvements it is possible to reduce the electricity consumption of offices from 65 MWh to 53 MWh and the thermal energy consumption from 89.6 MWh to 15.4 MWh. The highest electric saving is achieved by a photovoltaic plant. Even if the heat pump control requires a higher use of electricity, it permits to save almost 36 MWh of thermal energy. The total reduction of emissions of CO_2 is almost 20 t/year.

Table 63: Costs of energy efficiency improvements: materials, installation, masonry work, technical costs

ENERGY EFFICIENCY MEASURES	MATERIALS	INSTALLATION	MASONRY WORK	TECHNICAL COSTS	TOTAL
	€	€	€	€	€
Led	4,100	2,300	/	/	6,400
Insulation	18,730	47,358	29,850	3,000	98,938
Heat pump regolation	4,000	4,000	/	/	8,000
Photovoltaic	13,580	4,500	1,000	1,500	20,580
Total	33,822	58,158	30,850	4,500	127,330

Table 64: Energy saving and emission reduction achieved by energy efficiency improvements

TABLE OF GLOBAL RESULTS	ANTE	ENERGY SAVING (MWH)				POST
		LED	Photovoltaic	Heat pump control	Insulation	
Electricity consumed (MWh)	64.92	4.47	12.04	-8.08	3.30	53.18
Thermal energy consumed (MWh)	89.60			35.91	38.27	15.42
Emissions (t CO_2 eq/year) - Electric	28.12	1.94	5.22	-3.50	1.43	23.04
Emissions (t CO_2 eq/year) - Thermic	17.64	0.00	0.00	7.07	7.54	3.04
Emissions (t CO_2 eq/year) - Total	45.76	1.94	5.22	3.57	8.96	26.08

After the end of works, the energy performance indicator for thermal energy is reduced to 20.6 kWh/m², the EnPI for cooling to 11.7 kWh/m² and for lighting to 12 kWh/m².

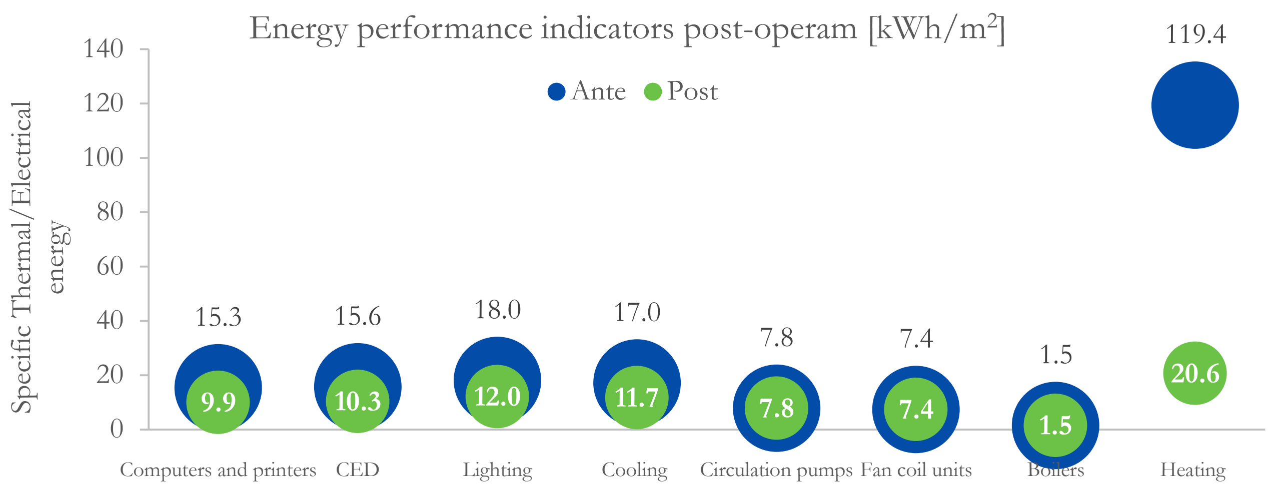


Figure 71: Energy efficiency improvements

Figure 72: 3i offices after renovation

CHAPTER 9

Conclusion

9.CONCLUSION

9.1. PARAMETRIC MULTI-OBJECTIVE ENERGY AND COST ANALYSIS IN THE LIFE CYCLE OF NEARLY ZERO-ENERGY BUILDINGS

Determining the best global solutions for nZEB design variables, in terms of energy, environmental and cost performance, is not an easy task, mainly because the variables affect each other through processes that are often not linear, and the optimisation goal of each variable can change significantly based on the optimisation goal and the importance of the key performance indicators (financing costs, net present value, primary energy demand, CO_2 emissions).

From the parametric calculation and the analysis of the five CRAVEzero case studies Aspern IQ, Alizari, Isola Verde, Les Heliades and MORE, some conclusions can be drawn, which are summarized below:

- The financing costs between the case studies are very different and range between about 1,200 EUR/m² and about 3,500 EUR/m².
- Within the individual case studies, the divergence between the highest and the lowest financing cost lies between 7 % and 16 %.
- The net present values range between 1,500 EUR/m² as the lowest value (case study Alizari) and more than 5,600 EUR/m² as the highest value (case study MORE).
- Within the case studies, the range between the highest and the lowest net present value is about 13-26 %.
- The balanced primary energy values range between 230 kWh/m²a and below zero (-22 kWh/m²a) which is a result of the variation of the climate and low heating demand in combination with high solar radiation.
- The reduction potential of the balanced primary energy demand ranges between 30 % and 85 %, in one case study (MORE) it is nearly 110 %.
- Similar reduction potentials can be achieved for the balanced CO_2 emissions (30-110 %), where the balanced CO_2 emissions range between 50 kg_{CO2}/m^2a and -5 kg_{CO2}/m^2a.

Summarizing these values it can be said, that very low primary energy and CO_2 emission values can be achieved with only slightly higher financing and life cycle costs.

Looking at the case study-specific results in detail the following summary is possible:

- Possible cost reductions, if each phase of the building life cycle is considered separately range between 6 % and 52 % per phase, the average reduction is 32 % per phase
- Possible cost reductions, if the minimum and maximum net present value is the starting point for the considerations, range between 4 % to 24 % per phase; the average reduction is 17 % per phase

In both cases, the higher reduction potential is given in the stages of consumption and operation (energy and maintenance costs) as well as for the phase of the replacement investment. The lowest reduction potential is given in the planning stage.

A detailed look at the average costs and average CO_2 emissions per investigated parameter shows that different parameters achieve the best investment cost to life cycle cost ratio. Nevertheless the parameters "district heating", "building envelope according to the national standard" and "no PV" is involved twice. Also the lowest average CO_2 emissions can be achieved by different parameters, but the trend is moving in the direction of “district heating” and “eff user behaviour”. This means that these two parameters are more often among the parameters with the lowest average CO_2 emissions.

Finally, also an indication of the most influencing factors (parameters) can be drawn:

- financing costs: heating, envelope, ventilation
- net present value: heating, ventilation
- PE balanced: heating, user behaviour
- CO_2 balanced: heating, user behaviour

If the climate was also varied, it could be seen that the climate has a noticeable influence on the results, especially on the net present value, the balanced primary energy demand and the balanced CO_2 emissions.

9.2. LCC SENSITIVITY ANALYSIS OF CRAVEZERO CASE STUDIES

In this Deliverable, the sensitivity analysis was extended to all available case studies, on the one hand aiming at identifying which input parameters affect the LCC the most and on the other hand aiming at providing this output as a range of values and not as a punctual one. In this way, the implications of uncertainty issues related to the assumptions on input parameters and boundary conditions can be highlighted.
Both methods showed comparable results and thus, can be considered complementary. The differential SA is the most straightforward methodology but only allows inspecting the effect on the output of single factors. The elementary effects method instead, gives an overview of the interactions among parameters.
In the elementary effects method the input factors, which have by far the strongest influence on the LCC output, are inflation energy cost and interest rate, whereas these factors showed a medium sensitivity index in the DSA. Concerning % maintenance cost, electricity cost and structural elements, these are still identified as relevant parameters by both methodologies. It is possible to state that the inflation of energy cost does not have the highest impact when considered alone (DSA); however, its stronger effect on the LCC output appears when combined with the variation of other parameters, in particular with the variation of electricity cost (parameter on which the inflation acts). The same conclusion can be carried out for the interest rate. Furthermore, the relevance of maintenance costs is confirmed by this SA. In fact, one of the objectives of CRAVEzero design approach is to allow reducing the maintenance cost for the envelope by combining optimal solution sets and using prefabricated elements.

One of the major issues related to nZEB market uptake is the uncertainty, connected to the costs and to the relationship between nZEB design and costs. In fact, the price of the house and its location represent the main criteria for the choice of the property. In this regard, a relevant outcome is that SA allows reducing uncertainty since it permits to better understand the variability of LCC output depending on assumptions made on boundary conditions and cost of building features. It provides an indication in which range a real LCC value can fluctuate, it imposes careful choice of specific boundary conditions and gives an indication on identifying the cost reduction potential among the input parameters, focusing on those, which affect the LCC the most. This can benefit the parametric multi-objective analysis illustrated in this deliverable too, since the total number of analysed parameters can be cut down according to SA results. In this way, the simulation effort can be reduced.

The main findings are summarized as follows:

- DSA – input ± 10 %: “ % maintenance cost” and “structural elements” are the most influencing parameters in this analysis.
- DSA – real input data: “ % maintenance costs”, “interest rate” are parameters which affect the LCC the most, showing similar behaviour to the previous case.

- Elementary effects method – input ± 10 %: input parameter "interest rate" reaches the first position as most influencing parameter among boundary conditions. The parameters " % maintenance costs – construction" and "structural elements" show, within this analysis, again a leading role.
- Elementary effects method – real input data: Combining the effects of literature values with a wide range of variation results, in this case, in a dominant role of the parameters "interest rate" and "inflation energy cost".
- LCC values from the simulations performed with the elementary effects method between the 20° and the 80° percentile showed an average deviation of 2.8 % in the case of input ± 10 % and 11.7 % with real input data.
- Both methods showed comparable results and thus, can be considered complementary.
- A relevant outcome of the sensitivity analysis is that this analysis allows reducing uncertainty since it permits to better understand the variability of LCC output depending on assumptions made on boundary conditions and cost of building features.

9.3. LESSONS LEARNED - RENOVATION PROJECT: FROM ENERGY AUDIT TO ENERGY EFFICIENCY IMPROVEMENTS

The renovation of a building requires an in-depth study from the point of view of energy. The energy efficiency improvements permit to save money and energy, but sometimes they require a high investment cost and are too complicated. Therefore, it is essential to analyse the building and its energy consumption in order to identify unusual situations and to understand the most sensitive zones for improvements.
This chapter presents the example of the renovation of offices of 3i Group in order to improve the comfort of workers, to reduce operative costs and to renovate the building. The steps described are:

- Energy audit: the analysis of bills, of the building structure and of the HVAC system permits to calculate energy performance indicators. The highest EnPI is represented by lighting and cooling; it means that the measures should reduce the energy consumption of these consumers;
- Energy efficiency improvements: the measures considered are a photovoltaic plant, wall insulation, LED lighting and heat pump control. They are evaluated from energetic, environmental and economic point of view, in order to choose the best solution. In particular, energy saving, reduction of emission of equivalent tons of CO_2 and economic parameters like simple payback, NPV, IP and IRR are calculated;
- For each measure, complexity, investment cost and simple payback time are defined. The lighting substitution is the improvement with the lowest parameters. Instead, the insulation requires a higher investment cost and is more complicated;
- Costs analysis: the total cost is divided into materials, installation, masonry work and technical costs. It is possible to observe how the expenditure for the four energy efficiency measures is divided;
- Energy and CO_2 saving: energy consumption is calculated before and after the improvements. It is possible to calculate the reduction of consumption of electricity and thermal energy and of emissions for each energy efficiency measure. The PV plant shows the highest electricity decrease; on the other side, even if the heat pump operation (use of heat pump instead of gas boiler) requires more electricity, it causes an important reduction of thermal energy consumed by the building.
- Finally, the energy performance indicators post operam are recalculated, in order to evaluate the effectiveness of the energy efficiency improvements and to observe the reduction of consumption of each utility of the building.

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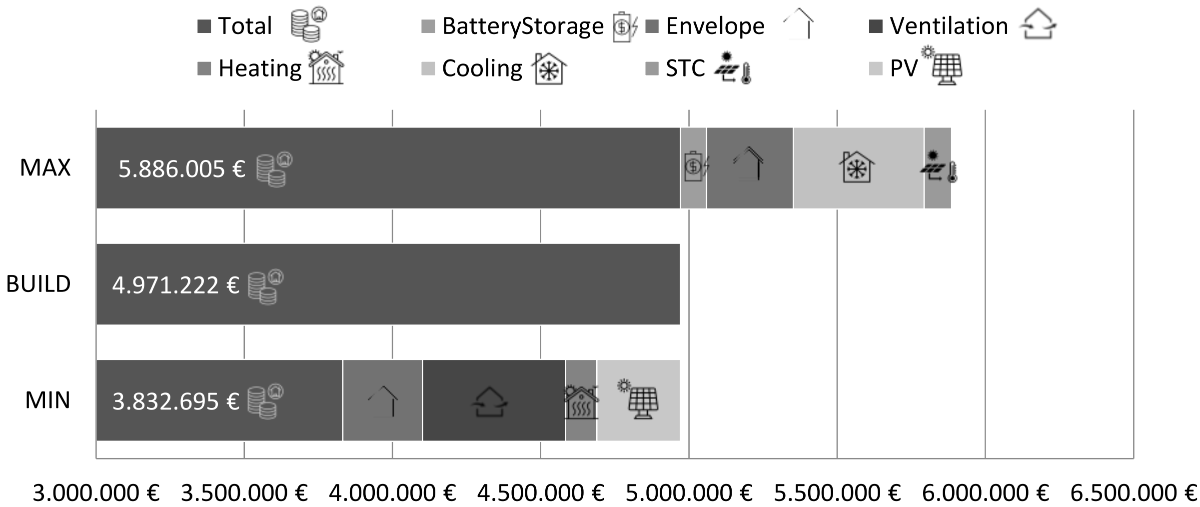
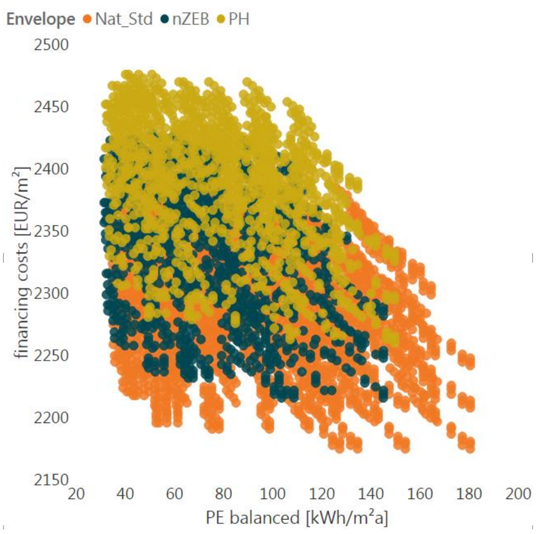
11. APPENDIX

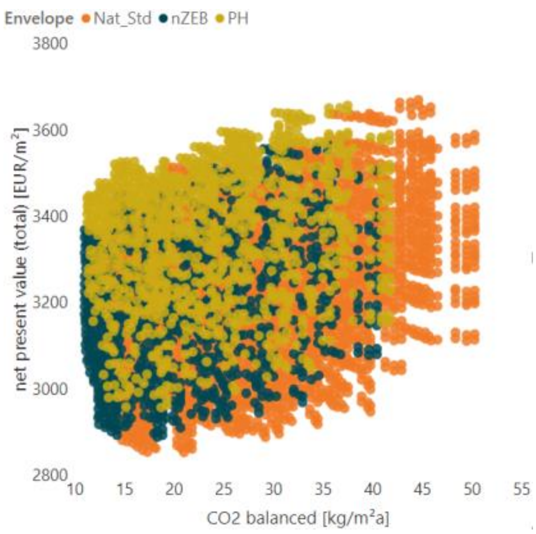
11.1. ASPERN IQ

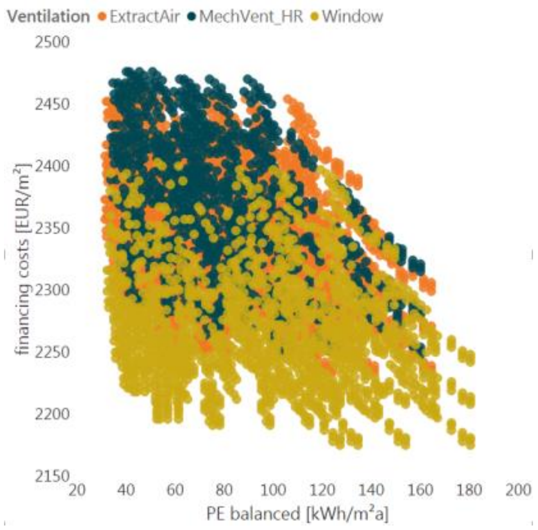
11.1.1. OVERVIEW FINANCING COSTS

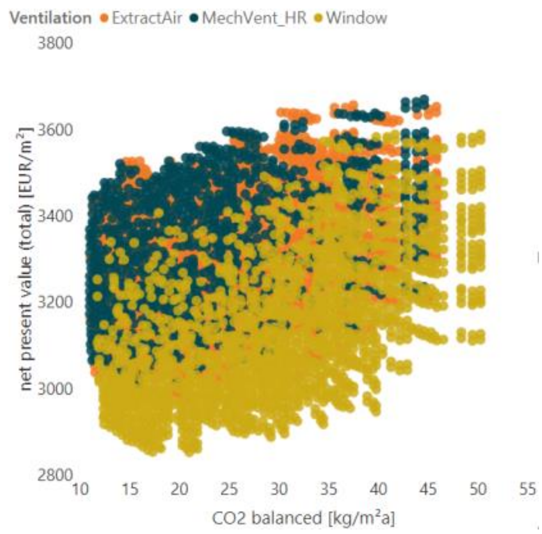


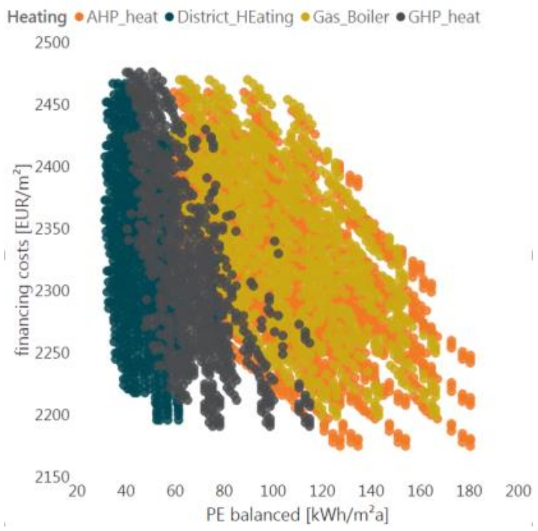
11.1.2. COMBINING ENERGY AND COST EFFICIENCY

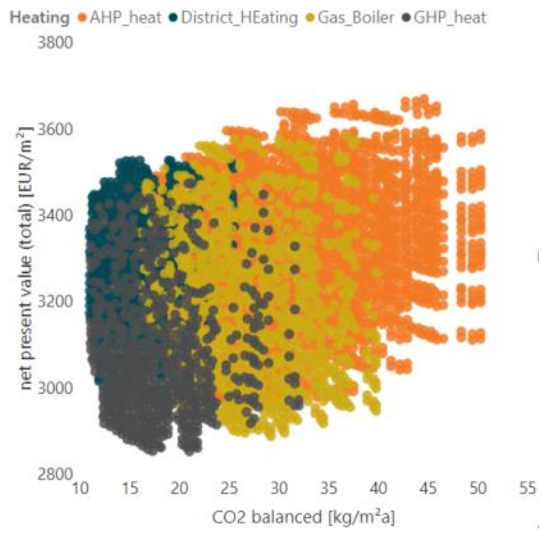


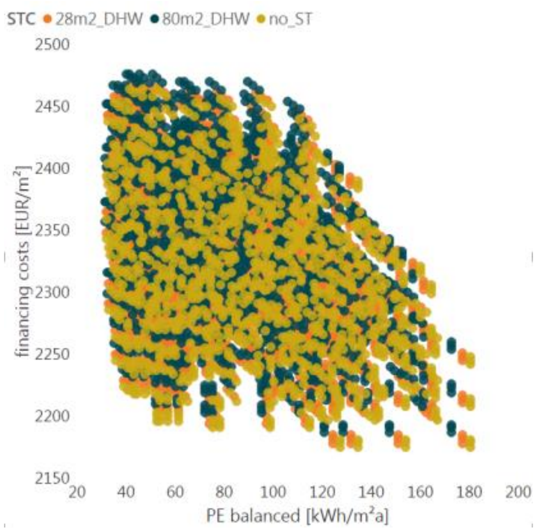


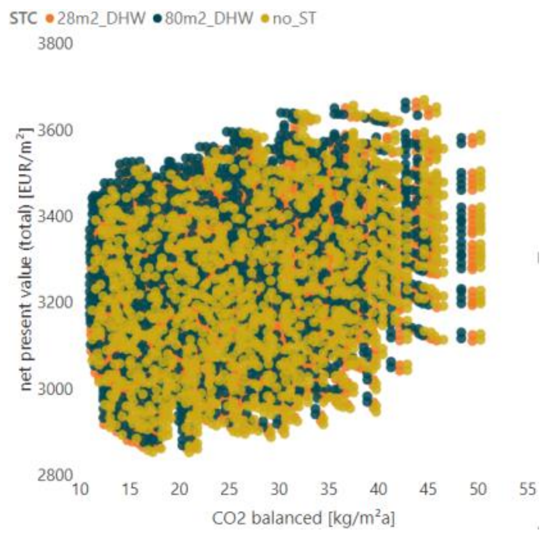

Ventilation ExtractAir MechVent_HR Window
2500
2450
2400
2350
2300
2250
2200
2150
financing costs [EUR/m²]
20 40 60 80 100 120 140 160 180 200
PE balanced [kWh/m²a]

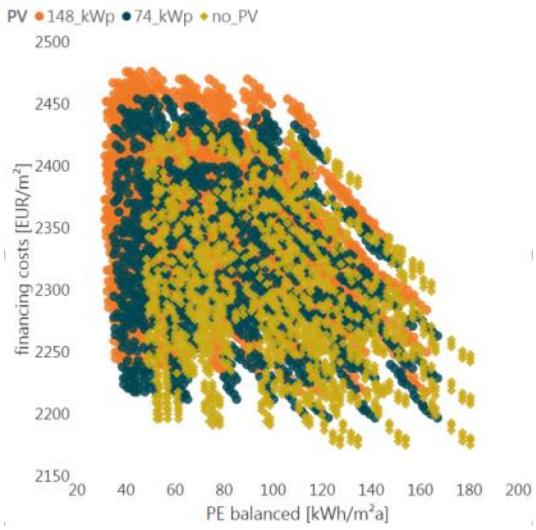

Ventilation ExtractAir MechVent_HR Window
3800
3600
3400
3200
3000
2800
net present value (total) [EUR/m²]
10 15 20 25 30 35 40 45 50 55
CO2 balanced [kg/m²a]

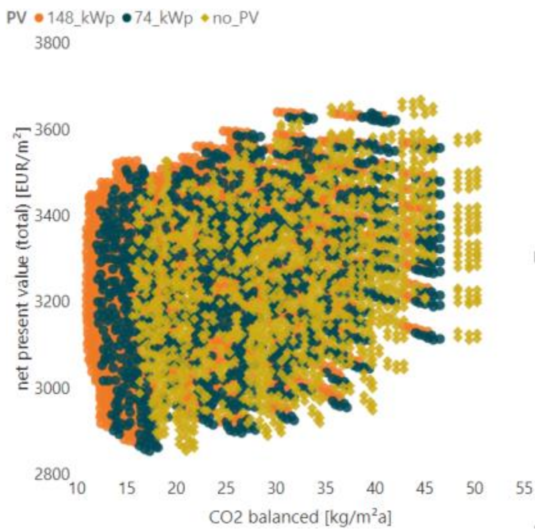

Heating AHP_heat District_HEating Gas_Boiler GHP_heat
2500
2450
2400
2350
2300
2250
2200
2150
financing costs [EUR/m²]
20 40 60 80 100 120 140 160 180 200
PE balanced [kWh/m²a]

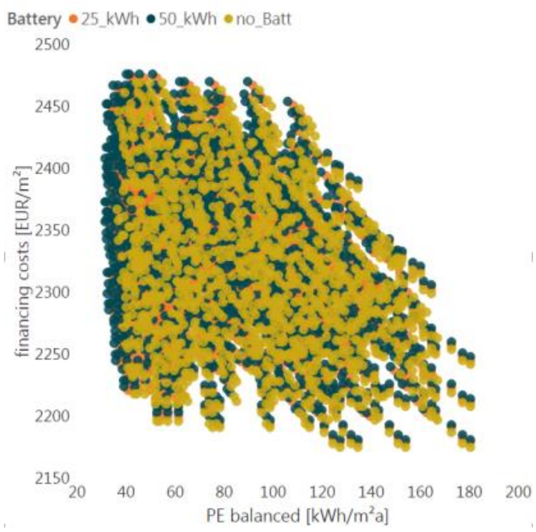

Heating AHP_heat District_HEating Gas_Boiler GHP_heat
3800
3600
3400
3200
3000
2800
net present value (total) [EUR/m²]
10 15 20 25 30 35 40 45 50 55
CO2 balanced [kg/m²a]

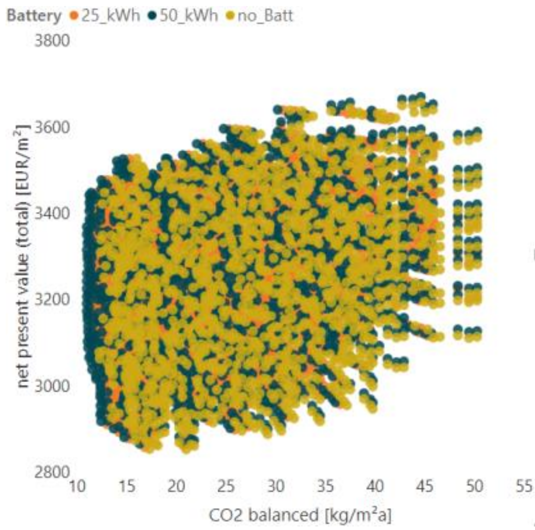

STC 28m2_DHW 80m2_DHW no_ST
2500
2450
2400
2350
2300
2250
2200
2150
financing costs [EUR/m²]
20 40 60 80 100 120 140 160 180 200
PE balanced [kWh/m²a]

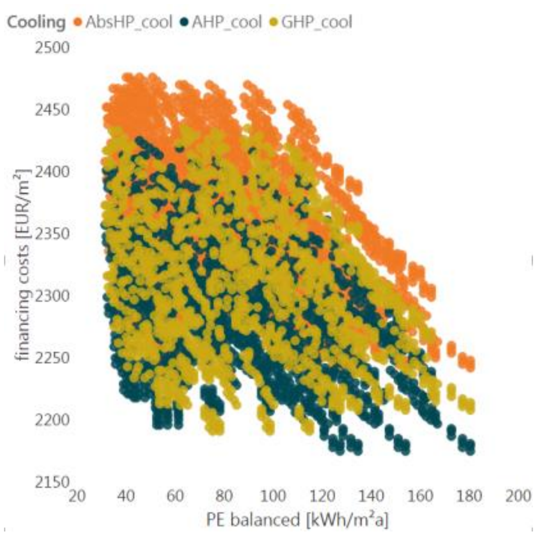

STC 28m2_DHW 80m2_DHW no_ST
3800
3600
3400
3200
3000
2800
net present value (total) [EUR/m²]
10 15 20 25 30 35 40 45 50 55
CO2 balanced [kg/m²a]

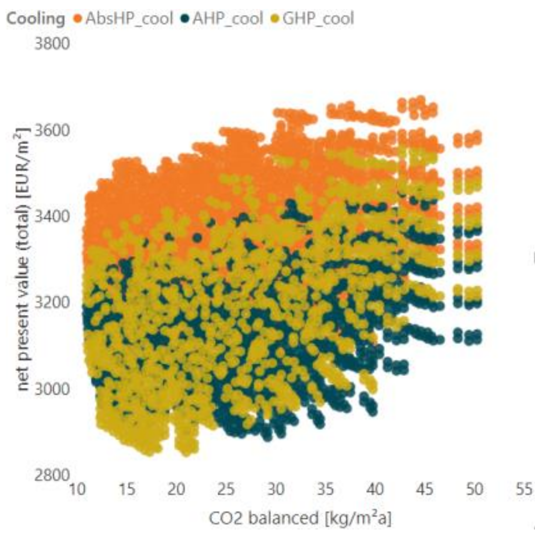

PV 148_kWp 74_kWp no_PV
financing costs [EUR/m²]
2500
2450
2400
2350
2300
2250
2200
2150
20 40 60 80 100 120 140 160 180 200
PE balanced [kWh/m²a]

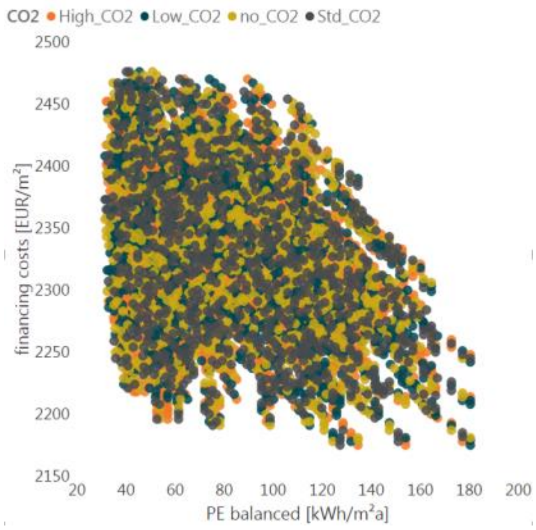

PV 148_kWp 74_kWp no_PV
net present value (total) [EUR/m²]
3800
3600
3400
3200
3000
2800
10 15 20 25 30 35 40 45 50 55
CO2 balanced [kg/m²a]

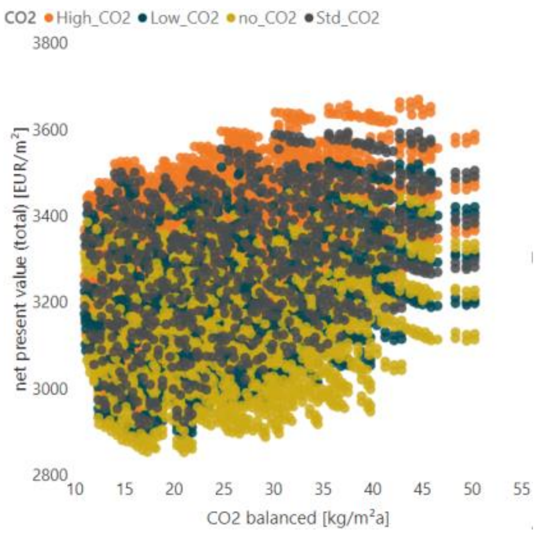

Battery 25_kWh 50_kWh no_Batt
financing costs [EUR/m²]
2500
2450
2400
2350
2300
2250
2200
2150
20 40 60 80 100 120 140 160 180 200
PE balanced [kWh/m²a]

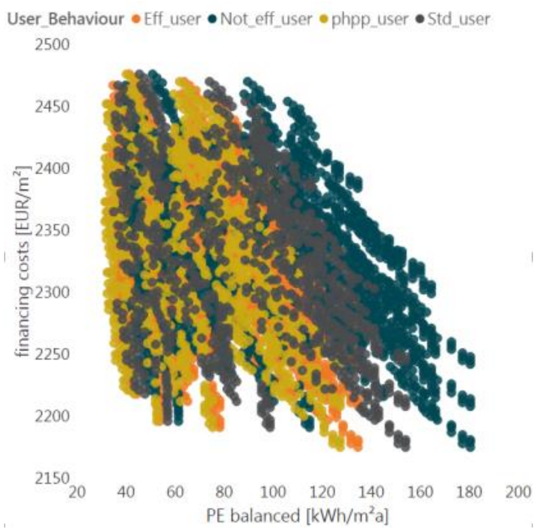

Battery 25_kWh 50_kWh no_Batt
net present value (total) [EUR/m²]
3800
3600
3400
3200
3000
2800
10 15 20 25 30 35 40 45 50 55
CO2 balanced [kg/m²a]

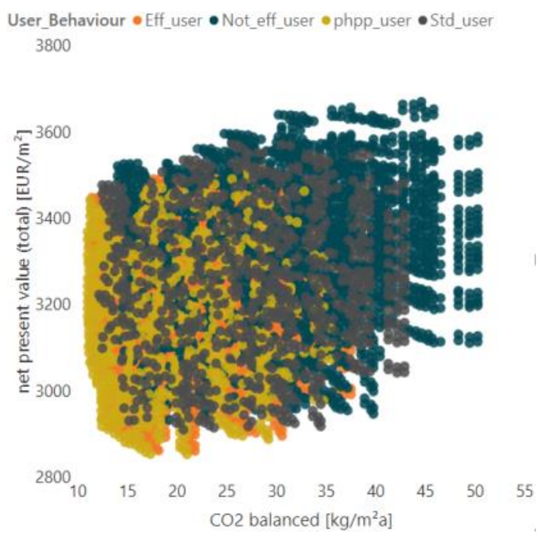

Cooling AbsHP_cool AHP_cool GHP_cool
financing costs [EUR/m²]
2500
2450
2400
2350
2300
2250
2200
2150
20 40 60 80 100 120 140 160 180 200
PE balanced [kWh/m²a]


Cooling AbsHP_cool AHP_cool GHP_cool
net present value (total) [EUR/m²]
3800
3600
3400
3200
3000
2800
10 15 20 25 30 35 40 45 50 55
CO2 balanced [kg/m²a]

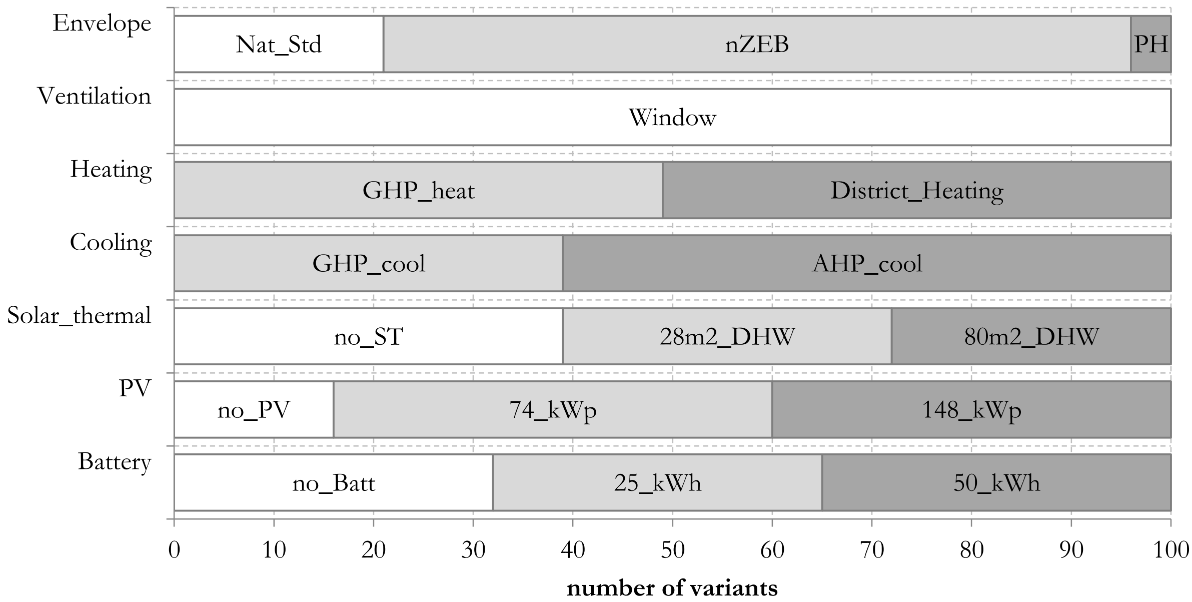

CO2 ● High_CO2 ● Low_CO2 ● no_CO2 ● Std_CO2
financing costs [EUR/m²]
PE balanced [kWh/m²a]


CO2 ● High_CO2 ● Low_CO2 ● no_CO2 ● Std_CO2
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

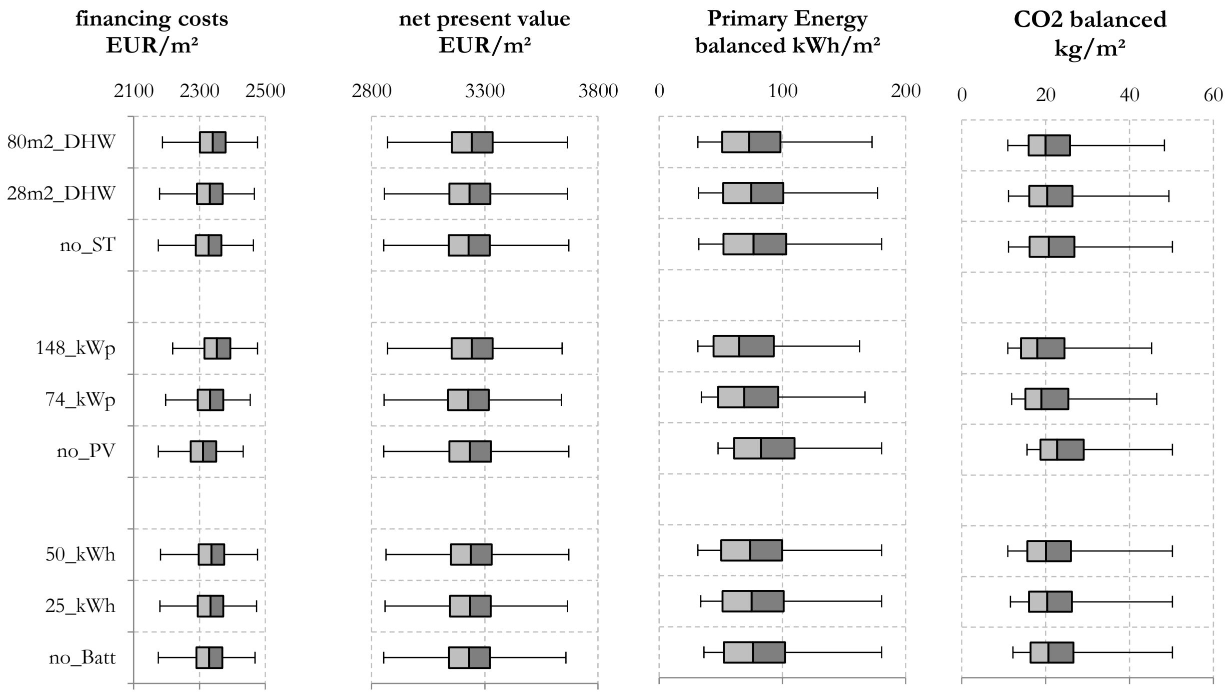

User_Behaviour ● Eff_user ● Not_eff_user ● phpp_user ● Std_user
financing costs [EUR/m²]
PE balanced [kWh/m²a]

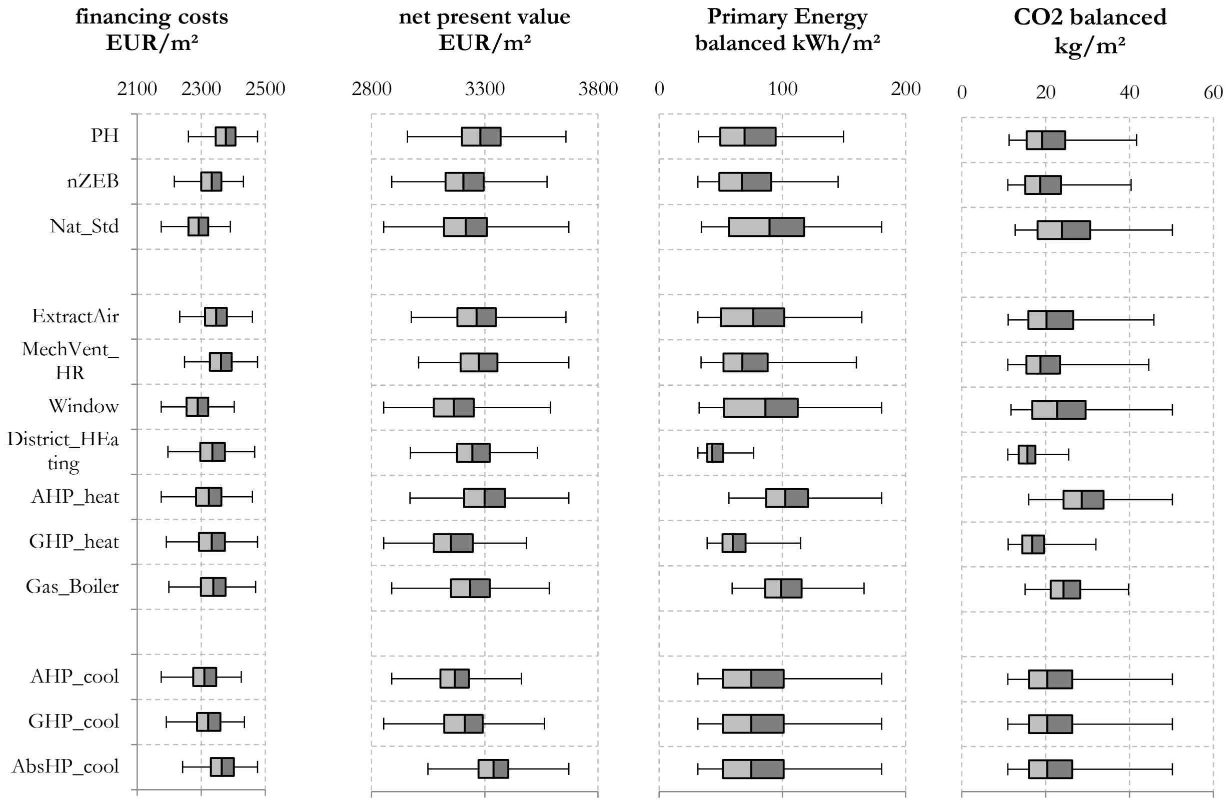

User_Behaviour ● Eff_user ● Not_eff_user ● phpp_user ● Std_user
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

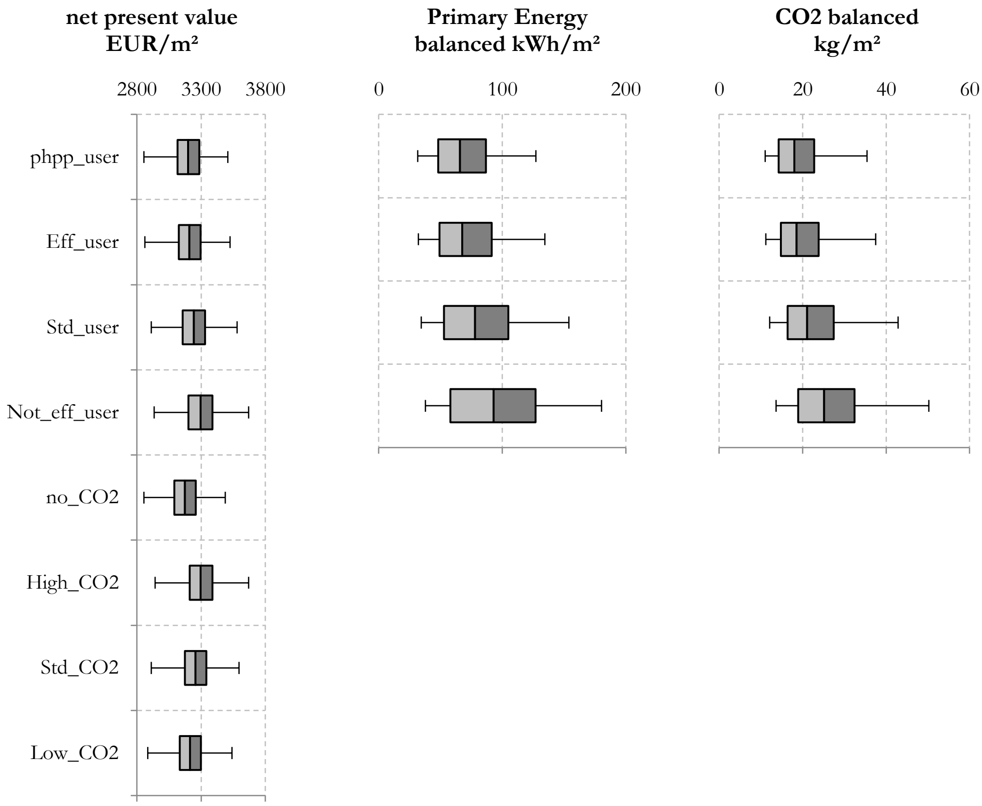
11.1.3. TOP100 EVALUATION



11.1.4. BOXPLOTS




financing costs EUR/m²
net present value EUR/m²
Primary Energy balanced kWh/m²
CO2 balanced kg/m²
2100 2300 2500
2800 3300 3800
0 100 200
0 20 40 60
PH
nZEB
Nat_Std
ExtractAir
MechVent_HR
Window
District_HEating
AHP_heat
GHP_heat
Gas_Boiler
AHP_cool
GHP_cool
AbsHP_cool


net present value EUR/m²
Primary Energy balanced kWh/m²
CO2 balanced kg/m²
2800 3300 3800
0 100 200
0 20 40 60
phpp_user
Eff_user
Std_user
Not_eff_user
no_CO2
High_CO2
Std_CO2
Low_CO2

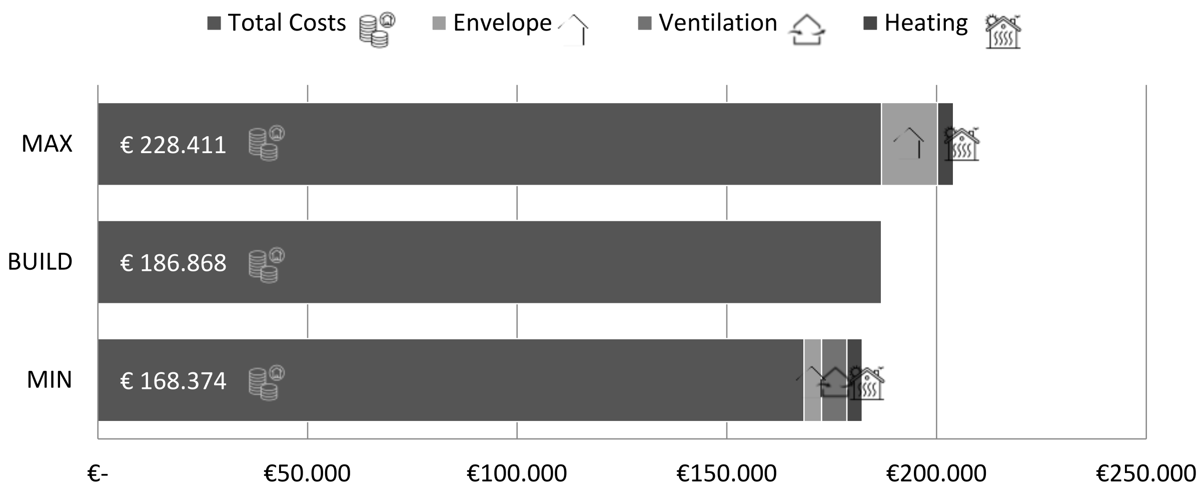
11.1.5. DATA FROM THE BOXPLOTS

		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
Low CO2 costs	minimum	2175	2884	31	11
	median	2333	3214	75	20
	maximum	2476	3540	180	50
	standard deviation	56	117	31	7
standard CO2 costs	minimum	2175	2913	31	11
	median	2333	3255	75	20
	maximum	2476	3596	180	50
	standard deviation	56	120	31	7
High CO2 costs	minimum	2175	2942	31	11
	median	2333	3297	75	20
	maximum	2476	3671	180	50
	standard deviation	56	126	31	7
No CO2 costs	minimum	2175	2854	31	11
	median	2333	3173	75	20
	maximum	2476	3489	180	50
	standard deviation	56	117	31	7
Not efficient user behaviour	minimum	2175	2934	38	14
	median	2333	3296	93	25
	maximum	2476	3671	180	50
	standard deviation	56	133	38	9
Standard user behaviour	minimum	2175	2911	34	12
	median	2333	3244	78	21
	maximum	2476	3581	154	43
	standard deviation	56	123	30	7
Efficient user behaviour	minimum	2175	2862	32	11
	median	2333	3208	68	19
	maximum	2476	3525	135	38
	standard deviation	56	119	25	6
PHPP default user behaviour	minimum	2175	2854	31	11
	median	2333	3198	66	18
	maximum	2476	3507	127	35
	standard deviation	56	119	24	5
No battery storage	minimum	2175	2854	36	12
	median	2329	3231	76	21
	maximum	2469	3658	180	50
	standard deviation	56	129	31	7
25 kWh battery storage	minimum	2179	2859	34	12
	median	2333	3235	75	20
	maximum	2473	3665	180	50
	standard deviation	56	129	31	7
50 kWh battery storage	minimum	2181	2864	31	11
	median	2336	3238	74	20
	maximum	2476	3671	180	50
	standard deviation	56	129	32	7
No PV	minimum	2175	2854	48	16
	median	2311	3234	83	23
	maximum	2433	3671	180	50
	standard deviation	53	131	31	7
74 kWp PV	minimum	2197	2855	34	12
	median	2332	3227	69	19
	maximum	2454	3639	167	47
	standard deviation	53	128	31	7
148 kWp PV	minimum	2218	2871	31	11
	median	2353	3243	65	18
	maximum	2476	3641	163	45
	standard deviation	53	128	30	7
No solar thermal	minimum	2175	2854	32	11
	median	2327	3228	77	21
	maximum	2464	3671	180	50
	standard deviation	56	130	32	8
28 m² solar thermal	minimum	2178	2857	32	11
	median	2331	3233	75	20

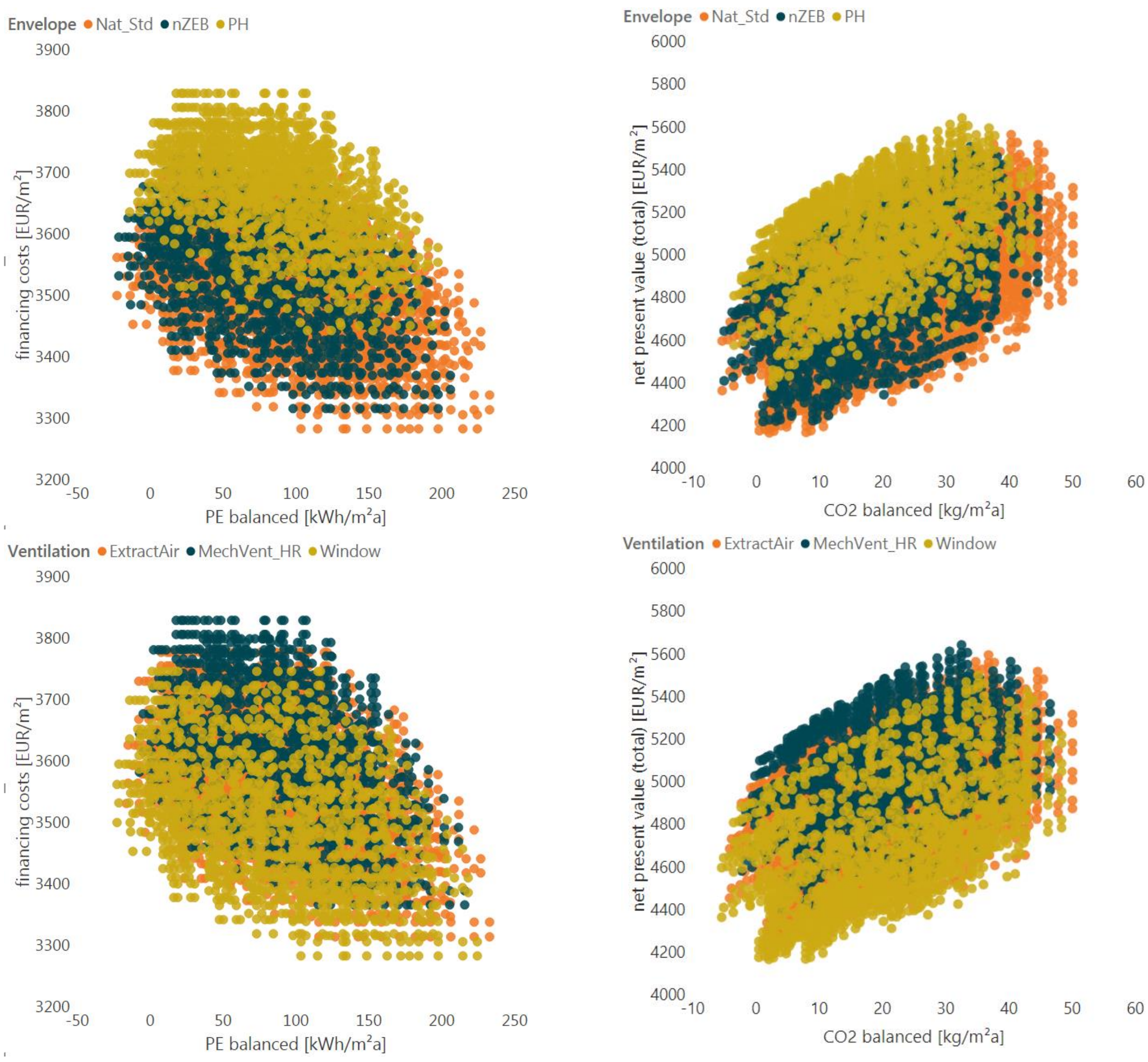
		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	maximum	2467	3665	177	49
	standard deviation	56	129	32	7
80 m² solar thermal	minimum	2187	2870	31	11
	median	2340	3243	73	20
	maximum	2476	3665	173	48
	standard deviation	56	128	30	7
absorption heat pump cooling	minimum	2242	3049	31	11
	median	2364	3338	75	20
	maximum	2476	3671	180	50
	standard deviation	50	100	31	7
Ground source heat pump	minimum	2191	2854	31	11
	median	2322	3211	75	20
	maximum	2435	3563	180	50
	standard deviation	51	122	31	7
Air source heat pump	minimum	2175	2889	31	11
	median	2310	3168	75	20
	maximum	2425	3462	180	50
	standard deviation	52	94	31	7
Gas boiler heating	minimum	2199	2889	59	15
	median	2338	3236	99	24
	maximum	2470	3585	166	40
	standard deviation	54	123	22	5
ground source heat pump	minimum	2191	2854	39	11
	median	2333	3151	60	17
	maximum	2476	3484	115	32
	standard deviation	58	121	14	4
Air source heat pump	minimum	2175	2969	56	16
	median	2324	3299	102	29
	maximum	2460	3671	180	50
	standard deviation	57	126	25	7
district heating	minimum	2196	2971	31	11
	median	2335	3245	43	16
	maximum	2467	3533	77	25
	standard deviation	54	103	8	3
window ventilation	minimum	2175	2854	32	12
	median	2289	3163	86	23
	maximum	2403	3590	180	50
	standard deviation	47	126	35	8
mechanical ventilation with heat recovery	minimum	2248	3007	34	11
	median	2362	3273	67	19
	maximum	2476	3671	160	45
	standard deviation	47	111	26	6
Extract air ventilation	minimum	2233	2975	31	11
	median	2347	3264	76	20
	maximum	2460	3658	165	46
	standard deviation	47	119	31	7
national standard envelope	minimum	2175	2854	34	13
	median	2292	3215	90	24
	maximum	2391	3671	180	50
	standard deviation	44	136	36	8
nZEB envelope	minimum	2216	2889	31	11
	median	2333	3205	67	19
	maximum	2432	3575	145	40
	standard deviation	44	118	26	6
passive house envelope	minimum	2260	2958	32	11
	median	2377	3280	69	19
	maximum	2476	3658	150	42
	standard deviation	44	120	28	6

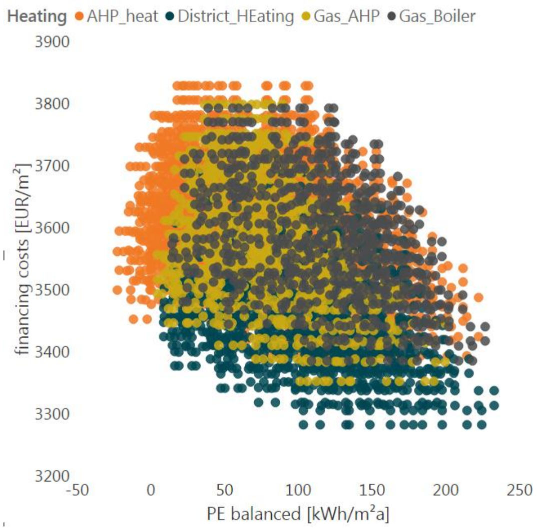
11.2. MORE

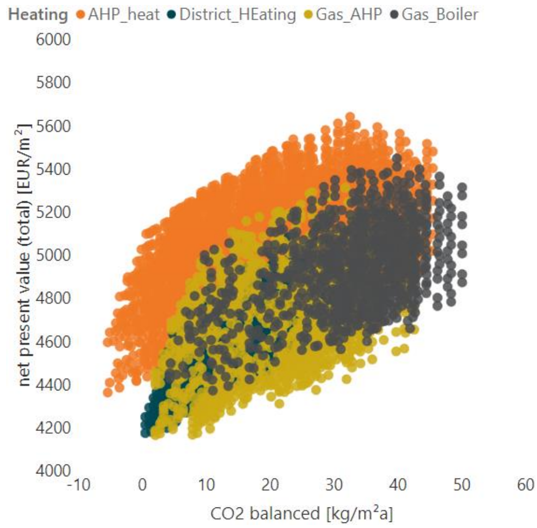
11.2.1. OVERVIEW FINANCING COSTS

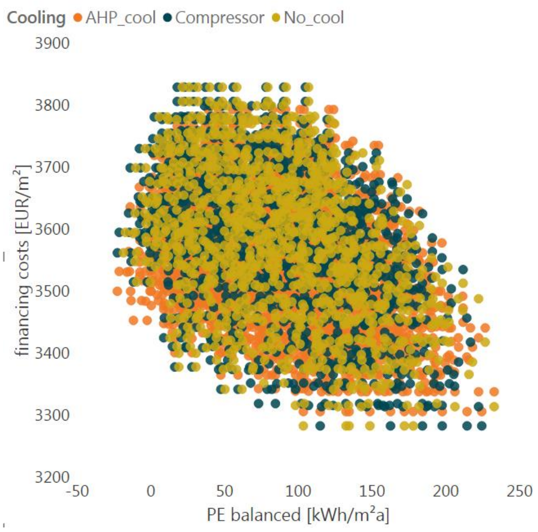


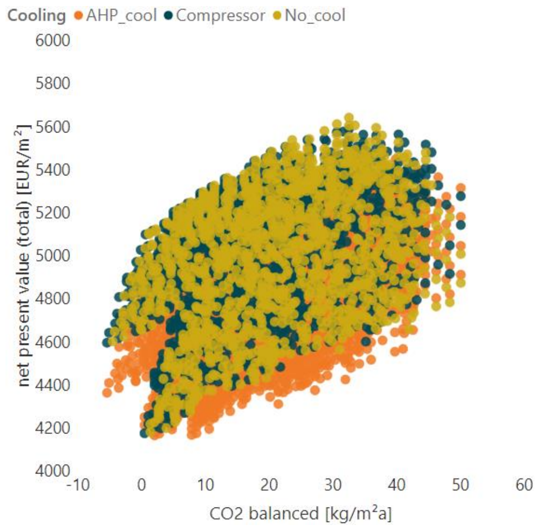
11.2.2. COMBINING ENERGY AND COST EFFICIENCY

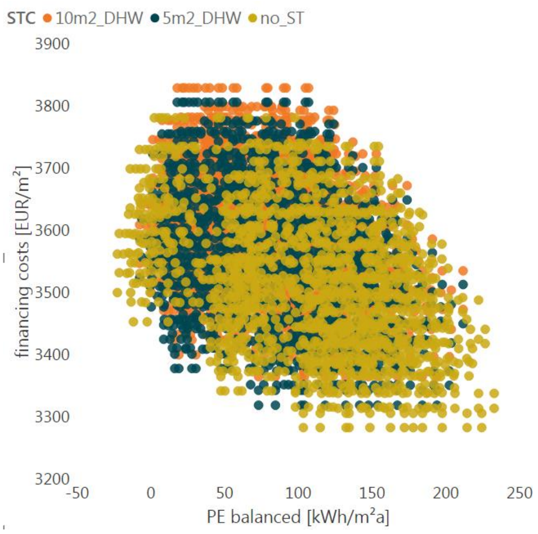


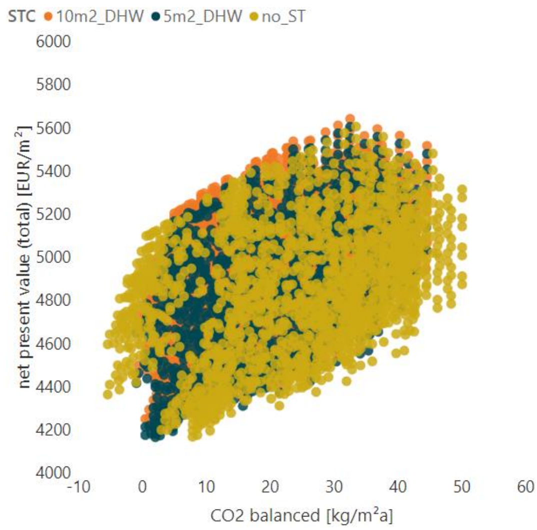

Heating ● AHP_heat ● District_HEating ● Gas_AHP ● Gas_Boiler
financing costs [EUR/m²]
PE balanced [kWh/m²a]

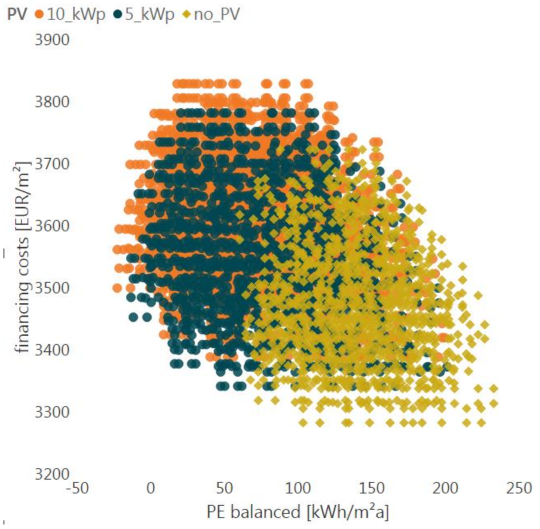

Heating ● AHP_heat ● District_HEating ● Gas_AHP ● Gas_Boiler
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

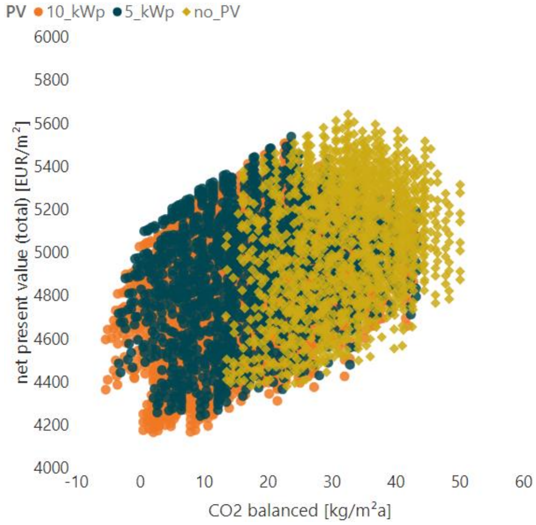

Cooling ● AHP_cool ● Compressor ● No_cool
financing costs [EUR/m²]
PE balanced [kWh/m²a]

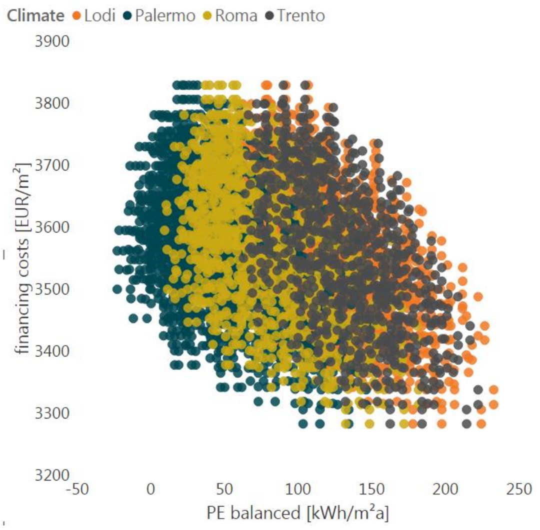

Cooling ● AHP_cool ● Compressor ● No_cool
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

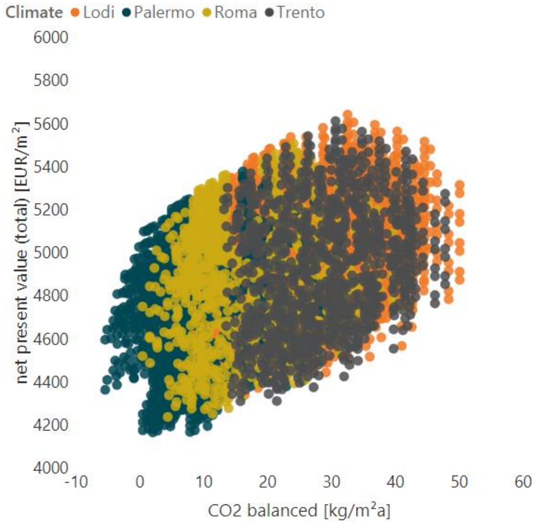

STC ● 10m2_DHW ● 5m2_DHW ● no_ST
financing costs [EUR/m²]
PE balanced [kWh/m²a]

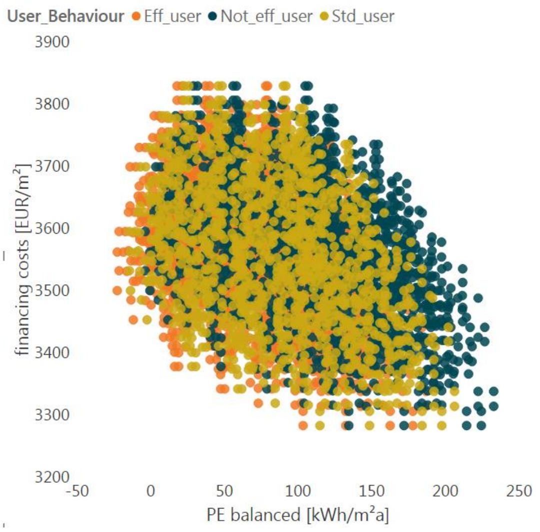

STC ● 10m2_DHW ● 5m2_DHW ● no_ST
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

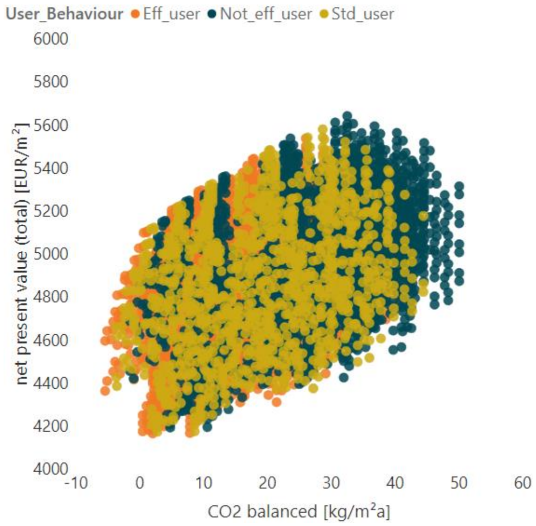

PV ● 10_kWp ● 5_kWp ◆ no_PV
financing costs [EUR/m²]
3900
3800
3700
3600
3500
3400
3300
3200
-50 0 50 100 150 200 250
PE balanced [kWh/m²a]


PV ● 10_kWp ● 5_kWp ◆ no_PV
net present value (total) [EUR/m²]
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
-10 0 10 20 30 40 50 60
CO2 balanced [kg/m²a]

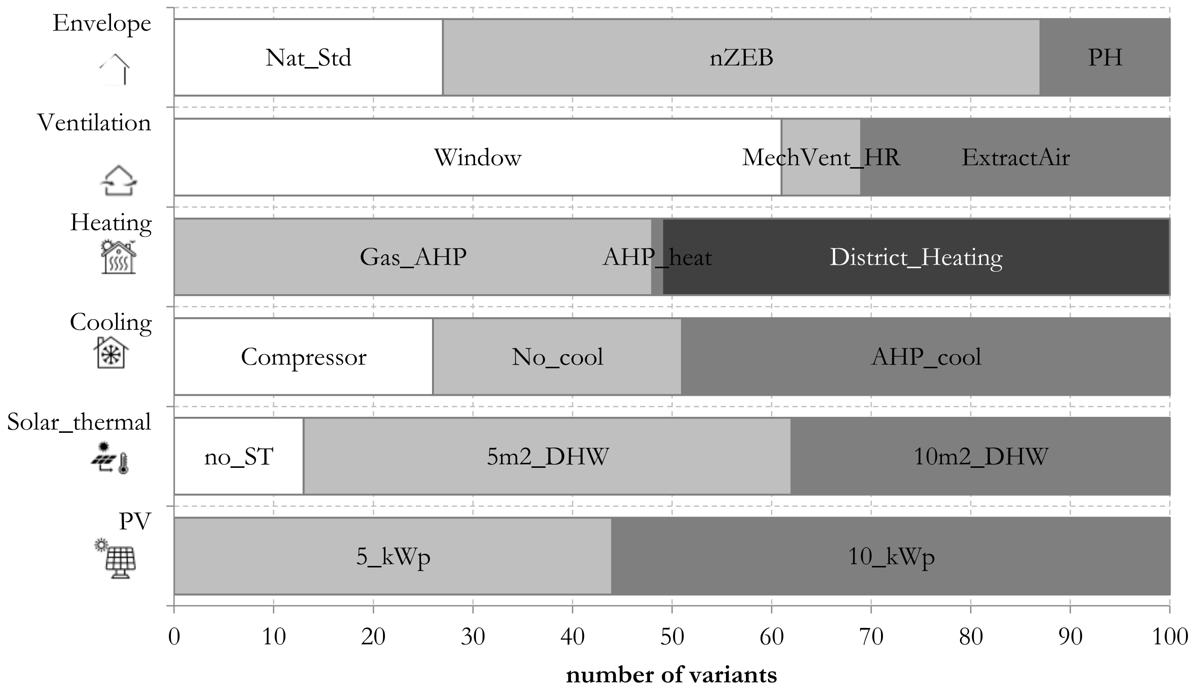

Climate ● Lodi ● Palermo ● Roma ● Trento
financing costs [EUR/m²]
3900
3800
3700
3600
3500
3400
3300
3200
-50 0 50 100 150 200 250
PE balanced [kWh/m²a]


Climate ● Lodi ● Palermo ● Roma ● Trento
net present value (total) [EUR/m²]
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
-10 0 10 20 30 40 50 60
CO2 balanced [kg/m²a]

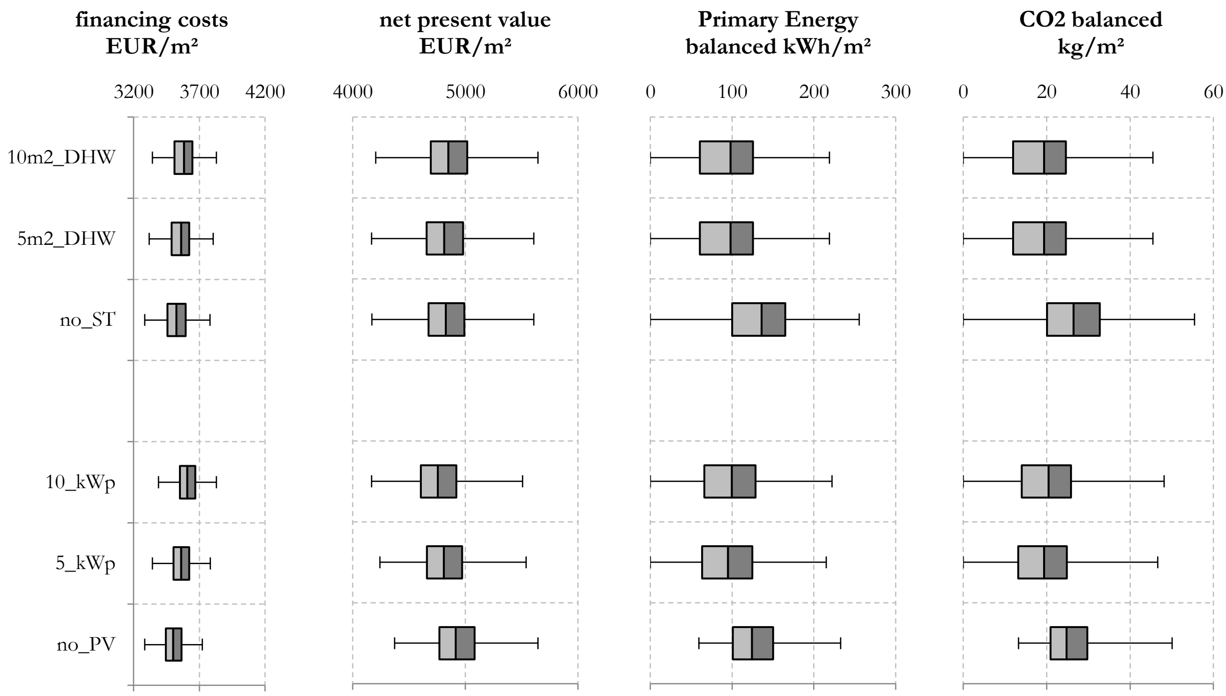

User_Behaviour ● Eff_user ● Not_eff_user ● Std_user
financing costs [EUR/m²]
3900
3800
3700
3600
3500
3400
3300
3200
-50 0 50 100 150 200 250
PE balanced [kWh/m²a]

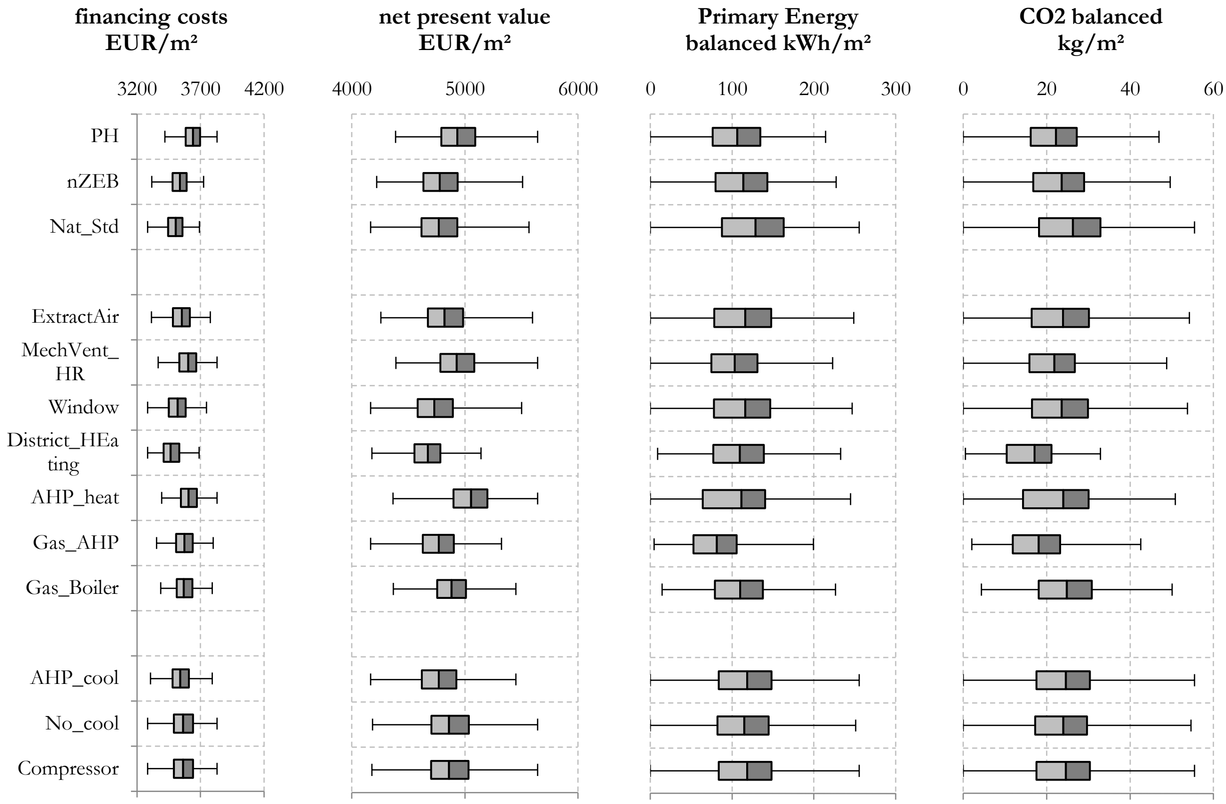

User_Behaviour ● Eff_user ● Not_eff_user ● Std_user
net present value (total) [EUR/m²]
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
-10 0 10 20 30 40 50 60
CO2 balanced [kg/m²a]

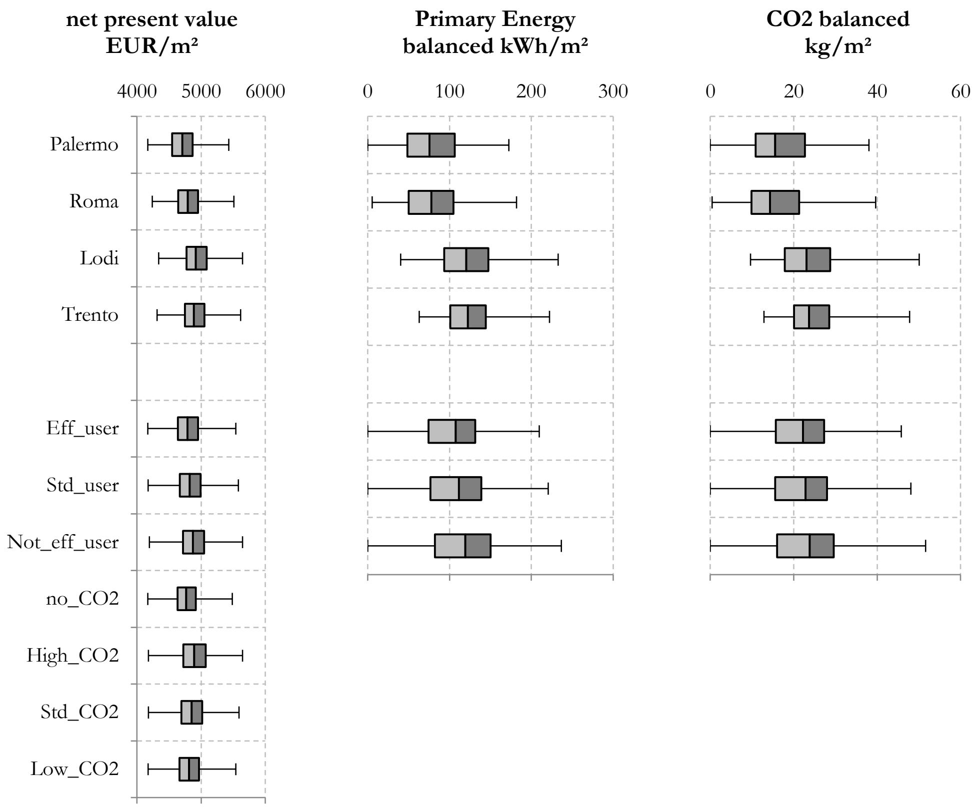
11.2.3. TOP100 EVALUATION



11.2.4. BOXPLOTS




financing costs EUR/m²
net present value EUR/m²
Primary Energy balanced kWh/m²
CO2 balanced kg/m²
3200
3700
4200
4000
5000
6000
0
100
200
300
0
20
40
60
PH
nZEB
Nat_Std
ExtractAir
MechVent_HR
Window
District_HEating
AHP_heat
Gas_AHP
Gas_Boiler
AHP_cool
No_cool
Compressor


net present value EUR/m²
Primary Energy balanced kWh/m²
CO2 balanced kg/m²
4000
5000
6000
0
100
200
300
0
20
40
60
Palermo
Roma
Lodi
Trento
Eff_user
Std_user
Not_eff_user
no_CO2
High_CO2
Std_CO2
Low_CO2

11.2.5. DATA FROM THE BOXPLOTS

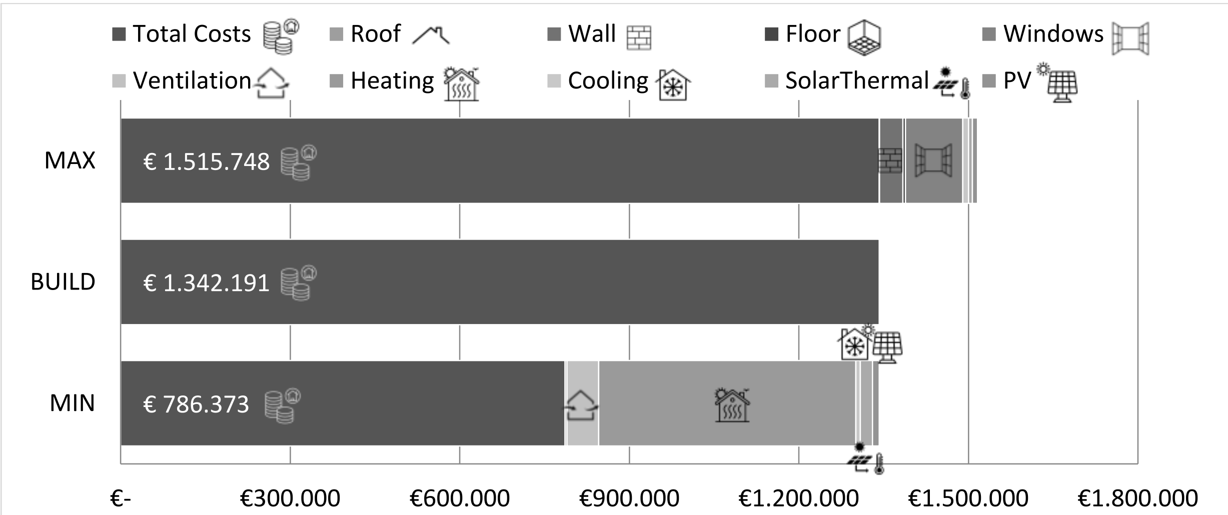
		financing costs (EUR/m²)	net present value (EUR/m²)	pE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
Low CO2 costs	minimum	3283	4175	-23	-5
	median	3559	4813	96	19
	maximum	3829	5539	233	50
	standard deviation	101	227	45	9
Standard CO2 costs	minimum	3283	4177	-23	-5
	median	3559	4854	96	19
	maximum	3829	5591	233	50
	standard deviation	101	236	45	9
High CO2 costs	minimum	3283	4177	-23	-5
	median	3559	4895	96	19
	maximum	3829	5644	233	50
	standard deviation	101	248	45	9
No CO2 costs	minimum	3283	4167	-23	-5
	median	3559	4768	96	19
	maximum	3829	5486	233	50
	standard deviation	101	220	45	9
Not efficient user behaviour	minimum	3283	4195	-4	-2
	median	3559	4874	115	22
	maximum	3829	5644	233	50
	standard deviation	101	239	47	10
Standard user behaviour	minimum	3283	4175	-14	-4
	median	3559	4822	97	19
	maximum	3829	5582	206	44
	standard deviation	101	234	43	9
Efficient user behaviour	minimum	3283	4167	-23	-5
	median	3559	4788	85	17
	maximum	3829	5540	187	40
	standard deviation	101	230	40	8
Trento	minimum	3283	4312	63	13
	median	3559	4889	122	24
	maximum	3829	5614	222	48
	standard deviation	101	217	31	6
Lodi	minimum	3283	4339	40	10
	median	3559	4917	120	23
	maximum	3829	5644	233	50
	standard deviation	101	221	37	8
Roma	minimum	3283	4239	6	0
	median	3559	4794	78	14
	maximum	3829	5509	182	40
	standard deviation	101	217	35	7
Palermo	minimum	3283	4167	-23	-5
	median	3559	4708	53	10
	maximum	3829	5429	150	33
	standard deviation	101	224	36	7
No PV	minimum	3283	4371	60	13
	median	3502	4916	124	25
	maximum	3723	5644	233	50
	standard deviation	91	223	33	7
5 kWp PV	minimum	3342	4242	-13	-3
	median	3561	4809	82	16
	maximum	3782	5540	202	43
	standard deviation	91	225	41	8
10 kWp PV	minimum	3389	4167	-23	-5
	median	3608	4756	77	15

		financing costs (EUR/m²)	net present value (EUR/m²)	pE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	maximum	3829	5510	200	43
	standard deviation	91	231	42	8
No solar thermal	minimum	3283	4169	-23	-5
	median	3526	4827	113	21
	maximum	3781	5608	233	50
	standard deviation	99	231	47	10
5 m² solar thermal	minimum	3319	4167	-8	-1
	median	3561	4811	91	19
	maximum	3806	5607	212	45
	standard deviation	97	239	42	9
10 m² solar thermal	minimum	3342	4204	-8	-1
	median	3583	4848	91	19
	maximum	3829	5644	212	45
	standard deviation	97	239	42	9
compressor cooling	minimum	3283	4177	-23	-5
	median	3564	4858	96	19
	maximum	3829	5644	233	50
	standard deviation	104	241	45	9
No cooling	minimum	3283	4183	-19	-5
	median	3564	4861	97	19
	maximum	3829	5644	233	50
	standard deviation	104	239	44	9
Air source heat pump cooling	minimum	3306	4167	-23	-5
	median	3540	4770	96	19
	maximum	3793	5451	233	50
	standard deviation	92	216	45	9
Gas boiler heating	minimum	3386	4366	14	4
	median	3569	4883	110	25
	maximum	3793	5451	227	50
	standard deviation	84	180	42	9
Gas boiler heating + air source heat pump	minimum	3353	4167	4	2
	median	3574	4769	81	18
	maximum	3799	5322	200	43
	standard deviation	89	196	36	8
Air source heat pump	minimum	3394	4365	-23	-5
	median	3607	5055	89	19
	maximum	3829	5644	222	45
	standard deviation	88	214	50	10
District heating	minimum	3283	4177	9	0
	median	3465	4674	110	17
	maximum	3690	5142	233	33
	standard deviation	84	166	44	7
Window ventilation	minimum	3283	4167	-23	-5
	median	3521	4730	93	18
	maximum	3746	5501	224	48
	standard deviation	95	227	47	10
Mechanical ventilation with heat recovery	minimum	3366	4391	-7	-2
	median	3603	4926	96	20
	maximum	3829	5644	216	47
	standard deviation	95	215	40	8
Extract air ventilation	minimum	3314	4257	-16	-4
	median	3552	4821	100	20
	maximum	3777	5597	233	50
	standard deviation	95	227	47	10
National standard envelope	minimum	3283	4167	-23	-5
	median	3505	4768	106	21

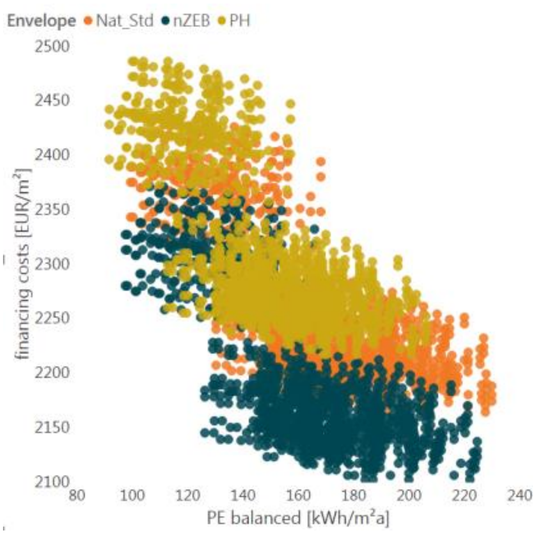
		financing costs (EUR/m²)	net present value (EUR/m²)	pE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	maximum	3692	5566	233	50
	standard deviation	82	235	50	10
nZEB envelope	minimum	3316	4220	-21	-5
	median	3538	4778	92	19
	maximum	3725	5510	206	45
	standard deviation	82	221	43	9
Passive house envelope	minimum	3420	4387	-14	-4
	median	3642	4933	92	19
	maximum	3829	5644	201	43
	standard deviation	82	217	40	8

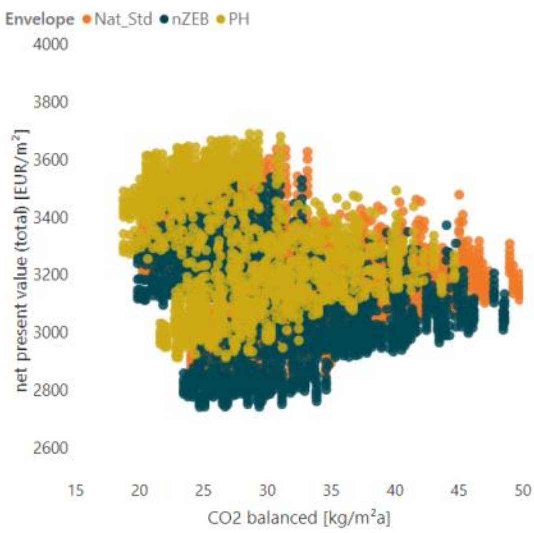
11.3. ISOLA NEL VERDE

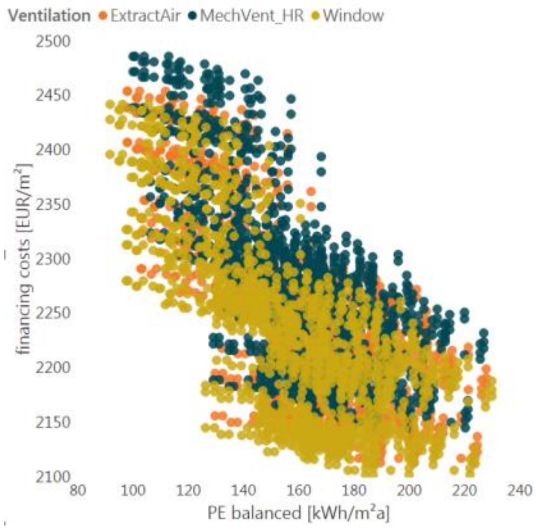
11.3.1. OVERVIEW FINANCING COSTS

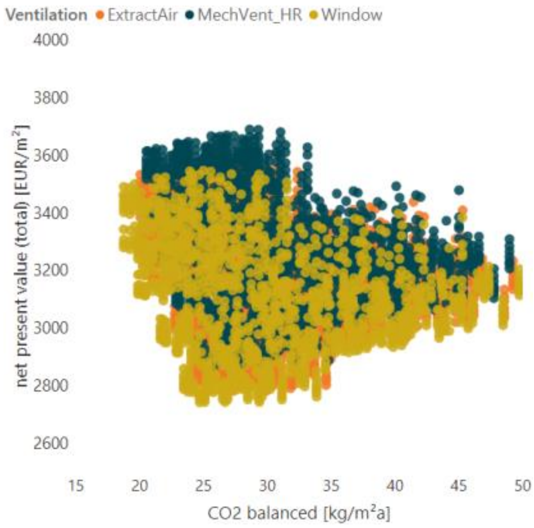


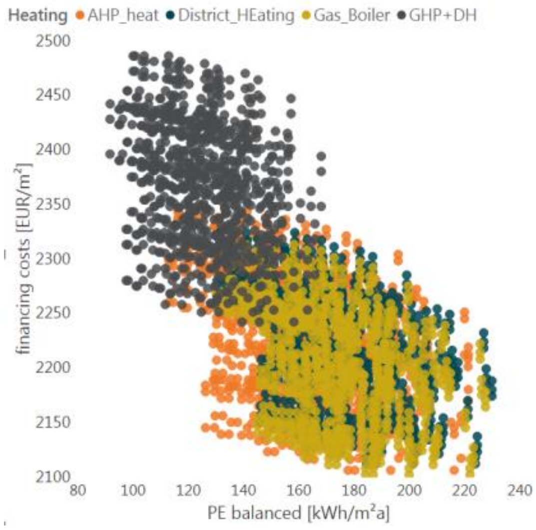
11.3.2. COMBINING ENERGY AND COST EFFICIENCY

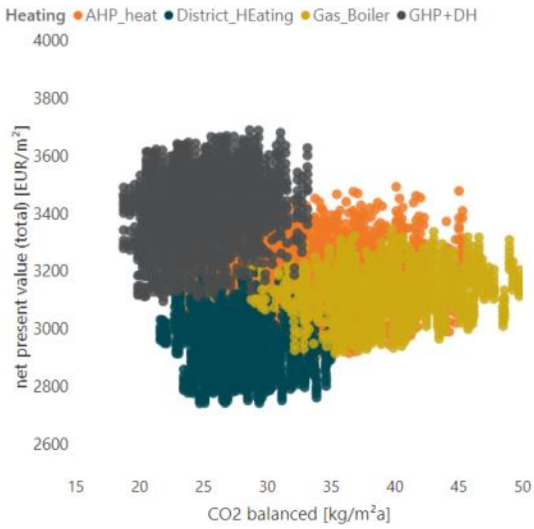


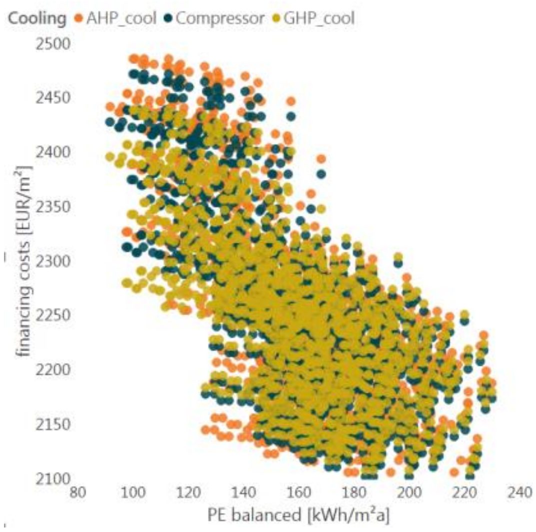


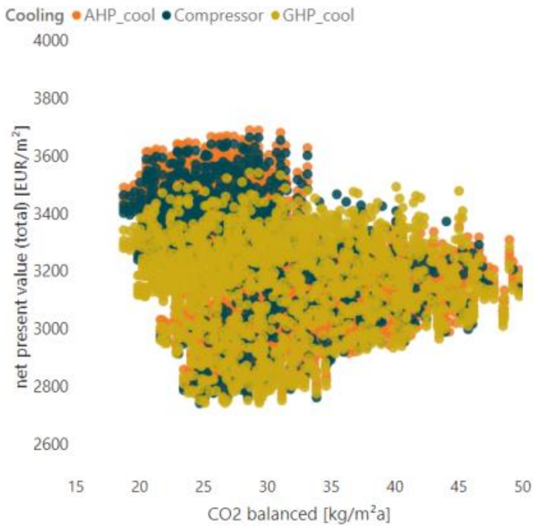

Ventilation ● ExtractAir ● MechVent_HR ● Window
financing costs [EUR/m²]
2100 2150 2200 2250 2300 2350 2400 2450 2500
80 100 120 140 160 180 200 220 240
PE balanced [kWh/m²a]

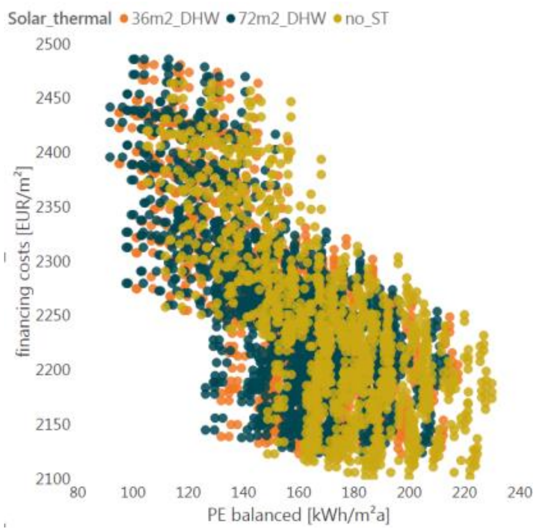

Ventilation ● ExtractAir ● MechVent_HR ● Window
net present value (total) [EUR/m²]
2600 2800 3000 3200 3400 3600 3800 4000
15 20 25 30 35 40 45 50
CO2 balanced [kg/m²a]

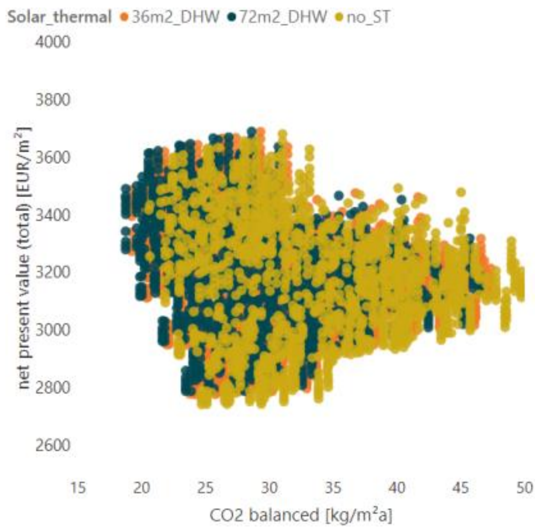

Heating ● AHP_heat ● District_HEating ● Gas_Boiler ● GHP+DH
financing costs [EUR/m²]
2100 2150 2200 2250 2300 2350 2400 2450 2500
80 100 120 140 160 180 200 220 240
PE balanced [kWh/m²a]

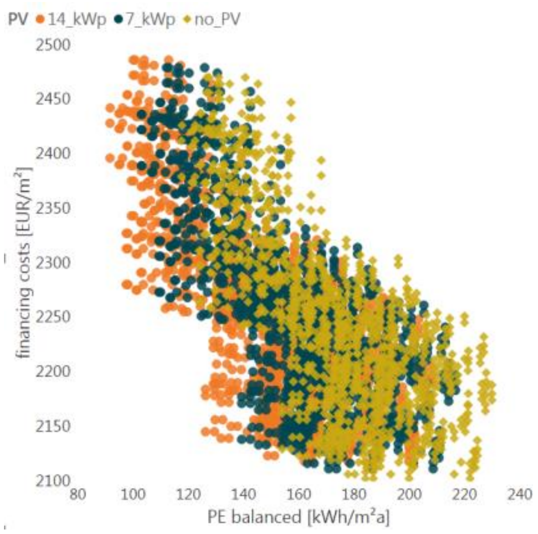

Heating ● AHP_heat ● District_HEating ● Gas_Boiler ● GHP+DH
net present value (total) [EUR/m²]
2600 2800 3000 3200 3400 3600 3800 4000
15 20 25 30 35 40 45 50
CO2 balanced [kg/m²a]

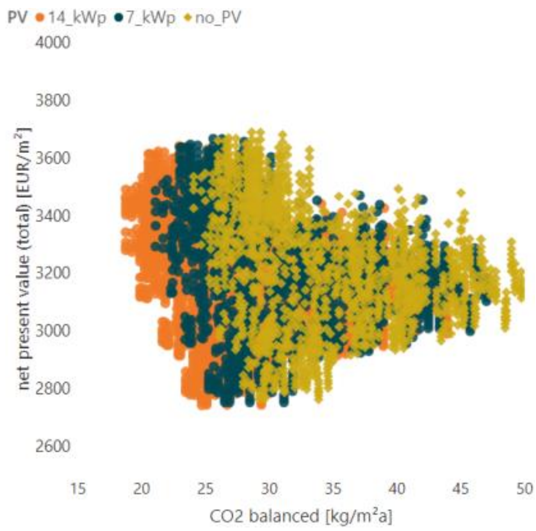

Cooling ● AHP_cool ● Compressor ● GHP_cool
financing costs [EUR/m²]
2100 2150 2200 2250 2300 2350 2400 2450 2500
80 100 120 140 160 180 200 220 240
PE balanced [kWh/m²a]

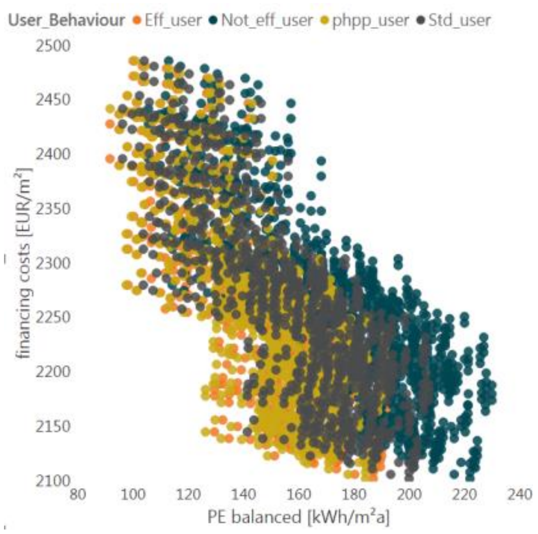

Cooling ● AHP_cool ● Compressor ● GHP_cool
net present value (total) [EUR/m²]
2600 2800 3000 3200 3400 3600 3800 4000
15 20 25 30 35 40 45 50
CO2 balanced [kg/m²a]

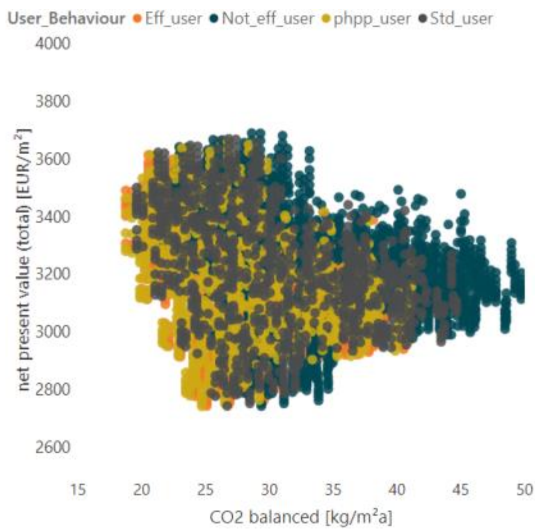

Solar_thermal ● 36m2_DHW ● 72m2_DHW ● no_ST
financing costs [EUR/m²]
PE balanced [kWh/m²a]

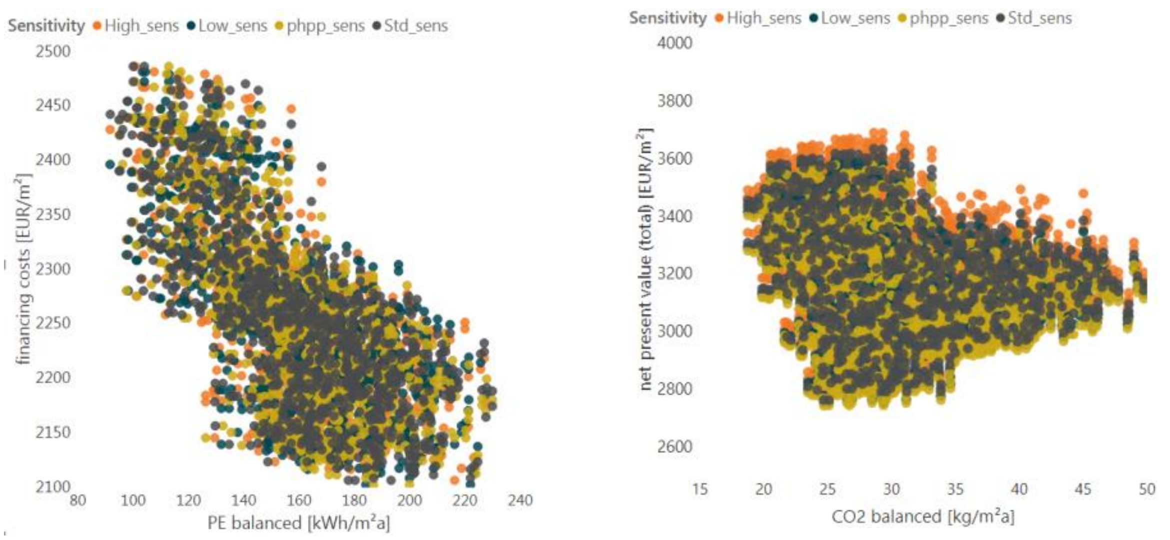

Solar_thermal ● 36m2_DHW ● 72m2_DHW ● no_ST
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]


PV ● 14_kWp ● 7_kWp ◆ no_PV
financing costs [EUR/m²]
PE balanced [kWh/m²a]

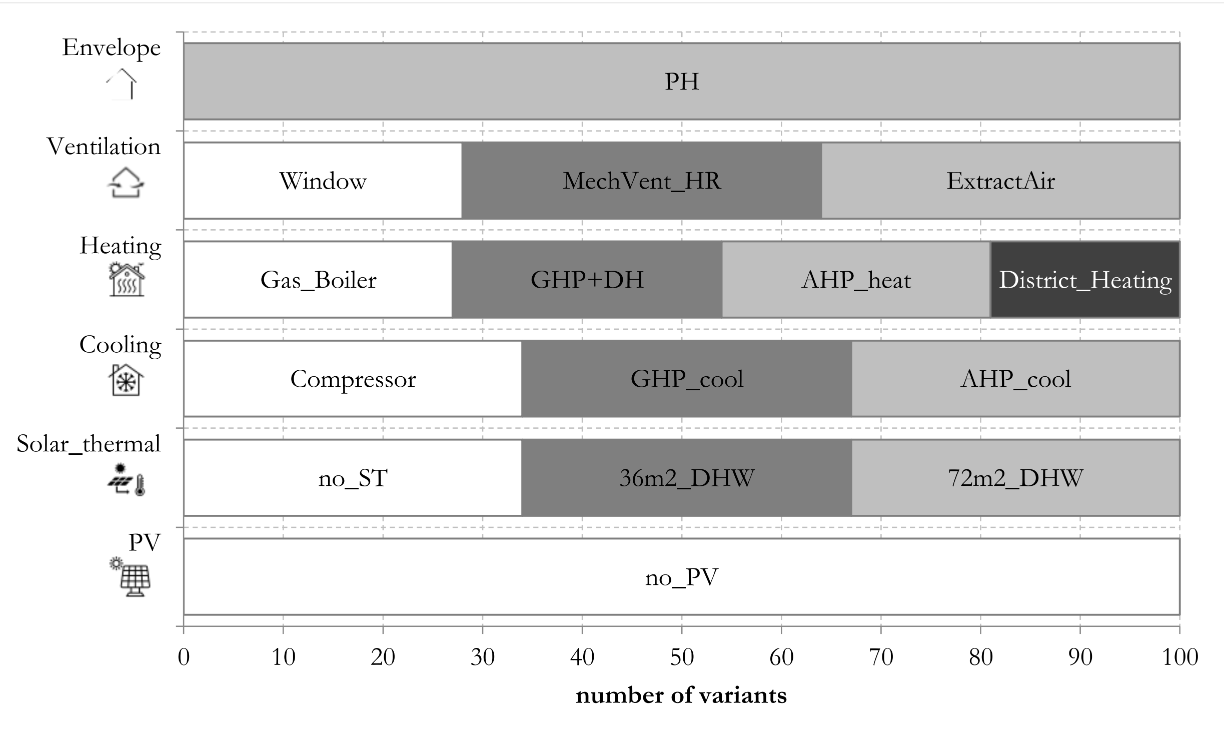

PV ● 14_kWp ● 7_kWp ◆ no_PV
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]


User_Behaviour ● Eff_user ● Not_eff_user ● phpp_user ● Std_user
financing costs [EUR/m²]
PE balanced [kWh/m²a]

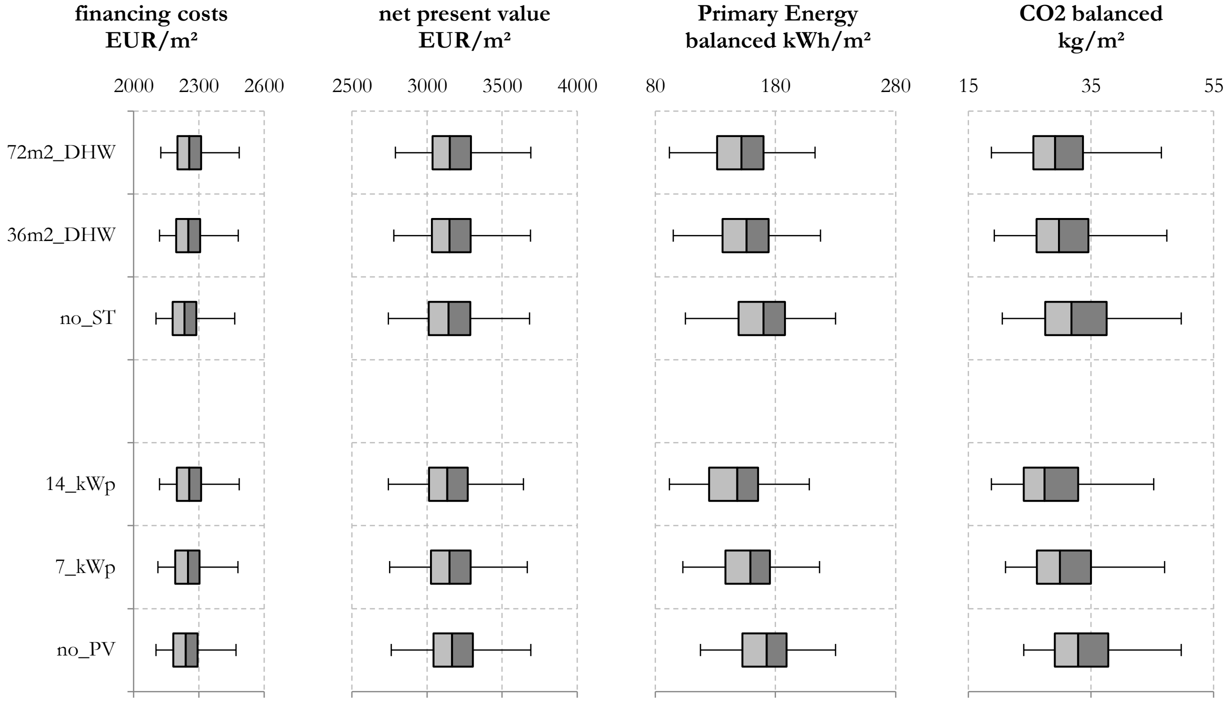

User_Behaviour ● Eff_user ● Not_eff_user ● phpp_user ● Std_user
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

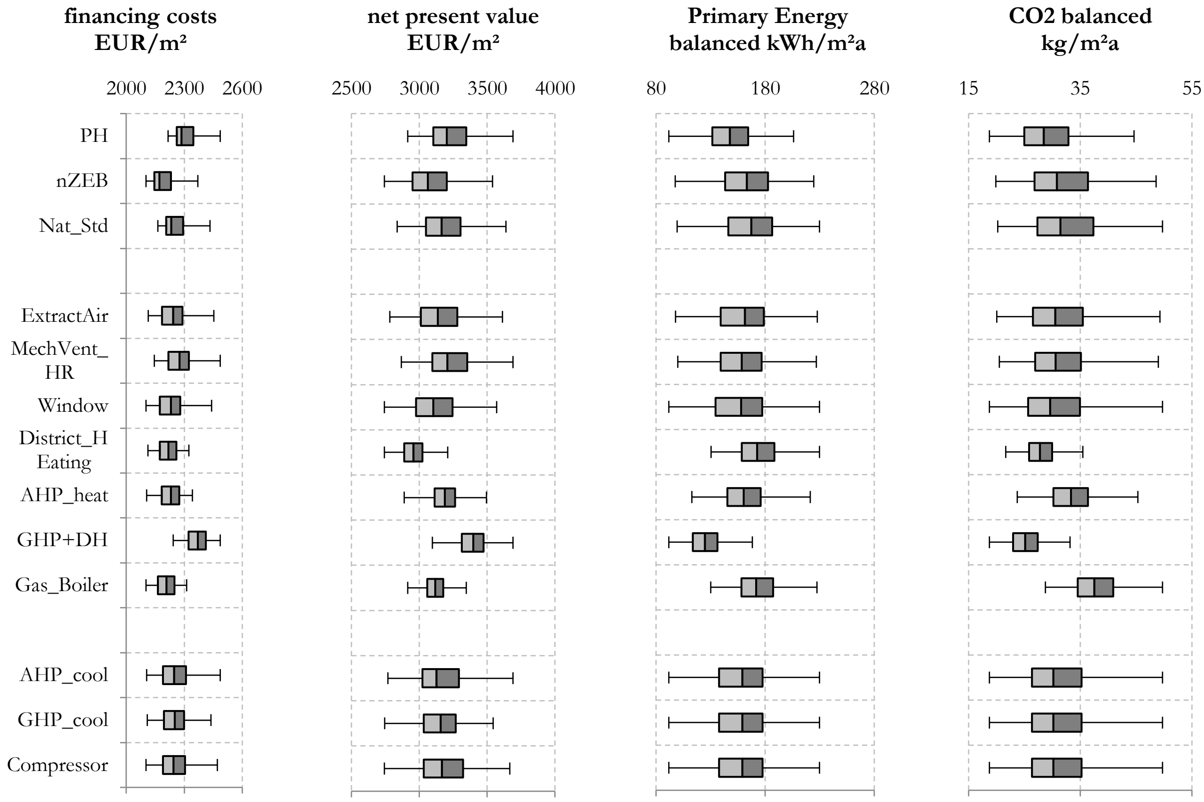


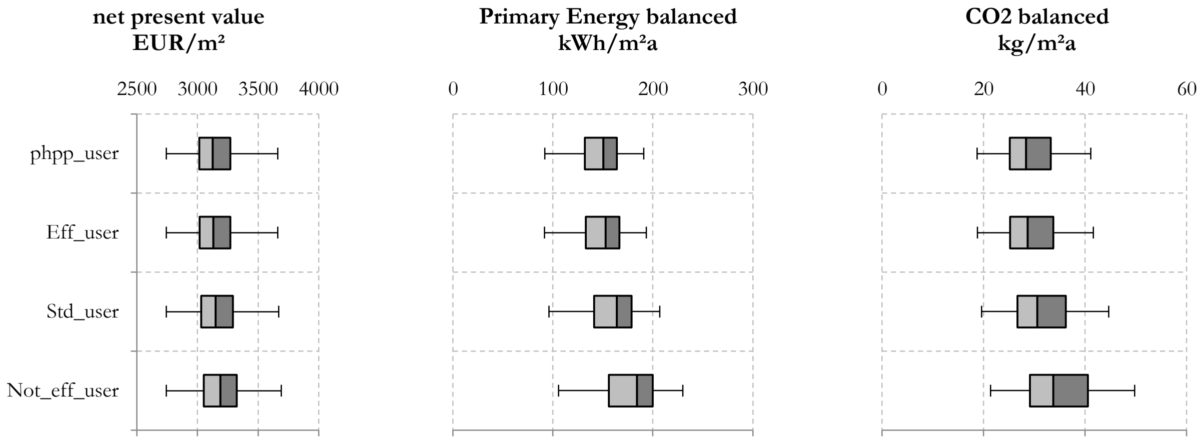
11.3.3. TOP100 EVALUATION



11.3.4. BOXPLOTS







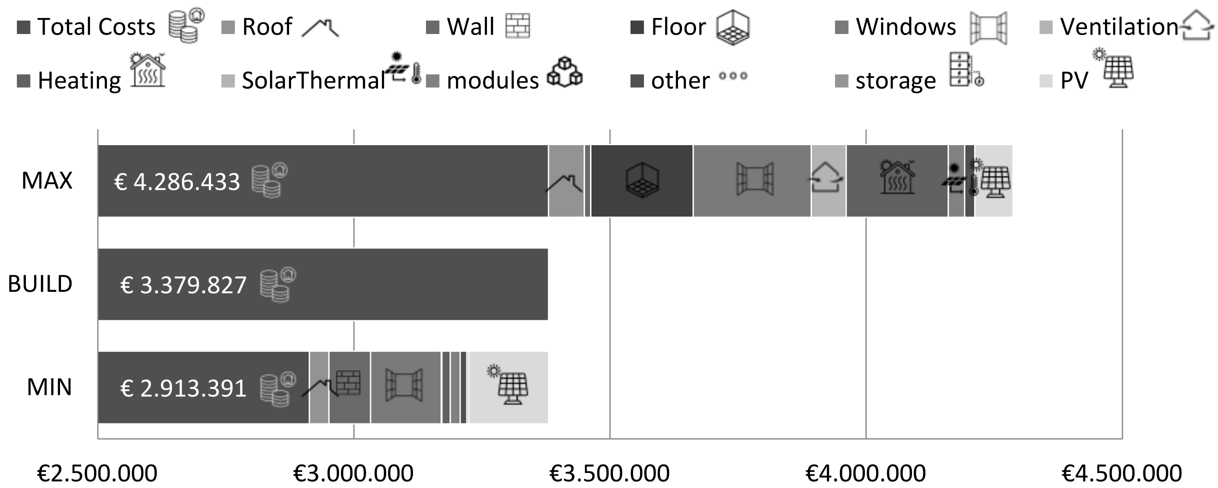
11.3.5. DATA FROM THE BOXPLOTS

		financing costs (EUR/m²)	net present value (EUR/m²)	pE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
Not efficient user behaviour	minimum	2102	2743	106	21
	median	2248	3189	184	34
	maximum	2486	3691	230	50
	standard deviation	84	191	29	7
standard user behaviour	minimum	2102	2743	96	20
	median	2248	3151	164	31
	maximum	2486	3671	207	45
	standard deviation	84	185	26	6
efficient user behaviour	minimum	2102	2743	92	19
	median	2248	3130	153	29
	maximum	2486	3662	193	42
	standard deviation	84	183	23	5
PHPP default user behaviour	minimum	2102	2743	92	19
	median	2248	3127	150	28
	maximum	2486	3663	191	41
	standard deviation	84	184	22	5
No PV	minimum	2102	2762	118	24
	median	2240	3167	173	33
	maximum	2470	3691	230	50
	standard deviation	84	188	25	6
7 kWp PV	minimum	2111	2752	103	21
	median	2250	3150	159	30
	maximum	2479	3668	217	47
	standard deviation	84	187	26	6
14 kWp PV	minimum	2118	2743	92	19
	median	2256	3134	148	27
	maximum	2486	3643	208	45
	standard deviation	84	184	27	6
No solar thermal	minimum	2102	2743	105	21
	median	2234	3143	170	32
	maximum	2464	3682	230	50
	standard deviation	84	192	27	6
36 m² solar thermal	minimum	2119	2778	95	19
	median	2251	3150	156	30
	maximum	2481	3690	218	47
	standard deviation	84	185	27	6
72 m² solar thermal	minimum	2124	2789	92	19
	median	2256	3151	152	29
	maximum	2486	3691	213	46
	standard deviation	84	183	26	6
compressor cooling	minimum	2102	2743	92	19
	median	2245	3166	159	30
	maximum	2472	3666	230	50

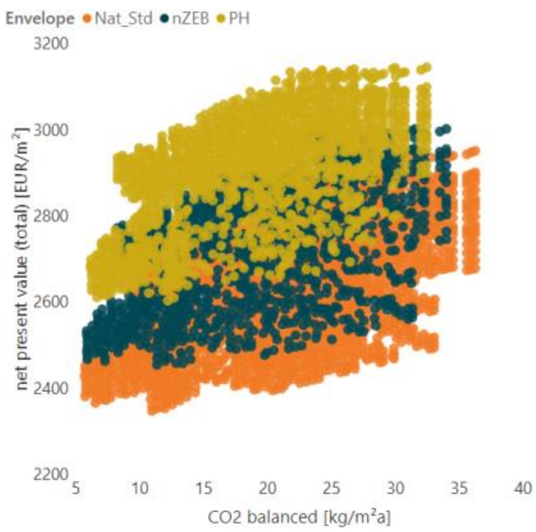
		financing costs (EUR/m²)	net present value (EUR/m²)	pE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	standard deviation	87	197	28	6
Ground source heat pump cooling	minimum	2108	2744	92	19
	median	2251	3158	159	30
	maximum	2439	3544	230	50
	standard deviation	74	162	28	6
Air source heat pump cooling	minimum	2106	2769	92	19
	median	2248	3127	159	30
	maximum	2486	3691	230	50
	standard deviation	91	198	28	6
Gas boiler heating	minimum	2102	2915	130	29
	median	2208	3117	172	38
	maximum	2313	3347	228	50
	standard deviation	52	82	20	4
Ground source heat pump + district heating	minimum	2242	3096	92	19
	median	2370	3398	125	25
	maximum	2486	3691	168	33
	standard deviation	56	111	15	3
Air source heat pump	minimum	2106	2889	113	24
	median	2231	3189	160	33
	maximum	2343	3494	221	45
	standard deviation	55	108	22	4
district heating	minimum	2112	2743	130	22
	median	2218	2957	173	28
	maximum	2324	3209	230	35
	standard deviation	52	95	21	3
window ventilation	minimum	2102	2743	92	19
	median	2232	3104	158	30
	maximum	2442	3570	230	50
	standard deviation	82	181	29	6
mechanical ventilation with heat recovery	minimum	2145	2867	100	21
	median	2276	3206	159	31
	maximum	2486	3691	227	49
	standard deviation	82	179	26	6
Extract air ventilation	minimum	2113	2782	98	20
	median	2243	3136	161	31
	maximum	2454	3613	228	49
	standard deviation	82	181	28	6
national standard envelope	minimum	2164	2836	99	20
	median	2233	3164	167	31
	maximum	2433	3638	230	50
	standard deviation	70	178	29	6
nZEB envelope	minimum	2102	2743	98	20
	median	2171	3063	163	31
	maximum	2371	3540	225	49
	standard deviation	70	177	28	6
passive house envelope	minimum	2217	2915	92	19
	median	2286	3201	148	28
	maximum	2486	3691	206	45
	standard deviation	70	173	24	5

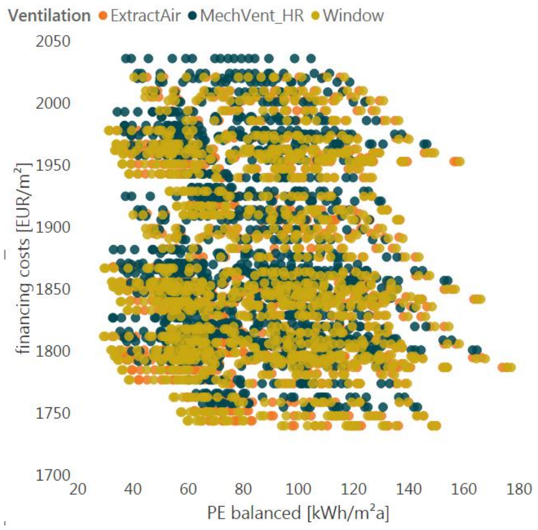
11.4. LES HELIADES

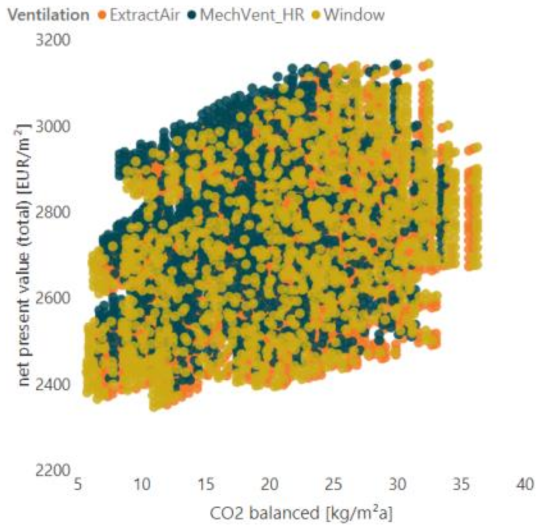
11.4.1. OVERVIEW FINANCING COSTS

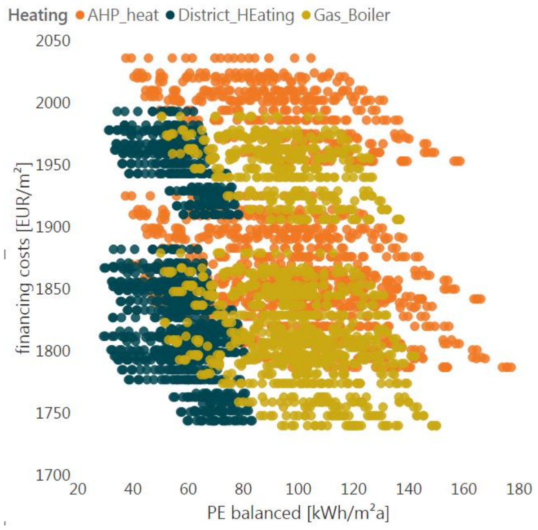


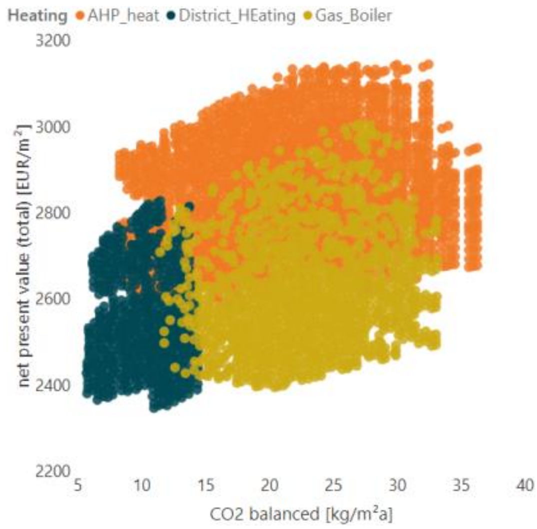
11.4.2. COMBINING ENERGY AND COST EFFICIENCY

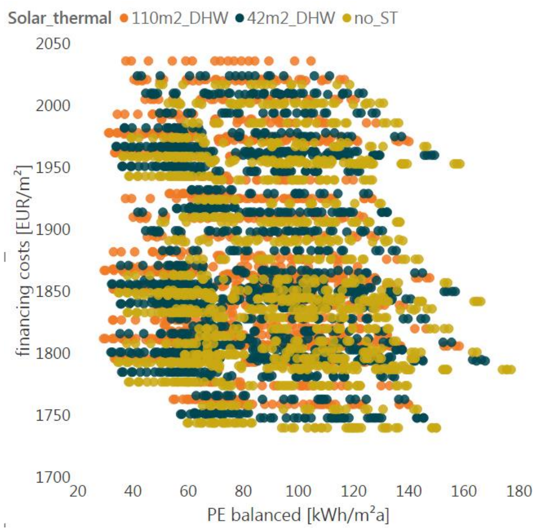


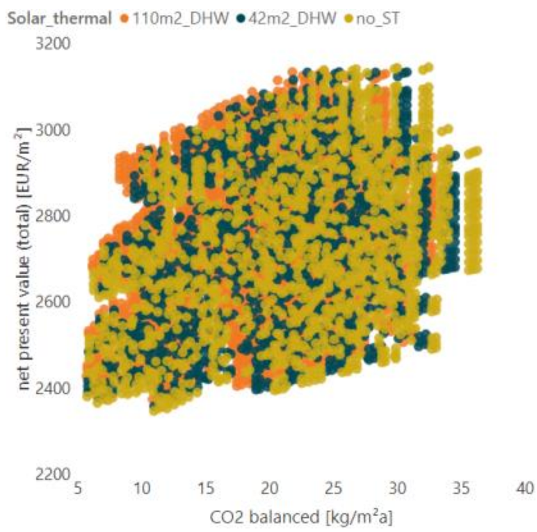

Ventilation ExtractAir MechVent_HR Window
financing costs [EUR/m²]
2050
2000
1950
1900
1850
1800
1750
1700
20 40 60 80 100 120 140 160 180
PE balanced [kWh/m²a]


Ventilation ExtractAir MechVent_HR Window
net present value (total) [EUR/m²]
3200
3000
2800
2600
2400
2200
5 10 15 20 25 30 35 40
CO2 balanced [kg/m²a]

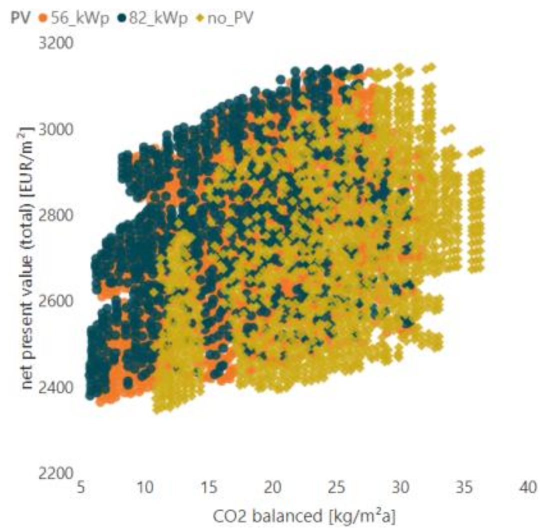

Heating AHP_heat District_HEating Gas_Boiler
financing costs [EUR/m²]
2050
2000
1950
1900
1850
1800
1750
1700
20 40 60 80 100 120 140 160 180
PE balanced [kWh/m²a]

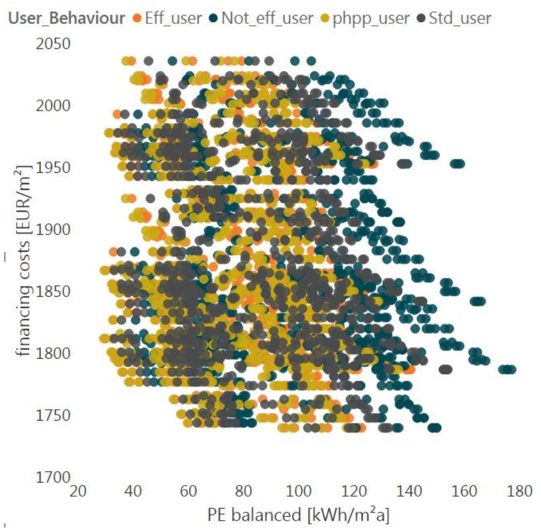

Heating AHP_heat District_HEating Gas_Boiler
net present value (total) [EUR/m²]
3200
3000
2800
2600
2400
2200
5 10 15 20 25 30 35 40
CO2 balanced [kg/m²a]

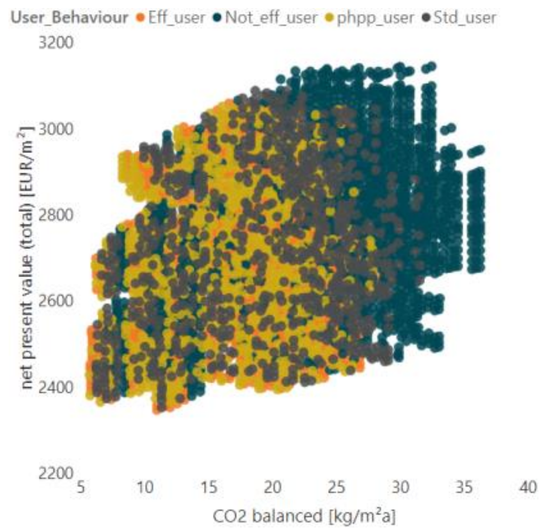

Solar_thermal 110m2_DHW 42m2_DHW no_ST
financing costs [EUR/m²]
2050
2000
1950
1900
1850
1800
1750
1700
20 40 60 80 100 120 140 160 180
PE balanced [kWh/m²a]

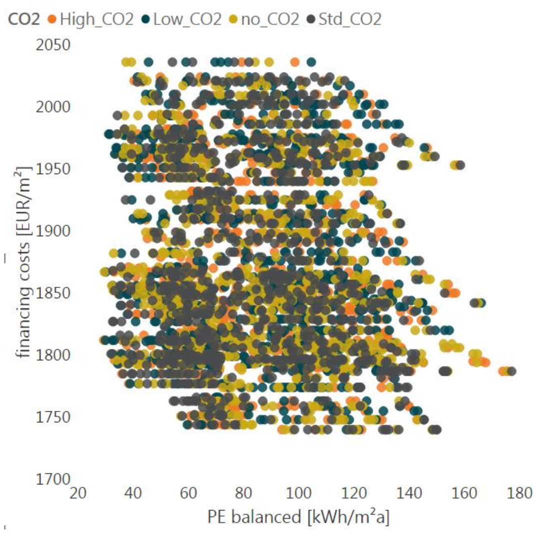

Solar_thermal 110m2_DHW 42m2_DHW no_ST
net present value (total) [EUR/m²]
3200
3000
2800
2600
2400
2200
5 10 15 20 25 30 35 40
CO2 balanced [kg/m²a]

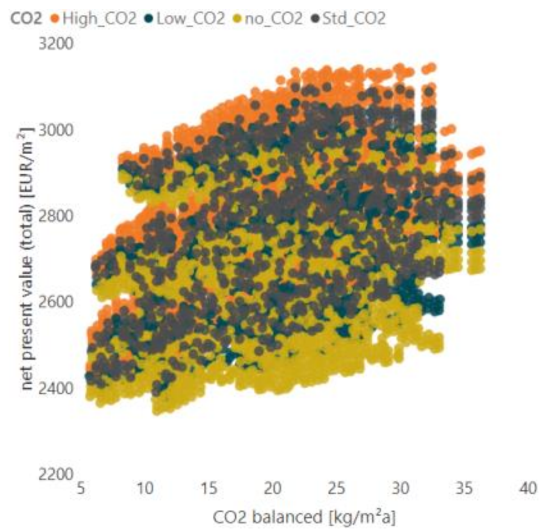

PV ● 56_kWp ● 82_kWp ◆ no_PV
financing costs [EUR/m²]
2050
2000
1950
1900
1850
1800
1750
1700
20 40 60 80 100 120 140 160 180
PE balanced [kWh/m²a]

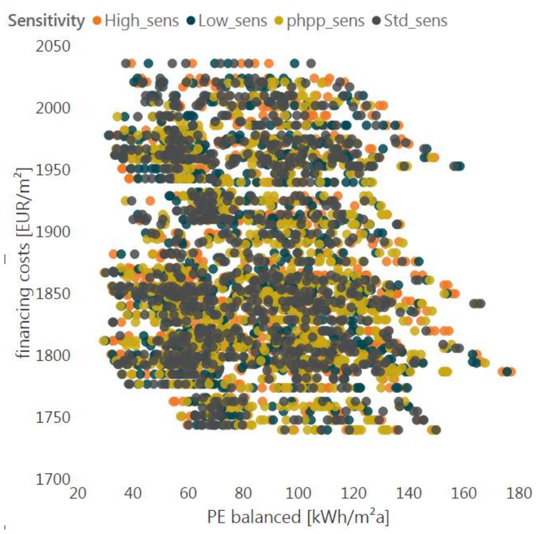

PV ● 56_kWp ● 82_kWp ◆ no_PV
net present value (total) [EUR/m²]
3200
3000
2800
2600
2400
2200
5 10 15 20 25 30 35 40
CO2 balanced [kg/m²a]

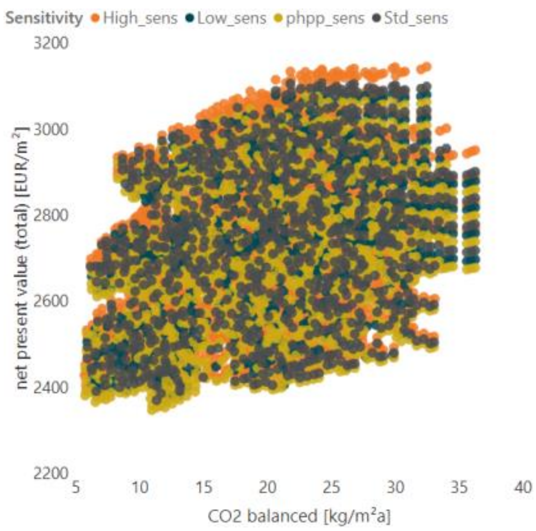

User_Behaviour ● Eff_user ● Not_eff_user ● phpp_user ● Std_user
financing costs [EUR/m²]
2050
2000
1950
1900
1850
1800
1750
1700
20 40 60 80 100 120 140 160 180
PE balanced [kWh/m²a]


User_Behaviour ● Eff_user ● Not_eff_user ● phpp_user ● Std_user
net present value (total) [EUR/m²]
3200
3000
2800
2600
2400
2200
5 10 15 20 25 30 35 40
CO2 balanced [kg/m²a]

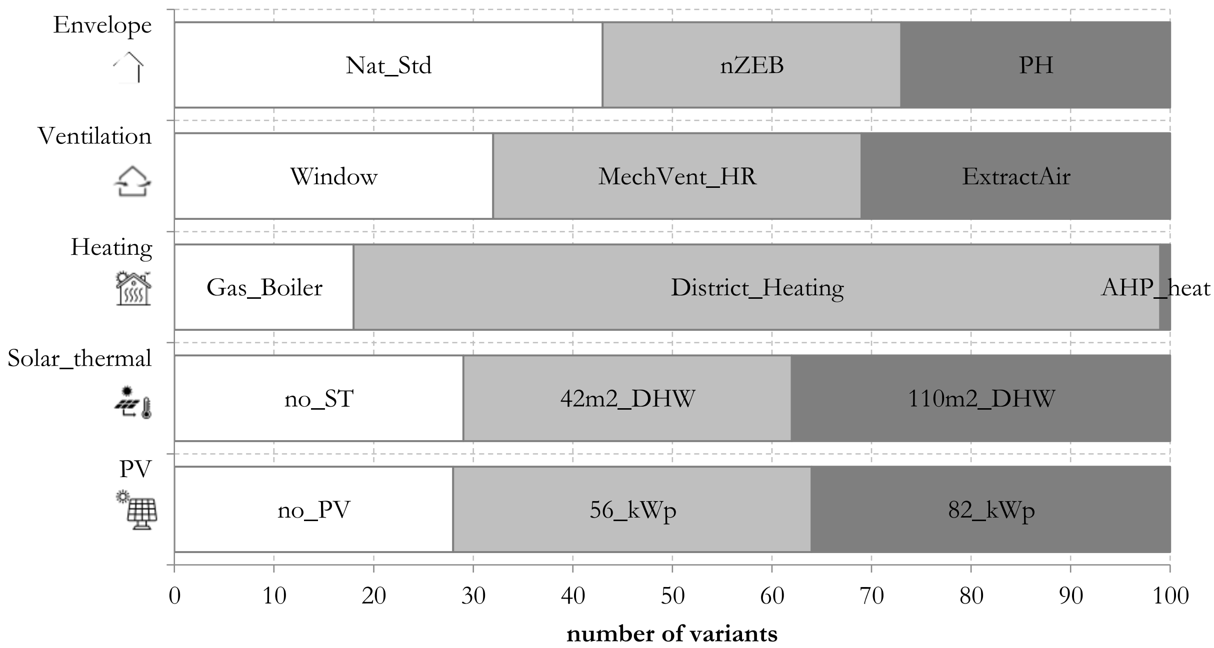

CO2 ● High_CO2 ● Low_CO2 ● no_CO2 ● Std_CO2
financing costs [EUR/m²]
2050
2000
1950
1900
1850
1800
1750
1700
20 40 60 80 100 120 140 160 180
PE balanced [kWh/m²a]


CO2 ● High_CO2 ● Low_CO2 ● no_CO2 ● Std_CO2
net present value (total) [EUR/m²]
3200
3000
2800
2600
2400
2200
5 10 15 20 25 30 35 40
CO2 balanced [kg/m²a]

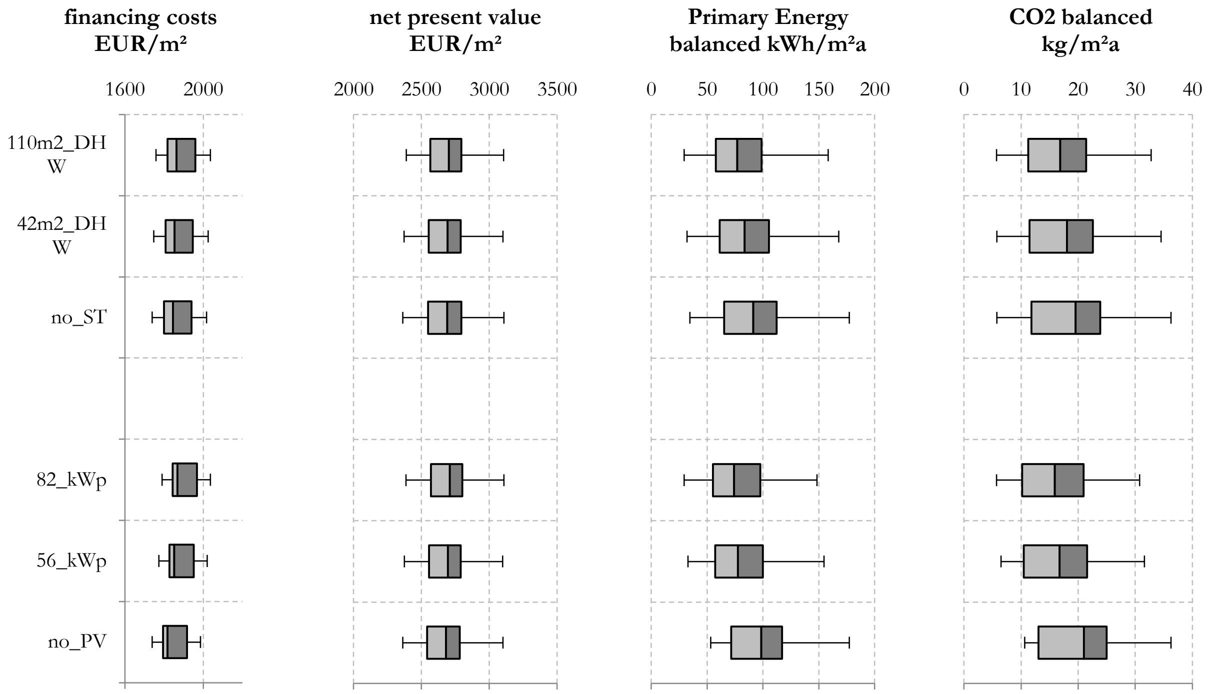


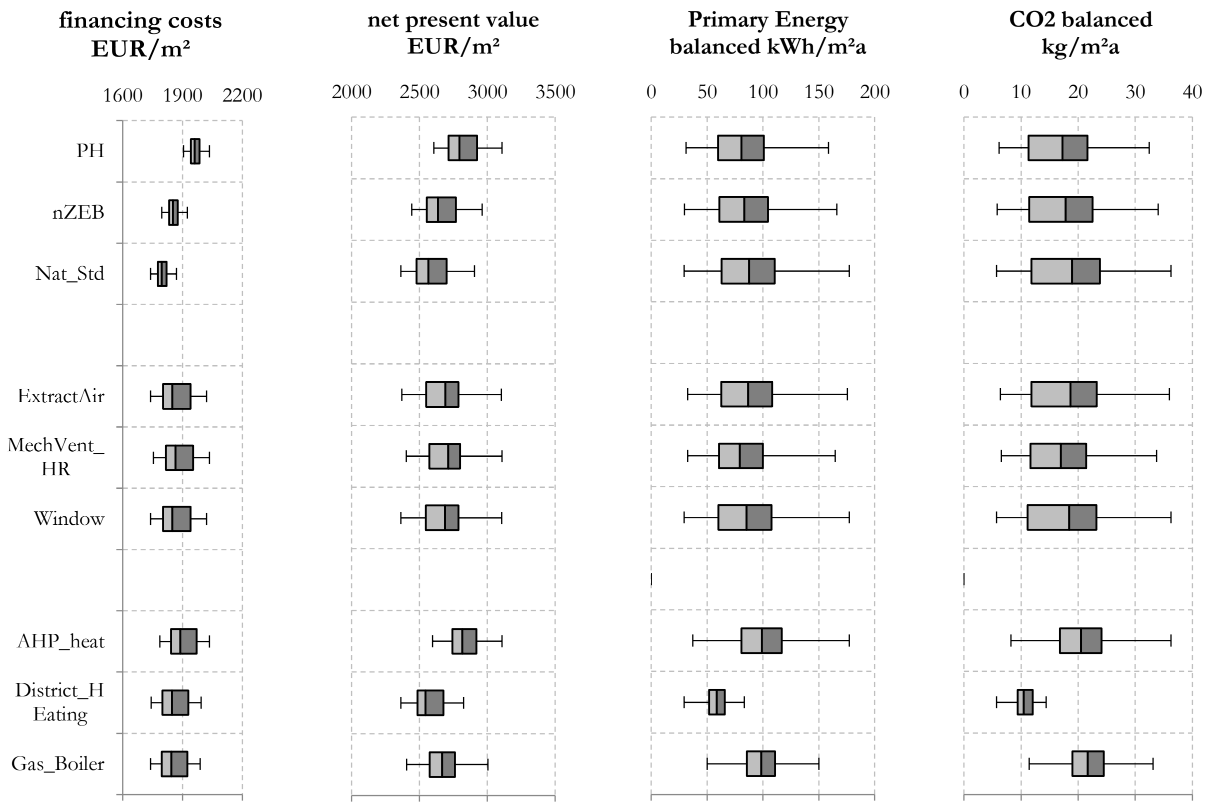


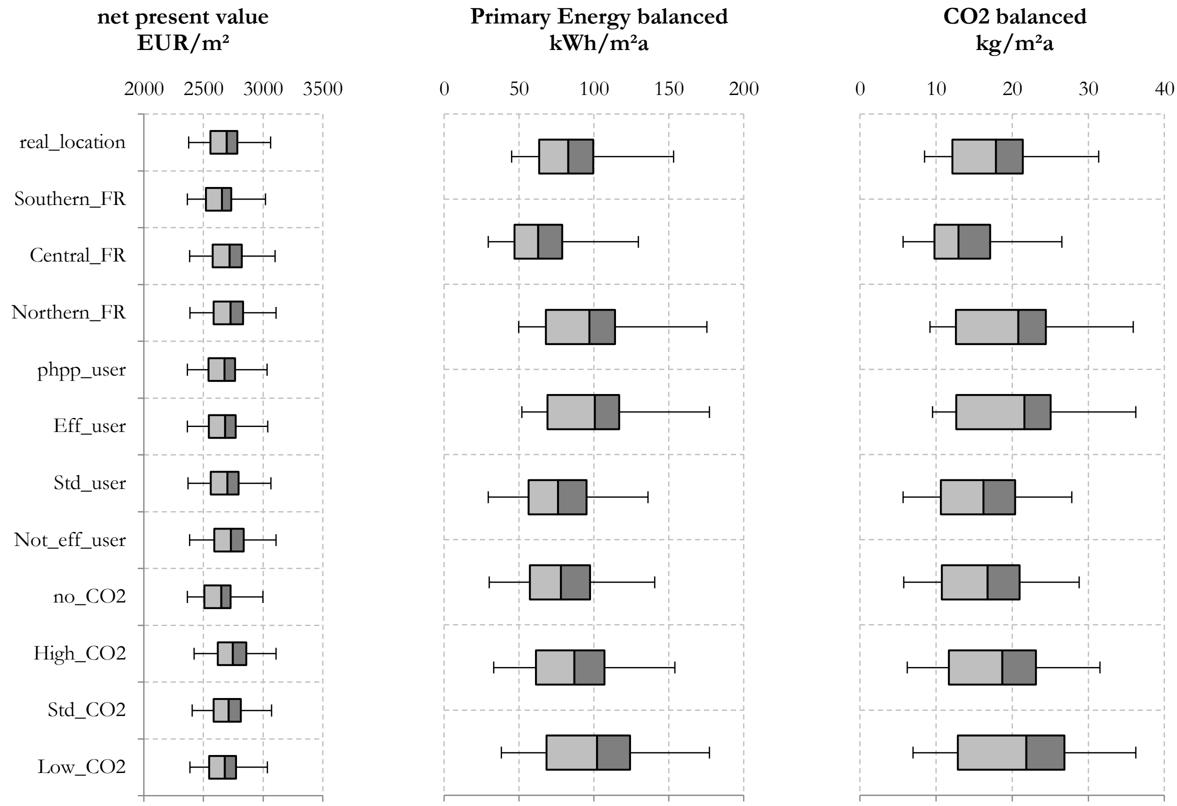
11.4.3. TOP100 EVALUATION



11.4.4. BOXPLOTS







11.4.5. DATA FROM THE BOXPLOTS

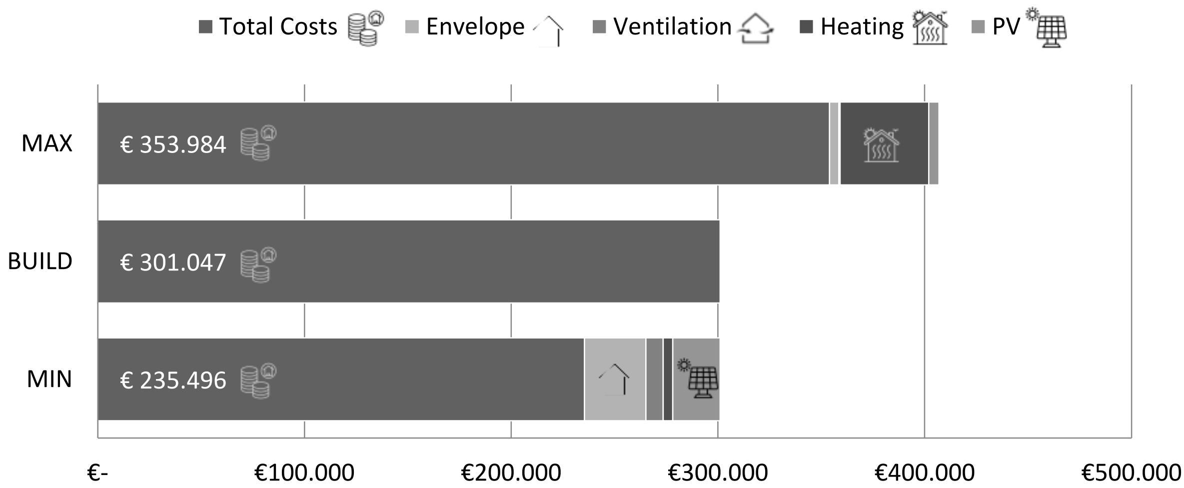
		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
Low CO2 costs	minimum	1740	2385	29	6
	median	1855	2679	83	18
	maximum	2036	3035	177	36
	standard deviation	76	148	28	7
Standard CO2 costs	minimum	1740	2405	29	6
	median	1855	2712	83	18
	maximum	2036	3071	177	36
	standard deviation	76	151	28	7
High CO2 costs	minimum	1740	2420	29	6
	median	1855	2747	83	18
	maximum	2036	3108	177	36
	standard deviation	76	156	28	7
No CO2 costs	minimum	1740	2363	29	6
	median	1855	2650	83	18
	maximum	2036	2999	177	36
	standard deviation	76	147	28	7
Not efficient user behaviour	minimum	1740	2384	38	7
	median	1855	2729	102	22
	maximum	2036	3108	177	36
	standard deviation	76	162	32	8
standard user behaviour	minimum	1740	2371	33	6
	median	1855	2699	87	19
	maximum	2036	3066	154	32
	standard deviation	76	155	27	6
efficient user behaviour	minimum	1740	2364	30	6
	median	1855	2681	78	17
	maximum	2036	3040	141	29
	standard deviation	76	151	24	6
PHPP default user behaviour	minimum	1740	2363	29	6
	median	1855	2677	76	16

		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	maximum	2036	3033	136	28
	standard deviation	76	150	23	5
Northern France	minimum	1740	2385	52	10
	median	1855	2726	101	22
	maximum	2036	3108	177	36
	standard deviation	76	159	28	7
Central France	minimum	1740	2384	50	9
	median	1855	2718	97	21
	maximum	2036	3100	176	36
	standard deviation	76	158	27	7
Southern France	minimum	1740	2363	29	6
	median	1855	2654	63	13
	maximum	2036	3020	130	27
	standard deviation	76	144	21	5
Real location of case study	minimum	1740	2374	45	8
	median	1855	2694	83	18
	maximum	2036	3062	153	31
	standard deviation	76	151	23	6
No PV	minimum	1740	2363	53	11
	median	1818	2683	98	21
	maximum	1986	3103	177	36
	standard deviation	73	159	27	6
56 kWp PV	minimum	1774	2375	33	6
	median	1852	2696	78	17
	maximum	2020	3100	155	32
	standard deviation	73	155	26	6
82 kWp PV	minimum	1790	2386	29	6
	median	1868	2709	74	16
	maximum	2036	3108	148	31
	standard deviation	73	154	26	6
No solar thermal	minimum	1740	2363	35	6
	median	1845	2691	91	20
	maximum	2017	3108	177	36
	standard deviation	75	160	29	7
42 m² solar thermal	minimum	1748	2373	32	6
	median	1853	2693	84	18
	maximum	2024	3103	168	35
	standard deviation	75	155	27	6
110 m² solar thermal	minimum	1759	2389	29	6
	median	1864	2703	77	17
	maximum	2036	3107	158	33
	standard deviation	75	153	26	6
Gas boiler heating	minimum	1740	2406	50	11
	median	1844	2666	98	22
	maximum	1989	3005	150	33
	standard deviation	73	122	20	4
district heating	minimum	1744	2363	29	6
	median	1847	2545	59	10
	maximum	1993	2825	83	14
	standard deviation	73	107	11	2
Air source heat pump	minimum	1787	2595	37	8
	median	1890	2815	99	21
	maximum	2036	3108	177	36
	standard deviation	73	112	27	5
Window ventilation	minimum	1740	2363	29	6
	median	1850	2687	85	18
	maximum	2021	3106	177	36
	standard deviation	75	159	29	7
mechanical ventilation with heat recovery	minimum	1755	2402	33	7
	median	1865	2711	79	17
	maximum	2036	3108	165	34
	standard deviation	75	152	25	6
Extract air ventilation	minimum	1740	2370	33	6
	median	1850	2690	87	19

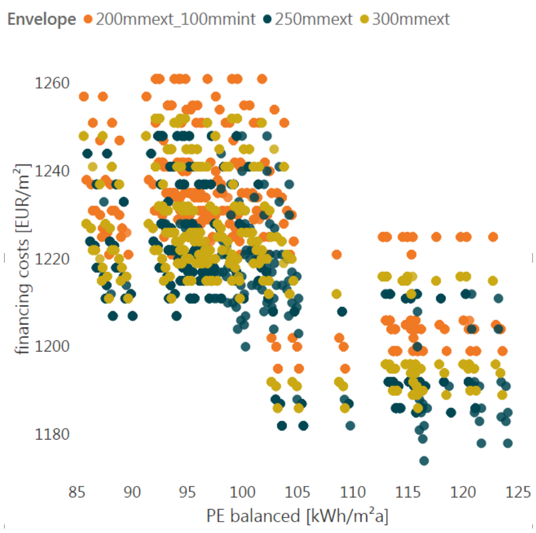
		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	maximum	2021	3103	176	36
	standard deviation	75	157	28	7
national standard envelope	minimum	1740	2363	29	6
	median	1796	2567	87	19
	maximum	1870	2906	177	36
	standard deviation	31	128	30	7
nZEB envelope	minimum	1796	2443	30	6
	median	1852	2636	83	18
	maximum	1925	2962	166	34
	standard deviation	31	123	27	6
Passive house envelope	minimum	1906	2606	31	6
	median	1962	2793	81	17
	maximum	2036	3108	159	32
	standard deviation	31	120	26	6

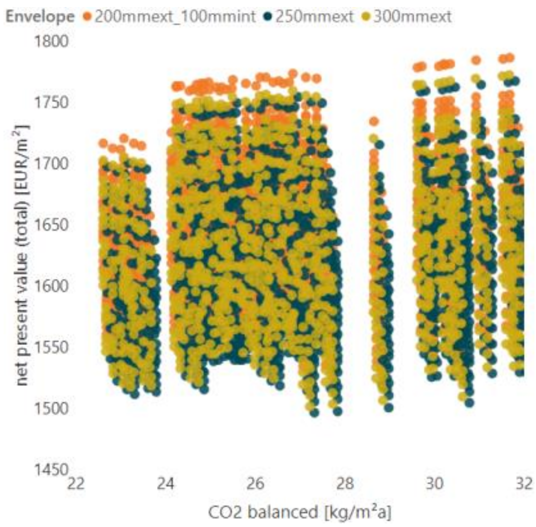
11.5. ALIZARI

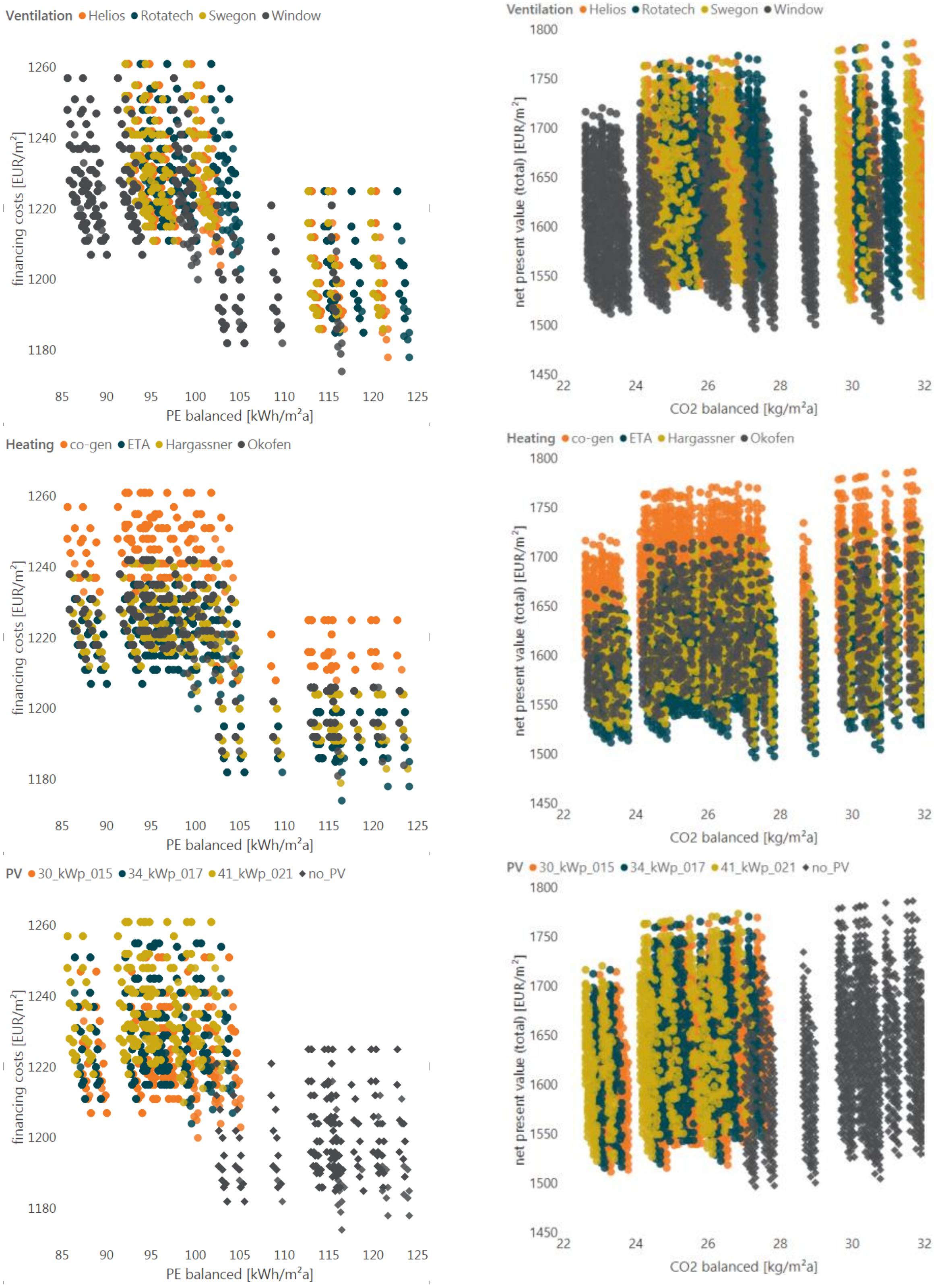
11.5.1. OVERVIEW FINANCING COSTS

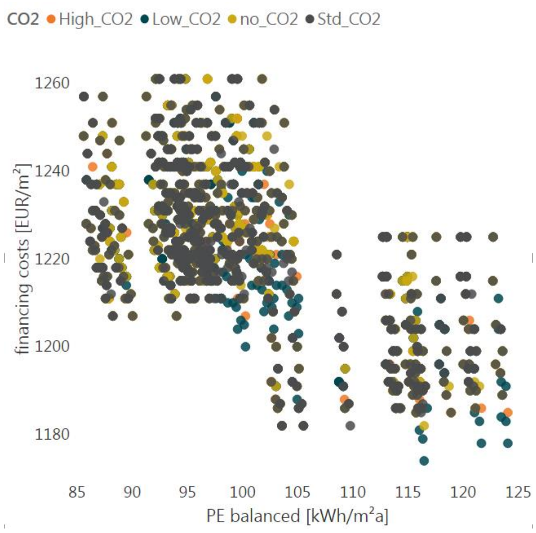


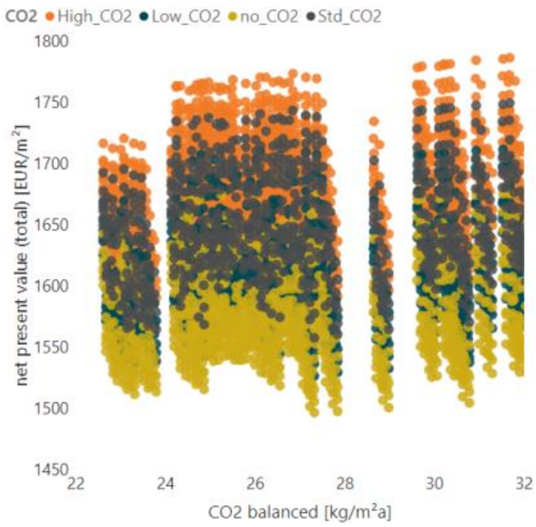
11.5.2. COMBINING ENERGY AND COST EFFICIENCY

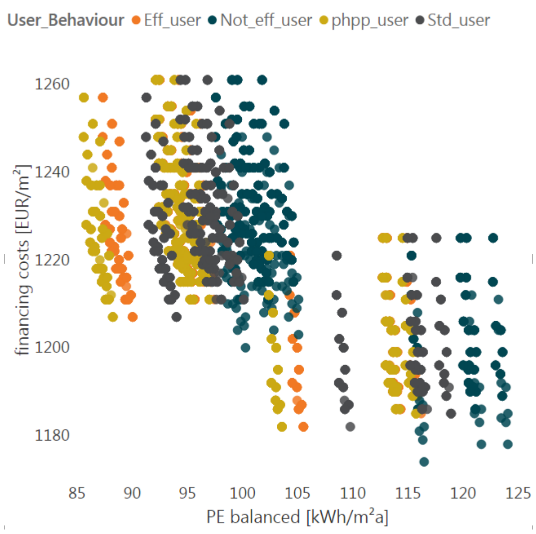


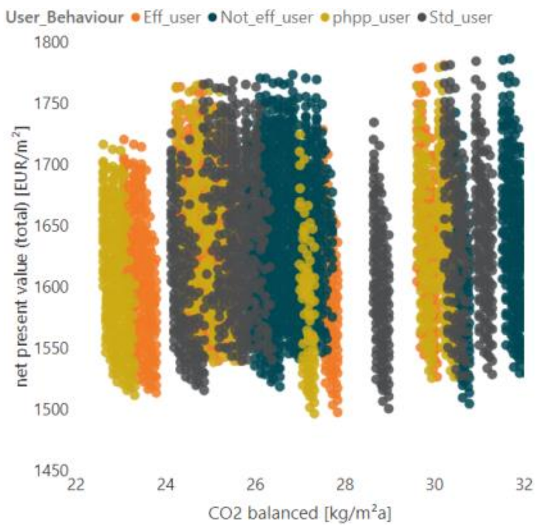


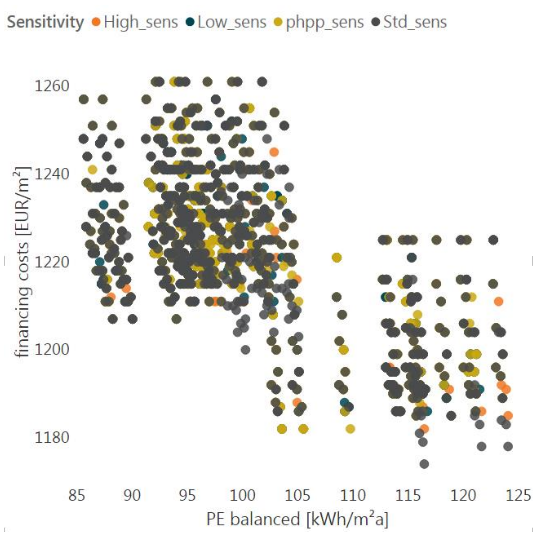

Ventilation Helios Rotatech Swegon Window
financing costs [EUR/m²]
PE balanced [kWh/m²a]
Ventilation Helios Rotatech Swegon Window
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]
Heating co-gen ETA Hargassner Okofen
financing costs [EUR/m²]
PE balanced [kWh/m²a]
Heating co-gen ETA Hargassner Okofen
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]
PV 30_kWp_015 34_kWp_017 41_kWp_021 no_PV
financing costs [EUR/m²]
PE balanced [kWh/m²a]
PV 30_kWp_015 34_kWp_017 41_kWp_021 no_PV
net present value (total) [EUR/m²]
CO2 balanced [kg/m²a]

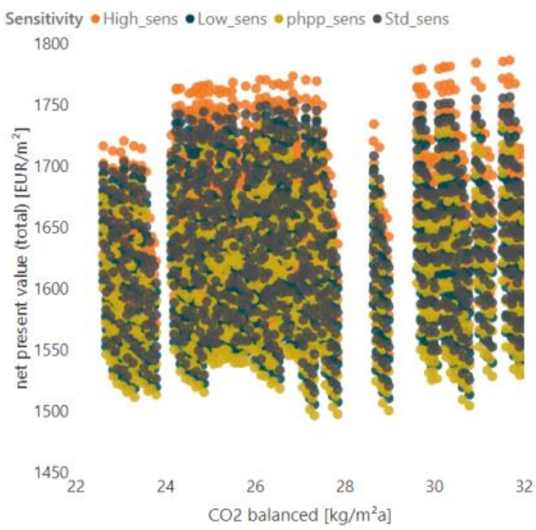

CO2 High_CO2 Low_CO2 no_CO2 Std_CO2
financing costs [EUR/m²]
1260
1240
1220
1200
1180
85 90 95 100 105 110 115 120 125
PE balanced [kWh/m²a]


CO2 High_CO2 Low_CO2 no_CO2 Std_CO2
net present value (total) [EUR/m²]
1800
1750
1700
1650
1600
1550
1500
1450
22 24 26 28 30 32
CO2 balanced [kg/m²a]

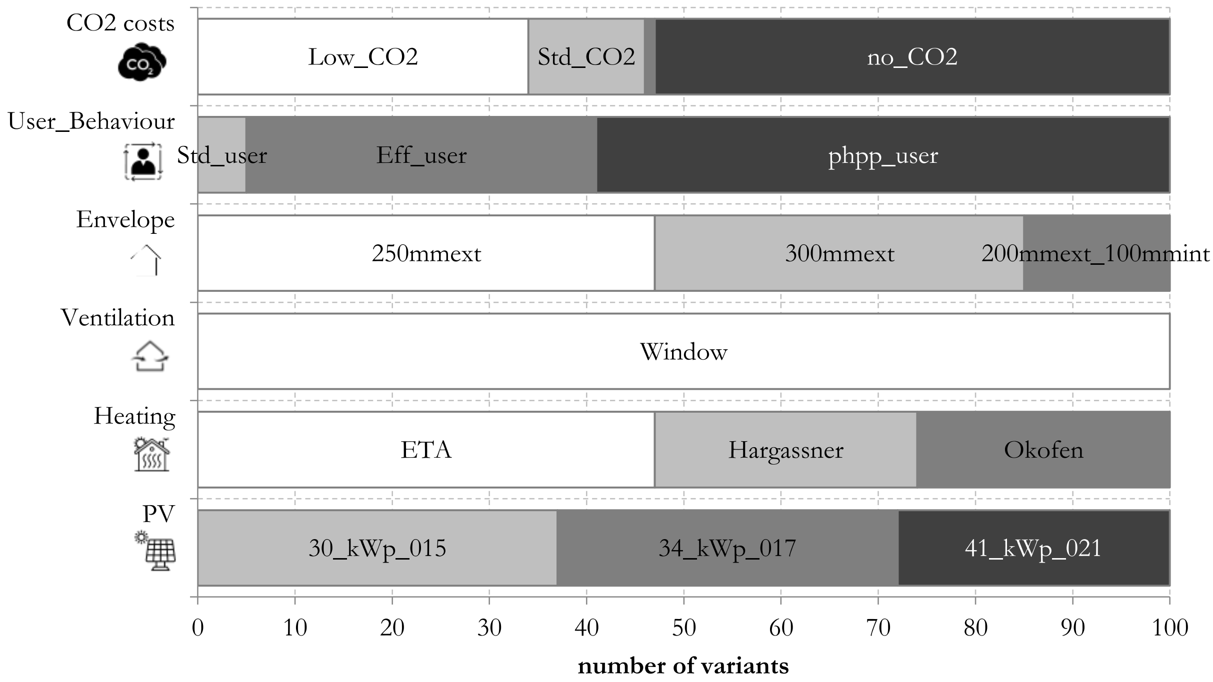

User_Behaviour Eff_user Not_eff_user phpp_user Std_user
financing costs [EUR/m²]
1260
1240
1220
1200
1180
85 90 95 100 105 110 115 120 125
PE balanced [kWh/m²a]


User_Behaviour Eff_user Not_eff_user phpp_user Std_user
net present value (total) [EUR/m²]
1800
1750
1700
1650
1600
1550
1500
1450
22 24 26 28 30 32
CO2 balanced [kg/m²a]

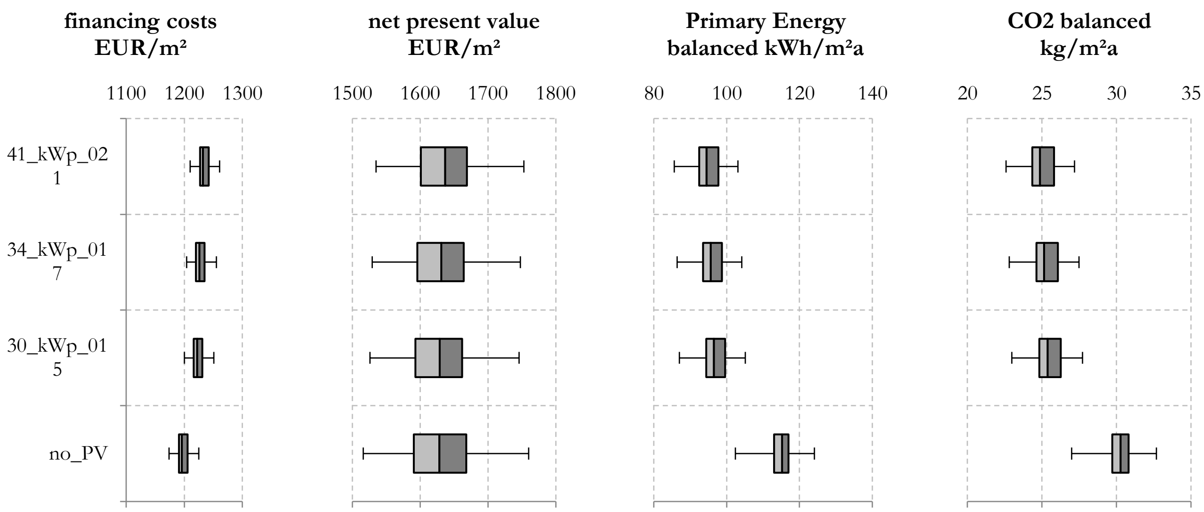

Sensitivity High_sens Low_sens phpp_sens Std_sens
financing costs [EUR/m²]
1260
1240
1220
1200
1180
85 90 95 100 105 110 115 120 125
PE balanced [kWh/m²a]

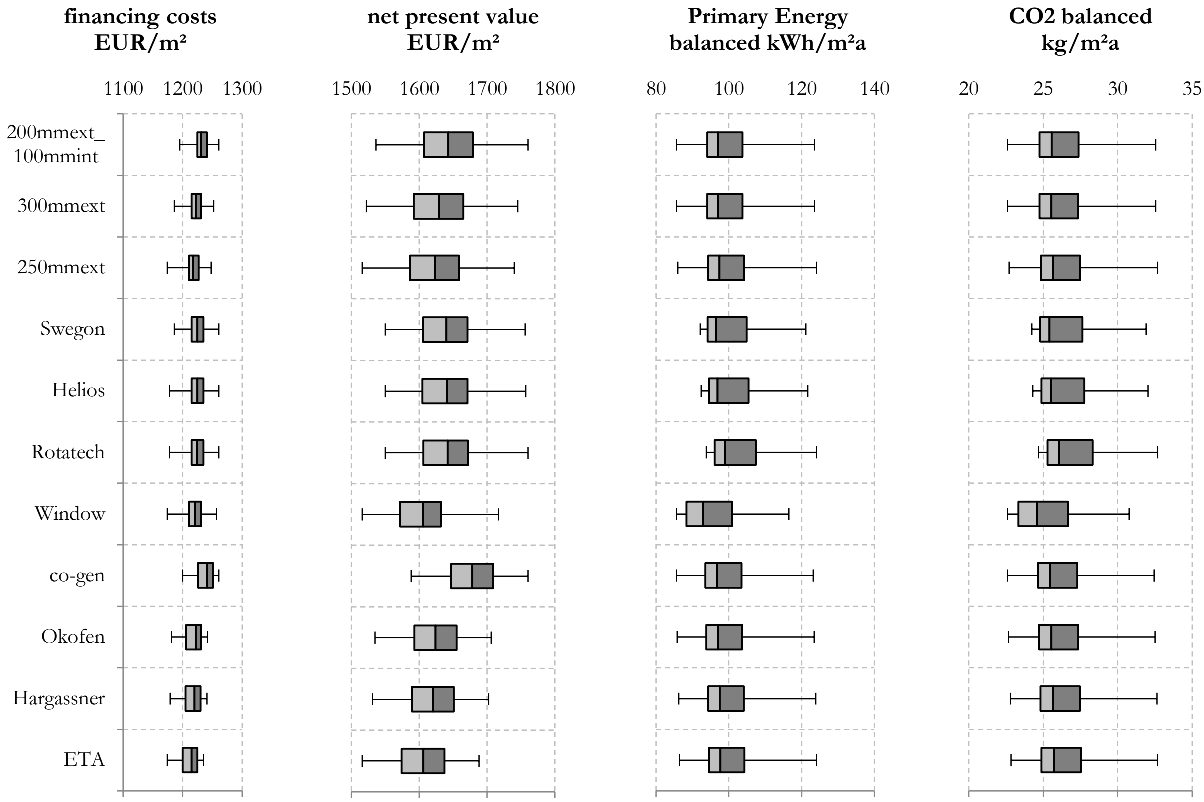

Sensitivity High_sens Low_sens phpp_sens Std_sens
net present value (total) [EUR/m²]
1800
1750
1700
1650
1600
1550
1500
1450
22 24 26 28 30 32
CO2 balanced [kg/m²a]

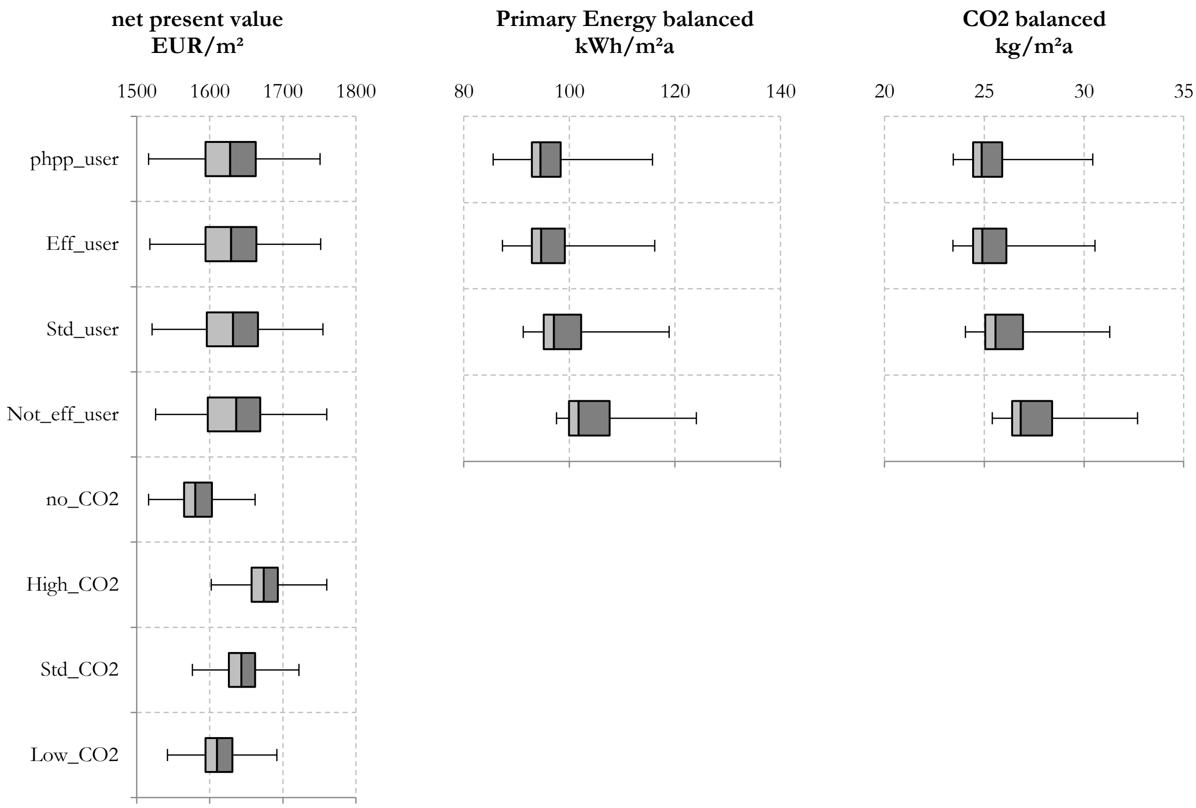
11.5.3. TOP100 EVALUATION



11.5.4. BOXPLOTS




financing costs EUR/m²
1100
1200
1300
net present value EUR/m²
1500
1600
1700
1800
Primary Energy balanced kWh/m²a
80
100
120
140
CO2 balanced kg/m²a
20
25
30
35
200mmext_ 100mmint
300mmext
250mmext
Swegon
Helios
Rotatech
Window
co-gen
Okofen
Hargassner
ETA


net present value EUR/m²
1500
1600
1700
1800
Primary Energy balanced kWh/m²a
80
100
120
140
CO2 balanced kg/m²a
20
25
30
35
phpp_user
Eff_user
Std_user
Not_eff_user
no_CO2
High_CO2
Std_CO2
Low_CO2

11.5.5. DATA FROM THE BOXPLOTS

		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
Low CO2 costs	minimum	1174	1542	86	23
	median	1224	1610	97	26
	maximum	1261	1692	124	33
	standard deviation	18	33	9	2
Standard CO2 costs	minimum	1182	1576	86	23
	median	1224	1643	97	26
	maximum	1261	1722	124	33
	standard deviation	18	33	9	2
High CO2 costs	minimum	1182	1602	86	23
	median	1224	1674	97	26
	maximum	1261	1760	124	33
	standard deviation	18	34	9	2
No CO2 costs	minimum	1182	1516	86	23
	median	1224	1580	97	26
	maximum	1261	1662	124	33
	standard deviation	18	32	9	2
Not efficient user behaviour	minimum	1174	1526	98	26
	median	1224	1636	102	27
	maximum	1261	1760	124	33
	standard deviation	18	48	9	2
standard user behaviour	minimum	1182	1521	91	24
	median	1224	1632	97	26
	maximum	1261	1755	119	31
	standard deviation	18	47	9	2
efficient user behaviour	minimum	1182	1518	87	23
	median	1224	1629	95	25
	maximum	1261	1752	116	31
	standard deviation	18	47	9	2
PHPP default user behaviour	minimum	1182	1516	86	23
	median	1224	1628	95	25
	maximum	1261	1751	116	30
	standard deviation	18	47	9	2
No PV	minimum	1174	1516	102	27
	median	1196	1629	115	30
	maximum	1225	1760	124	33
	standard deviation	12	52	5	1
30 kWp PV	minimum	1200	1526	87	23
	median	1222	1629	96	25
	maximum	1251	1746	105	28
	standard deviation	12	46	4	1
34 kWp PV	minimum	1204	1529	86	23
	median	1226	1631	96	25
	maximum	1255	1748	104	27
	standard deviation	12	46	4	1
41 kWp PV	minimum	1210	1535	86	23
	median	1232	1637	95	25
	maximum	1261	1753	103	27
	standard deviation	12	45	4	1
ETA boiler	minimum	1174	1516	86	23
	median	1215	1606	98	26
	maximum	1235	1688	124	33
	standard deviation	15	39	9	2
Hargassner boiler	minimum	1179	1531	86	23
	median	1220	1620	97	26
	maximum	1241	1702	124	33
	standard deviation	15	39	9	2
Ökofen boiler	minimum	1181	1535	86	23
	median	1222	1624	97	26
	maximum	1242	1706	123	33
	standard deviation	15	39	9	2
Co-generation plant	minimum	1200	1588	86	23
	median	1241	1678	97	25

		financing costs (EUR/m²)	net present value (EUR/m²)	PE balanced (kWh/m²a)	CO2 balanced (kg/m²a)
	maximum	1261	1760	123	32
	standard deviation	15	39	9	2
Window ventilation	minimum	1174	1516	86	23
	median	1221	1606	93	25
	maximum	1257	1717	116	31
	standard deviation	18	43	9	2
Rotatech ventilation unit	minimum	1178	1550	94	25
	median	1224	1642	99	26
	maximum	1261	1760	124	33
	standard deviation	18	46	9	2
Helios ventilation unit	minimum	1178	1550	92	24
	median	1225	1641	97	26
	maximum	1261	1757	122	32
	standard deviation	18	46	9	2
Swegon ventilation unit	minimum	1186	1550	92	24
	median	1225	1640	96	25
	maximum	1261	1756	121	32
	standard deviation	18	45	9	2
250 mm external wall insulation	minimum	1174	1516	86	23
	median	1218	1623	97	26
	maximum	1248	1740	124	33
	standard deviation	17	47	9	2
300 mm external wall insulation	minimum	1186	1522	86	23
	median	1222	1629	97	26
	maximum	1252	1745	124	33
	standard deviation	17	46	9	2
200 mm external and 100 mm internal wall insulation	minimum	1195	1536	86	23
	median	1231	1643	97	26
	maximum	1261	1760	124	33
	standard deviation	17	46	9	2