PAPER • OPEN ACCESS

Life cycle cost reduction and market acceleration for new nearly zero-energy buildings

To cite this article: T Weiß *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012002

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012002 doi:10.1088/1755-1315/323/1/012002

Life cycle cost reduction and market acceleration for new nearly zero-energy buildings

Weiß T [1], Pernetti R[2], Garzia F[2], Köhler B[3], Stobbe M[3], Meier K[4], Berggren B[5]

[1]AEE INTEC, Austria; [2]EURAC, Italy; [3]Fraunhofer ISE, Germany; [4]ATP Sustain, Germany; [5]Skanska Sverige AB

t.weiss@aee.at

Abstract. 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. 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 [1].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 [2]. The EU Horizon project CRAVEzero focuses on proven and new approaches to reduce the costs of nZEBs at all stages of the life cycle. The primary goal is to identify and eliminate the extra costs for nZEBs related to processes, technologies, building operation and to promote innovative business models considering the cost-effectiveness for all stakeholders in the building's lifecycle. As a result, an international database for benchmarking actual nZEB life cycle costs (LCC) including urban and building planning, construction, commissioning, operation, maintenance, management, end-of-life, has been developed. Furthermore, an operative methodology to achieve the best conditions towards optimal cost nZEBs has been set-up.

1. Stakeholder centred life cycle processes

In addition to legal and urban boundaries, buildings are essentially defined by the client. Owners or investors want to construct or renovate buildings for a specific purpose. Also, the buildings technical quality and the comfort standard have to be achieved within project specific budget limitations. Architects and specialist planners translate the client's ideas and wish into real plans and are responsible for the appropriate execution of the building project. Construction companies and craftsmen from numerous different disciplines are involved in constructing the building. There is a constant coordination process between the client, the planners and the contractors in order to prepare the construction of a building and if necessary, to react to changing conditions like costs, schedules, changed requests from the client, weather, etc [3].

Especially in the planning phase, the choice and combination of building materials and technologies and the execution on the construction site as well as the overall integral planning, construction and operation are of great importance. The range of services provided to buildings in the urban context today has also changed over time and gained new aspects. Nearly zero energy buildings increasingly become active participants of our energy supply infrastructure and raise new challenges concerning the quality of planning, construction and operational phase of a building. This results in new approaches to innovative energy concepts for both the building and districts. Innovations related to the realisation of nZEBs arise in different life cycle phases of buildings and at different points of the value chain in the building industry.

To reduce costs and accelerate processes, and assure the quality of nZEBs the right decisions have to be taken at the ideal time within the overall process.

In order to be able to optimise existing processes, technical qualifications, actions to be taken and roles must be known and tasks and functions of the stakeholders assigned.

The assessment of the process for nZEBs depends strongly on the perspective. Building owners, investors, tenants, the construction industry, providers of energy efficiency solutions and planners have different interests and are involved in different phases in the life cycle of buildings. There is a general lack of understanding, transparency and uniform methods when it comes to the overall process of nZEBs. Which costs and time horizons are significant for different actors and to what extent?

In the life cycle of a building, there are different interests of the actors and derived from this also different perspectives, observation periods and target values. There is the tenant/user, the real estate agent, the building contractor, planner, property manager, investor, owner and also the company which is directly or indirectly involved with the building. As shown in Table 1, these actors are involved in the overall process over a certain period of time. While the tenant is primarily interested in the operational phase, the planner is usually more likely to deal with the building only until its completion. If a property is financed and used by the tenant himself, the entire life cycle up to a change of use is usually of interest. Depending on the approach, this can be between about 25 years after repayment of the bank loan and up to 50 years after increased consideration of the use. For society as a whole, the entire service life of a building, including its demolition and disposal, usually counts.

The period under consideration must, therefore, be determined in advance with the parties involved. For most of the considerations of the entire building, between 25 and 50 years have proven to be reasonable.

Table 1. Stakeholders time expectancy of a project and optimization goals

STAKEHOLDERS	OPTIMIZATION CRITERIA		TIME EXPECTANCY
	Costs	Energy	
Tenant / user	Rental costs, operating costs	Final energy demand	3 – 30 years
Real estate agents	Market price	Energy performance certificate	1 – 2 years
Construction company	Building costs		1 – 5 years (Guarantee)
Planner	Planning costs, building costs	Energy performance certificate	1 years
Property management	Maintenance costs, renovation costs	Final energy demand	1 – 50 years (Contract)
Investor	Investment cost		1 – 5 years
Building owner / landlord	Financing costs	final energy demand	20 - 50 years
Building owner (public)	Net present value	Primary energy, final energy, CO_2	50 – 100 years
Society	Life cycle costs, climate protection	Primary energy, CO_2	> 100 years

In addition to low rental costs, the tenant is also interested in low operating costs and thus in a good energy standard, e.g. so that he has low heating costs. The building contractor is usually anxious to keep his building costs low. In the case of owner-occupied real estate, both cost components are important, the initial investment as well as the running costs. For the company, the total costs and also the effects such as CO_2 emissions are important.

In addition to the optimisation criteria and thus the benefits that can be directly assessed in monetary terms, there are also different benefits and additional benefits for the individual actors, which often cannot be assessed directly in monetary terms and therefore do not appear in the life cycle cost analysis. These benefits and additional benefits are shown in Figure 1. This concerns marketability, rentability, value development, comfort, but also image, climate protection or regional goals such as energy autonomy. Where possible, these benefits and additional benefits should be taken into account in the decision-making process. However, examples exist where increased productivity, higher revenue, reduced employee turnover, reduced absenteeism, etc. have been quantified [4]. Additionally, studies do exist which may be used as a basis for analysing added values.

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012002 doi:10.1088/1755-1315/323/1/012002

Studies show that staffs in high quality nZEBs perceive a positive effect of their work environment and productivity [5] [4] [6]. In one case, a 10 000 m2 office building, increased productivity of 0.3 % were reported, equal to 8 €/m2a. Two studies have found reduced absenteeism in green buildings [5]. An American study showed that roughly 20-25 % of 534 tenants/companies reported higher employee morale, easier to recruit employees and more effective client meetings [7]. Additionally, 19 % reported lower employee turnover. In addition to well-being and productivity, higher revenues from rent or sales may be expected. Bleyl et al. reviewed previous studies and concluded that higher rent income might range roughly between 5 % and 20 %. Furthermore, higher market valuations may range from below 10 % to up to 30 %. It should be noted, in relation to nZEBs and productivity and wellbeing, that a recent study pointed out that social factors may have a greater impact, in monetary terms, compared to environmental factors [8].

The value of a positive news article about a specific building or a specific project could also be comparable to advertising costs in the specific source, in which the article is published [9]. One way to discuss the importance to investigate different co-benefits may be to rank them as presented in Figure 1. The classification is a subjective judgement, highlighting the relevance and the difficulty in valuing the co-benefits discussed above.

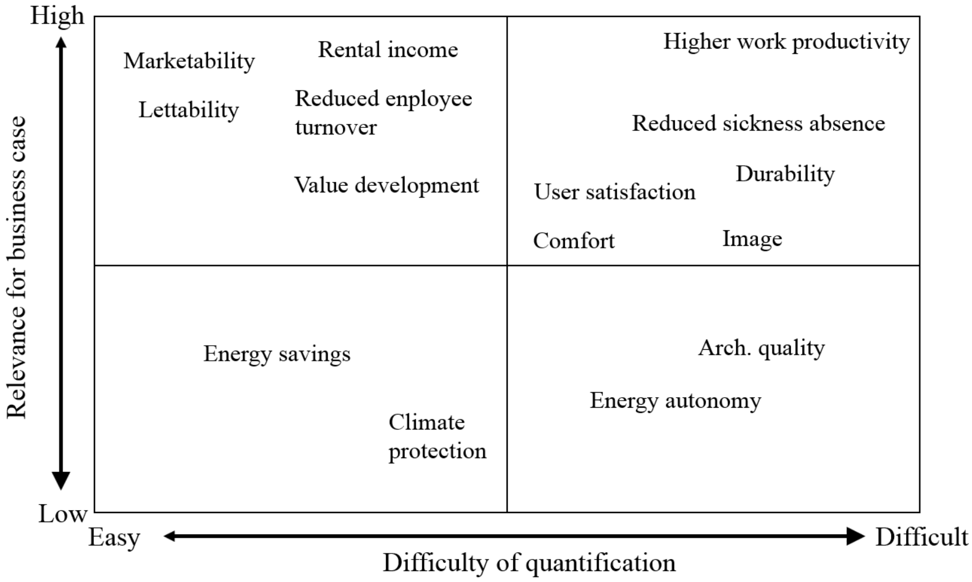

Figure 1. Co-benefits classifications, based on Bleyl et al. [1].

2. nZEB Technologies

For realising nZEBs, which are cost-efficient for all stakeholders throughout their lifecycles, the knowledge about possible cost developments of the most relevant technologies is essential. Furthermore, the identification of currently realised and promising technology sets for the future can help to reduce the cost of nZEBs and accelerate the respective market.

For the deduction of cost reduction potentials, there are in principle two approaches; the Top-down learning curve analysis and the Bottom-up analysis. Compared to the Top-down approach more detailed data and information is needed for the Bottom-up analysis. Therefore, the learning/ experience curve approach was chosen for the deduction of cost reduction potentials for all identified technologies, whereas the Bottom-up analysis was only conducted for three central technologies (PV, solar thermal, electricity storage). The calculation of cost reduction potentials with the experience curve approach is based on market and cost data as well as the determination of learning rates.

Even though the applied methodologies are widespread and established, it has to be mentioned that there are several uncertainties, which can influence the development of costs, especially over a relatively long period until 2050. The calculated market development can vary due to changing requirements or political changes, the actual learning rate can vary, and global commodity prices can fluctuate, which can also lead to price increases instead of decreases.

2.1. Top-down:

The various technologies analysed have different cost reduction potentials. The basis for the deduction of cost reduction potentials are current market and cost levels as well as market forecasts for each technology – if available for whole Europe and in case of limited data available only for Germany.

Established, fossil fuel-based technologies (oil and gas boilers) have the lowest cost reduction potential until 2050 (only about 1% and 9% respectively). A major reason is the comparably high CO_2-emissions, which contradict the climate protection targets of the European Union and will therefore lose market shares leading to only a small increase in the cumulative production volume. A slightly higher market share is predicted for biomass boilers which are more environmentally friendly as they use a renewable fuel. Biomass boilers have a cost reduction potential of approx. 14% until 2050.

Heat pumps are seen as a central heating (and probably cooling) technology in an energy system based on fluctuating renewable energies as they are one important technology for the coupling of the electricity and heating sector. Therefore, a strong market increase is expected to result in cost reductions of more than 20% by 2050.

Ventilation systems (central and decentralised) are of major importance for energy efficient buildings. They supply fresh air, reduce ventilation heat losses when equipped with heat recovery systems and assure good air quality by removing moisture, moulds, pollutants and vapours. Especially in airtight buildings assuring good air quality is almost impossible without mechanical ventilation. The market for ventilation systems will most probably grow in the coming decades leading to cost reductions of around 46% - 52% by 2050.

Thermal and electrical storages become more important in an energy system based on fluctuating renewable energies. Both storage types have substantial cost reduction potentials of about 29% (thermal) and 65% (electrical) by 2050.

With increasing indoor comfort requirements and further global warming, the need for air conditioning/ cooling is increasing leading to a strong market increase and associated cost reduction potentials of about 29% by 2050.

PV is an established renewable energy source with a global market, but still has the potential for optimisation. In all future scenarios with low green-house gas emissions, PV plays a key role in meeting emission targets and generating the required amount of renewable electricity. High cost reduction potentials are expected as fast market development is indispensable until 2050 for the achievement of the climate and emission targets of the Paris Agreement. The estimated cost reduction potential is around 49% by 2050. In addition to the established use on the roof, building-integrated PV (BiPV) is a promising and growing new field.

Solar thermal systems – even though already widespread – still have cost reduction potentials of 38% by 2050. Like for PV systems, there is the possibility to integrate solar thermal systems in the building envelope (e.g. the façade) and replace elements leading to overall lower costs for realising nZEBs.

For the building sector, insulation plays an important role in reducing overall energy demands especially concerning the heating demand in moderate and cold climate regions. However, for established and widespread insulation materials no further cost reduction is expected; cost reductions are only expected for new/ innovative materials and by improved mounting processes.

Besides insulating a building, there are additional passive strategies such as night cooling or natural ventilation, which reduce the end energy demand of a building and become increasingly important for the realisation of nZEBs. However, deriving cost reduction potentials is not possible based on the available data.

The derived cost reduction potentials of the Top-down approach are summarised in Figure 2.

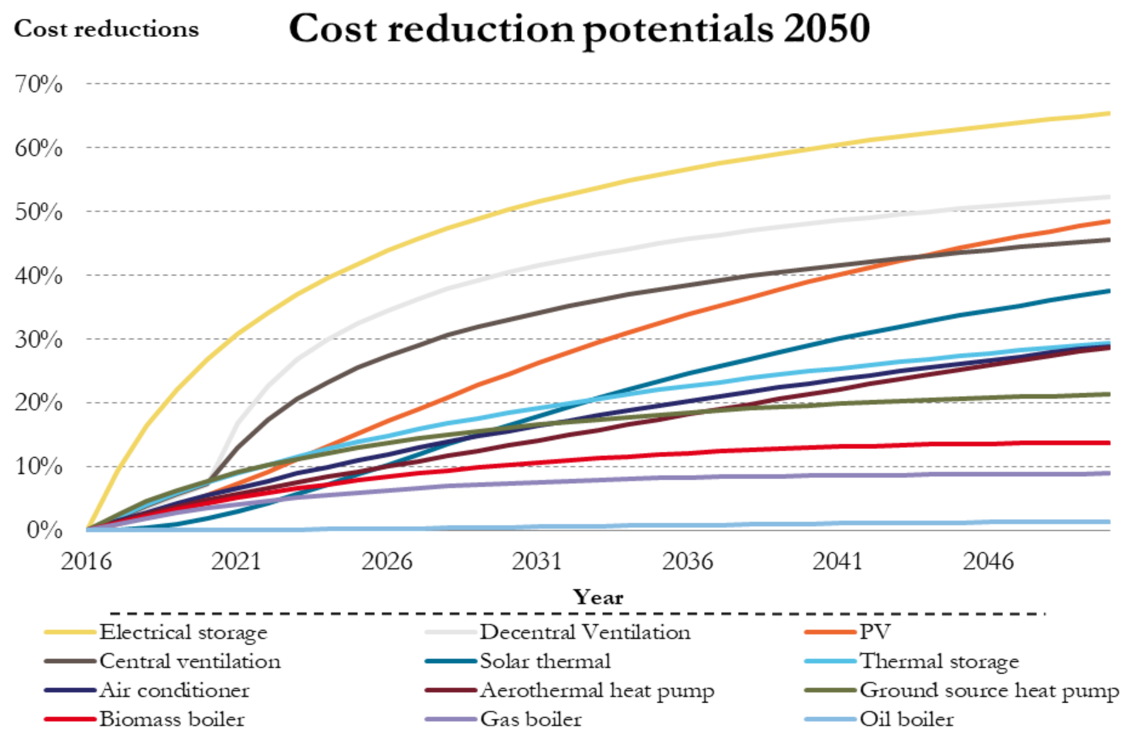

Figure 2. Cost reduction potentials till 2050 of major nZEB technologies calculated with the Top-down learning curve approach.

2.2. Bottom-up:

With the Bottom-up approach, specific cost drivers were determined for PV, solar thermal and electrical storages. For PV, cost reductions of up to 57% are estimated in different studies. Increased efficiency and material savings are the main possibilities for future cost reductions.

For solar thermal, the factors identified for possible cost reductions are the amount of material used, material changes, simplification of the system, faster assembly and changes in production methods; efficiency shows no high potential for further optimisation. Until 2030, cost reductions of up to 43% are described. For stationary batteries, the bottom-up analysis show cost reduction potentials of up to 65%. The main drivers are economy of scale and technological improvements such as an increased energy density, material savings and use of cheaper material.

Environmental pressure and policies on energy-efficient buildings with lower greenhouse gas emissions are probably the main reasons for the focus and increase in local renewable energy and energy-saving technologies powered by electricity instead of fossil fuels. The building sector plays an important role in reducing total greenhouse gas emissions and is currently still responsible for 32% of the world's final energy demand. Today, the energy supply is mainly based on fossil fuels causing CO2-emissions. Market demand for efficient and renewable technologies is a key factor for realising cost reduction potentials. The EPBD is thus an important factor in boosting the market for technologies like solar thermal, heat pumps, thermal insulation, PV and storages.

3. Life Cycle Cost Analysis

In the CRAVEzero project twelve case studies all over Europe, as can be seen in Figure 3 have been evaluated. The ISO 15686-5 [10] provides the main principles and features of an LCC calculation, while the European Code of Measurement one describes an EU-harmonised structure for the breakdown of the building elements, services, and processes, in order to enable a comprehensive evaluation of the building life costs.

The tool PHPP [11] has been used for the energy performance analysis. This tool summarises all the information dealing with the energy-related features of the building components and services and provides a comprehensive overview of the technologies installed.

Figure 3. CRAVEzero case studies

3.1. 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 within CRAVEzero is based on standard values from EN 15459:2018 that provides yearly maintenance costs for each element, including operation, repair, and service, as a percentage of the initial construction cost. For the passive building elements, an average yearly value accounting for 1.5% of the construction cost has been assumed for the evaluation. The value has been cross-checked with average values coming from the experience of the industry partners.
The analysed case studies are located in different European countries, i.e. Austria, Germany, France, Italy, and Sweden, with specific characteristics in terms of climate conditions, construction, and energy market. Therefore, in order to compare the results of the case studies and to draw a general overview of the costs of the current nZEB practices, a normalization of the collected data is needed. In particular, the construction costs have been normalised considering the data from the ECC (European Construction Costs) that calculated a European construction cost index that quantifies the ratio among the construction costs of EU countries. For the climate conditions, the normalisation has been carried out considering the Heating Degree Days of the building locations. Concerning the energy
process, a common value has been adopted, accounting for 0,160 €/kWh of final energy consumed.

3.2. Presentation of the results – case studies comparative analysis

The second part reports an overview of the results, with the comparison of relevant indicators, costs, and performances among the case studies considering the effect of local specificities, different context and use of the buildings (i.e. normalised results).
Figure 4 shows an overview of the average impact of all the phases on the LCC, the investment costs for design, material labor and other initial expenditures is around 60% of the LCC, while the energy and maintenance account for around 40%.
As it was expected, the energy costs during the life cycle of a nZEB represent a minor contribution to the LCC, with an average of around 15%. Figure 5 shows the absolute values in €/m^2 of the LCC. It is important to point out that the contribution from the renewable energy systems like PV is accounted as a reduction of the energy cost of the overall life cycle (calculated as a balance between energy consumed

IOP Conf. Series: Earth and Environmental Science 323 (2019) 012002 doi:10.1088/1755-1315/323/1/012002

and produced). In case of Greenhome , the energy costs reported in the chart assumes a negative value, since the energy produced is higher than the energy consumed, considering the large PV field installed.

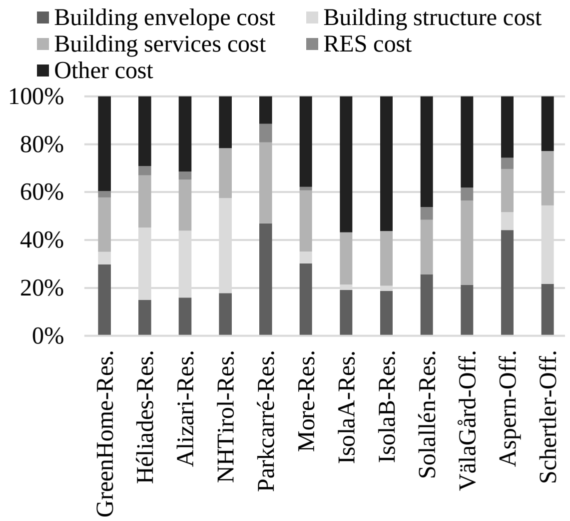

Figure 4. Construction cost breakdown

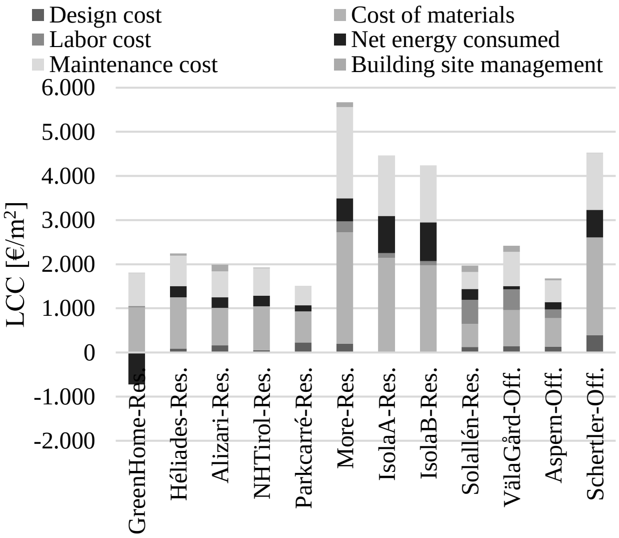

Figure 5. Life-cycle cost breakdown – normalized values.

Figure 4 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.

4. Multi- objective energy and life cycle costs analysis

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

As we have seen in the energetic-economic optimisation of buildings, there are different interests of the actors and, derived from this, different perspectives, time expectancies and goals. The term "multi-objective parametric analysis" in this report defines a method in which series of calculations are run by a computer program, systematically changing the value of parameters associated to one or more design variables. The key feature of this approach is that it allows evaluating the effect of individual design variables on energy, costs and environmental parameters in one step.

The multi-objective approach is based on the concept of Pareto frontier: a solution is optimal when no other feasible solution improves one of the objectives without affecting at least one of the other. In that case the multi-objective algorithms generate a set of solutions, known as the Pareto front. If the problem includes only two objectives, the Pareto front is a two-dimensional curve. This concept can also be applied to three or more objectives, although the results are more difficult to analyse. It is also important to note that this approach, rather than finding a single optimal solution, seeks to explore a set of optimal solutions and evaluate various trade-offs among them [12].

This approach was prototypically implemented in the case study Solallén based on the already gathered lcc data shown in the previous chapter. According to the defined general parameters in the previous chapter a set of ten different parameters with three to four levels are defined. The parameters consist of passive actions (Insulation standard, air-tightness, window U-values), active actions (ventilation-, PV-, heating-, cooling- and solar thermal system), user behaviour and economic sensitivities.

The analysis is performed for each parameter individually and in combination.
In total more than 31,000 different variants of different nZEB technology solution sets were calculated.
Figure 6 shows the overall results of the case study Solallén. In Figure 6 the financing costs of all investigated parameters are shown in relation to the balanced CO_2 emissions.
Figure 6 allows following short analysis:

- The financing costs range between 2100 Euro/m² and 2500 Euro/m². This is a range of ~ 20%.

- The balanced CO_2 emissions range between 14 kg/m²a and 52 kg/m²a. This is a range of ~70%.

Furthermore the analysis shows that similar financing costs can be achieved by the variants leftmost in the diagram and the variants rightmost. With these similar financing costs the balanced CO_2 emission can be reduced by nearly 70%.

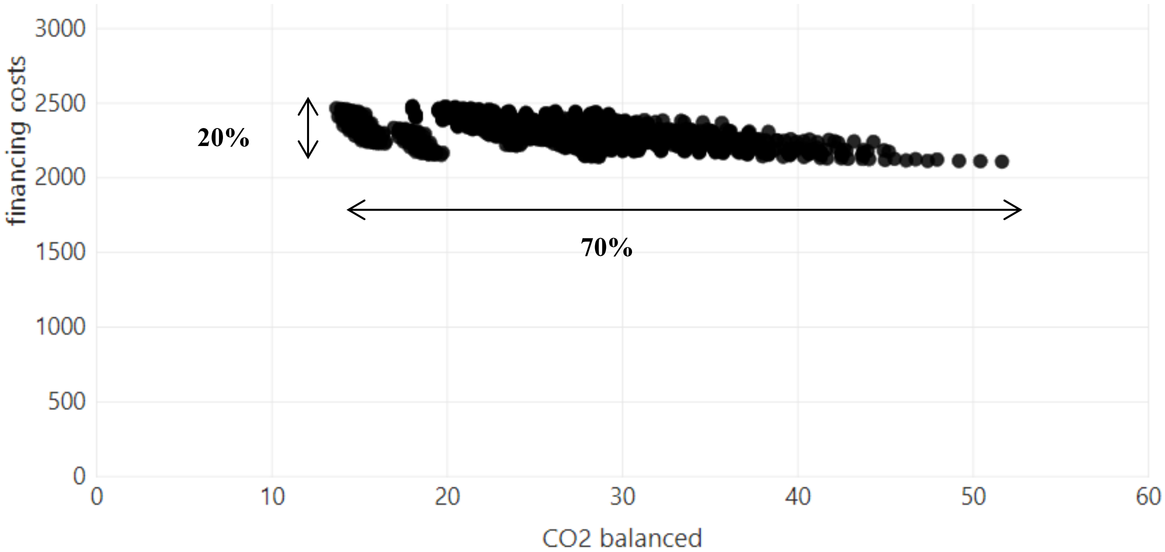

Figure 6. financing costs in relation to the balanced CO_2 emissions of all variants of the case study Solallén (related to treated floor area of the PHPP / CO_2 factors PHI/ without consideration of subsidies / no CO_2 credit for electricity fed into the grid)

5. Summary

On the basis of the results, the statement is confirmed: nZEBs are economical. It can now be shown that the additional costs of efficiency measures are so low that highly efficient buildings have the lowest life-cycle costs.

- In nZEBs, low energy demand is achieved through insulation and passive strategies is essential in order to be able to provide the remaining energy demand for the building operation (heating, cooling, ventilation, domestic hot water, and lighting) with onsite renewable energy.
- nZEB measures only have a small percentage influence on construction costs, but can reduce CO_2 emissions many times over.
- The energy standard has a small influence on the building and construction costs. Energy efficiency is therefore not a major cost driver in construction.
- The additional construction costs of nZEBs are compensated in the life-cycle of most technologies even without subsidies.
- The cost optimum of primary energy demand and CO_2 emissions is in the range of nearly zero and passive houses. Highly insulated envelopes and highly efficient windows are usually economical even without subsidies. This is also due to the long service life of these components in comparison to HVAC systems.
- The cost optimum curve in relation to CO_2 emissions is very flat. Low emissions and energy requirements can therefore be achieved with different energy concepts as long as the envelope is very efficient. This means architectural and conceptual freedom.
- The cost reduction potentials for nZEB technologies until 2050 vary from approx. 1% to 65%. Stationary batteries have the highest potential with 65%, followed by decentralised ventilation, PV, centralised ventilation with 52%, 49%, 46% and 38% respectively. Oil and gas boilers have the lowest potential of less than 10%.
- In many cases the return of investment in energy efficiency measures to reach the nZEB target is around 25-40 years, if calculated only in terms of energy cost saving. Nevertheless, as assessed by Berggren, Wallb, and Togeröc [13] the cost-effectiveness of nZEB construction becomes more apparent if the co-benefits and revenues are included in the analysis.

Acknowledgements

This work has been co-funded by the Horizon 2020 Framework Programme of the European Union within the project CRAVEzero - Grant Agreement No. 741223 (www.cravezero.eu)

References

[1] EPBD, *Implementing the Energy Performance of Buildings Directive - Featuring Country Reports 2012*. 2013.
[2] BPIE, "Nearly Zero Energy Buildings in Europe," 2016.
[3] S. Attia, "Integrative Project Delivery and Team Roles," in *Net Zero Energy Buildings (NZEB)*, 2018.
[4] J. S. Brew, "Finding the Value in Deep Energy Retrofits," *World Sustain. Built Environ. Conf. Proc.*, 2017.
[5] A. Thatcher and K. Milner, "Changes in productivity, psychological wellbeing and physical wellbeing from working in a 'green' building," *Work*, 2014.
[6] A. Singh, M. Syal, S. C. Grady, and S. Korkmaz, "Effects of green buildings on employee health and productivity," *Am. J. Public Health*, 2010.
[7] N. Miller, D. Pogue, Q. Gough, and S. Davis, "Green Buildings and Productivity," *J. Sustain. Real Estate*, 2009.
[8] H. Byrd and E. O. Rasheed, "The productivity paradox in green buildings," *Sustain.*, 2016.
[9] B. Berggren, M. Wall, T. Weiss, F. Garzia, and R. Pernetti, "LCC analysis of a Swedish Net Zero Energy Building – including Co-benefits," in *International Sustainable Energy Conference (ISEC), Graz*, 2018.
[10] BSI ISO 15686-5, "BS ISO 15686-5:2008 - Buildings & constructed assets – Service life planning – Part 5: Life cycle costing," *Int. Stand.*, 2008.
[11] Passive House Institute, "Passive House Planning Package (PHPP)," *passivehouse.com*, 2015. .
[12] G. Chiandussi, M. Codegone, S. Ferrero, and F. E. Varesio, "Comparison of multi-objective optimization methodologies for engineering applications," *Comput. Math. with Appl.*, 2012.
[13] B. Berggren, M. Wall, and Å. Togerö, "Profitable Net ZEBs – How to break the traditional LCC analysis," in *International Conference on Energy, Environment and Economics (ICEEE)*, 2017.