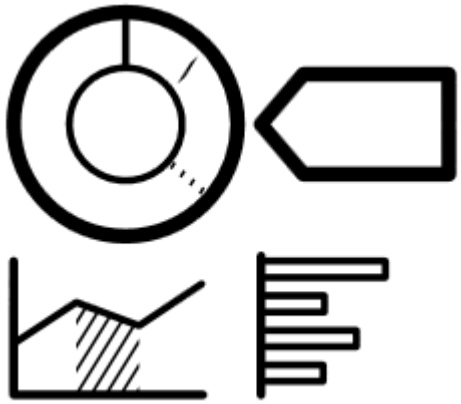
D2.4: KPIs for performance-based characterisation of nZEB



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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D2.4: KPIs for performance-based characterisation of nZEB

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FOREWORD

This report has been developed within Task 2.4 and concludes the activities of Work Package 'WP02 – Life Cycle Costs of nZEBs / Case Studies, part of the Horizon2020 - CRAVEzero project.
CRAVEzero focuses on proven and new approaches to reduce the costs of nearly-Zero Energy Buildings (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 lifecycle.
To evaluate and compare different configurations a performance-based characterisation of nZEB is needed. In task 2.1, the implementation of nZEBs at European level was analysed. In the section where the nZEB requirements for different countries were compared, a few key performance indicators (KPI) were defined to draw a comparison among different requirements. Later, the relevance of defining a full set of KPIs arose within task 2.2, where it was necessary to summarise and display the results collected from the case studies. In this document, the procedure followed to define the KPIs for the evaluation, as well as the set of benchmarks identified from the CRAVEzero the case studies is described.

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EXECUTIVE SUMMARY

Key Performance Indicators (KPIs) are defined to measure the performance of buildings and to provide easily accessible and useful information about building performance (H2020 project Exceed).
Within the project CRAVEzero, the definition of a set of KPIs aims to provide a comprehensive evaluation of nZEBs cost and performances and, starting from the project case studies, to introduce reference benchmarks for nZEBs in the EU.
This deliverable is coupled with D2.2 "Spreadsheet with LCCs", that reports the detailed specificities for the calculation of most the indicators as well as the normalisation factors applied.

The list of KPIs has been defined through a selection starting from a pre-defined set of indicators taken from literature and relevant research projects dealing with the building performance evaluation.
The list was submitted to the project partners, with the request to rate the KPIs on a scale of 1-3 ("3 - very interesting", "2 - interesting" and "1 - not interesting"). According to the ranking, it has been decided to include in the final list the KPIs with an average score ranging from 2 to 3. Table 1 reports the selected indicators.

Table 1. Selected indicators

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

The selected KPIs have been implemented within task 2.2 for the evaluation of the cost and performances of the CRAVEzero case studies.

In particular, the indicators have been combined in the CRAVEzero spreadsheet in both numerical and graphical form including a comprehensive description of the life cycle cost of nZEB normalised for an EU-wide comparison of the results.

One of the backbones of WP2 is the analysis of the exemplary nZEB case studies aimed at identifying a set of relevant benchmarks for nZEB performances and cost during the life cycle as a reference for the activities within the project. Thanks to the normalisation approach as described within D2.2 "Spreadsheet with LCCs", that considers the national specificities in terms of market and environmental issues, it is possible to adopt the average values calculated for the case studies, as reference benchmarks for new nZEBs (Figure 3).

It is important to point out that, although the results are referred to a limited number of case studies (i.e. 12), the detail of the data describing each nZEB and the relevance of the methodology applied allowed to reach a good level of reliability.

Table 2 summarises the main indicators calculated for the case studies, giving an overview of cost and performances of exemplary nZEB case studies across Europe.

Table 2. Indicators assessed for the case studies

Case Studies	**KPI Results**											
	Design	**Construction**	**Investment**	**Maintenance**	**Energy cost**	**Cost of RES**	**Energy demand heating**	**Energy demand for DHW**	**Energy produced from RES**	**Annual CO2 Emissions**	**U-opaque**	**U-glazing**
	€/m²	€/m²	€/m²	€/m²	€/m²	€/m²	kWh/m²	kWh/m²	kWh/m²	$kgCO_2/m^2$	W/(m²K)	W/(m²K)
Green-Home	-	1051.98	1051.98	748.55	-749.87	28.51	6.45	5.80	185.89	22.13	0.12	0.83
Les Héliades	91.11	1158.59	1249.71	691.41	355.37	43.88	22.56	18.88	12.00	11.60	0.22	1.51
Residence Alizari	161.38	852.99	1014.37	589.13	417.40	28.78	12.77	34.16	10.52	22.00	0.17	0.97
NH Tirol	52.10	994.92	1047.02	625.06	268.88	-	12.13	19.03	-	16.42	0.15	0.73
Parkcarré	230.42	697.11	927.53	439.60	142.73	53.33	23.27	14.82	25.94	10.59	0.27	0.85
More	201.14	2771.67	2972.82	2073.85	444.21	38.69	19.49	12.13	-	29.34	0.20	1.20
Isola nel Verde A	-	2249.89	2249.89	1370.61	644.71	-	30.03	23.53	2.88	46.00	0.25	1.18
Isola nel Verde B	-	2072.63	2072.63	1292.11	665.05	-	30.45	23.34	2.32	45.91	0.28	1.20
Solallén	125.74	1062.84	1188.58	384.15	216.51	56.80	18.38	6.26	4.44	27.49	0.07	0.92
Väla Gård	142.35	1291.63	1433.98	774.42	95.22	71.38	15.64	1.35	34.01	25.37	0.07	0.87
Aspern	131.82	844.76	976.58	497.95	178.22	39.44	16.78	7.15	14.55	13.32	0.10	0.92
I+R. Schertler	393.13	2215.74	2608.86	1283.76	499.64	-	17.42	0.20	-	83.78	0.21	0.75

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1.INTRODUCTION

Key Performance Indicators (KPIs) are defined to measure the performance of buildings and to provide easily accessible and useful information about building performance (H2020 project Exceed). Usually, KPIs guide design development, allow comparing design solutions and support the decision making process.
The KPIs approach is functional for benchmarking different building attributes or features, facilitating decision making, assessing specific project requirements, or ensuring compliance with regulations and standards. For instance policymakers and stakeholders can use selected indicators to monitor the building stock and progress towards meeting national targets, building managers and owners for monitoring building performance and for defining energy conservation measures (Balaras et al., 2014). Planners in the design phase can compare and test different design scenarios to optimize building construction and operation.
Within the project CRAVEzero, the definition of a set of KPIs aims to provide a comprehensive evaluation of nZEBs cost and performances and, starting from the project case studies, to introduce reference benchmarks for nZEBs in the EU.
This report presents the method for the selection of the relevant KPIs, to describe the approach for the assessment of the selected ones, to show the structure of the CRAVEzero nZEB spreadsheet and to identify a set of relevant benchmarks gathered from the CRAVEzero analysed case studies.
This deliverable is coupled with D2.2 "Spreadsheet with LCCs", that reports the detailed specificities for the calculation of most the indicators as well as the normalisation factors applied.

2.KPIS SELECTION

2.1. SELECTION PROCEDURE

The list of KPIs has been defined through a selection starting from a pre-defined set of indicators taken from literature and relevant research projects dealing with the building performance evaluation.
In particular, it has been surveyed CRAVEzero partners, requiring them to rate a list of KPIs. In the project, different stakeholders are involved: research institutes, general contractors, research and housing companies. AEE Intec and Fraunhofer ISE (research institute), ATP sustain (planning company), Köhler & Meizer (housing company) and Skanska (general contractor) participated in the survey. This heterogeneity provides different expertise and different points of view regarding nZEBs, which leads to different requirements when it comes to KPIs, ensuring a broad analysis spectrum in the selection phase.

The preliminary list contains a set of pre-defined of indicators belonging to two main classes, cost-and performance-indicators.
In particular, it includes the main parameters such as LCC, WLCC, investment cost, operation cost, both as absolute- and normalised-valuesas well as the overall energy performance of the building. Also, the survey introduced indicators combining cost and performances, such as LCC and investment cost vs renewable energy share, shape factor, usable floor surface, etc.
The list was submitted to the project partners, with the request to rate the KPIs on a scale of 1-3 ("3 - very interesting", "2 - interesting" and "1 - not interesting"). According to the ranking, it has been decided to include in the final list the KPIs with an average score ranging from 2 to 3.

Table 1 shows an example of the rating process, in green the indicators selected and in red the discarded ones.

Table 1: Example of the rating process.

KPIS	AEE INTEC	ATP	ISE	K&M	SKANSKA	MEAN
LCC	3	3	3	1	2	2.4
LCC/usable floor surface	3	3	3	3	3	3.0
LCC/usable to gross floor surface ratio	1	3	2	1	1	1.6
LCC/shape factor	1	1	1	1	1	1.0
LCC/ window to wall ratio	1	1	1	1	1	1.0

Table 2 reports the overall list of indicators and the outcomes of the survey among project partners.
The selected KPIs show a higher interest in general cost indicators, both absolute and normalised by usable floor surface. Energy indicators related to the relevant energy demand and renewable energy production categories came out with a high rating too as well as indicators on CO_2 emissions. The indicators combining cost and performance have been evaluated as less interesting, and have been discarded by the rating.

Table 2: list of KPIs with the relative evaluation

RATING	KPI	RATING	KPI
3	LCC/usable floor surface	2.4	Cooling energy demand for cooling
2.8	Investment cost/usable floor surface	2.4	Energy demand for hot water production
2.6	Operation cost/usable floor surface	2.4	Annual renewable energy generation
2.6	Renewable energy share	2.2	Maintenance cost/usable floor surface
2.6	PV annual electricity yield	2.2	Maintenance cost/investment cost
2.6	Annual CO_2 emissions	2.2	Final energy consumption
2.5	Life-cyde CO_2 emissions	2.2	Specific heating demand
2.4	LCC	2.2	Specific cooling energy consumption
2.4	WLC	2.2	Specific hot water energy consumption
2.4	Investment cost	2.2	Specific electricity energy demand
2.4	Operation cost	2	LCC/renewable energy installed capacity
2.4	Maintenance cost	2	Operation cost/PV energy production
2.4	Primary energy consumption	2	Electricity energy demand (lighting, appliances)
2.4	Heating demand for heating	2	Energy demand for ventilation
1.8	End-of-life cost	1.2	Maintenance cost/exchange technical equipment
1.8	End-of-life cost/usable floor surface	1	LCC/shape factor
1.6	LCC/usable to gross floor surface ratio	1	LCC/window to wall ratio
1.6	LCC/renewable energy share	1	LCC/air tightness
1.6	WLCC/LCC	1	Investment cost/shape factor
1.5	Operation cost/energy price	1	Investment cost/window to wall ratio
1.4	LCC/HVAC efficiency (SEER)	1	Investment cost/air tightness
1.2	LCC/average U-value opaque components	1	Investment cost/average U-value opaque components

Rating	KPI	Rating	KPI
1.2	LCC/average U-value glazing components	1	Investment cost/average U-value glazing components
1.2	LCC/generation system efficiency	1	Operation cost/average U-value opaque components
1.2	LCC/distribution system efficiency	1	Operation cost/average U-value glazing components
1.2	LCC/ventilation heat recovery efficiency	1	Operation cost/air tightness
1.2	Operation cost/distribution sys. efficiency	1	Operation cost/vent. heat recovery efficiency
1.2	Operation cost/HVAC efficiency (SEER)	1	Maintenance cost/renewable energy share

The selected KPIs have been implemented in Tasks 2.1 and 2.2 (see paragraph 3) to analyse the nZEB case studies and to build-up the display results and draw comparisons among case studies and countries, according to the specific need and the information availability related to the data collection.
It is also interesting going through the discarded KPIs, to better understand which indicators were rated very interesting and which were considered less relevant. Table 2 reports in red the proposed indicators, which received a rating below "2". This group includes all the cost parameters expressed in relation to building features, such as U-values, shape factor and performance parameters, such as air tightness, the heat recovery efficiency of the ventilation. It is relevant to point out that the end-of-life cost did not receive a high score and therefore has been discarded. This is mainly due to the lack of data and a shared approach to evaluate this indicator providing reliable figures, especially for nZEBs.

2.1. ASSESSMENT OF THE SELECTED KPIS

This section describes the selected indicators and provides an approach for the assessment.
The specific boundary conditions, references and normalisation factors of the indicators are defined in detail within Deliverable 2.2 "Spreadsheet with LCCs".

Indicator 1: **Investment cost [€]:** investment cost includes the amount due for design, construction (labour and materials) as well as for the building site management during the construction works

Indicator 2: **Operation cost** [€]: the operation includes the net energy cost during the life cycle for heating, cooling ventilation, domestic hot water production and electricity for lighting and appliances, considering the amount of energy supply for renewable energy sources:

$$O_c = \sum_{i=1}^{n} E_{el} - (E_{PV} + E_w) + E_{th} - E_{ST}, \text{ where:}$$

- E_{el}, E_{th}: electrical and thermal energy consumed during the life cycle
- E_{PV}, E_W, E_{ST}: renewable energy produced during the life cycle by photovoltaic, wind and solar thermal system

Indicator 3: **Maintenance cost** [€]: real and predicted cost for the maintenance of the envelope elements and the technical services of the building during the life cycle. The reference for standard, with a particular focus on the HVAC system, is the EN 15459:2017 "*Energy performance of buildings - Economic evaluation procedure for energy systems in buildings.*"

Indicator 4: **Life Cycle Cost LCC** [€]: represents the sum of the discounted costs, revenue streams, and values during the life span of the building, including design, construction, operation and end-of-life cost. It is evaluated according to the ISO 15686-5:2008 as follows:

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

- 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: a period of analysis (40 years).

Indicator 5: **Whole Life Cycle Cost** [€]: represents the sum of the discounted costs, revenue streams, and values during the life span of the building, including the same cost as Indicator 7 and the initial non-construction cost (cost of land, fees and enabling costs, externalities).

Indicator 6: **LCC /usable floor surface** [€/m²]: it stands for Life Cycle Cost normalised according to the net usable surface of the building, including all the heated spaces without considering the area of the walls (neither external nor internal partitions). The LCC is evaluated according to the standard ISO 15686-5 with a period of 40 years and with the boundaries described in Deliverable 2.2.

Indicator 7: **Investment cost/usable floor surface** [€/m²]: investment cost includes the amount due for design, construction (labour and materials) as well as for the building site management of the building, normalised according to the surface as defined for Indicator 1.

Indicator 8: **Operation cost/usable floor surface** [€/m²]: operation includes energy and maintenance cost during the life cycle normalised as for Indicator 1.

Indicator 9: **Final energy consumption** [kWh]: energy consumption of final energy for heating, cooling, ventilation, domestic hot water production, lighting and appliances for each energy carrier during the life cycle

Indicator 10: **Primary energy consumption** [kWh]: predicted or measured yearly primary energy consumption for heating, cooling, ventilation, domestic hot water production, lighting and appliances calculated as:

$$EP = \sum_{i=1}^{n} EF_i \cdot F_{FP},$$

Where: EF_i [kWh] is the final energy associated with one specific fuel or energy carrier, and F_{FP} [-] is the conversion factor from final to primary energy

Indicator 11: **Electricity energy demand** [kWh]: final energy demand for lighting and the supply of building appliances

Indicator 12: **Renewable energy share** [%]: the amount of the energy consumption for each contribution (i.e. heating, cooling, ventilation, domestic hot water production and electrical consumption for lighting and appliances covered by renewable energy sources integrated into the building (i.e. photovoltaic system, solar thermal panels and wind energy sources)

Indicator 13: **PV annual electricity yield** [kWh/year]: annual electricity produced by the photovoltaic plant integrated into the building

Indicator 14: **Annual CO_2 emissions** [tons CO_2/year]: yearly CO2 emissions due to the energy consumed. The amount is evaluated through the following equation:

$$CO_{2,\,year} \sum_{i=1}^{n} E_i \cdot F_{CO2,i}, \text{ where}$$

- E_i represents the energy consumption divided according to the energy fuel and carrier
- $F_{CO2,i}$ stands for the national conversion factor for each energy fuel and carrier.

Indicator 15: **Life-cycle CO_2 emissions** [tons CO_2]: total CO_2 emissions due to energy consumption during the life cycle of the building evaluated as the sum of the annual CO_2 emission calculated as for Indicator 6

Indicator 16: **Yearly energy demand for heating** [kWh]: yearly energy demand of final energy (predicted or calculated) for heating

Indicator 17: **Yearly energy demand for cooling** [kWh]: yearly energy demand of final energy (predicted or calculated) for cooling

Indicator 18: **Yearly energy demand for hot water production** [kWh]: yearly energy demand for the production of the domestic hot water

Indicator 19: **Energy demand for ventilation** [kWh]: final energy demand for ventilation

Indicator 20: **Yearly renewable energy generation** [kWh]: annual energy produced by the renewable energy sources integrated into the building

Indicator 21: **Specific heating demand** [kWh/m²]: yearly final energy demand for heating normalised according to the net heated surface (neglecting the surface of external walls and internal partition as well as the unheated spaces)

Indicator 22: **Specific cooling energy consumption** [kWh/m²]: yearly final energy demand for cooling normalised as for Indicator 19

Indicator 23: **Specific hot water energy consumption** [kWh/m²]: yearly final energy demand for producing domestic hot water normalised as for Indicator 19

Indicator 24: **Specific electricity energy demand** [kWh/m²]: yearly final energy demand for lighting and the supply of building appliances normalised according to the net usable surface

Indicator 25: **LC Maintenance cost/usable floor surface** [€/m²]: maintenance cost during the life cycle normalised according to the net usable surface

Indicator 26: **Maintenance cost/investment cost** [-]: the ratio between maintenance cost during the life cycle and investment cost.

Indicator 27: **LCC/renewable energy installed capacity** [€/Kwh]*: the* ratio between LCC and the expected energy production from the renewable energy sources installed on the building during the life cycle

Indicator 28: **Operation cost/PV energy production** [€/kWh]: the ratio between the operation cost (energy consumption and maintenance cost) and the expected energy production from the photovoltaic plant installed

3. IMPLEMENTATION OF THE KPIS IN THE NZEB SPREADSHEET

The selected KPIs have been implemented within task 2.2 for the evaluation of the cost and performances of the CRAVEzero case studies.

In particular, the indicators have been combined in the CRAVEzero spreadsheet in both numerical and graphical form including a comprehensive description of the life cycle cost of nZEB normalised for an EU-wide comparison of the results.

Figure 1 shows the first page of the CRAVEzero spreadsheet, including an overview section of the main features of the case study and the KPIs related to investment costs and energy consumption. In particular, it reports the investment cost with the breakdown and a special focus on design and construction, and a detailed analysis of labour and material cost for each building and HVAC element with the impact on the investment. Finally, there is a section dedicated to the energy performance of the nZEB, including specific energy demand, consumption CO_2 emission and production from renewable energy sources.

The second page of the CRAVEzero spreadsheet (Figure 2) focus on life-cycle cost KPIs, with a general overview of the cost during the life span (40 years), a distribution according to the phase with a special focus on the maintenance and a detailed breakdown of the specific costs for each unit surface during all the phases of the life cycle.

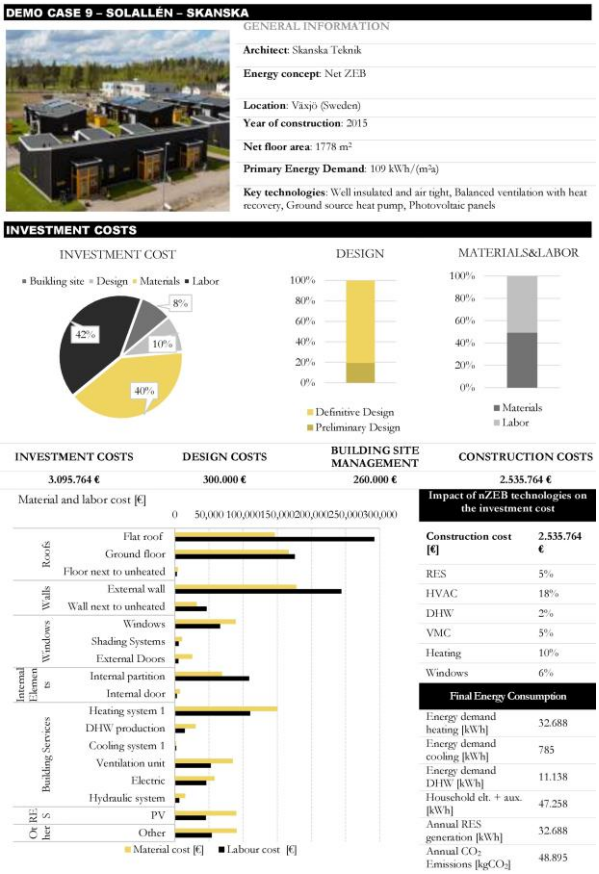


Figure 1: Investment KPIs.

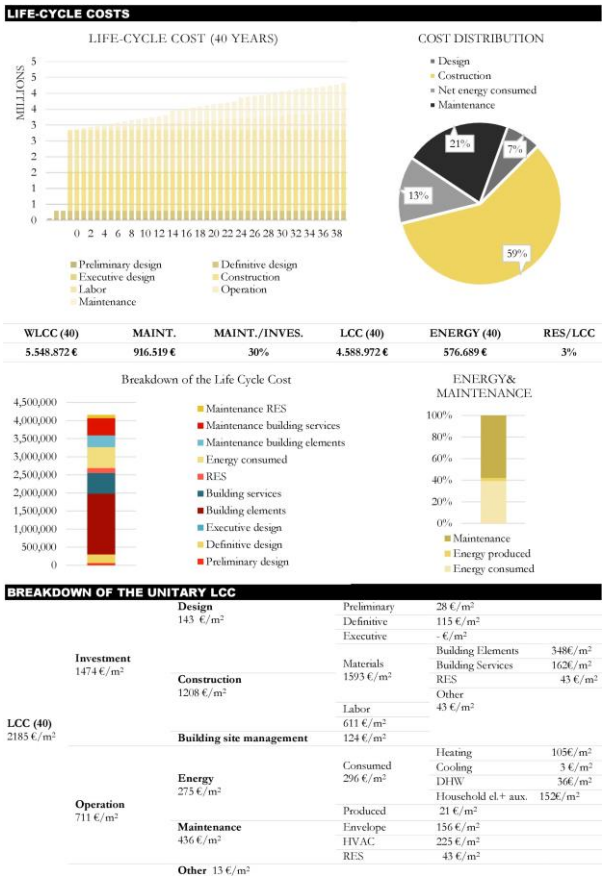


Figure 2: Life-cycle cost KPIs.

3.1. RELEVANT BENCHMARKS FROM THE CASE STUDIES

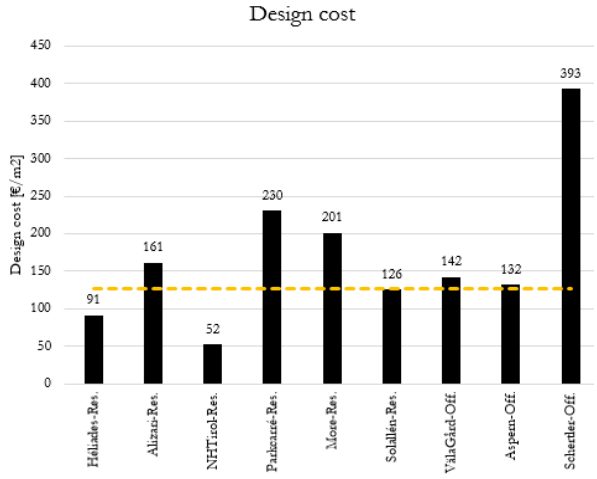
One of the backbones of WP2 is the analysis of the exemplary nZEB case studies aimed at identifying a set of relevant benchmarks for nZEB performances and cost during the life cycle as a reference for the activities within the project. Thanks to the normalisation approach as described within D2.2 "Spreadsheet with LCCs", that considers the national specificities in terms of market and environmental issues, it is possible to adopt the average values calculated for the case studies, as reference benchmarks for new nZEBs (Figure 3).
It is important to point out that, although the results are referred to a limited number of case studies (i.e. 12), the detail of the data describing each nZEB and the relevance of the methodology applied allowed to reach a good level of reliability.

Figure 3: Overview of the CRAVEzero case studies

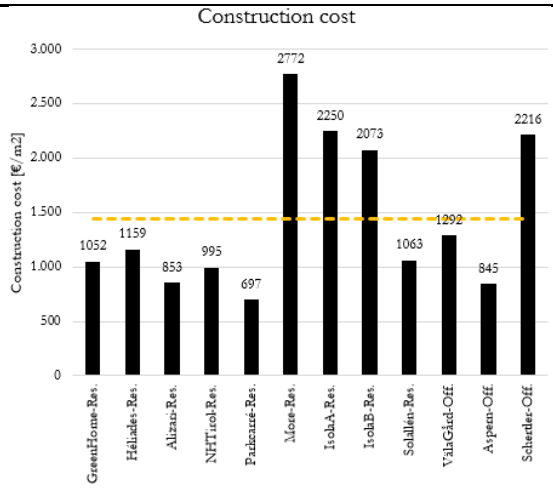
In the following, the main benchmarks identified for the CRAVEzero nZEB are reported.

3.1.1. COST BENCHMARKS

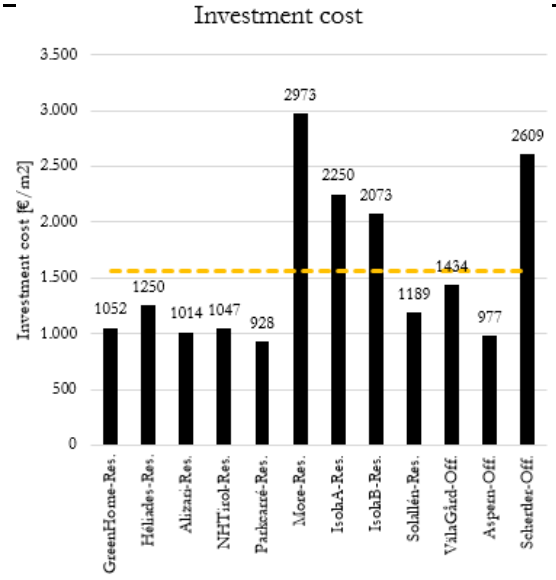
Design cost - Average value 127 €/m²



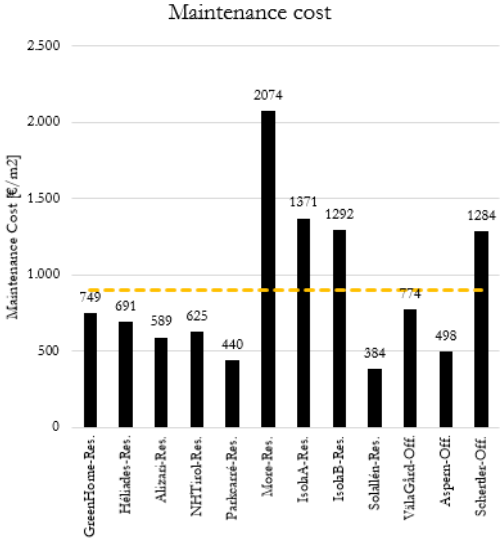
Construction cost - Average value 1439 €/m²



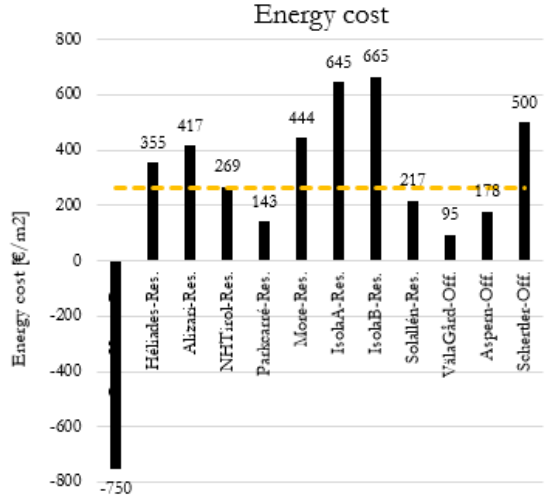
Investment cost Average value 1566 €/m²



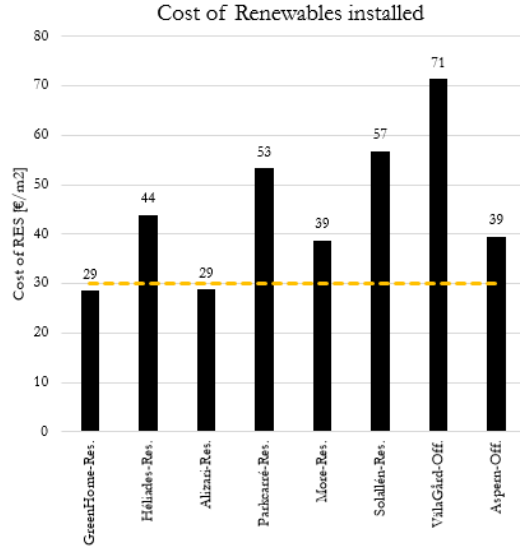
Maintenance cost – average value 898 €/m²



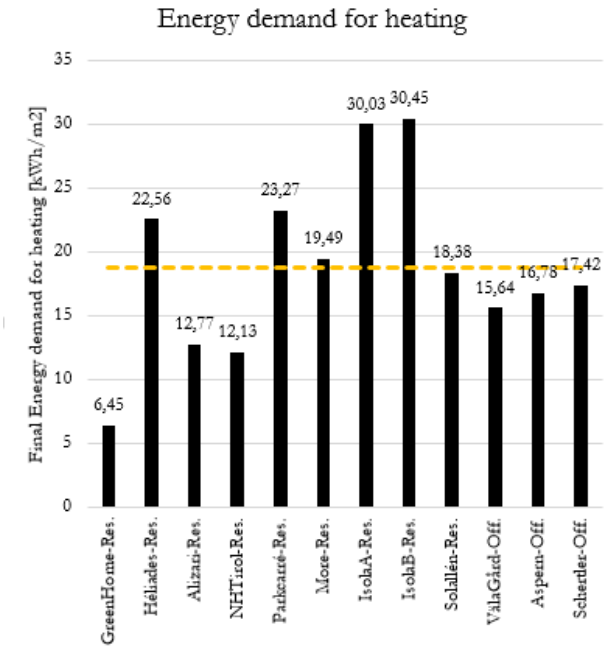
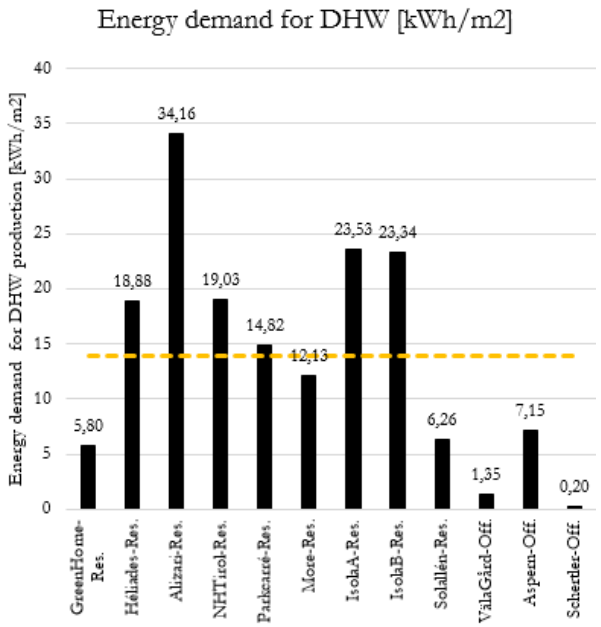
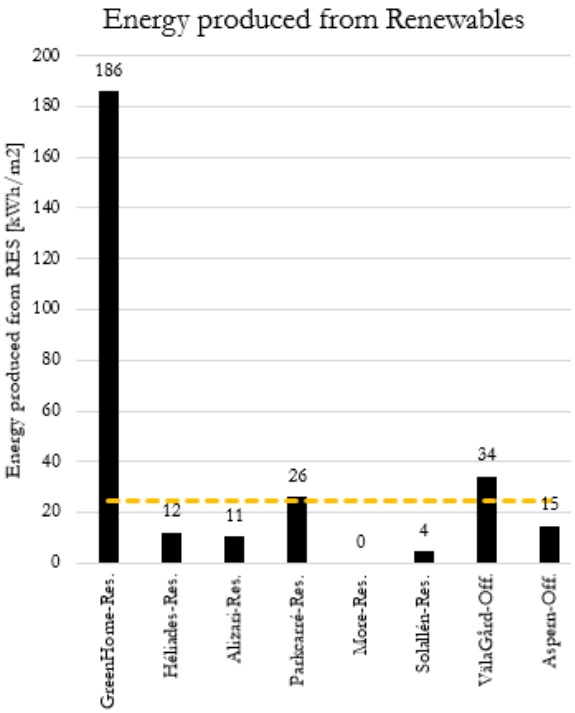
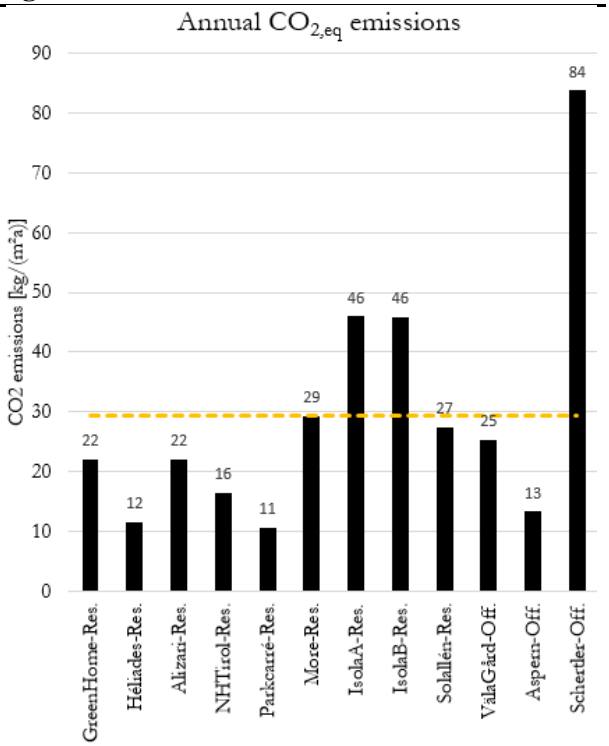
Energy cost – average value 265 €/m²



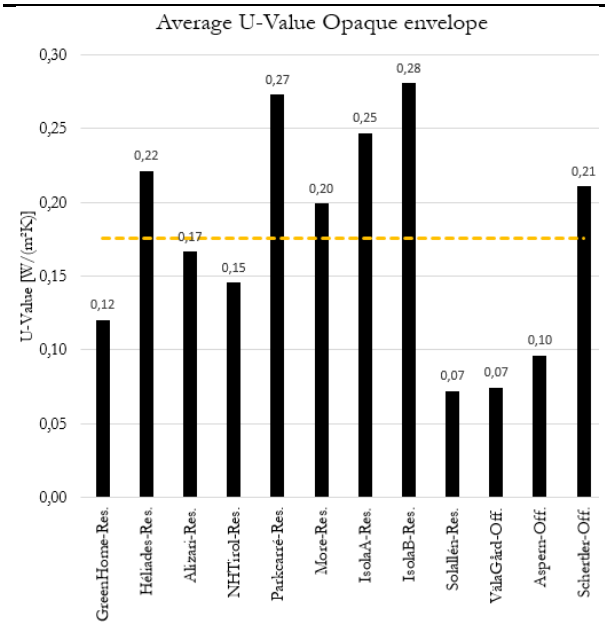
Cost of renewables – Average value 30 €/m2



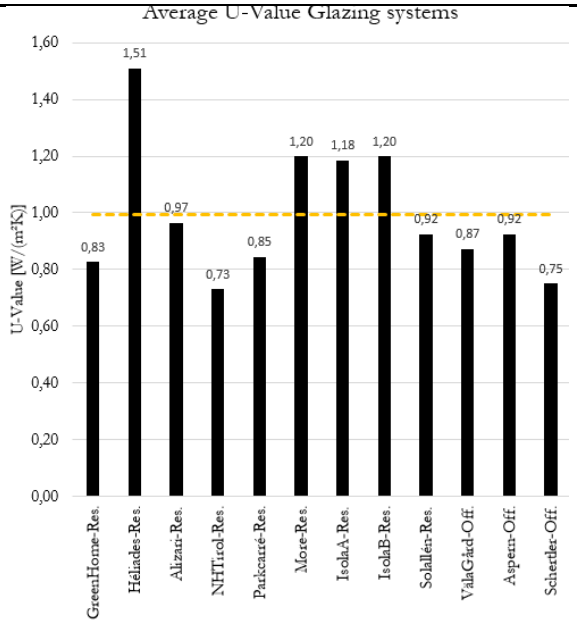
3.1.2. PERFORMANCE BENCHMARKS

Energy demand for heating Average value 18.8 kWh/m²	Energy demand for DHW Average value 13.9 kWh/m²
	
Energy produced from RES Average value 24 kWh/m²	**Annual CO_2 emissions - Average value 29 $kgCO_2/m^2$**
	

Thermal transmittance of the opaque envelope
Average value 0.18 W/(m² K)



Thermal transmittance of the glazing systems
Average value 0.99 W/(m² K)



4.CONCLUSIONS

The definition of suitable KPIs strongly depends on the purposes of the analysis. Within CRAVEzero, a set of exemplary case studies was evaluated and compared according to life cycle cost and performance, in order to provide a general overview of the nZEBs across Europe.

Table 3: Most relevant benchmark results of the CRAVEzero case studies

CASE STUDIES	KPI RESULTS											
	Design	Con-struc-tion	Invest-ment	Mainte-nance	Energy cost	Cost of RES	Energy demand heating	Energy demand for	Energy pro-duced	Annual CO2 Emis-	U-opaque	U-glaz-ing
	€/m²	€/m²	€/m²	€/m²	€/m²	€/m²	kWh/m²	kWh/m²	kWh/m²	kgCO₂/m²	W/(m²K)	W/(m²K)
Green-home	-	1051.98	1051.98	748.55	-749.87	28.51	6.45	5.80	185.89	22.13	0.12	0.83
Les Hélia-des	91.11	1158.59	1249.71	691.41	355.37	43.88	22.56	18.88	12.00	11.60	0.22	1.51
Residence Alizari	161.38	852.99	1014.37	589.13	417.40	28.78	12.77	34.16	10.52	22.00	0.17	0.97
Nh Tirol	52.10	994.92	1047.02	625.06	268.88	-	12.13	19.03	-	16.42	0.15	0.73
Parkcarré	230.42	697.11	927.53	439.60	142.73	53.33	23.27	14.82	25.94	10.59	0.27	0.85
More	201.14	2771.67	2972.82	2073.85	444.21	38.69	19.49	12.13	-	29.34	0.20	1.20
Isola nel verde a	-	2249.89	2249.89	1370.61	644.71	-	30.03	23.53	2.88	46.00	0.25	1.18
isola nel verde b	-	2072.63	2072.63	1292.11	665.05	-	30.45	23.34	2.32	45.91	0.28	1.20
Solallén	125.74	1062.84	1188.58	384.15	216.51	56.80	18.38	6.26	4.44	27.49	0.07	0.92
Väla Gård	142.35	1291.63	1433.98	774.42	95.22	71.38	15.64	1.35	34.01	25.37	0.07	0.87
Aspern	131.82	844.76	976.58	497.95	178.22	39.44	16.78	7.15	14.55	13.32	0.10	0.92
I+R. Schertler	393.13	2215.74	2608.86	1283.76	499.64	-	17.42	0.20	-	83.78	0.21	0.75

The KPI selection has been carried out through a survey on the relevant stakeholders within the consortium, who rated the relevance of each pre-defined indicator. Accordingly, the selection of the most relevant indicators has been carried out, as a reference for the activities within the project and for providing interesting benchmarks on the nZEB features, performances and cost across Europe.
The consistency of the results is increased by the level of detail of the data and information used for evaluating the benchmarks and, although the number of case studies is quite small, the benchmarks as calculated within the project are relevant indicators for analysing the nZEB building stock across Europe.
Table 3 summarises the KPI results as repoerted in Section 3.

5. APPENDIX – DETAILED CASE STUDY RESULTS

Annex 1 summarises all the indicators and relevant values calculated for the CRAVEzero case studies. The values are normalised according the approach described in D2.2 "Spreadsheet with LCCs".

	Indicator	Unit	GreenHome-Res.	Héliades-Res.	Alizari-Res.	NHTirol-Res.	Parkcarré-Res.	More-Res.	IsolaA-Res.	IsolaB-Res.	Solallén-Res.	VälaGärd-Off.	Aspern-Off	Schertler-Off.
Geometry	Treated floor area (PHPP)	k m²	9.27	4.65	2.19	44.96	1.19	0.13	1.28	1.59	1.78	1.67	6.63	2.93
	NFA	k m²	9.27	4.59	2.78	44.96	1.11	0.13	1.41	1.75	1.78	1.67	8.82	2.76
	GFA	k m²	10.83	540	283	52.56	1.29	0.18	1.64	2.02	2.10	1.82	10.62	3.23
	GFA/NFA	%		18	2		16	38	16	16	18	9	20	
General Information	Construction cost index	%	103	103	103	100	97	94	94	94	134	134	100	100
	Shape factor	m²/m³	-	0.4	0.4	-	0.4	0.8	0.5	0.5	-	0.4	0.4	-
	Window to wall ratio	%	35	19	15	25	17	19	11	10	5	12	5	27
	HDD	°C	2702	2377	2702	4256	3730	2616	2616	2616	4010	3720	2844	3413
	Building use / Typology	-	Res	Res	Res	Res	Res	Res	Res	Res	Res	Off	Off	Off
Design	Design cost	M€	-	0.43	0.47	2.36	0.25	0.02	-	-	0.30	0.32	1.17	1.09
	Design cost (GFA)	k€/m²	-	0.08	0.17	0.05	0.19	0.14	-	-	0.14	0.18	0.11	0.34
	Design cost (NFA)	k€/m²	-	0.10	0.17	0.05	0.22	0.19	-	-	0.17	0.19	0.13	0.40
	Design cost (GFA-CCI)	k€/m²	-	0.08	0.16	0.05	0.20	0.15	-	-	0.11	0.13	0.11	0.34
	Design cost (NFA-CCI)	k€/m²	-	0.09	0.16	0.05	0.23	0.20	-	-	0.13	0.14	0.13	0.39
	Design cost/LCC	%	-	0.00	0.01	0.00	0.02	0.00	-	-	0.01	0.01	0.01	0.01
Materials	Cost of materials	M€	9.8	5.5	2.4	45	0.71	0.3	2.8	3.20	1.2	1.8	5.7	6.2
	Cost of materials (GFA)	k€/m²	0.91	1.02	0.87	0.86	0.58	1.72	1.73	1.59	0.60	1.01	0.54	1.91
	Cost of materials (NFA)	k€/m²	1.06	1.20	0.89	1.00	0.67	2.36	2.01	1.85	0.70	1.10	0.65	2.23
	Cost of materials (GFA-CCI)	k€/m²	0.87	0.99	0.84	0.85	0.60	1.83	1.85	1.70	0.44	0.75	0.54	1.90
	Cost of materials (NFA-CCI)	k€/m²	1.02	1.16	0.85	1.00	0.70	2.52	2.15	1.97	0.53	0.82	0.64	2.22
	Materials/LCC	%	50	53	44	50	45	45	49	48	27	38	39	48
Labor	Labor cost	M€	0.29	-	-	-	-	0.03	0.14	0.16	1.28	1.06	1.78	-
	Labor cost (GFA)	k€/m²	0.03	-	-	-	-	0.17	0.08	0.08	0.61	0.58	0.17	-
	Labor cost (NFA)	k€/m²	0.03	-	-	-	-	0.23	0.10	0.09	0.72	0.63	0.20	-
	Labor cost (GFA-CCI)	k€/m²	0.03	-	-	-	-	0.18	0.09	0.09	0.46	0.43	0.17	-
	Labor cost (NFA-CCI)	k€/m²	0.03	-	-	-	-	0.25	0.10	0.10	0.54	0.47	0.20	-
	Labor/LCC	%	2.5	-	-	-	-	4.4	2.4	2.4	28.0	21.9	12.1	-
Other	Building site management	k€	63	223	431	634	-	14	-	-	260	229	344	17
	Non-construction cost	k€	-	16	28	-	307	8	2	-	960	410	3236	165
	Building site management (GFA)	k€/m²	0.01	0.04	0.15	0.01	0.00	0.08	-	-	0.12	0.13	0.03	0.01
	Building site management (NFA)	k€/m²	0.01	0.05	0.16	0.01	0.00	0.11	0.00	-	0.15	0.14	0.04	0.01

	Indicator	Unit	GreenHome-Res.	Héliades-Res.	Alizari-Res.	NHTirol-Res.	Parkcarré-Res.	More-Res.	IsolaA-Res.	IsolaB-Res.	Solallén-Res.	VälaGärd-Off.	Aspern-Off.	Schertler-Off.
	Non-construction cost (GFA)	k€/m²	0.00	0.00	0.01	0.00	0.24	0.04	0.00	0.00	0.46	0.23	0.31	0.05
	Non-construction cost (NFA)	k€/m²	0.00	0.00	0.01	0.00	0.28	0.06	0.00	0.00	0.54	0.25	0.37	0.06
	Building site management/LCC	%	1	2	8	1	0	2	0	0	6	5	2	0
	Non-construction cost/LCC	%	0	0	1	0	19	1	0	0	21	9	22	1
Investment	Investment cost	M€	10.19	6.18	3.36	48.02	0.99	0.37	2.97	3.39	3.10	3.44	9.01	7.26
	Investment cost (GFA)	k€/m²	0.94	1.10	1.04	0.90	0.77	2.02	1.82	1.67	1.35	1.77	0.82	2.25
	Investment cost (NFA)	k€/m²	1.09	1.30	1.05	1.05	0.90	2.78	2.11	1.94	1.60	1.92	0.98	2.63
	Investment cost (GFA-CCI)	k€/m²	0.90	1.06	1.00	0.90	0.80	2.16	1.94	1.79	1.01	1.32	0.81	2.23
	Investment cost (NFA-CCI)	k€/m²	1.05	1.25	1.01	1.05	0.93	2.97	2.25	2.07	1.19	1.43	0.98	2.61
	Investment/LCC	%	88	60	60	53	60	55	51	50	67	71	61	57
Energy	Energy consumed	M€	2.16	1.12	0.69	14.49	0.40	0.06	1.02	1.30	0.62	0.35	2.07	1.88
	Energy consumed (NFA-HDD-Price)	k€/m²	0.28	0.45	0.52	0.27	0.31	0.44	0.66	0.68	0.23	0.23	0.28	0.50
	Cost of energy produced	M€	7.97	0.24	0.14	0.00	0.21	0.00	0.03	0.03	0.04	0.20	0.77	0.00
	Net energy consumed	M€	-5.81	0.88	0.56	14.49	0.19	0.06	1.00	1.27	0.58	0.14	1.31	1.88
	Net energy consumed (GFA)	k€/m²	-0.54	0.16	0.20	0.28	0.15	0.31	0.61	0.63	0.28	0.08	0.12	0.58
	Net energy consumed (NFA)	€/m²	-0.63	0.19	0.20	0.32	0.17	0.43	0.71	0.73	0.32	0.09	0.15	0.68
	Net energy consumed (GFA-HDD)	k€/m²	-0.62	0.22	0.23	0.20	0.12	0.38	0.73	0.75	0.22	0.07	0.14	0.54
	Net energy consumed (NFA-HDD)	k€/m²	-0.73	0.25	0.23	0.24	0.14	0.52	0.85	0.87	0.25	0.07	0.16	0.63
	Energy price (energy consumed)	€/kWh	0.155	0.114	0.089	0.141	0.159	0.186	0.210	0.210	0.187	0.120	0.146	0.200
	Average price	€/kWh	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
	Net energy consumed (GFA-HDD-Price)	k€/m²	-0.64	0.30	0.41	0.23	0.12	0.32	0.56	0.57	0.18	0.09	0.15	0.43
	Net energy consumed (NFA-HDD-Price)	k€/m²	-0.75	0.36	0.42	0.27	0.14	0.44	0.65	0.67	0.22	0.10	0.18	0.50
	Energy consumed/LCC	%	19	11	12	16	24	8	18	19	14	7	14	15
	Energy produced/LCC	%	-69	-2	-2	0	-13	0	0	0	-1	-4	-5	0
	Net Energy consumed/LCC	%	-50	9	10	16	11	8	17	19	13	3	9	15
	Average	%	12	12	12	12	12	12	12	12	12	12	12	12
Maintenance	Maintenance cost	M€	7.21	3.30	1.70	28.29	0.47	0.25	1.81	2.11	0.92	1.74	4.42	3.57
	Maintenance cost (GFA)	k€/m²	0.67	0.61	0.60	0.54	0.37	1.41	1.11	1.04	0.44	0.96	0.42	1.11
	Maintenance cost (NFA)	k€/m²	0.78	0.72	0.61	0.63	0.43	1.94	1.28	1.21	0.52	1.04	0.50	1.29
	Maintenance cost (GFA-CCI)	k€/m²	0.64	0.59	0.58	0.54	0.38	1.51	1.18	1.11	0.33	0.71	0.41	1.10
	Maintenance cost (NFA-CCI)	k€/m²	0.75	0.69	0.59	0.63	0.44	2.07	1.37	1.29	0.38	0.77	0.50	1.28

	Indicator	Unit	GreenHome-Res.	Héliades-Res.	Alizari-Res.	NHTirol-Res.	Parkcarré-Res.	More-Res.	IsolaA-Res.	IsolaB-Res.	Solallén-Res.	VälaGärd-Off.	Aspern-Off.	Schertler-Off.
	Maintenance/LCC	%	62	32	30	31	29	37	31	31	20	36	30	28
	Average	%	33	33	33	33	33	33	33	33	33	33	33	33
Operation	Operation cost	M€	1.39	4.18	2.26	42.8	0.66	0.30	2.81	3.38	1.49	1.88	5.72	5.45
	Operation cost (GFA)	k€/m²	0.13	0.77	0.80	0.81	0.51	1.73	1.72	1.67	0.71	1.03	0.54	1.69
	Operation cost (NFA)	k€/m²	0.15	0.91	0.81	0.95	0.59	2.37	1.99	1.94	0.84	1.12	0.65	1.97
	Operation cost (GFA-CCI-HDD-Price)	k€/m²	-	0.89	0.99	0.77	0.50	1.83	1.74	1.69	0.51	0.80	0.56	1.53
	Operation cost (NFA-CCI-HDD-Price)	k€/m²	-	1.05	1.01	0.89	0.58	2.52	2.02	1.96	0.60	0.87	0.68	1.78
	Operation cost/LCC	%	12	40	40	47	40	45	49	50	33	39	39	43
	Operation cost / PV energy production	€/kWh	1	76	77	-	23		692	834	189	33	45	-
LCC - TOT	LCC	M€	11.6	10.4	5.6	90.8	1.7	0.7	5.8	6.8	4.6	4.8	14.7	12.7
	LCC (GFA)	k€/m²	1.07	1.92	1.99	1.73	1.29	3.83	3.53	3.35	2.19	2.65	1.39	3.94
	LCC (NFA)	k€/m²	1.25	2.26	2.02	2.02	1.49	5.27	4.10	3.88	2.58	2.89	1.67	4.61
	LCC (GFA-CCI-HDD-Price)	k€/m²	0.91	1.99	2.14	1.67	1.30	4.07	3.68	3.47	1.64	2.25	1.40	3.76
	LCC (NFA-CCI-HDD-Price)	k€/m²	1.06	2.35	2.18	1.96	1.51	5.60	4.27	4.03	1.94	2.44	1.69	4.40
WLC	Whole-life cost	M€	11.58	10.37	5.64	90.81	1.96	0.68	5.78	6.77	5.55	5.23	17.97	12.87
Energy consumption	Heating demand	MWh	59.8	103.6	35.5	545.2	25.8	2.5	42.3	53.1	32.7	26.1	148.0	48.06
	Heating demand (NFA)	kWh/m²	6	23	13	12	23	19	30	30	18	16	17	17
	Energy consumed	kWh	385	273	215	2837	70	8	135	167	92	80	392	260
	Energy consumed (NFA)	kWh/m²	42	59	77	63	63	64	96	96	52	48	44	94
	Energy consumed (NFA-HDD)	kWh/m²	48	78	90	46	53	77	115	114	40	40	49	87
	Energy produced / Annual elt. yield	kWh	1723	55	29	0	29	0	4	4	8	57	128	0
	Energy produced / Annual elt. yield (NFA)	kWh/m²	186	12	11	0	26	0	3	2	4	34	15	0
	Construction cost/Energy consumed	€/kWh	26	20	11	16	11	37	21	19	14	23	15	24
	Renewable energy share	%	447	20	14	0	41	0	3	2	9	71	33	0
	PE consumption (non-renewable) (TFA)	kWh/m²	108	60	106	77	67	135	255	255	129	119	58	283
	Heating demand	MWh	60	104	35	545	26	2	42	53	33	26	148	48
	Specific heating demand	kWh/m²	6.45	22.56	12.77	12.13	23.27	19.49	30.03	30.45	18.38	15.64	16.78	17.42
	Cooling energy consumption	MWh	0.00	2.21	5.42	0.00	1.58	1.06	10.61	11.38	0.79	4.82	0.98	0.47
	Specific cooling energy consumption	kWh/m²	0.00	0.48	1.95	0.00	1.42	8.26	7.53	6.53	0.44	2.88	0.11	0.17
	Hot water energy consumption	MWh	53.77	86.65	94.84	855.53	16.43	1.55	33.15	40.73	11.14	2.25	63.06	0.56

	Indicator	Unit	GreenHome-Res.	Héliades-Res.	Alizari-Res.	NHTirol-Res.	Parkcarré-Res.	More-Res.	IsolaA-Res.	IsolaB-Res.	Solallén-Res.	VälaGärd-Off.	Aspern-Off.	Schertler-Off.
	Specific hot water energy consumption	kWh/m²	5.80	18.88	34.16	19.03	14.82	12.13	23.53	23.34	6.26	1.35	7.15	0.20
	Electricity energy demand	MWh	271.93	80.20	79.42	1436.68	26.04	3.10	48.66	61.42	47.26	46.45	180.06	211.01
	Specific Electricity energy demand	kWh/m²	29.34	17.47	28.61	31.96	23.49	24.21	34.53	35.20	26.58	27.81	20.42	76.48
Building elements	Building elements cost	M€	7.33	3.96	1.56	35.47	0.44	0.22	1.33	1.60	1.68	1.52	5.60	4.29
	Building elements cost (NFA)	k€/m²	0.79	0.86	0.56	0.79	0.39	1.72	0.95	0.92	0.95	0.91	0.64	1.56
	Building elements cost (NFA-CCI)	k€/m²	0.76	0.83	0.54	0.78	0.41	1.83	1.01	0.98	0.71	0.68	0.63	1.55
	Building elements cost/CC	%	72	72	63	79	58	66	45	47	66	52	75	70
Building envelope	Building envelope cost	M€	3.02	0.83	0.39	8.03	0.35	0.10	0.57	0.64	0.65	0.61	3.31	1.34
	Building envelope cost (NFA)	€/km²	0.33	0.18	0.14	0.18	0.32	0.79	0.40	0.37	0.37	0.37	0.38	0.49
	Building envelope cost (NFA-CCI)	k€/m²	0.31	0.17	0.14	0.18	0.33	0.84	0.43	0.39	0.27	0.27	0.37	0.48
	Building envelope cost/CC	%	30	15	16	18	47	30	19	19	26	21	44	22
Building structure	Building structure cost	M€	0.53	1.67	0.69	17.87	0.00	0.02	0.07	0.07	0.00	0.00	0.56	2.01
	Building structure cost (NFA)	k€/m²	0.06	0.36	0.25	0.40	0.00	0.13	0.05	0.04	0.00	0.00	0.06	0.73
	Building structure cost (NFA-CCI)	k€/m²	0.06	0.35	0.24	0.40	0.00	0.14	0.05	0.04	0.00	0.00	0.06	0.72
	Building structure cost/CC	%	5	30	28	40	0	5	2	2	0	0	8	33
Building services	Building services cost	M€	2.30	1.20	0.53	9.37	0.25	0.08	0.65	0.78	0.57	1.02	1.35	1.40
	Building services cost (NFA)	k€/m²	0.25	0.26	0.19	0.21	0.23	0.66	0.46	0.45	0.32	0.61	0.15	0.51
	Building services cost (NFA-CCI)	k€/m²	0.24	0.25	0.18	0.21	0.24	0.71	0.49	0.48	0.24	0.46	0.15	0.51
	Building services cost/CC	%	23	22	21	21	34	26	22	23	23	35	18	23
HVAC	HVAC cost	M€	1.10	0.44	0.28	4.47	0.09	0.03	0.47	0.55	0.45	0.71	1.35	0.85
	HVAC cost (NFA)	k€/m²	0.12	0.10	0.10	0.10	0.08	0.22	0.33	0.32	0.25	0.43	0.15	0.31
	HVAC cost (NFA-CCI)	k€/m²	0.11	0.09	0.10	0.10	0.09	0.23	0.35	0.34	0.19	0.32	0.15	0.31
	HVAC cost/CC	%	11	8	12	10	12	8	16	16	18	25	18	14
RES	RES cost	M€	0.27	0.21	0.08	0.00	0.06	0.00	0.00	0.00	0.14	0.16	0.35	0.00
	RES cost (NFA)	k€/m²	0.03	0.05	0.03	0.00	0.05	0.04	0.00	0.00	0.08	0.10	0.04	0.00
	RES cost (NFA-CCI)	k€/m²	0.03	0.04	0.03	0.00	0.05	0.04	0.00	0.00	0.06	0.07	0.04	0.00
	RES cost/CC	%	3	4	3	0	8	1	0	0	5	6	5	0
	LCC/Renewable energy installed capacity	€/W_p	86	228	186	-	50	-	1979	1870	104	65	429	-
Other	Other cost	M€	4.00	1.61	0.77	9.76	0.09	0.13	1.69	1.90	1.17	1.10	1.92	1.40
	Other cost/CC	%	40	29	31	22	12	38	57	56	46	38	26	23
	PV capacity	W_p/m²	12	10	12	0	30	0	2	2	19	37	4	0
	Annual CO_{2eq} emissions	kg/(m²a)	22	12	22	16	11	29	46	46	27	25	13	84
	PE demand	kWh/m²a	93	52	82	66	62	98	200	200	109	109	36	257
	PER demand	kWh/m²a	44	69	109	70	54	70	134	134	58	58	49	169

	Indicator	Unit	GreenHome-Res.	Héliades-Res.	Alizari-Res.	NHTirol-Res.	Parkcarré-Res.	More-Res.	IsolaA-Res.	IsolaB-Res.	Solallén-Res.	VälaGärd-Off.	Aspern-Off.	Schertler-Off.
U-Values	U-Value opaque components	W/(m² K)	0.12	0.22	0.17	0.15	0.27	0.20	0.25	0.28	0.07	0.07	0.10	0.21
	U-Value glazing components	W/(m² K)	0.83	1.51	0.97	0.73	0.85	1.20	1.18	1.20	0.92	0.87	0.92	0.75

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