Towards the definition of a nZEB cost spreadsheet as a support tool for the design

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Abstract. The 2010 Energy Performance of Buildings Directive (EPBD recast) [1] established that all new buildings have to reach, by the end of 2020, the nearly-Zero Energy (nZEB) target as set by the Member States. In order to achieve the nZEB standards, while keeping investments sustainable, it is strategic to focus more on the operational phase and to guide the decision-support with a lifetime perspective. In this regard, a crucial step is to adopt a shared methodology for evaluating the Life-Cycle Cost (LCC), in order to minimize the effect of uncertainties, the impact of calculation approach and the variability of the boundaries at EU level. The H2020 CRAVEzero project developed a LCC spreadsheet, aimed at calculating a set of relevant indicators for assessing the cost during the investment phase (design, labour and material costs) as well as during the operational phase of a building (energy and maintenance costs). The LCC spreadsheet implements an approach for normalising the results according to the main relevant boundaries that can affect the comparability at EU level (e.g. energy prices, the national construction costs, the climatic conditions, etc.). Moreover, it introduces a sensitivity analysis that aims to provide the impact that the boundary conditions can have on the results, reducing the uncertainties in the LCC calculations due to a long-term perspective (http://www.cravezero.eu/lcc_spreadsheet/). This paper presents the structure of the LCC calculation approach defined within the project, the structure of the spreadsheet and the main indicators as evaluated for a set of relevant nZEB case studies across Europe.

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

H2020 CRAVEzero project aims at changing the approach, identifying the costs of nZEBs in a life cycle perspective in order to propose solutions for cost optimisation or cost shifting.

In this regard, a structured methodology for assessing building Life Cycle Cost (LCC), with benchmarks, exemplary cases and standard values is needed. This paper presents the results of the work carried out within the CRAVEzero “Cost Reduction and market Acceleration for Viable nZEBs” as a starting point for developing a structured and EU-wide approach for LCC evaluations, including data collection templates, references and standard costs to be adopted for preliminary evaluations.
The approach has been traduced in the so-called “CRAVEzero nZEB spreadsheet” implementing a comprehensive and structured methodology to evaluate the LCC, which was used for analysing a set of 12 exemplary nZEBs representing current best practices across Europe.

The paper also presents an overview of the results, including the comparison of relevant costs and performance indicators among the case studies and a differential Sensitivity Analysis (SA), aimed at identifying the main boundaries and inputs affecting the LCC of a building.

2. Case studies and data collection

The first step of the analysis is to set-up the framework for the data collection. Following a series of workshops and feedback loops with project partners and potential stakeholders, we developed a reference template structured in three main parts:

1. General project information: it includes the main information of a case study (i.e. building features, context, principles for the business model),
2. Non-construction costs: it deals with the enabling and preliminary costs for the building construction,
3. Life-Cycle Costs: it reports all the costs for building elements and services from the design phase until the construction and operation, including maintenance and energy costs.

The data collection template is structured according to the approach provided by two primary sources: the Standard ISO 15686-5 (Buildings and constructed assets - Service life planning - Part 5: Life-cycle costing) [2]; providing the main principles and features of an LCC calculation and the European Code of Measurements [3], defining an EU-harmonised structure for the breakdown of the building elements, services, and processes, in order to enable a comprehensive evaluation of the LCC.

The defined approach has been implemented for the analysis of the 12 exemplary case studies, representative of the best nZEB practices across Europe (Table 1).

| Case study    | Location                | Year | Typology | NFA [m²] |
|--------------|-------------------------|------|----------|----------|
| Green Home   | Nanterre (France)       | 2016 | Residential | 9267     |
| Les Héliades | Angers (France)         | 2015 | Residential | 4590     |
| Résidence Alizari | Malaunay (France) | 2015 | Residential | 2776     |
| NH - Tirol   | Innsbruck (Austria)     | 2008/2009 | Residential | 44959   |
| Parkcarré    | Eggenstein (Germany)    | 2014 | Residential | 1109     |
| More         | Lodi (Italy)            | 2014 | Residential | 128      |
| Isola Nel Verde A | Milan (Italy)  | 2012 | Residential | 1409     |
| Isola Nel Verde B | Milan (Italy)   | 2012 | Residential | 1745     |
| Solallén     | Växjö (Sweden)          | 2015 | Residential | 1778     |
| Väla Gård    | Helsingborg (Sweden)    | 2012 | Office    | 1670     |
| Aspern       | Vienna (Austria)        | 2012 | Office    | 8817     |
| I.+R. Schertler | Lauterach (Austria) | 2011/2013 | Office    | 2759     |

The following sections present an overview of the methodology for the case study analysis and the main results from the application.

3. Methodology for calculating Life Cycle Cost

The ISO 15686-5:2008 standard provides a structured methodology for calculating LCC of buildings, setting the general principles, phases, and assumptions of the evaluation. It defines two main indices:

1. The Life Cycle Cost (LCC), focused on design, construction, and operation phase
2. The Whole-Life Cost (WLC) including the initial non-construction costs for enabling the building.

Table 2 shows the phases and contributions to be included in the analysis of LCC and WLC.
Table 2. Phases and costs in WLC and LCC

| Life cycle processes | Included costs                                      |
|----------------------|-----------------------------------------------------|
| 1. Political decision and urban design phase | Non-construction cost (cost of land, fees and enabling costs, externalities) |
| 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 | The residual value of the elements                   |

Although both LCC and WLC evaluation includes all the cost until the end of life, the presented analyses neglected both dismantling and residual values, since no structured and relevant data from the case studies was available.

Following the framework of ISO 15686-5:2008 standard, the first step for the calculation of the LCC is to set the time period, according to the purpose of the analysis. The standard indicates that the largest period to be selected is 100 years. On the one hand, shorter periods allow more reliable assessments, since the time-uncertainties are less affecting. On the other hand, longer periods, while having more uncertainties in the results, allow for more comprehensive evaluations, including maintenance costs. As stated in [4] “the International standard ISO 15686-5:2008 recommends that the estimated service life of a building should not be less than its design life”. Furthermore, [5] suggested an analysis period between 25 and 40 years, since the present value of future costs, which arise after 40 years might not be consistent because of a large number of uncertainties. Therefore, for the purposes of this analysis, a period of 40 years has been selected. Regarding the actualisation of future costs over the 40 years lifespan, a common value of interest rate for all the case studies has been adopted. The selected value is taken from FRED Economic Database [6], which provides an average interest rate of 1.51% for the time period going from 2008 (year of construction of the oldest case study) to 2017.

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:

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

- 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).

Finally, costs are grouped according to the life cycle phases: design, construction, building site management, operation, and maintenance. The effective estimation of energy and maintenance costs required a set of assumptions, described in the following sections.

3.1. Determination of the energy costs

In order to provide a homogeneous and comparable estimation of the energy costs of the case studies, since the official bills were not available in most of the cases, the evaluation was based on the calculated energy demand. As stated before, energy performance analysis was carried out by using the PHPP tool [7], which allows the implementation of the data dealing with the energy performance of a building, including the features of the envelope, HVAC system and renewables installed.
In particular, energy costs ($C_{\text{energy}}$) were estimated through the difference of the cost due to the energy consumed ($C_{\text{consumed}}$), including heating, domestic hot water production, cooling and household/auxiliaries electricity and the revenues from the energy produced ($C_{\text{produced}}$) thanks to the renewables installed, i.e. the contributions of final energy generated by a photovoltaic system and solar thermal system), both calculated on monthly base during month $i$ (Equation 2):

$$C_{\text{energy}} = \sum_{i=1}^{12} C_{\text{consumed},i} - C_{\text{produced},i} \quad (2)$$

For each country the unitary energy prices (€/kWh) applied to calculate the costs for the energy consumed and produced, have been taken from Eurostat [8], considering the average values in the period 2010 – 2017. Most of the case studies are supplied by electricity, since the most common technology adopted is the heat pump. Nevertheless, for other energy fuels, the same approach the costs definition has been adopted.

As a general assumption, for the evaluations described in this report, a common value for considering the increase of the energy price has been adopted. According to the data reported in [8], the inflation of electricity prices in CRAVEzero countries from 2010 to 2017 amounts to 1.0%, and this value is used in the LCC evaluation.

3.2. Maintenance costs

Maintenance costs for the case studies were not fully available with a relevant level of accuracy and detail. In fact, the analysed buildings were built between 2009 and 2016, and only minor maintenance had already taken place. Therefore, the analysis within CRAVEzero is based on standard values from the literature. In particular, the standard EN 15459:2017 “Energy performance of buildings - Economic evaluation procedure for energy systems in buildings” [9] provides the life span and the yearly maintenance costs for each element, including operation, repair, and service, as a percentage of the initial construction cost. For the passive building elements, an average yearly value accounting for 1.5% of the construction cost was assumed for the evaluation, while the standard reports more detailed figures for the HVAC components (for both life span and annual maintenance). The value was crosschecked with average values coming from the experience of the industry partners.

4. Approach for the normalisation of Life Cycle Cost in the EU

The analysed case studies are located in different European countries (Table 1), i.e. Austria, Germany, France, Italy, and Sweden. Each country presents specific characteristics in terms of climate conditions, construction, and energy market. Therefore, in order to compare the results of the case studies and to draw a general overview of the costs of the current nZEB practices across Europe, a normalisation of the collected data is needed. In this regard, the following sections present an overview of the normalisation factors adopted for comparing the data of the case studies for construction, climate conditions and energy prices.

4.1. Construction cost

The impact of the construction costs on the life cycle is affected by several country-related factors. In fact, the price of the materials can be influenced by several national and international economic factors, as well as the costs of transports, strongly affected by the fuel costs, and the labour cost. In order to reduce the perturbations of the results caused by these national specificities, it is essential to find a common factor to normalise the construction costs.

Table 3. Construction cost index for CRAVEzero countries according to ECC [10].

| Country     | Construction cost index |
|-------------|-------------------------|
| France      | 103.87%                 |
| Austria     | 100.67%                 |
| Germany     | 96.62%                  |
| Italy       | 93.63%                  |
| Sweden      | 134.19%                 |
The ECC [10] has calculated a comprehensive European construction cost index that quantifies the ratio among the construction costs of EU countries, considering the above-mentioned factors. Table 3 reports the normalisation factors of the construction costs adopted within CRAVEzero.

4.2. Year of construction
Another factor influencing the costs of investment and operation is the adopted reference year for the actualisation, usually the year of the construction. For this analysis, considering that 10 out of 12 case studies were built between 2012 and 2015, in order to simplify the evaluation process, the normalisation of the year of construction was neglected.

4.3. Climate
It is important to normalise the energy costs according to the climate conditions of the building location, to neglect their effect on energy consumption. In this regard, the heating degree days (HDD) was assumed as a normalisation factor. The values were derived from the report “U-value and better energy performance” [11], which provides the HDD for a set of reference cities of the EU-countries.

4.4. Energy price
Finally, in order to compare the energy costs, a normalisation, which considers differences in energy prices among countries, was implemented. 0.16 €/kWh has been assumed as the average energy price for the normalisation. This value was calculated considering the average price for each energy vector and its weight among the other energy vectors according to the technology installed.

5. Key performance indicators and sensitivity analysis
To display the results of the data analysis of each case study, a set of key performance indicators is proposed. A list of performance indicators 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 4 presents the selected indicators.

| KPI                        | Rating | KPI                                | Rating |
|----------------------------|--------|------------------------------------|--------|
| LCC / usable floor surface | 3      | Cooling energy demand for cooling  | 2.4    |
| Investment cost / usable   | 2.8    | Energy demand for hot water        | 2.4    |
| floor                      |        | production                         |        |
| Operation cost / usable    | 2.6    | Annual renewable energy generation | 2.4    |
| floor                      |        |                                    |        |
| Renewable energy share     | 2.6    | Maintenance cost / usable floor     | 2.2    |
| PV annual electricity yield| 2.6    | Maintenance cost / investment cost  | 2.2    |
| Annual CO2 emissions       | 2.6    | Final energy consumption           | 2.2    |
| Life-cycle CO2 emissions   | 2.5    | Specific heating demand            | 2.2    |
| LCC                        | 2.4    | Specific cooling energy consumption| 2.2    |
| WLC                        | 2.4    | Specific hot water energy consumption| 2.2 |
| Investment cost            | 2.4    | Specific Electricity energy demand  | 2.2    |
| Operation cost             | 2.4    | LCC / renewable energy installed capacity | 2   |
| Maintenance cost           | 2.4    | Operation cost / PV energy         | 2      |
| Primary energy consumption | 2.4    | Electricity energy demand (lighting, | 2      |
| Heating demand for heating | 2.4    | Energy demand for ventilation      | 2      |

5.1. Sensitivity analysis
One of the main drawbacks of the LCC analysis is the high level of uncertainty affecting the evaluation of the costs during the building life cycle. In fact, on the one hand, the calculation requires a series of simplifications and assumptions for defining the input parameters, and, on the other hand, the complex cost structure and the uncertainties in predicting future events that may affect the results [12, 13]. A
proper cost analysis requires the quality of input data and accurate long-term forecasts of these values over the analysed lifespan [12]. The difficult access to this type of data leads to uncertainty in LCC methods, limiting their application. Hence, to tackle the uncertainty issue, the CRAVEzero LCC evaluation includes a sensitivity analysis to define the impact of the uncertain boundaries and input values on the LCC. SA measures the effect on the outputs, caused by input variation, due to uncertainty or risk. In this way it is possible to define uncertainty-adjusted LCC ranges, allowing decision makers to concentrate on the analysis of the most critical parameters [13].

The present paper reports the outcome of differential SA. This method belongs to the class of the “One factor At a Time” (OAT) screening techniques, since it evaluates the effect of the variation of a single input parameter on the output, while the other set of inputs are set equal to their baseline value:

$$s\% = \frac{\Delta O}{O_{un}} \cdot \frac{\Delta I}{I_{un}}$$ (3),

Where:

- $s\%$: Sensitivity index
- $O_{un}$: Baseline value
- $\Delta I$: Input variation
- $\Delta O$: Output variation
- $I_{un}$: Baseline value

Figure 1 and Figure 2 report the results of the SA for one of the case studies, i.e. Résidence Alizari, in terms of Sensitivity Index and LCC variation around the baseline. In particular, the analysis focused on boundary conditions and general assumptions that are mainly affected by uncertainty issues: interest rate, energy cost and its inflation rate, maintenance cost (evaluated as a % of the construction cost) and operational cost. As shown in Figure 1, the maintenance and the lifespan of the buildings have the highest impact on the LCC, that can range from 2610 and 2675 €/m² according to the variation of the inputs.

![Figure 1. Sensitivity index (s%) of boundary and assumptions – Résidence Alizari.](image1)

![Figure 2. LCC variability according to the variations of boundaries and assumptions](image2)
6. Spreadsheet

The set of selected KPIs, shown in Section 5, have been combined in the CRAVEzero nZEB spreadsheet describing, in both numerical and graphical form, the normalised life cycle cost of nZEBs for an EU-wide comparison of the results.

Figure 3 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 CO₂ emission and production from renewable energy sources. The second page (Figure 4) 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 3. Investment KPIs.](image)

![Figure 4. Life-cycle cost KPIs.](image)

7. Comparative analysis

This section reports a general overview of the application of the methodology described in Section 3 and 4 to the CRAVEzero case studies, providing a comparative analysis highlighting the impact of the different phases on the overall LCC is provided. It is important to point out that the results are normalised according to the criteria illustrated in Section 4, in order to ensure the comparability of the indicators. Figure 5 shows the overview of LCC calculated considering a period of 40 years for the twelve case studies, with a breakdown of the cost for each phase. It is possible to point out that design cost has a reduced impact on the LCC, ranging from 3% (Case NH-Tirol) to 15% (Parkcarré), but with an average value of 5%. Cost of materials ranges from around 27% (for the case study Solallén) up to 53% (i.e. Les
Héliades). Since labour costs were in most cases, either not available or included in the cost of materials, a reliable breakdown of the construction costs into materials costs and labour costs was not possible.

As it was expected, for the analysed case studies the energy costs during the life cycle of an nZEB represent a minor component of the LCC, with an average of around 12% (Figure 7). It is important to point out that the contribution from the renewable energy sources (RES) is accounted for as a reduction of the energy cost (calculated as a balance between energy consumed and produced).

Figure 6 shows an overview of the average impact of all the phases on the LCC, the investment costs for design, construction and other initial expenditures is around 54% of the LCC, while the energy and maintenance account for around 44%.

**Figure 5.** LCC breakdown.

**Figure 6.** LCC breakdown – average.

Figure 7 displays the energy cost in relation to the average U-value of the opaque components. Figure reports the breakdown of the cost for the building elements, highlighting the impact on the construction costs. It shows that in some cases the structural elements represent a significant contribution to the construction, according to the complexity and the dimension of the building. On the other hand, nZEB related technologies have a small impact on the construction costs, although in comparison to a traditional building the cost for the HVAC system and the integration of renewables is more significant.

**Figure 7.** Correlation between energy cost and U-value.

**Figure 8.** Construction cost breakdown.
8. Conclusion and further development
This paper presents an operative methodology for an EU-wide evaluation of Life Cycle Cost, including boundary conditions, reference values, normalisation factors and sensitivity analysis. In addition, it reports an overview of the main results for 12 exemplary case studies analysed within the H2020 CRAVEzero project. The H2020 CRAVEzero project, is going to release an effective tool for producing the nZEB spreadsheet, including all the main indicators for analysing in detail the performances in terms of cost and energy of a building, identifying the main phases and elements affecting both the investment and the Life Cycle Costs. At EU level, a shared and operative LCC methodology and a comprehensive database with detailed building Life Cycle Cost evaluation represent the strategic references for a broader implementation of LCC analyses, providing useful benchmarks for comparison and increasing the reliability of LCC. The broad application of the LCC analysis will foster the market uptake of nZEBs, highlighting the cost-effectiveness and benefits during the life cycle. More information are available on the project website: http://www.cravezero.eu

9. References
[1] EPBD recast-European Commission. Energy Performance of Buildings Directive 2010/31. EU of the European Parliament and of the Council of. 2010;19.
[2] ISO ISO. 15686-5: Buildings and Constructed Assets-Service-Life Planning-Part 5: Life-Cycle Costing. Geneva, Switzerland: International Organization for Standardization. 2008.
[3] CEEC. Code of Measurement for Cost Planning. n.d. https://www.ceeecorg.eu/. Accessed July 2018.
[4] Dwaikat LN, Ali KN. Green buildings life cycle cost analysis and life cycle budget development: Practical applications. Journal of Building Engineering. 2018;18:303–11.
[5] Kirk SJ, Dell’Isola AJ. Life cycle costing for design professionals; 1995.
[6] FRED Economic Data. Interest Rates, Discount Rate for Euro Area. https://fred.stlouisfed.org/series/INTDSREZQ193N. Accessed July, 2018.
[7] Feist W, Pfluger R, SCHNEIEDERS J, Kah O, Kaufman B, Krick B, et al. Passive House Planning Package Version 7. Darmstadt: Rheinstrabe, Germany. 2012.
[8] Eurostat. Electricity prices for households in the European Union 2010-2017, semi-annually. http://epp.eurostat.ec.europa.eu. Accessed in July, 2018.
[9] EN 15459-1:2017 Energy performance of buildings–economic evaluation procedure for energy systems in buildings - Part 1: calculation procedure May 2017.
[10] European Construction Costs. Cost Index. http://constructioncosts.eu/cost-index/. Accessed July 2018.
[11] Ecofys. U-values For Better Energy Performance Of Buildings. https://www.ecofys.com/en/. Accessed July 2018.
[12] Di Giuseppe E, Iannaccone M, Telloni M, D’Orazio M, Di Perna C. Probabilistic life cycle costing of existing buildings retrofit interventions towards nZEB target: Methodology and application example. Energy and Buildings. 2017;144:416–32.
[13] Langdon D. Life cycle costing (LCC) as a contribution to sustainable construction: A common methodology. Literature Review, Davis Langdon Management Consulting. 2007.

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