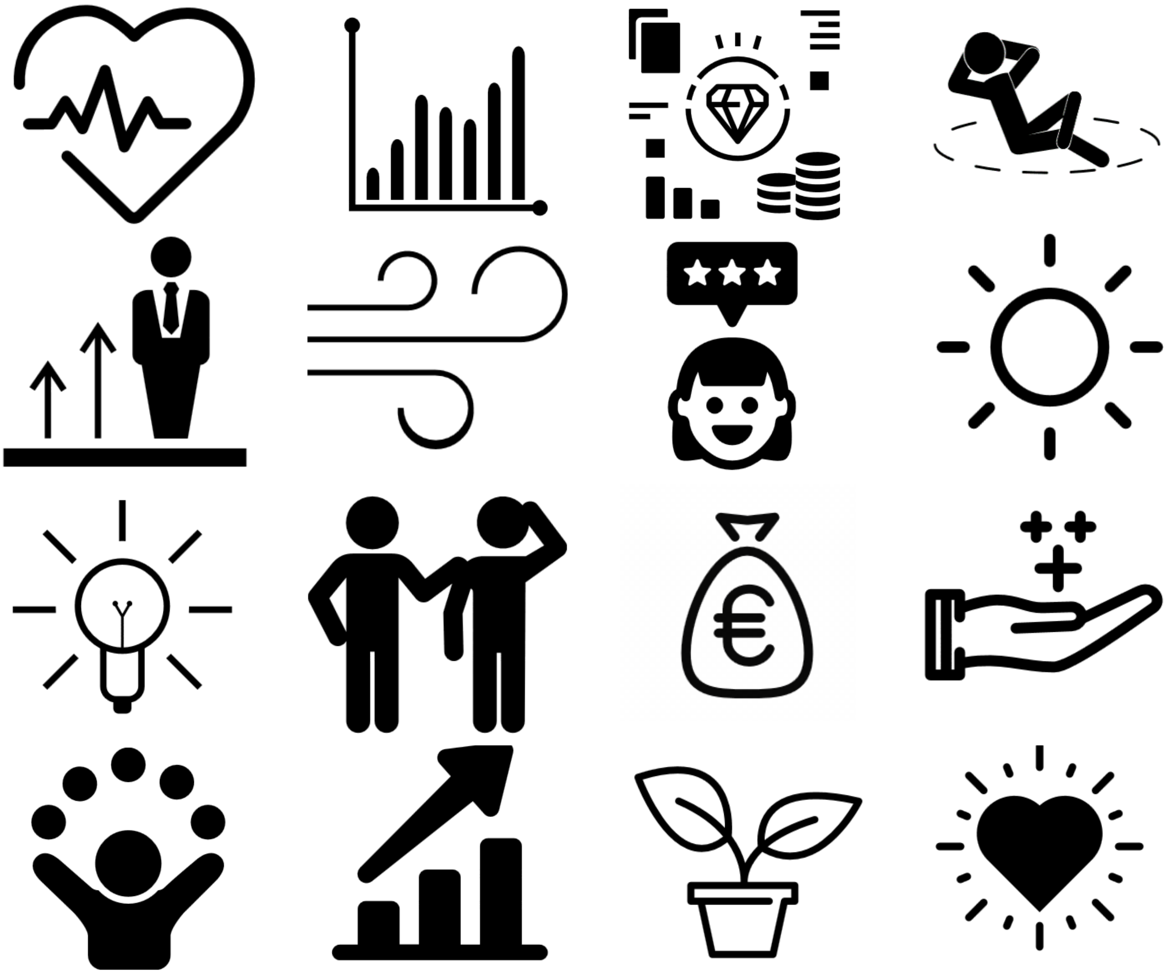
D6.4: Co – Benefits of nZEBs



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

CRAVEzero - Grant Agreement No. 741223
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Co-funded by the Horizon 2020

Framework Programme of the European Union

D6.4: Co – Benefits of nZEBs

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February, 2020

FOREWORD

This report summarises the results of Work Package 'WP06.4 – Co – Benefits of nZEBs', which is part of the Horizon2020 - CRAVEzero project.

Cost optimal and nearly zero-energy performance levels are principles initiated by the European Union (EU) Directive on the Energy Performance of Buildings, which was revised in 2010 and amended in 2018 (European parliament and the council of the EU, 2010). These will be a major driver in the construction sector in the coming years, as all new buildings in the EU are expected to be nearly zero energy buildings (nZEB) from 2021. The goal of nearly zero-energy can be achieved with existing technologies and practices. Most experts agree that a broad shift towards nearly zero energy buildings will require significant adjustments to the existing structures of the building market.

In order to achieve these goals, specific incentives are put into the focus of the building owners. These include first and foremost significant energy savings and an increase in the value of the building. However, specific additional incentives, so-called co-benefits, are often forgotten. These relate very often primarily to the occupants and employees who are in the buildings every day.

Especially for nZEB office buildings, it is important to understand that the following co-benefits also have important roles:

- Health benefits
- Increased productivity
- Lower staff turnover
- Reduced sick leaves
- Employment creation
- Market potential
- Owner as energy producer
- Added value for a nZEB property
- Integration of RES
- CO_2 emission savings
- Increased energy security
- Aesthetics and architectural integration
- Increased value of land/context
- Increased reputation and good publicity
- Press clipping increase
- Reduced vacancy due to nZEB
- Faster rental of the building
- Higher rental income
- Increased financing by lower interest rate
- Increased financing from bank loan
- Prefabricated building – quality control
- Prefabrication – cost and time efficiency and control
- Prefabricated building – on-site work
- Prefabricated building – façade integration

Employees spend at least 40 hours a week in the office, a total of 2080 hours per year (Attema, Fowell, Macko, & Neilson, 2019). Given the immense amount of time people spend at work, the desire for a workplace that promotes productivity and health seems understandable.

To show the relevance of these co-benefits, the following Figure 1 shows how the individual co-benefits are structured in terms of relevance for business cases and difficulty of qualification.

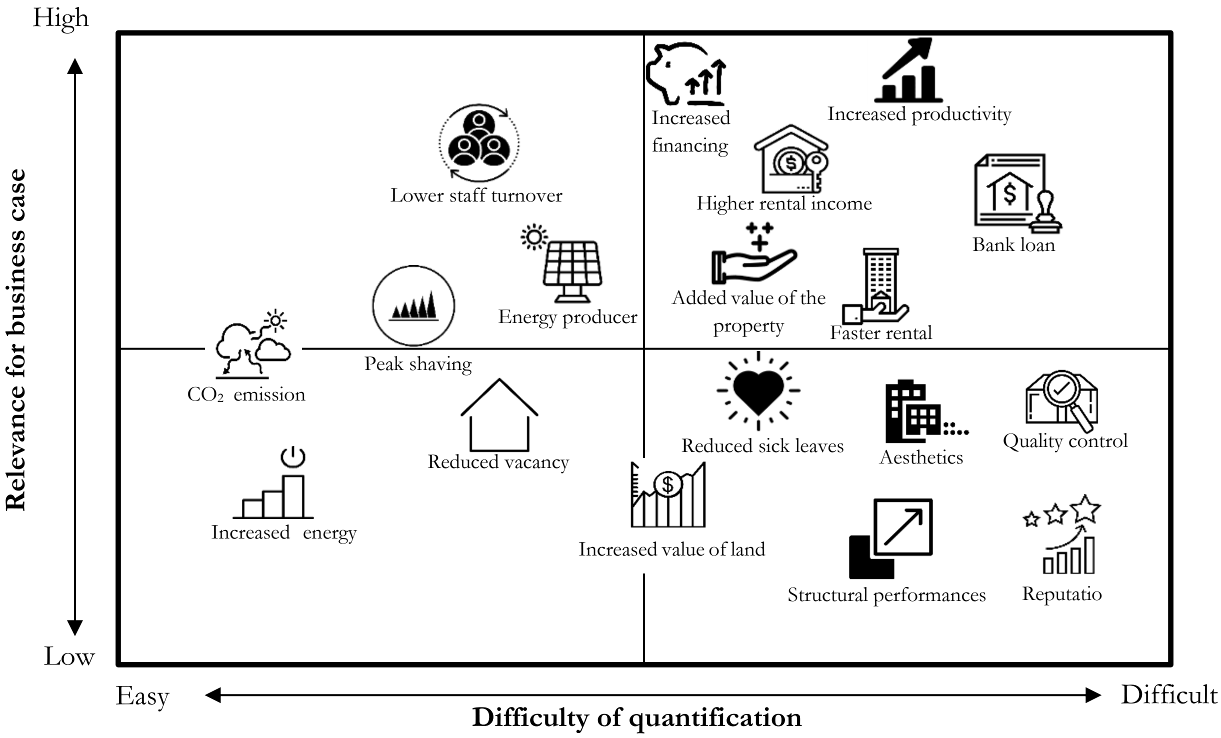

Figure 1: Co-benefits structured in terms of relevance for the business case and difficulty of quantification

Published by AEE INTEC, Austria

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CHAPTER 1

Added Values of nZEBs

1 ADDED VALUES

1.1 Literature review

The establishment of nZEBs focuses on potential measures to mitigate climate change by reducing non-renewable energy consumption and thus CO_2 emissions. This is necessary because social as well as economic barriers are constantly appearing (Economidou et al., 2011).

In most cases, the focus is on the fact that nZEBs reduce energy consumption and the costs of implementing energy-saving measures (Ferreira et al., 2016). However, there are other relevant advantages that often recede into the background. These are mainly concerned with indoor comfort, improved air quality and the associated reduced sick leaves, health benefits and increased productivity. In addition, lower burdens due to energy price fluctuations are expected, which in turn will have a positive effect on operation and maintenance costs (Ferreira and Almeida, 2015). These benefits improve building quality and users' well-being and offer economic benefits in addition to reducing energy bills.

These advantages can be very complex. This is due in particular to the fact that research is still in the early stages of such considerations. For these reasons, it is often difficult to find statistically founded robust values that allow individual co-benefits to be quantified. However, there are studies that can at least serve as a basis for such quantifications. Recent papers that deal with employee turnover and employee satisfaction (Miller et al., 2009), productivity (Hedge, Miller and Dorsey, 2014), (Thatcher and Milner, 2014) and employee absenteeism (Singh et al., 2010) already provide estimations of how to implement a sound co-benefit evaluation.

Studies show that employees in nearly zero energy buildings perceive a positive effect of their working environment and productivity (Thatcher, 2014), (Singh, 2010). In one case, a 10,000 m^2 office building, an increase in productivity of 0.3 % was reported, equivalent to 8 €/m^2a.

A study has noted a decline in absenteeism in nearly zero energy buildings (Thatcher, 2014).

An American study showed that around 20-25 % of 534 companies reported higher employee morale, easier recruitment of staff and more effective customer meetings (Miller, 2009). In addition, 19 % reported lower employee turnover.

In addition to well-being and productivity, higher revenues from rent or sales may be expected. Bleyl et al. 2017 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 green buildings, productivity and wellbeing, that a recent study pointed out, that social factors may have a more significant impact, in monetary terms, than environmental factors (Hugh, 2016).

The value of positive news articles 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 (Berggren, 2017).

In order to obtain a targeted overview of the users' understanding of co-benefits, a survey was launched as part of the EU Horizon 2020 project CoNZEBs (2017-2019). The focus was placed on indoor air quality, comfort, building location and low energy costs (Zavrl et al., 2019).

Depending on the perspective of the stakeholders, the interests, target criteria, and co-benefits can vary significantly. Figure 1 shows the criteria and co-benefits according to the interests of the different stakeholders. In order to achieve low heating costs, for example, the tenant is not only interested in low rental costs but also in low operating costs and therefore a good energy standard. As a general rule, the building contractor aims to keep his construction costs low. For properties used by the owner, both cost components are essential, the initial investment and the operating costs. For public owners and users, the total life cycle costs and also the effects such as CO_2 emissions are of interest.

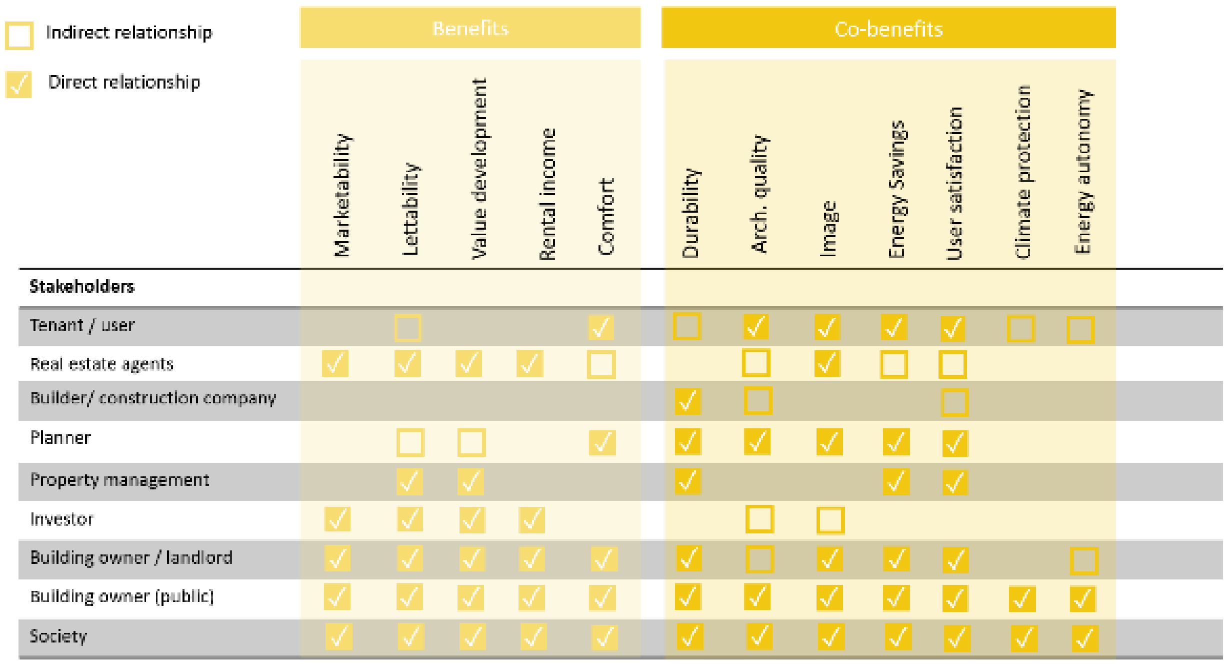


Figure 2: Stakeholder related benefits and co-benefits of nZEBs

In order to assess the direct monetary value of a building, there are various co-benefits for the individual stakeholders, which often cannot be assessed directly in monetary terms and therefore do not appear in the life cycle cost analysis. These concern marketability, rentability, value development, comfort, but also image, climate protection or regional goals such as energy autonomy. As far as possible, these advantages and additional benefits should be taken into account by the various stakeholders in the relevant decision-making process. These additional criteria can often overlap with the main criteria. An example is the use of an air-source heat pump in a very noise-sensitive environment. The air-source heat pump may perform relatively well in terms of energy and costs, including life cycle costs, but can cause problems due to increased noise pollution on the property and adjacent land. For this reason, it is crucial to quantify the added value of nZEBs in monetary terms by communicating and presenting business opportunities in such a way that potential investors understand and weigh up the pros and cons of an investment (Bleyl, 2016).
One way to highlight the importance of different co-benefits is to structure them as presented in Table 1.

Table 1: Overview of different co-benefits (with focus on monetary and environmental values) based on results of SKANSKA (Koppinen & Morrin, 2019)

Benefit	*Energy-related savings*	*Resource efficiency*	*Business opportunities*	*Healthy indoor environment*	*Improved financial terms*
Features	Energy efficient technology (Building envelope, installations) On-site RE-generation Energy storage (building related, e.g. using electricity when the tariff is low or using the structure to store heat)	No waste to landfill (100% recycling) Design to cost (and design to fit)-methods that save material, fuel, transports etc.	Promise of green performance to get land for building purposes or cheaper price for the land Earning credibility and long-term trust from officials at for example municipalities or customers Opening door to co-operations with common goals	More and better daylight Improved ventilation Lower noise-level Thermal comfort	Lower rate on bank loans for nZEBs Possibility to receive external funding Better terms for insurances
Direct value	Lower operational costs Lower CO_2 emissions Energy security	Lower costs during production Lower CO_2 emissions	Higher profit	Higher word productivity Reduced employee turnover Reduced sick-leave Lower rental vacancies	Lower economical risks

Benefit	*Energy-related savings*	*Resource efficiency*	*Business opportunities*	*Healthy indoor environment*	*Improved financial terms*
Indirect value	Increased property value Possibility to get a bigger loan for the investment Positive publicity and image, market differentiation Lower risk for future price increases	Saving natural resources	New business opportunities and co-operations	Increased property value	

There are more and more studies that shows the frequency of the various thematic areas in recent studies, which are particularly relevant for the different co-benefits. It can be seen that especially in the last few years the interest in individual co-benefits has increased significantly. Especially Indoor Air Quality, Thermal Comfort and Lighting & Daylight have been frequently discussed in studies published in recent years (Kunkel & Kontonasiou 2015); (Pracki & Blaszczak, 2016), (Attema, Fowell, Macko, & Neilson, 2019).

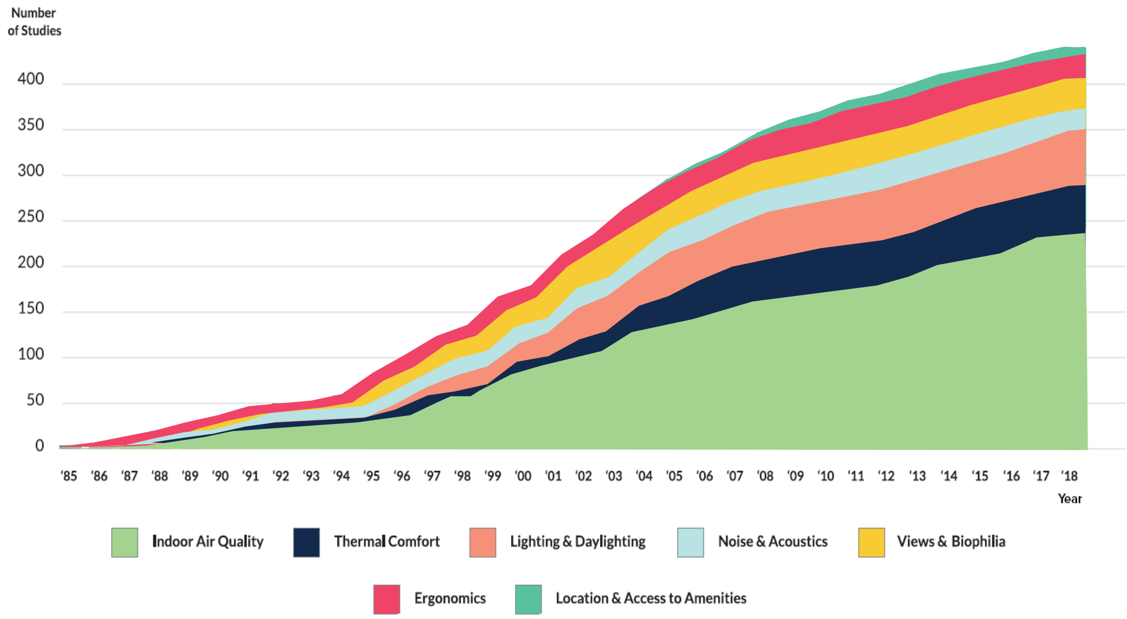


Figure 3: Cumulative studies of key design elements affecting occupants based on (Attema, Fowell, Macko, & Neilson, 2019)

2 CO-BENENFITS OF CRAVEZERO CASE STUDIES

In the course of this report, numerous co-benefits and their mean of quantification are examined in detail. A detailed description and quantification methodology of the co-benefits analyzed in this report can be found in chapter 3.

2.1 Introduction

This chapter deals especially with the co-benefits, which are often associated with nZEBs. These co-benefits can have currently underestimated positive effects on the payback time of nZEB investments and improved occupant satisfaction.

In two CRAVEzero case studies, various co-benefits such as increased productivity, improved health, advertising value e.g. are examined in order to show the effects of individual co-benefits on payback time in particular. The results of these studies are presented in the following chapter.

2.2 Methodology

Using the calculation bases of (Berggren, Wall, & Togerö, 2017), effects of various co-benefits on the life cycle costs of nZEB were quantified. The following formulae explain the procedure of these calculations.

The value of reduced energy consumption and exported energy described in the first formula summarizes the reduced energy costs (REC). For this purpose, the profitability of the increased costs associated with increased energy efficiency and the environmental values of the building were evaluated. In addition, investment costs were compared with energy efficiency and other sustainable values. Maintenance and renewal costs are not included in this formula.

$$REC = \sum \frac{EI \cdot \alpha + EE \cdot \beta}{\left(1 + \frac{r - i - \gamma}{1 + i + \gamma}\right)^{t}}$$

EI …………..... reduced imported energy
EE ...………… increased exported energy
α………………energy tariff of EI
β ………........energy tariff of EE
r …………..… nominal discount rate
i …………..… inflation rate
γ ………...…… increase in energy tariffs

The net present value of five other factors can also be quantified in order to expand the economic concept. These additional values are:

Reduced employee turnover costs (RETC)

$$RETC = \sum \frac{\varepsilon \cdot Emp(RC + IC + RPC + LI + DC)}{(1 + R)^{t}}$$

ε …………… reduced employee turnover
Emp………….. quantity of employees
RC …………... recruitment cost per employee
IC …………… introduction course for new employee,

RPC ………… reduced productivity cost (new employee and supervisor),
LI …………… lost income during vacancy,
DC …………... decommissioning cost and
R ……………... discount rate

Reduced sick leave costs (RSAC)

$$\mathrm{RSAC} = \sum \frac{\mathrm{Emp} \cdot 0.8\mathrm{SC} \cdot \phi \cdot \kappa}{(1 + \mathrm{R})^{t}}$$

SC ……………... average salary costs per employee
ϕ ……………… average sickness absence
$\varkappa$ ……………… reduced sickness absence

Increased productivity value (IPV)

$$IPV = \sum \frac{Emp \cdot SC \cdot IP}{(1 + R)^{t}}$$

IP ……………. *increased productivity per employee.*

Public publicity value (PPV)

$$PPV = \sum AIP \cdot AC$$

AIP……….......article in press
AC …………... advertising costs in the specific source (paper, internet, etc.)

Reduced sick pay (RSAS)

$$RSAS = \sum \frac{WW \cdot 0.2S \cdot \phi \cdot \kappa}{(1 + R)^{t}}$$

WW ………… quantity of wageworkers in the household
S ……………... salary

Discount rate (R)

$$R = \frac{\mathrm{r} - \mathrm{i}}{1 + \mathrm{i}}$$

Furthermore, the value of the reduced land price can also be included in a valuation. Since this is usually done in the initial phase of a construction process, discounting of these values is not required. This means that no equation is actually required to express the capital value. Additional there can be grants/contributions from the state or municipal e.g. PV grants.

Based on these calculations of (Berggren, Wall, & Togerö, 2017), a sensitivity analysis was carried out to show the effects that different co-benefits can have on the payback time of an nZEB.

2.3 Case study: Aspern IQ

2.3.1 Introduction

Figure 4: Aspern IQ (©Kurt Kuball/Wirtschaftsagentur Wien)

General information

- Owner: City of Vienna
- Architect: ATP Wien
- Energy concept: Renewable power, environmental heat, and waste heat
- Location: Vienna (Austria)
- Year of construction: 2012
- Net floor area: 8817 m²

Key technologies

- Groundwater heat pump
- Photovoltaics

Aspern IQ is located in Vienna's newly developed urban lakeside area "Aspern" - Austria's largest urban development project and one of the largest in Europe. The building was designed in line with Plus Energy standards and is conceived as a flagship project which shows the approach to create a Plus Energy building adapted to locally available materials and which offers the highest possible level of user comfort while meeting the demands of sustainability. The Technology Centre received a maximum number of points in the Austrian klima-aktiv declaration and had also been awarded an ÖGNB Building Quality Certificate. The energy demand of the building has actively been lowered by measures in the design of the building form (compactness), orientation and envelope. A balanced glazing percentage, the highly insulated thermal envelope in passive house standard, optimized details for reduced thermal bridges and an airtight envelope (Blower Door Test=0,4 1/h) beating the Austrian building regulation OIB 6 by 55 %. (Weiss, 2014), ('Ein Leuchtturm der Nachhaltigkeit als Gründungsakt für aspern Die Seestadt Wiens', 2013)

With the Aspern IQ technology centre, the Vienna Business Agency is providing a major impetus for positioning the lakeside city of Aspern as an urban living space of the 21st century. In order to create the ideal environment for entrepreneurial innovation, the highest sustainable standards were implemented in planning and construction. The Plus Energy commercial property offers a state-of-the-art working environment for innovative, technology-oriented companies.

In Aspern, companies find space and development opportunities for innovation, technology and production.

This includes the energetic optimisation of the building envelope, the demand-oriented control of the building services, the 130 kWp, 1,300 m² photovoltaic system, the own fountain water, which is used for cooling and the server waste heat for heating. The minimal energy consumption is also supported by external sun protection, which provides shade depending on the position of the sun and radiation intensity, and a highly efficient ventilation system, adapted to the individuals present inside the room. (Das Technologiezentrum Aspern IQ, 2019)

2.3.2 Methodology

2.3.2.1 Sensitivity analysis

In CRAVEzero deliverables 6.1 and 6.2, a sensitivity analysis (SA) was performed for the investigated case studies, to identify which input parameters affect the life cycle cost (LCC) the most. In this way, the implications of uncertainty issues related to the assumptions on input parameters and boundary conditions could be highlighted. The same methodology has been adopted in this deliverable to give a better insight in the co-benefit analysis developed within the CRAVEzero framework and to determine the impact of the co-benefits on the value of an nZEB.

The equations of the quantified co-benefits as described in chapter 3 have been used to perform the SA of one office building, the case study Aspern IQ, located in Vienna (Austria). As reported in the co-benefits description, the quantification was one of the main challenges faced in this analysis. Furthermore, among the quantified parameters, not for all of them baseline values from literature could be found. For this reason, only a minor fraction of the listed co-benefits could be investigated with the SA.

SA workflow was designed as follows: firstly, input values and variation ranges must be selected. Since literature data about input values is scarce and data about their possible variation ranges even more difficult do rely on, input parameters have been varied over a predefined range, in this case +-10%. Secondly, SA requires selecting an output in order to measure its value when the input varies. The tool calculates the savings generated by the positive action of the co-benefits on the business value. These savings are used to calculate the time needed to pay back the additional investment for the nZEB. The accumulated total savings after 30 years have been chosen as output for the SA. Finally, the analysis was performed applying two methodologies, as previously done in D6.1 and D6.2. The first one consists of a differential sensitivity analysis. This represents the simplest screening technique. In the second step, the elementary effects (EE) method was implemented.

Differential sensitivity analysis

This method belongs to the class of the One Factor At a Time (OAT) screening techniques. In differential analyses, all parameters are set equal to their baseline value. Then, the impact on the LCC of one parameter at a time is investigated, keeping the other parameters fixed. Sensitivity index (s%) is calculated as follows:

$$s\% = \frac{\frac{\Delta \mathrm{O}}{\mathrm{O_{un}}}}{\frac{\Delta \mathrm{I}}{\mathrm{I_{un}}}}$$

Where: ΔO is the output variation, O_{un} is the output baseline value, ΔI is the input variation and I_{un} is the input baseline value.

Elementary effects method

The EE method was proven to be a very good compromise between accuracy and efficiency (Campolongo, Cariboni, Saltelli, 2007), since a good exploration of the design space with a reduced number of simulations can be ensured (Castagna M.). With this method, SA can be carried out for different combinations of input values, analysing the effects of parameters interactions.

An elementary effect is defined as a change of the output caused by a change in a single input parameter, while keeping all other model parameters fixed. As pointed out in (Hedge, Miller, Dorsey, 2014), to obtain robust sensitivity measures, more elementary effects per parameter have to be computed, varying directions of change and base values. Nevertheless, only a reduced part of the possible elementary effects can be analysed, therefore a so-called Design of Experiment (DoE) has to be generated to choose carefully the combinations. The mean elementary effect associated with a factor i is then given by the average of the single elementary effect (EE) associated with that factor:

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

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

μ_i^* is the absolute mean of the single elementary effects associated with factor i. σ_i^2 is the variance of the elementary effects associated with factor i.
The main limitation is that, while the impact of a given variable is investigated, the other parameters remain unchanged. Even if the interactions of the parameters cannot be investigated in a global perspective, this characteristic permits to determine which parameter causes the greatest effect.

Baseline values
As indicated above, SA measures the effects on a selected output when the input is varied of a determined quantity around its baseline value. A literature research was carried out in order to determine reliable baselines. For instance, based on results coming from (Hedge, Miller, Dorsey, 2014), (Singh et al., 2010), (Thatcher, Milner, 2014) the productivity increase due to a better working environment by 0.3% was set. Another example is the co-benefit, which identifies the reduced sickness absence; in this case 7.5% was adopted as baseline value (Singh et al., 2010), (Thatcher, Milner, 2014).

Table 2: Baseline values for the co-benefits analysis.

Co-Benefits	Baseline value [%]	References
Yield reduction due to high quality nZEB	0.5	(Global Property Guide, 2020)
Reduced vacancy	3.5	(Whole Building Design Guide, 2019)
Higher rent	5	(Bleyl, et al., 2017), (Whole Building Design Guide, 2019)
Increased productivity	0.3	(Hedge, et al., 2014), (Singh, et al., 2010), (Thatcher, Milner, 2014)
Lower staff turnover	0.5	(Thatcher, Milner, 2014)
Reduced sick leaves	7.5	(Singh, et al., 2010), (Thatcher, Milner, 2014)

Working with different baseline values coming from literature, whereas its variation range has to be fixed and equal to all co-benefits due to lack of literature data, raises an issue: the variation ranges can be very different, up to factor 10, as the two co-benefits previously indicated show. For this reason, the SA was performed testing two different approaches:

1. Baseline values from literature: to each co-benefit a baseline value from literature has been assigned, as indicated in table 1.
2. Uniform baseline for all the co-benefits: 1 % as baseline value. In this way during the SA all the co-benefits have been submitted to the same variation.

2.3.2.2 Cost-benefit analysis of nZEBs for project developers

In the Aspern IQ reference building, in order to be able to filter out the influences of the individual co-benefits, the economic and energetic building data were used in order to be able to map the influences as accurately as possible. A parametric cost-benefit analysis with changing individual parameters of the co-benefits was performed to see how the added values affect the project. For this purpose, the data shown in Table 3 below were determined. The assumed property value was determined using a comparative value method with comparable buildings in Austria.

Table 3: Data of the reference building

Financial		
Residential/non residential	Non-residential	
Saleable / rentable area	6,600.00	m²
Expected sales year of property	30	years
Assumed property value	3,914.00	€/m²
Rents to tenants	144.00	€/m²a
Expected yield	10	10 %
Rental or owner-occupation	Rental	
Estimated vacancy rates	6	6 %
Number of employees	250.00	employees
Energy		
Treated floor area	6,633.00	m²
Heating demand	50.00	kWh/m²a
Cooling demand	10.00	kWh/m²a
Electricity demand	40.00	kWh/m²a

Furthermore, with regard to the fact that this is a nearly zero-energy building, there are additional aspects concerning the economy which cannot be ignored under any circumstances. This concerns particularly the additional costs and the energy targets of the construction of a nearly zero-energy building.

Table 4: Aspects which are based on high quality nearly zero energy buildings

Financial		
Additional nZEB costs	171.60	€/m²
Funding	0.00	€/m²
Equity capital, or bank loan	Equity Capital	
Bank loan duration	0.00	years
CO_2 follow-up costs		€ per ton CO_2
Energy		
Heating demand	21.00	kWh/m²a
Cooling demand	2.00	kWh/m²a
Electricity demand	18.00	kWh/m²a
PV yield	14.55	kWh/m²a
PV yield: self-consumption	10.00	kWh/m²a

Based on this building data, the different co-benefits were considered in Aspern IQ. Calculation results with and without the consideration of co-benefits clearly show the influence of the individual parameters on the overall cost curve over the duration of 30 years and especially the breakeven of the additional nZEB investments as can be seen in Figure 5 and 6. The following list shows the applied co-benefits.

- Yield reduction due to high quality nZEB
- Reduced vacancy
- Higher rent
- Faster rental of the building
- Reduced maintenance costs
- Number of press clippings
- Increased productivity
- Lower staff turnover
- Reduced sick leaves

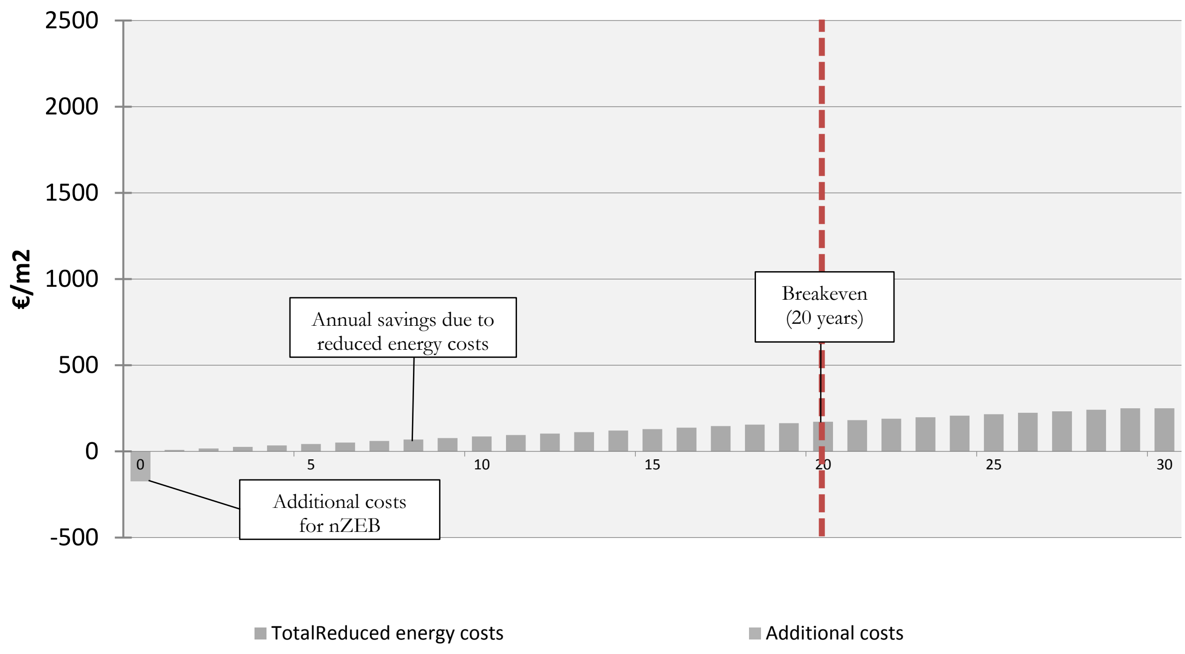


Figure 5: Payback time without co-benefits (20 years)

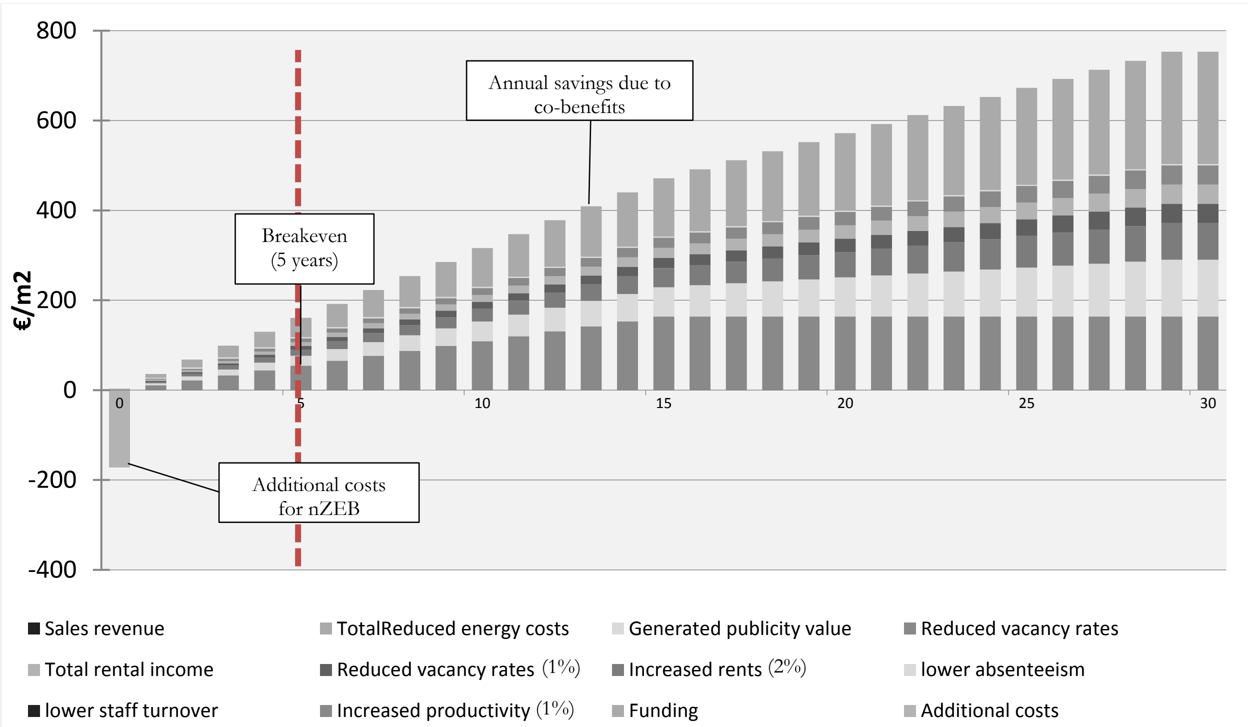


Figure 6: Costs based on the entered parameters

Figure 6 clearly shows that the additional costs for the nZEB standard of ~ 170 €/m² have a considerable influence on the payback period of the additional nZEB investment and the economic success. These result from the quantification of all additional benefits implied by the high quality of nZEB. The payback time considering all co-benefits leads to a breakeven in less than 5 years as can be seen in Figure 6 whereas without considering co-benefits, by just focusing on payback by operational energy cost savings would lead to a breakeven of 20 years as can be seen in figure 5. Co-benefits, such as lower staff turnover, reduced vacancy rates or total rental income are important factors to support the success of a nZEB in terms of payback time and economic success.

2.3.3 Results / documentation

2.3.3.1 Sensitivity analysis

SA has been performed first, applying the DSA method and then the EE method. For each one of these methods, the two approaches for the baseline values, previously illustrated, are displayed. Moreover, the discount rate has been inserted as a variable parameter to add the effect of its variation to the SA. In DSA the effects, the sensitivity index for 3 scenarios was calculated: discount rate 1, 2 and 3 %. In the EE method, the discount rate was added to the investigated parameters.

Differential sensitivity analysis

Figure 7: Sensitivity index related to real values baseline – discount rate 1, 2 and 3%.

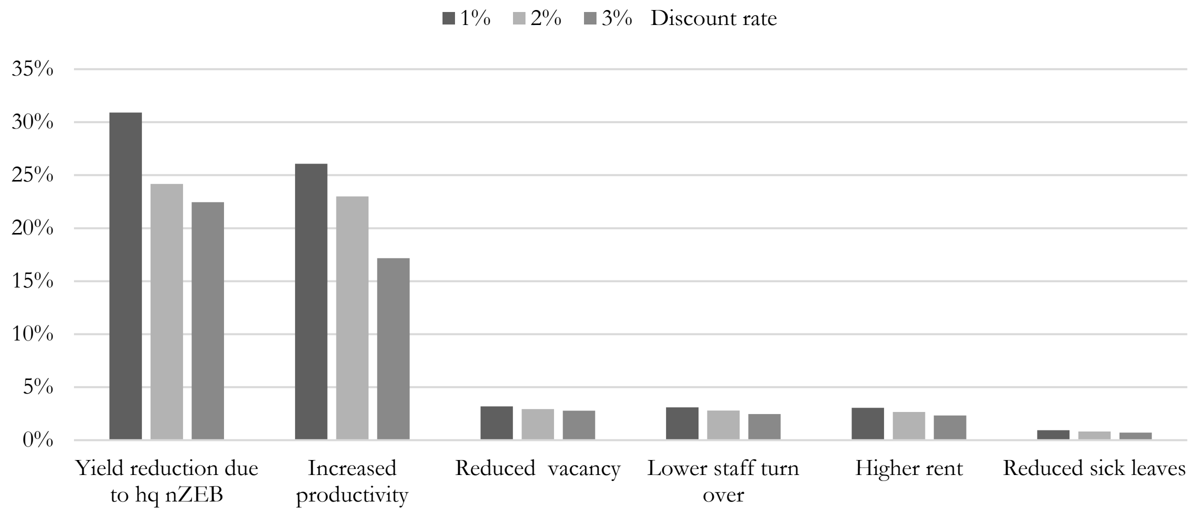


Figure 8: Sensitivity index related to common baseline (1%) – discount rate 1, 2 and 3%.

In the first approach, where real values for the baselines are adopted, the three most influencing co-benefits are “higher rent”, “yield reduction due to a high quality nZEB” and “Reduced vacancy”. However, quite different outcomes are obtained if the second approach is considered: the most influencing values by far are “yield reduction due to hq nZEB” and “increased productivity”.

Another observation, which emerges from the results, is that the most influencing parameters present a stronger dependence on the discount rate parameter.

Elementary effect method

The elementary effects method has produced similar results to the differential sensitivity analysis, confirming what is reported in the previous paragraph.

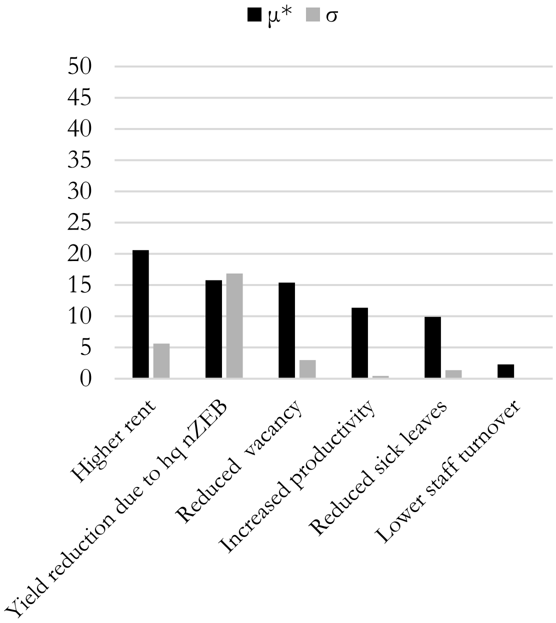


Figure 9: μ* and σ related to real values baseline.

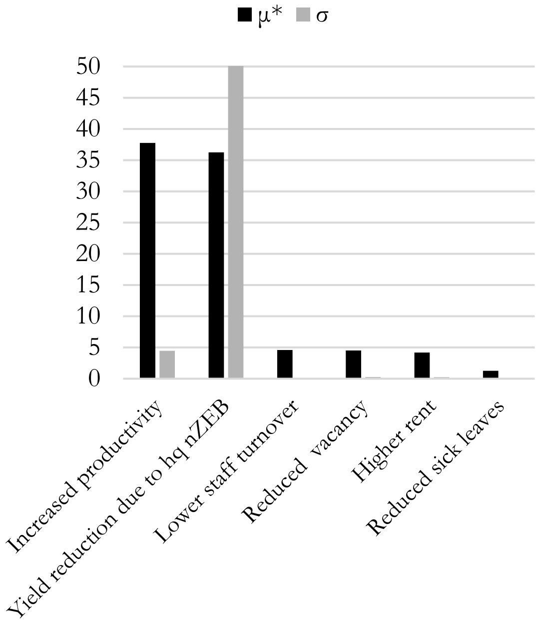


Figure 10: μ* and σ related to common baseline 1%.

In (Berggren et al., 2018), increased productivity is indicated as the co-benefit with the largest relative impact. This statement is confirmed by results obtained with the second approach, which applies a fixed variation of 1 % equal to all co-benefits. A productivity increase of 1 % corresponds to 22 €/(m²a) of labour cost savings, assuming an average monthly salary per employee of 3,000 € and employer & social costs (excl. holiday allowance) equal to 60 %. Nevertheless, the questions that should be further investigated are "how much can actually the productivity increase vary?", "Is it plausible a productivity increase of 1 %? And 2 %?". (Bleyl et al., 2017) state that in some cases a rent increase related to a green building can range from below 4 % up to 21 %. For the purpose of this analysis a 5 % rent increase has been conservatively selected for the approach which takes into account baseline values from literature. Nevertheless, in this case, this co-benefit showed the highest sensitivity index and μ*.

2.3.3.2 Cost-benefit analysis of nZEBs for project developers

In this chapter various co-benefits are analysed in respect to the overall payback time of the additional nZEB investment of Aspern IQ.

The following Figures 11 to 13 show the analysed co-benefits and their effect on payback time in comparison. In this specific case, six different co-benefits were examined and compared with each other using box plot[1] diagrams. Each of the six fringe benefits (lower vacancy rate, higher rent, faster rental, higher productivity, lower staff turnover, lower sickness absence) was analysed in terms of its impact on payback time. The individual co-benefits were analysed with regard to their expected impact on the project. For example, the effects that a higher rent of 1 to 10 % would have on the project were determined. These different variants were carried out with all selected co-benefits in order to be able to show which influences

[1] The box plot is a graphical representation to characterize the distribution of continuous features based on the empirical quartiles (25 % values). The interquartile distance is shown as a box from which lines are drawn to the minimum and maximum. The median is described by a line in the box. Optionally, the position of the arithmetic mean is marked by an x. The outliers are represented as points.

can be associated with the different percentage changes. For all co-benefits the control of 1 to 10 % was chosen. The only exception is the co-benefit "faster rental of the building" where the period 1 to 5 months was used to see the respective effects of the co-benefits on the discounted payback period.

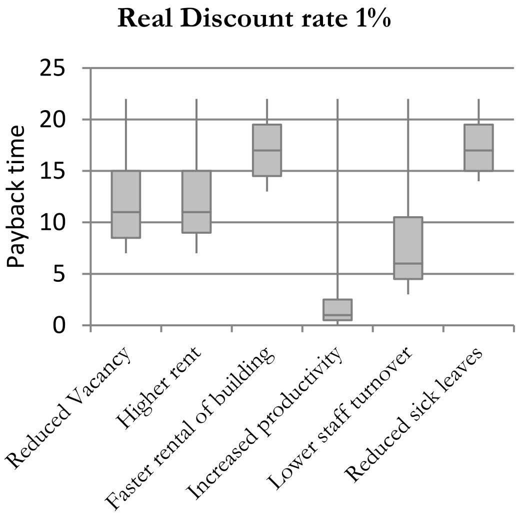


Figure 11: Boxplot real discount rate 1%

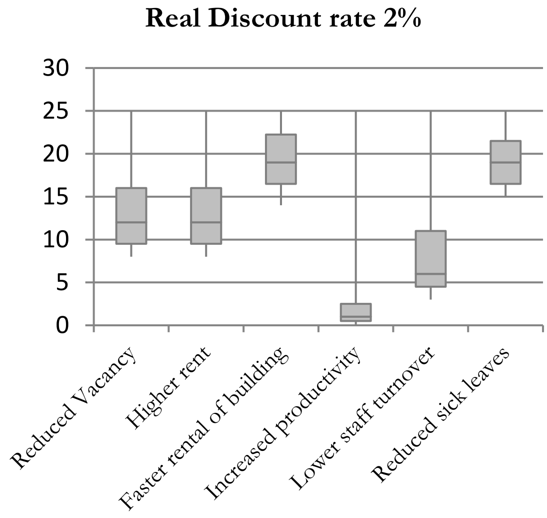


Figure 12: Boxplot real discount rate 2%

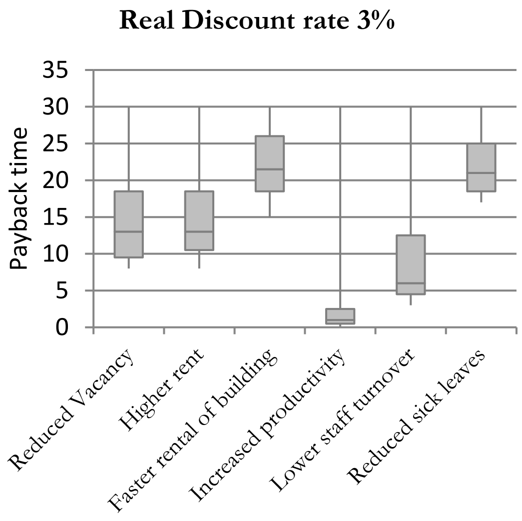


Figure 13: Boxplot real discount rate 3%

In Figure 11-13, the differences that result from various assumptions of the real discount rate can be seen. The real discount rate is used to convert between one-time costs and annualized costs.

Depending on how high the real discount rate is set, it can be seen that the payback time of each co-benefit is different. The higher the real discount rate, the longer the payback time. If we look at the individual co-benefits, we can see that increased productivity has the greatest influence on the payback time. But lower staff turnover also has a big influence. The smallest influences of the considered co-benefits are the faster rental of building and reduced sick leaves. Still all co-benefits have a huge influence in the economic consideration of nZEBs usually exceeding the effects by a return of investment by energy cost savings alone by far.

To further analyse the effects of co-benefits a differential life cycle analysis of the case study Aspern IQ with additional investment costs of 170 €/m² and with varied co-benefits compared to a state of the art building without additional nZEB investment as a baseline. The effects on costs, revenues, break-even and success in particular are shown as benchmarks in a graph over a period of 30 years as can be seen in Figure 14.

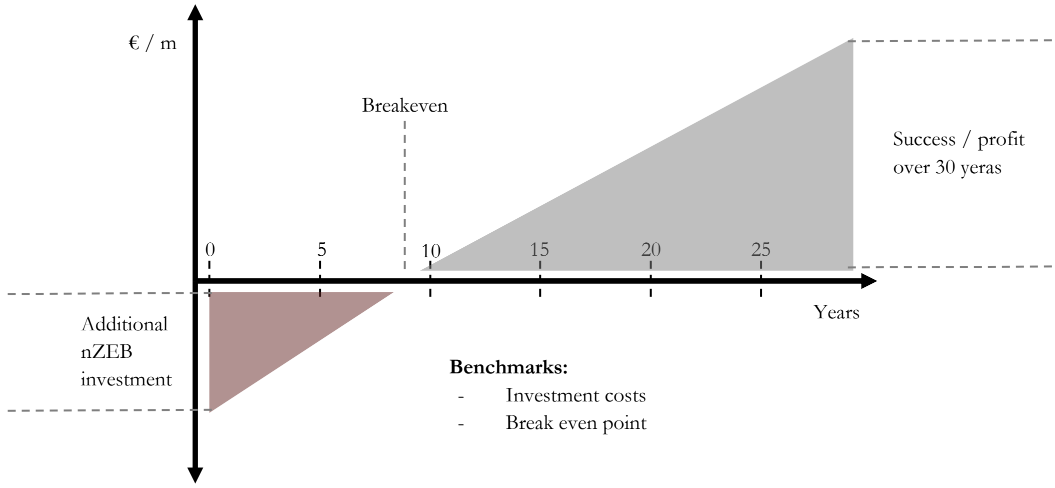


Figure 14: Additional investment, breakeven and profit over 30 years

As shown in Figure 15, the energy payback time without the influence of co-benefits is more than 20 years. This is the reference for comparing the influences of different co-benefits on the financial results. The following graphs (Figure 16 to Figure 20) show the changes in breakeven and profit depending on different co-benefits (the additional investments of ~170 €/m² are kept constant). This makes it possible to show the influence different co-benefits have on the payback time and profit.

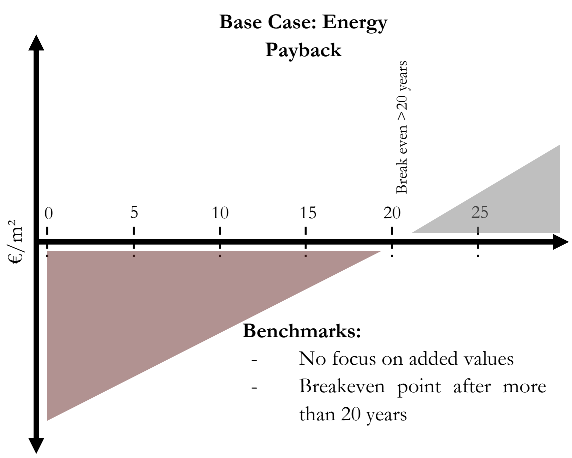


Figure 15: Reference case: energy payback

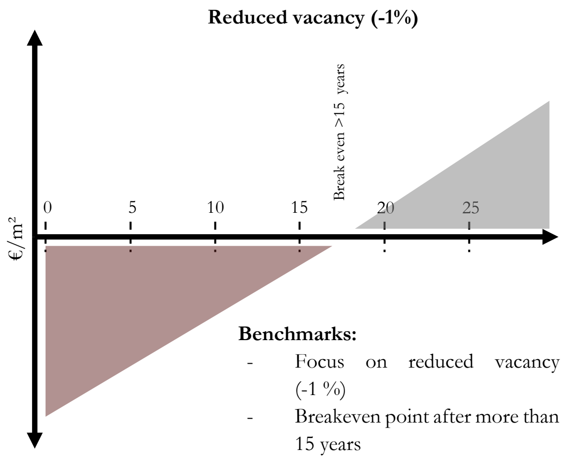


Figure 16: Reduced vacancy (-1 %)

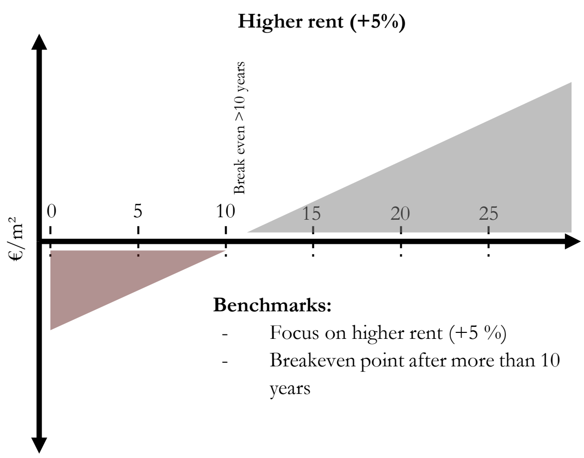


Figure 17: Higher rent (+5 %)

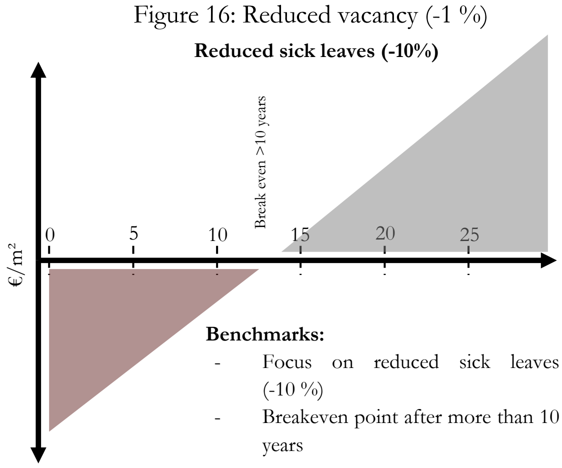


Figure 18: Reduced sick leaves (-10 %)

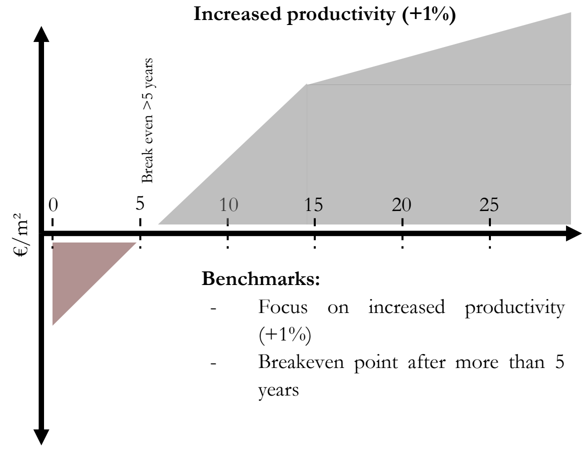


Figure 19: Increased productivity (+1 %)

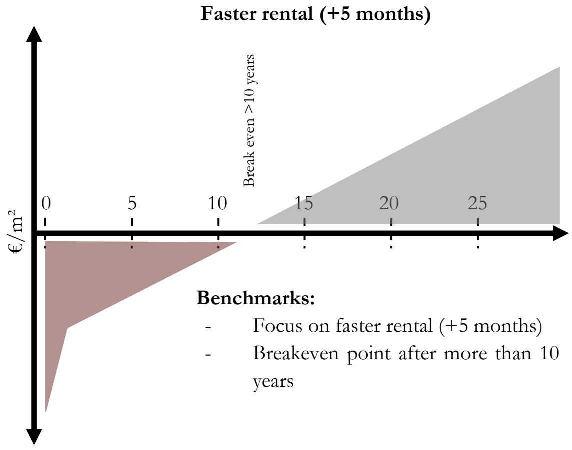


Figure 20: Faster rental (+5 months)

Table 5: Results of the co-benefit variants

	Additional nZEB Investment	***Return of Investment / Break even***	***Success/ Profit over 30 years***
Reference *Case: Energy payback*	170 €/m²	>20 years	45 €/m²
Reduced vacancy (-1 %)	170 €/m²	>15 years	81 €/m²
Higher rent (+5 %)	170 €/m²	>10 years	221 €/m²
Reduced sick leaves (-10 %)	170 €/m²	>10 years	154 €/m²
Increased productivity (+1 %)	170 €/m²	>5 years	347 €/m²
Faster rental (+5 months)	170 €/m²	>10 years	111 €/m²

Figure 16 to Figure 20 are based on the following detailed calculations:

Table 6: Calculation of the reduced vacancy rates as shown in Figure 16

Vacancy rates		
Reference case rents	144	€/m² (saleable area) per month
Adopted lower level vacancy	1 % units	
Increased rental income due to lower vacancy rates:	**1.44/ m² (saleable area)**	

Table 7: Calculation of the faster rental as shown in Figure 17

Rents		
Reference case vacancy:	2%	
Reference case rents	144	**€/m²a**
Adopted rent %:	5	%
Increased level of rent if the property is rented out externally	**7**	**€/m²a**
Increased rental income after taking into account the assumed vacancy level	**7**	**€/m²a**

Table 8: Calculation of the reduced sick leaves as shown in Figure 18

Sick leave		
Total in € per square meter (saleable area) per employee	28.800 **€**	
Savings thanks to reduced absenteeism	4 €/ m²	115 €/employee
Calculation		
reference case absenteeism percentage	2 %	
Days per year	229,00 days	
reference case number of sick days per year and person	**4,6 days**	
reference case number of sick days per year and person	4,6 days	
Reducing absenteeism	10 %	
Number reduced sick days per person and year:	**0,46 days**	
Number reduced sick days per year, the total of all of the property:	**114,5 days**	
Number reduced sick days per person and year:	0,46 days	
Total number of employees in the building:	250 Employees	
Days per year	229,00 days / year	
Average annual labor costs per employee (incl. Employer):	57.600 employee	
Savings thanks to reduced absenteeism	**28.800 €**	

Table 9: Calculation of the increased productivity as shown in Figure 19

Productivity		
	Total in € Per m²	**Total in € per employee**
Total savings through productivity improvement	144.000 € 22 €/m²	576 € / employee
Calculation		
Average monthly salary per employee	3.00/ month	
Number of months of qualifying for salary	12 months, i.e. including holiday	
Employer	60,00 %	
This corresponds to an average salary cost for renter incl. holiday at:	**57.600 / year and employee of the tenant**	
Total number of employees in the building:	250 People	
Average annual labor costs per employee (incl. Employer):	57.600 / year	
productivity Improvement	1%	
Total savings through productivity improvement	**144.000 €**	

Table 10: Calculation of the faster rental as shown in Figure 20

Faster rentals	
Number of months quicker rentals	5 months
Corresponding:	0,4167 year
Reference case rents per year	144 €/ m2 (saleable area)
Savings due to faster rental	**60/ m2 (saleable area)**

2.3.4 Discussion and conclusion

In the course of this chapter, the co-benefits have been analysed in particular with regard to their influence on the payback time and profit over a time period of 30 years for the case study Aspern IQ. Increased productivity of the employees due to higher building quality and comfort and a possible higher rental income due to a better building standard are the most important factors with regard to the payback time and profit. But also the other co-benefits, which were examined here in more detail, have a significant influence.

Even influences which are usually not considered and harder to quantify, such as the productivity of the employees, reduced sick leaves or reduced vacancies, can significantly influence the economic success of an nZEB. The analyzed case study Aspern IQ illustrates once again that it is often not sufficient to include only energy related cost savings in the payback calculation, as rentability is typically influenced by co-benefits to a more significant extent even though they cannot be quantified easily and estimations have to be made based on literature and recent studies.

2.4 Case study 2

2.4.1 Introduction

Figure 21: Väla Gård (© Skanska Sverige AB)

General information

- Owner: Skanska
- Architect: Tengbom
- Energy concept: Passive house design with PV-panels and groundsource heat pump
- Location: Helsingborg (Sweden)
- Year of construction: 2012
- Net floor area: 1 800 m²

Key technologies

- Passive House design
- Groundsource heat pump
- Photovoltaics
- Presence controlled

Väla Gård is a two-storey office building, built in the southern part of Sweden (Helsingborg, 56.086, 12.742). Skanska has developed one of the greenest office buildings to date at the historic Väla Gård site outside Helsingborg. The office building, which was designed by Tengbom Arkitekter, are reminiscent of contemporary versions of traditional farmhouses in Skåne with a gable roof. The aim was to blend the offices sympathetically into the historical environment.

The environment has been at the core of every decision – from project planning to moving in; energy-smart materials, recycling of all leftover material, built with a high level of insulation and equipped with PV-panels and a ground-source heat pump. The building is certified under Leadership in Energy and Environmental Design (LEED) at the highest level, LEED Platinum. It is a plus energy building, which was the first building in the world to achieve the highest ranking, "Deep Green, in Skanskas Color Palette™. Väla Gård received the highest LEED score in Europe and the third-highest score in the world when it was built (2013).

The strategy for reaching a Net ZEB balance was a three-step approach. The thermal losses and heat gains were reduced in order to have low heating and cooling demand. A ground source heat pump (GSHP) was chosen in order to lower the need for imported energy. Finally, the building was equipped with PV panels, to generate renewable energy.

The foundation is a concrete slab on ground with 350 mm insulation. The external walls are concrete walls with 295 mm insulation. The roof is insulated with 370-520 mm insulation. Windows and glazed entrance have a U-value of 0.90-1.00 W/m²K. Windows towards southeast and southwest have solar shading.

The ventilation is designed with a mechanical balanced ventilation system with heat recovery of 84 % with variable air volume (VAV). The ventilation is controlled by presence, temperature and CO_2. The GSHP produces space heating and

hot water. If there is cooling demand, the airflow increases with cooled air in the room. The cooling coil lowers the supply air temperature using free cooling from the boreholes in the GSHP system.
The lighting system consists of energy-efficient light fixtures, controlled by presence and daylight. To minimize tenant electricity (reducing standby losses), the main part of the electrical outlets, plug loads, are turned off when the building alarm is switched on.
The building is designed with 288 PV panels with 5 inverters, giving the building an installed capacity of 70 kWp.
A more detailed description of Väla Gård may be found in (Elsevier, 2013) (Statistic Sweden Labour market, 2020) (Berggren, 2015).

2.4.2 Method

Based on the equations presented in section 2.2 Methodology, the following parameters were investigated:

- Reduced energy costs (due to decreased energy demand)
- Increased rental income (due to lower vacancy rate)
- Publicity value (based on number of press clippings)
- Increased productivity
- Lower staff turnover
- Lower sick leaves

To investigate the effect of the co-benefits listed above, a reference building is defined, towards which the case study, Väla Gård, is compared to. The reference building and boundary conditions are described in Table 11. Input data for the investigated parameters are described in Table 12.
Initially, each parameter is investigated followed by a combination of all parameters. A sensitivity analysis is included. The sensitivity analysis involves a variation of each parameter by ±25 %, when all parameters are combined.

Table 11: Summary of reference building and boundary conditions

Financial info – reference building	
Type of building	Non-residential
Saleable/rentable area	1 600 m²
Rent to tenants	70 €/m²a
Vacancy rate	15 %
Employees	70 persons
Energy – reference building	
Treated floor area	1 670 m²
Heating energy (electricity)	22 kWh/m²a
Cooling energy (electricity)	5 kWh/m²a
Electricity, excluding heating and cooling	65 kWh/m²a
Boundary conditions	
Nominal discount rate	7 %
Inflation	2 %
Tariff for imported energy	0.12 €/kWh
Tariff for exported energy	0.10 €/kWh
Annual energy tariff increase	2 %
Average salary costs	6 350 €/employee
Average employee turnover, Sweden (1)	4 %
Average sick leave	6 days/year
Value for publicity	3 500 €/article

Table 12: Input data for investigated parameters

Reduced energy costs	
Heating energy	4
Cooling energy	1
Electricity, excluding heating and cooling	35
Increased rental income	
Vacancy rate	5 %
Publicity value	
Press clippings	10 articles
Increased productivity	
Increased productivity	0.5 %
Lower staff turnover	
Reduced employee turnover	0.5 %
Lower sick leaves	
Reduced sickness absence	10 %

2.4.3 Results

The case study reported increased costs amounting to 450 000 € (281 €/m²) compared to if the office would have been a "normal office". Regarding cost reductions, a state grant was given for the PV-panels, amounting to roughly 82 000 € or 51 €/m².

Increased production costs, consultants and certification costs are included. The result from the LCC-analysis for the energy savings is presented in Figure 22, left side. The total energy saving in the case study (excluding the effect from the PV-panels) amounts to 60 kWh/m²a. Including the effect from the PV-panels, reducing the imported energy and the benefit from exported energy, the annual value for the reduced value for energy costs amounts to 12 €/m²a. As can be seen, the cumulative savings (including the effect from the PV-panels) does not exceed the increased costs within a short time perspective. After roughly 40 years, the cumulative savings exceed the additional costs.

Increased rental income, a vacancy rate of 5 % instead of 15 %, results in an increased income of 7 €/m²a, almost 60 % of the value for the energy savings. However, savings from the rental income is not affected by energy price; the cumulative savings are lower and will never exceed the increased costs, see Figure 22, right side.

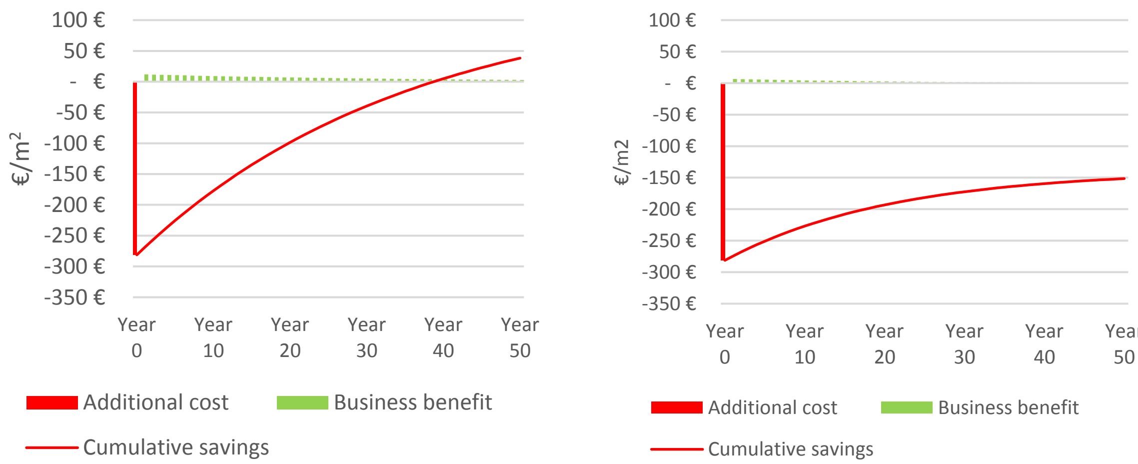


Figure 22 Left: LCC-analysis for energy savings at Väla Gård. Right: LCC-analysis for increased rental income for Väla Gård

The publicity value of ten press clippings are rather high, 35 000 € (22 €/m²). However, as the publicity does not last over time, in this case study only press clippings the first year is included, the cumulative effect is low, see Figure 23 left side.

Except for the value of press clippings (which are not recurring), increased productivity of 0.5 %, has the highest business benefit, amounting to 17 €/m²a, see Figure 23, right side. The annual value is almost 40 % higher compared to the value of energy savings. However, also here, the savings from the increased productivity is not affected by energy price. The cumulative savings, therefore, exceed the increased costs after roughly 40 years, the same time period as for energy savings.

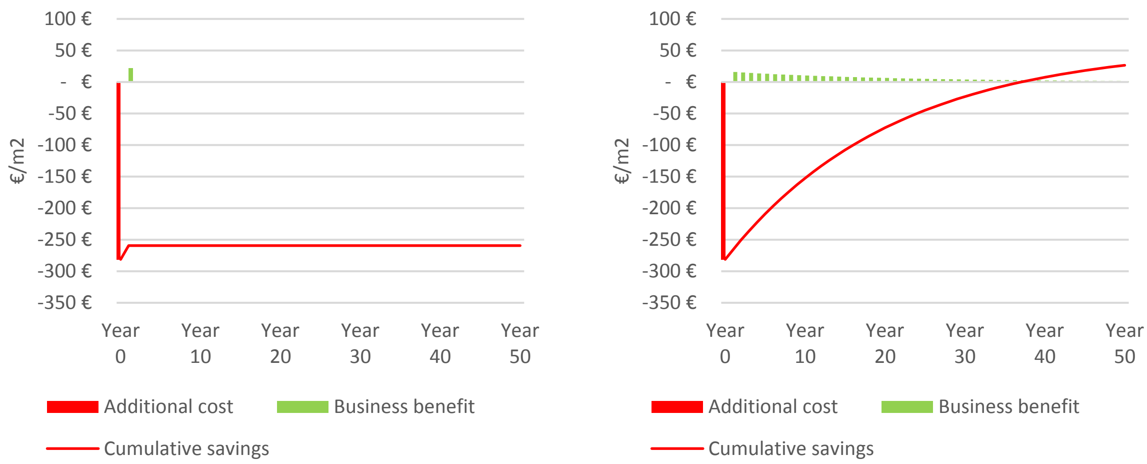


Figure 23 Left: LCC-analysis for publicity value of press clippings for Väla Gård. Right: LCC-analysis for increased productivity for Väla Gård

The value of lower staff turnover and lower sick leaves is similar to increased rental income. The annual value is 8 €/m²a and 7 €/m²a, respectively. Also here, the cumulative value never exceeds the additional costs, see Figure 24.

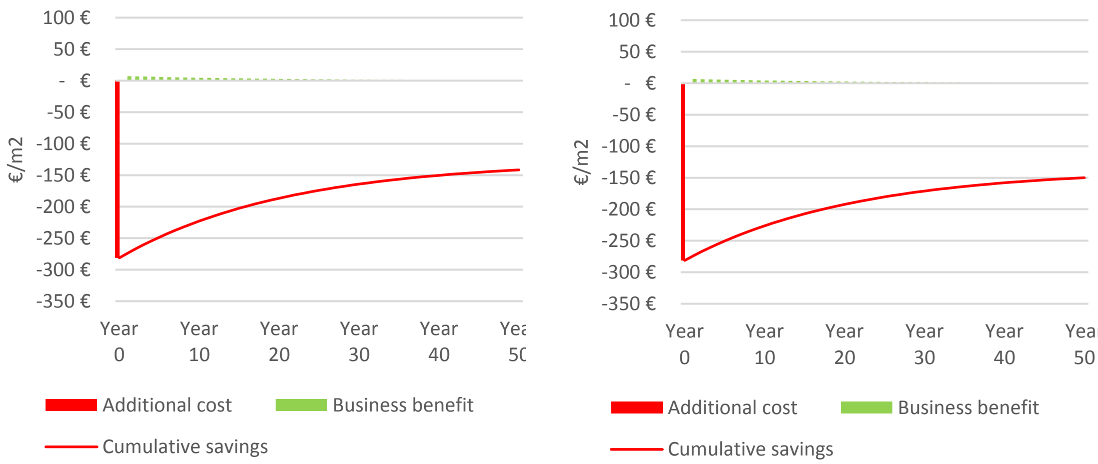


Figure 24 Left: LCC-analysis for reduced employee costs for Väla Gård. Right: LCC-analysis for Reduced sick leaves for Väla Gård

In Figure 25, all co-benefits investigated above have been included. A base case (BC) is presented together with a worst-case and an optimal case. The base case is a case where all co-benefits above have been included together with the additional costs and the cost reductions received in the project. In the worst case, the additional costs have been increased by 25 % and the business benefits have been reduced by 25 %. In the optimal case the changes are the opposite. I.e. additional costs have been reduced by 25 % and the business benefits have been reduced by 25 %. In the base case, the cumulative savings exceed the additional costs after roughly four years. In the optimal and worst case, the cumulative savings exceed the additional cost after roughly three and eight years respectively.

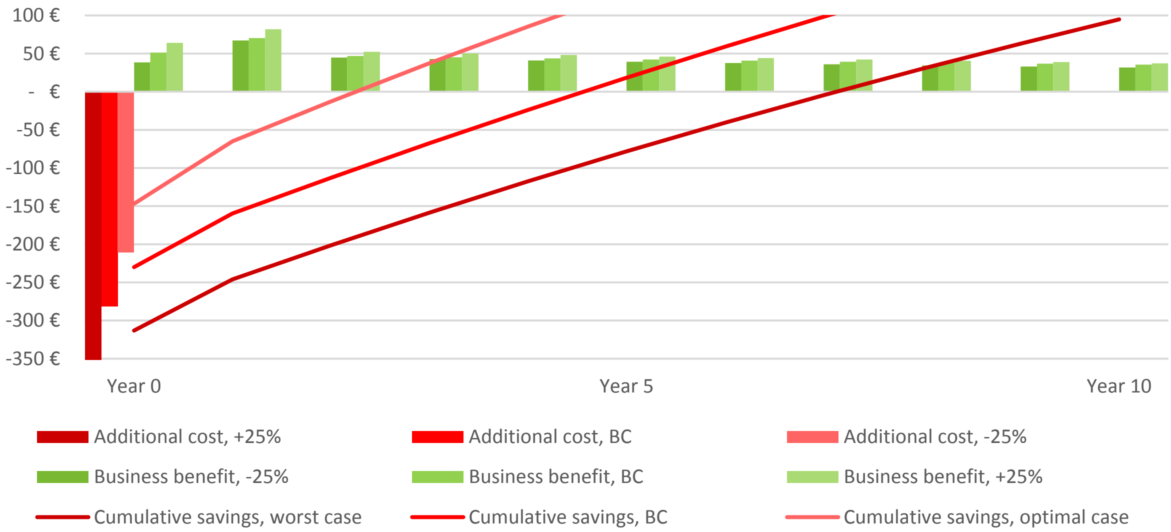


Figure 25: LCC-analysis for Väla Gård, including all benefits listed in Section 2.4.2 Method.

2.4.4 Discussion and conclusion

In this case study examples of how green values could be quantified in monetary terms are shown. Reduced employee turnover, reduced sick absence and increased productivity in this study is based on assumptions, i.e. should not be mistaken for verified results.

The case study shows that it may be hard to find it profitable to build a "green building" if one only account for improved energy performance or a single co-benefit. The profitability is significantly affected by further values than energy savings, which cannot balance the initial extra-investment for reaching the target nZEB or Net ZEB if a short time perspective for evaluating profit is applied. However, the study shows that it may be very profitable to build green buildings if one accounts for several green values. Even if a worst-case scenario is applied.

CHAPTER 3
Description of Co-Benefits

3 DESCRIPTION OF CO-BENEFITS

The co-benefit analysis represents a new and challenging topic, since there is not a consolidated approach for the evaluation of the added values of the nZEBs.

Nevertheless, in the following sections, CRAVEzero partners describe, according to their experience and to literature analysis, the general features and, when available, the quantification techniques for including the co-benefit in the revenue stream.
The analysis within CRAVEzero included 18 co-benefits associated with the target nZEB that can be translated in revenue to be considered in the Life Cycle Analysis. These co-benefits are related to one or more phases of the life cycle and can be limited during time (i.e. can be considered during one phase as a punctual contribution to the business model) or continue during one or more phases of the building life cycle (e.g. continuous contribution during the operation).

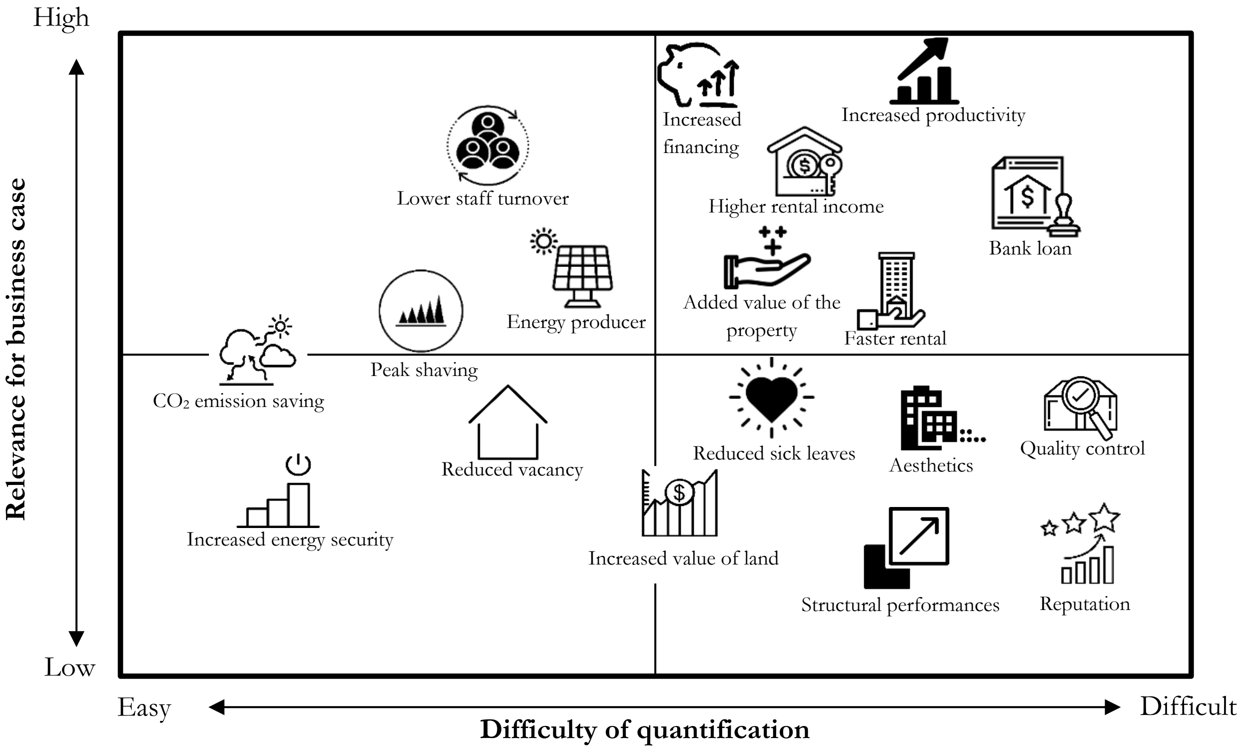


Figure 26: Co-benefits structured in terms of relevance for the business case and difficulty of quantification based on Bleyl et al. 2017

In order to have an overview of the analysed co-benefits, Figure 26 reports the ratio between the difficulty of quantification, due to the lack of data and the relevance for the nZEB business case, considering the impact at an individual level based on an assessment of CRAVEzero partners.[2]

3.1 Increased productivity

General description

A new building reaching the nZEB target is usually characterised by an enhanced Indoor Environmental Quality (IEQ), thanks to the more accurate design and advanced energy concept. **Improved quality in terms of reduced internal pollutants, acoustic and lighting can increase the level of satisfaction and the capacity of concentration, leading to increased productivity** of the occupants. This co-benefit is valuable for non-residential buildings and in particular for offices and

[2] The contributions of the co-benefit at macro and societal level are not considered within this report

working places, where employees spent their working hours. It occurs during the operation phase and, in case of proper building management and maintenance, can be continuous, and can last until the end of life of the building.
This co-benefit has an influence at single building level and has an impact on the economic revenues of the companies working in the building, thanks to the enhanced productivity of the employees.

CO-BENEFIT	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Employees working in the building and related company

Quantification techniques

There are several studies that investigate the impact of the IEQ on productivity, providing different quantification methods and reference values (Bleyl et al., 2017; Hedge, Miller, & Dorsey, 2014; Singh, Syal, Grady, & Korkmaz, 2010; Thatcher & Milner, 2014).
Based on previous findings (Hedge et al., 2014; Singh et al., 2010; Thatcher & Milner, 2014), it is possible to estimate that the productivity may increase by 0.5 % for nZEBs.
In two studies, reduced absenteeism was also found (Singh et al., 2010; Thatcher & Milner, 2014).
Finally, in Berggren et al (2018), the contribution as revenue in the LCC of an office building (i.e. Valä Gard) is calculated with the following equation:
Increased productivity value (**IPV**) is calculated according to the following equation:

$$IPV=\sum(Emp \cdot SC \cdot IP)/(1+R)^t$$

where *Emp* is the number of employees, *SC* is the average salary costs per employee, IP is the increased productivity per employee (that we estimated, for the purposes of the project, accounting for 0.5 %) and *R* is the adopted discount rate. The definition of the proper discount rate according to the national context and to the business model is very important for an accurate evaluation of this indicator, as well also for the other co-benefits to assess during the building operation phase.
The following figure shows the typical company spend breakdown throughout real estate / space life cycle. It shows the different impact on costs of employees, operations, construction and design.

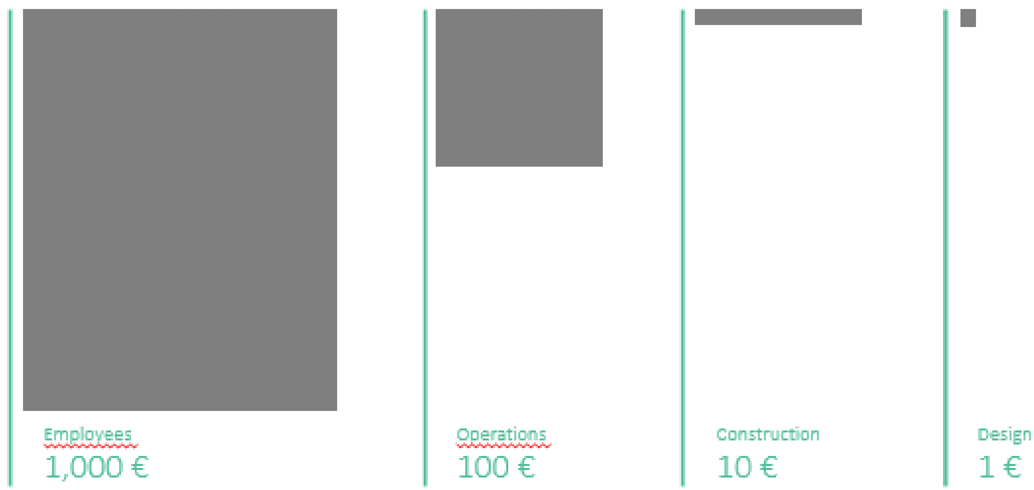
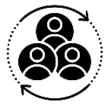


Figure 27: Typical company spend breakdown throughout real estate / space lifecycle based on (Attema, Fowell, Macko, & Neilson, 2019)

3.2 Lower staff turnover

General description



This co-benefit is **strongly influenced by the Indoor Environmental Quality (IEQ)** of the working spaces, as the other co-benefits related to the employees 'behaviour.

In fact, a more comfortable working space leads to **an enhanced satisfaction of the building occupants that would be less inclined in changing their working place**.

This benefit occurs during the operation phase and, in case of proper building management and maintenance, can be continuous, and can last until the end of life of the building.

This co-benefit influences the economic revenues of the companies working in the building, thanks to a reduced effort in hiring and training new employees

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Employees working in the building and related company,

Quantification techniques

There are several studies that found connections between the IEQ on the satisfaction of the users for their working place, (Bleyl et al., 2017; Miller, & Dorsey, 2014; Singh, Syal, Grady, & Korkmaz, 2010).

In order to estimate the impact of such co-benefit on the revenue stream of the company, it is necessary to estimate the recruitment cost for a new employee, considering the involved staff and the invested working hours, the reduced productivity costs and the eventual costs for an introduction course.

Reduced employee turnover costs (RETC) are valued according to the following equation (Berggen et al.):

$$RETC=\sum(\varepsilon \cdot Emp(RC+IC+RPC+LI+DC))/(1+R)^{\wedge}t$$

where ε is the reduced employee turnover, *RC* is the recruitment cost per employee, *IC* is the introduction course for new employee, *RPC* is the reduced productivity cost (new employee and supervisor), *LI* is the lost income during vacancy and *DC* is the decommissioning cost.

It is crucial to assign a reference value to the reduction of the employee turnover, that for the purposes of CRAVEzero we estimated to account for 0.5 % in comparison to a standard building.

3.3 Reduced sick leaves

General description

This co-benefit is **strongly influenced by the Indoor Environmental Quality (IEQ)** of the working spaces, as the other co-benefits related to the employees 'behaviour. Fisk's work is a milestone in the environment. **This studies about indoor climate conducted in 2000 measured the sickness derived from indoor air quality, such as allergies and asthma, and estimated an amount of related costs to health ranging between 18 € and 72 € for asthma and from 21 € to 49 € for other respiratory diseases, per year, per worker.** In case of renovation, these costs can be seen as a shadow benefit, often not considered by the building industry and buyers too.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Employees working in the building and related company,

Quantification techniques

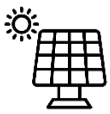
The quantification of this index is connected to the salary of the employees and the foreseen reduction of the number of day-absence. In particular, it is possible to make this estimation through the following formula: Reduced sickness absence salary (RSAC) is valued according to Eq. 4.

$$RSAC=\sum(Emp\cdot 0.8SC\cdot \phi\cdot \varkappa)/(1+R)^{\wedge}t$$

where Emp is the quantity of employees, SC is the average salary costs per employee, ϕ is the average sickness absence and $\varkappa$ is the index for the reduced sickness absence.

3.4 Financial co-benefits: owner as energy producer

General description



With the advent of new nZEB technologies, it is possible for most technical solution sets not only to supply the heating and DHW demand in an energy-saving way. The **plant operators are** also **becoming energy producers. A large number of Business Models have emerged in this field.**

The following considerations are based on Köhler und Meinzer investigations, as a real estate developer, on a large sample of existing multifamily buildings where the real performance of the nZEB technology sets are measured.

Which stakeholder ultimately benefits from a technical solution set depends strongly on the adopted business model. In a contracting model (e.g. in a district combined heating and power -CHP- plant), the tenants and owners of a property are "dependent" from their provider. In this model, the financial advantages are mainly for the contractors or plant operators who sell their product to the end customer (electricity, DHW ...). Considering the high level of basic costs (depreciation, maintenance, running costs ...) and the small share of direct energy costs, the customers have little incentive to save energy, since it does not lead to a significant economic benefit. The price advantage per kWh for them is not evident compared to big commercial providers.

Another approach is to turn the owner community of the building into a plant operator, so the consumer becomes a producer (prosumer). The initial investment costs are taken into account by the Real Estate Developer in his calculation, becoming an attractive product for the buyers of the apartments. The owner community determines on its own responsibility the price of the electricity and the DHW, which the users receive from the plant. The profits generated flow into the reserve account, from which the bills for the maintenance and operation of the plant are denied. If electricity is still available after self-consumption and storage on site, it can be sold to the public grid. The goal is to achieve a high self-consumption rate in order to become more independent from the public network.

The measurable financial advantage is connected, in our example, with many factors:

- the “prosumers” themselves set the price they want to pay for their self-produced energy
- the excess energy produced is fed into the public grid
- is the level of remuneration (currently falling prices)
- one waives the feed-in tariff in order to avoid cumbersome billing and tax formalities, which (as of today) are out of all proportion to the financial return

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative, Qualitative	Operation	owners

3.5 Added value for a nZEB property

General description

nZEB buildings promise lower costs for the operating phase after the initial additional costs of design and construction in comparison to a traditional building. Through optimized planning and smart operation, savings potentials for heating, cooling, domestic hot water and electricity are achieved. On the one hand, the main savings are due to reduced energy consumption and, on the other hand, as described in Chapter 3.4, energy produced and sold to the grid.

This additional value can be material or immaterial. In terms of **intangible assets, positive attributes, such as sustainable, environmentally conscious, CO_2-neutral**, etc. are in the foreground. Likewise, the ability to make a change of perspective from a "pure consumer" to an "energy producer" may be a strong argument in the upcoming public awareness in the climate change debate.

The **material advantages include the financial benefits** mentioned in Chapter 3.4. In addition to the possible generation of the costs for the maintenance through the system, it is possible to increase the asset value.

In the current real estate market, these advantages are nowadays not very selective. Pressure from investors to find profitable investment opportunities, as well as the pressure of apartment seekers in urban areas, is driving up real estate prices. In this "environment", the condition of an asset and its technical equipment often play a minor role, while he desires for affordable housing is in the foreground here.

However, the increase of energy prices for fossil fuels and measures like CO_2 emission tax will develop into noticeable disadvantages for the consumer and the demand for nZEB homes will increase rapidly. Since the fluctuations of market forces and public opinion, it is difficult to provide a unique quantification of the added market value in Euros. The emerging market pressures through increasing energy costs and taxes will play the most important role.

It is foreseeable that the achievement of the climate will further advance the development of the market price nZEB's. Insofar, buildings that meet the nZEB requirements will have a higher market potential.

The main factors that will have an impact on the development of the asset value for buildings are:

- development of policies and legislation in the national and European context (the higher the claims arising from these future regulations, the higher the demand and asset value of NZEB buildings)
- public appreciation of sustainable buildings and technologies
- change of perspective due to the possibility to become an energy producer
- cost-neutral implementation of nZEB targets through the profit-making of energy plants

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative, Qualitative	Operation	owners, sellers, buyers

3.6 Peak shaving

General description

The shaving of peak loads for heating, cooling and electricity is **a continuous co-benefit during the operational building life cycle.**

There are **several main actions that can be applied to reduce peak loads**, on the one hand working on the building structure (i.e. to optimize the window to wall ratio, to install high insulation performance to reduce maximum peak load, increasing the inertia of the building by integrating Phase Change Materials (or high inertial materials) into main structure, and on the energy storage (i.e. Heat storage for domestic hot water production, electrical storage via batteries (stationary or electrical vehicles). On the other hand, it is possible to focus on the control and management of the building operation, by stopping electrical appliances usage at peak time, delaying heating/cooling appliances usage at peak time and use building inertia, increasing/decreasing the indoor temperature set point and/or the water temperature at peak time, to over cool/heat the building before peak time and maximising the use of renewable energies production available at peak time

The peak shaving has effect both at general and single-building level. At general level it is possible to reduce the maximum demand required from the district network and grid. Consequently, the investment cost in deploying new district network will be lowered and we'll reduce the CO_2 emission and taxes, giving an economic impact on the energy system. Moreover, at single level the **energy bill for end-user will be reduced by lowering the fixed costs for using the infrastructure and by exploiting the cheapest energy tariffs during the day.**

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	End users, district energy production companies

Quantification techniques

The economic advantages of the peak shaving capacity are strongly related to the energy tariff of the building. In particular, the fluctuations during the day or the different hourly tariff scheme represent the key factors for determining the added value of the peak shaving. In order to evaluate the economic benefits of the shaving, it is necessary to estimate the amount of energy of the building during its standard operation (i.e. activation of the HVAC system according to the building occupancy schedule) and the relative cost for the energy supply. The second step is the evaluation of the amount of energy that can be shifted, especially in terms of peak power demand, towards a lower energy price without compromising the level of comfort of the occupants.

The difference between the cost of the standard operation, with the "price-aware" ones represents the value of the co-benefit. In order to ensure the reliability of the benefit estimation, a calibrated hourly energy model is recommended.

3.7 CO_2 emission savings

General description

Due to the fact that 40 % of the total energy consumption and 36 % of the greenhouse gas emissions in Europe are attributable to buildings, the energetic renovation of buildings is considered to have great potential for reducing carbon dioxide (European parliament and the council of the EU, 2010). In the residential sector, single-family homes in particular are responsible for 60 % of total CO_2 emissions (Petersdorff, Boermans, & Harnisch, 2006).

Since 2005, the increased use of district heating and renewable energy sources, the decline in the use of natural gas and domestic heating oil, and the improved thermal quality of buildings have led to emission savings in the building sector (Anderl, Burgstaller, Gugele, & Gössl, 2018).

The main actions as identified in D3.1 that have an influence on this co-benefit are:

- Funding schemes for nZEBs
- Regional efficiency improvement targets supporting nZEB
- Optimize building envelope (compactness and insulation)

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Planning, Operation	Inhabitants, Employees, Planer

Quantification techniques

There are **several studies dealing with different areas of the building sector which cause high CO_2 emissions and where savings can be achieved** (Zhang & Wang, 2016).
The **nZEB balance is essentially composed of three elements** (Georges, Haase, Houlihan Wiberg, Kristjansdottir, & Risholt, 2015):

- **Annual total energy use** (Qu) Its evaluation is divided into two consecutive steps. Firstly, energy demand is established (using the current Norwegian regulation as mentioned above). Secondly, the system efficiency, including auxiliaries, is Life cycle emissions analysis of two nZEB concepts computed in order to determine the resulting energy use for each building service. Qu is obtained by summing the energy uses of each building service.
- **Annual PV electricity production** (Qp).
- **Embodied emissions** (EmE) in material for the entire building lifetime of n years, EmE(n). Following the nZEB definition, n is 60 years. The embodied emissions data include materials for the construction of the building including technical and heating systems as well as emissions from replacements made during the lifetime.

Using symmetric CO_2e factors, the net balance for an all-electric building can then be formulated in the following way:

$$\Delta E(n) = EmE(n) + \sum_{i=1}^{n} f(i) \times (Q\mathrm{d} - Q\mathrm{e})$$

where n is the building lifetime expressed in years (60 years); Qd is the yearly electricity delivered to the building; Qe is the yearly electricity exported to the grid by the building; and f(i) is the yearly averaged CO_2e factor in gCO_2e/kWh for electricity for year i.

3.8 Increased energy security

General description

Implementation of mitigation measures, like **reducing cooling-related peak power demand and shifting demand to off-peak periods, increasing the diversification of energy sources as well as the share of domestic energy sources used in a specific energy system** (Ürge-Vorsatz et al., 2014), can **play an essential role in increasing the sufficiency of resources** to meet national energy demand at competitive and stable prices and improving the resilience of the energy supply system. Specifically, mitigation actions result in: strengthening power grid reliability through the enhancement of properly managed on-site generation and the reduction of the overall demand, which result in reduced power transmission and distribution losses and constraints (Passey, Spooner, MacGill, Watt, & Syngellakis, 2011).

The main actions as identified in D3.1 that have an influence on this co-benefit are:

- Assessment of the energy efficiency and renewable energy potentials
- Consideration of Thermal / Electrical Microgrids on District Level
- Consideration of Seasonal Storage on District Level
- Assesment of the Potential for Decentralized renewable power generation
- Energy performance Calculation

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Construction, Operation	Grid operators

Quantification techniques

Energy security is a difficult concept to define, and therefore to measure (Sovacool & Brown, 2010). In order to achieve system stability, a strategy should be adopted that leads to greater sovereignty over the energy of local sources. It is essential to measure energy security by using a composite diversity indicator that aggregates at the global level (Jansen, Arkel, & Boots, 2004). **This diversity indicator takes into account the diversity of primary energy resources as well as the origin of these resources**, i.e. whether they are imported into geographically and socio-economically similar regions or produced internally. The diversity indicator increases with growing diversity of the energy system, but decreases with higher import dependency. In summary, the higher the compound diversity indicator, the more secure the energy system is (McCollum et al., 2013).

$$I = -\sum\nolimits_j \{(1 - m_j) * (p_j * lnp_j)\}$$

Where:

- I: compound energy diversity indicator (resources + imports)
- p_j: share of primary energy resource j in total primary energy consumption
- m_j: share of primary energy resource j that is supplied by (net) imports (at the global level, imports are replaced by the traded quantities)

3.9 Aesthetics and architectural integration

General description

The aesthetic of a building represents a significant feature for the definition of its value and relevance on the market. The impact of this feature on the property value has been largely cited as a co-benefit of energy efficiency measures (Skumatz, L. 2009), and it is very often mentioned as one of the main reasons in case of building renovation. In case of existing buildings, a company or a private individual can decide to renovate own buildings by making them nZEB. This process can give a new aspect to the structure which becomes more aesthetically pleasing with the possibility of remaining, or becoming, integrated with the architectural context. Therefore, it is easier to assess such added value in case of building renovation.

In general, **measures to improve the energy performance of the building envelope are an opportunity to take care also the aesthetic value of the building, with a positive impacts for the customer**: visibility and related economic revenue. The aesthetic value of the renovated building will always depend on the characteristics of the building and "how" the renovation measure is implemented (IEA, Annex 56).

This co-benefit has a clear impact for the single building but also for the society, that can benefit from an added aesthetic value given from the building to the surroundings, and it has an impact during the operation phase and, in case of effective maintenance, can last until the end of life of the construction.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Qualitative	Operation	Customers and society

Quantification techniques

Quantifying the added value related to the aesthetic and architectural integration is very complicated, and we did not find in literature a coherent methodology to provide a physical indicator. In fact, the evaluation of the aesthetic quality is highly subjective, and strongly depends on the cultural context where the building is located and the perception of the potential investor.). In case of a building renovation, the interventions need to be set-up properly, since measures that alterate the identity of a building could also represent a negative co-benefit that should be weighed against the remaining benefits (cost, energy and carbon emissions reductions). In all these cases, the question of "how" measures are implemented is decisive and the quality of the design process is crucial (IEA, Annex 56).

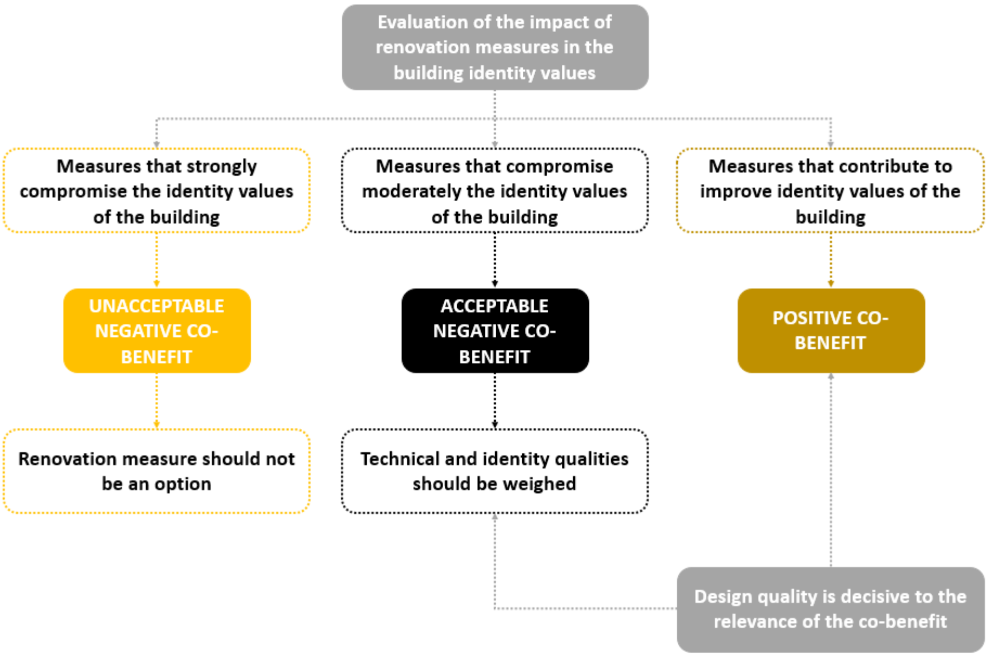


Figure 28: IEA EBC Annex 56. energy efficiency measures and impact on the building value

Another significant issue in the assessment of aesthetic value is the architectural integration of the renewable energy systems, mainly solar thermal and photovoltaic panels. A controlled and coherent integration of these elements must be achieved simultaneously from all points of view, functional, constructive, and aesthetic. When a solar system is integrated in the building envelope (as roof covering, facade cladding, sun shading, balcony fence…), it must properly take over the functions and associated constraints of the envelope elements where it is installed, while preserving the global design quality of the building (SHC IEA Task 41 2012).

3.10 Increased value of land/context

General description

New buildings can have positive effects on existing neighbourhoods through creating more vibrant neighbourhoods and populating vacant lots, usually linked to external . **Building new houses increases resident population, improve the aesthetics of the area and raise surrounding property values** (DeSalvo, 1974). New construction can be more aesthetically pleasing than unkempt lots or dilapidated buildings, which improves the views from existing houses.
According to Hamilton (1976) the increase in the value of the land and of the houses in the neighbourhood depends on the size of the new building compared to the adjacent ones. New houses will tend to sell for higher prices than comparably sized neighbouring used houses; however, the price premium for a new house could vary depending on its size relative to its neighbours.
The presence of nZEB building can be an incentive for the redevelopment of an urban, extra-urban or rural area. The construction of nZEBs can increase the value of the context in which the building is inserted, as a consequence it can lead to a major interest of people to move in that land to build other offices, shops, services or commercial activities. Moreover, the presence of nZEB efficient building can promote the creation of a network for smart use of energy. This co-benefit is valuable in all phases, it is continuous and

can be amplified by every service present in the neighbourhood, having an impact at both single and multi-building level.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Qualitative	Operation	Customers and people who lives in the area near the building

Quantification techniques

According to Zahirovich-Hebert and Gibler (2014), the change in land or structure may have a “neighbourhood effect” that alters the land and the structure values on surrounding properties. This study examines the value of newly constructed houses inside built up areas as well as the influence of new residential construction on surrounding property values. In particular, it employs a hedonic estimation of the impact of new construction on house sales prices in Baton Rouge, Louisiana over an 18-year period.. In particular, the results indicate that increasing new nearby construction has a significant positive impact on the price at which a house will sell. Each **newly constructed house within one-quarter mile of the subject property**, and whose sale occurs within a year prior to a subject house sale, **increases the sales price of a house by 0,27%**. The construction of new buildings **can increase the value of the area in which they are located, both by increasing the value of nearby buildings and by increasing the value of the building itself**.

3.11 Increased reputation and good publicity

General description

More and more companies create shared value by developing profitable business strategies that also deliver social benefits. It is possible to create new profit opportunities while supporting the society and helping to solve important global problems (Measuring Shared Value, 2011).
NZEB buildings ensure high performances in terms of energy, sustainability and ecological footprint, which represent critical indicators that currently have an impact on the public opinion. The company that constructs, designs or owns an nZEBs can enrich its portfolio and it has an impact on visibility and appreciation by the customer.
This co-benefit interests the operation phase of different kind of buildings and it can last until the end of life of the building.
This results in economic revenues of the company derived from more customers attracted by the new green and sustainable strategy of the company.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Qualitative	Operation	Owner, design and construction companies

Quantification techniques

A simple correlation to link the construction of green buildings or green value pursued by a company and the increased reputation doesn’t exist. Even if there is no correlation, it is possible to directly estimate the increase in reputation through the analysis and monitoring of the company's web marketing, press clipping and, more indirectly, to calculate the social value created by the company’s business through the measurement of the shared value.
Many companies have begun to measure their social and environmental performance without considering business benefits and continue to measure their financial results without regard for social impact. Shared value measurement builds upon these existing measurement systems and approaches but focuses on the intersection of business and social value creation. Existing social performance measurement practices cover sustainability, social and economic development impact, reputation, and compliance.

Sustainability indicators have proliferated globally. More than 3,500 organizations in more than 60 countries, for example, use the Global Reporting Initiative's (GRI) voluntary sustainability standards to report on their environmental, social, and governance (ESG) performance. Sustainability and related certification standards have met important needs. They have heightened corporations' awareness of their impact on society and triggered meaningful improvements in social and environmental performance.
Company's reputation is certainly conditioned by the themes and topics discussed on web, the pursuit of a green building activity easily helps the customer to understand and follow company's values.
A valuable approach to assess part of the impact of good publicity for a company is to quantify the number of additional press releases dealing with nZEBs. It can be related to a new headquarter of the company or with the activities related to the participation to the design and construction of a new building. (Berggren et al. 2018) provides a quantification of the co-benefit through the following equation:

$$PPV=\sum AIP \cdot AC$$

where AIP is article in press and AC is the advertising costs in the specific source (paper, internet, etc.), that would be avoided thanks to the additional publicity of the nZEB building.
Through this assessment, it is feasible to estimate the avoided costs for press releases, and this can be considered in the definition of the business model. Nevertheless, this equation does not take into account the impact of the press-release for the publicity of the company, and associated benefits of the increased visibility since the economic quantification is quite difficult.
To conclude, on the one hand, the pursuit of green values and nZEB allow the company to reach a higher number of users, even who previously was unaware of the existence of the company. On the other hand, green buildings lead to positive attitude and, consequently, to better brand loyalty, obtaining, a community more closely linked to our service/product.

3.12 Reduced vacancy due to nZEB

General description

A new building reaching the nZEB target or in general high energy efficiency and additional "green values" is often better marketable compared to other, standard buildings and thereby reduces the risks of lost income. According to (Kok and Jennen 2012) and (Berggren et al. 2018) one can distinguish between two major types of vacancies, which can be reduced by nZEBs/ green buildings. These are:

- Reduced vacancy with respect to open positions, and
- Reduced vacancy with respect to the rental of a building, parts of a building/ apartments.

This benefit occurs during the operation phase.
The co-benefit has an **influence at a single building level**. It has an **impact on the companies working in a building by reduced vacancies of open positions and associated costs**.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Employees working in the building and related company

Quantification techniques

There are only a few studies investigating and quantifying the impact of nZEBs and associated additional values on the vacancy days of open positions. In (Berggren et al. 2018), the contribution as revenue in the LCC of an office building (i.e. Valagard) with respect to open positions is calculated as part of the reduced employee turnover costs (RETC) with the following equation:

$$RETC=\sum(\varepsilon * Emp(RC+IC+RPC+LI+DC))/(1+R)^t$$

With:

- ε: reduced employee turnover,
- RC: recruitment cost per employee,
- IC: introduction course for new employee,
- RPC: reduced productivity cost (new employee and supervisor),
- LI: lost income during vacancy,
- DC: decommissioning cost,
- R: adopted discount rate.

The lost income of during vacancy is based in (Berggren et al. 2018) on an assumed vacancy of 3 months, salary costs and the nominal discount rate. The number of days a position is vacant is, however, mainly depending on the sector and availability of qualified employees in the market. Having a nZEB/ green building can be an essential factor when all other job related factors are similar for different positions, but it is most likely not the major issue for the job decision.

3.13 Faster rental of building

General description

A new building reaching the nZEB target or in general a high energy efficiency and additional "green values" is often better marketable compared to other, standard buildings and thereby reduces the risks of lost income. According to (Kok and Jennen 2012) and (Berggren et al. 2018) one can distinguish between two major types of vacancies, which can be reduced by nZEBs/green features of the buildings. These are:

- Reduced vacancy with respect to the rental of a building, parts of a building, apartments, and
- Reduced vacancy with respect to open positions.

The latter is addressed in Section 3.12. The co-benefit of faster rental occurs during the operation phase, and it is mainly important in building stocks/ markets with a high vacancy rate. **In these markets additional values can have a high impact, while, with very low vacancy rates, the benefit is lower as other factors gain importance (e.g. simply finding an office or apartment)**. To date, only few studies were conducted analysing the effect of nZEBs/green buildings on the time needed for renting a property. According to (Ramboll A/S 2019) more than 50 % of property owners do not know if green features have an impact on the vacancy rates, which shows a huge knowledge gap.

The co-benefit has an influence at single building level and it has an impact on the economic revenues of the companies renting a building by a reduction of lost rental income and reduced costs for renting (less marketing/ advertising, estate agents etc. needed).

Besides the actions listed above, all actions helping to improve the energy performance and comfort are indirectly influencing this co-benefit. Furthermore, building certificates (e.g. DGNB, LEED) can help to communicate the quality of the building in the public and thereby lead to faster rental of the building.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Owner, Company renting

Quantification techniques

There are only a few studies investigating the impact of nZEBs and associated additional values on the vacancy time of buildings or parts of them as mentioned above. As mentioned in (Ramboll A/S 2019) most building owners do not know if green features have an impact on the marketability and speed of renting. This is a

major reason for the fact that there is currently almost no study available quantifying this effect. Furthermore, the vacancy rate and speed of renting is highly influenced by other factors like e.g. the growth of an urban area and generally the stress in the housing sector of an area. These factors can strongly differ from region to region and therefor generally valid numbers are difficult/ impossible to derive. Generally, the effect could be calculated by assessing large building portfolios and the vacancy rates as well as usual times needed for renting and relate the results to the energy performance of the properties.
In (Mangialardo et al. 2019) the effect of certification on the market absorption of offices in the Milan area was assessed. The authors calculated that the vacancy rate of certified buildings was only half of the rate in uncertified buildings (7 % vs. 14 %). They also observed that after six months more than 80 % of the areas in certified buildings were leased while only 21 % in uncertified buildings were leased in the same time. Both values show a faster rental of energy efficient buildings in Milan.
In the LCC assessment, the co-benefit of faster rental can be considered in the operation phase as a faster increase in rental income.

3.14 Higher rental income

general description

A new building reaching a high energy efficiency or even nZEB standard can be rented at higher prices than buildings with lower energy efficiency. A good energy efficiency label as defined in the EPBD increases the market value compared to low-efficiency buildings. This co-benefit is in principle valuable for both residential and non-residential buildings.
This benefit occurs during the operation phase and can be considered as continuous until the end of life of the building.
This co-benefit has an influence at single building level and has an impact on the economic revenues of the company or single person renting the building or parts of it. Thereby it can also have an influence on the societal level, as higher rents can have a negative impact on the most vulnerable members of a society when the higher rents lead to the situation that the people / companies cannot afford the higher rents anymore.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Company/ person renting the building or parts of it, tenants

Quantification techniques

There are several studies that investigating the impact of a higher energy efficiency on achievable higher prices and rents, like e.g. (Bleyl et al. 2017), (Sayce and Wilkinson 2019), (Kok and Jennen 2012), (Berggren et al. 2018), (Zancanella et al. 2018)).
A study conducted in the Netherlands showed that buildings with an energy level D or worse achieved 6.5 % lower rents compared to buildings with an efficiency label A, B or C (Kok and Jennen 2012). Another study showed 2 – 6.3 % higher rents in social housing in the Netherlands for more energy efficient buildings (Sayce and Wilkinson 2019). In the study only non-residential buildings were assessed. In **(Berggren et al. 2018) a possible increase in the rental income of 5 – 20 % is reported based on (Bleyl et al. 2017).** In (Sayce and Wilkinson 2019) several studies, which assessed the impact of energy efficiency on achievable prices and rents are compared. For Germany a premium of approx. 3 % or 0.76 €/m² in private rented dwellings was observed, in Ireland dwellings with an energy label A achieved 1.8 % higher rents than buildings with a D-label and buildings rated F/G achieved 3.2 % lower rents (compare (Sayce and Wilkinson 2019)). Even though most studies show a positive effect of energy efficiency / high energetic standards on rents and sale prices, it has to be mentioned that there are also other factors having a high influence on rents and decision making and there are also studies showing that energy labels or other certificates do not have a measureable influence on prices. An overview of several studies is provided in (Zancanella et al. 2018). The

comparison in (Zancanella et al. 2018) observed an average increase in residential rents of 3 – 5 % and an increase in asset prices of 3 – 8 %. The observed effect in the commercial sector was higher in the sales price increase (10 – over 20 %) and slightly lower in the rent increase (2 – 5 %).
In (Zancanella et al. 2018) several methodologies to calculate "green values" are described. These are:

- Added value of energy performance:
  - The hedonic pricing method (valuation of a building according to building characteristics → much data needed)
  - Comparison of transaction prices (buildings compared must have similar characteristics/ properties and each characteristic must be valued separately; consideration of location necessary)
  - Willingness to payback investments in energy efficiency measures
- Net present value of costs of energy savings
- Net present value of investment [in energy efficiency]

Furthermore, methods to value energy efficiency by the market are described in (Zancanella et al. 2018):

- Claimed value, willingness to pay
- Impacts observed on property markets

In the LCC assessment, the co-benefit of higher rents can be considered as a premium (in per cent) on the average achievable rent in the respective rea, where the analysed building is located. HRI value (i.e. the additional income due to the higher rental fee thanks to the nZEB target during the life cycle) can be analysed through the following equation:

$$\mathrm{HRI} = \sum_{i=1}^{n} \mathrm{ARV}_i + \mathrm{hri}_i,$$

Where:

- HRI: Higher Rental Income during the life cycle
- N: number of years of the life cycle
- ARV_i: average rental value for the building during year i
- hri_i: additional rental value during year i for the

3.15 Increased financing by lower interest rate

General description

The erection of a nZEB is usually financed to a certain extent by bank loans. **During the user phase of the building, a large share of the operational costs may be the costs for interest payments**. The interest rate given by the bank may, therefore, have a great impact on the operational costs. Today, banks may choose to reduce the interest rate for loans, if the loan is taken out for a energy-efficient building (SBAB, 2019; Swedbank, Gröna Bolånet, 2019). If the interest rate is decreased, also the operational costs decrease. **The stakeholder may then choose to increase the bank loan for supporting the extra-investment for reaching the nZEB target, without increasing the operational costs.**
This co-benefit has an influence at a single building level and have an impact on the economic revenues of the stakeholders who invest in buildings.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Investors

Quantification techniques

The reduction of the interest rate that the banks can apply for buildings reaching the nZEB can be easily translated into an increased loan to request at the beginning of the project. It can be calculated through the following equation:

$$IL=L_{\alpha}\cdot\left(\frac{i_{\alpha}}{i_{alt}}-1\right)$$

where *IL* is the increased bank loan, L_a is the loan for the base case, i_a is the interest rate for the base case and i_{alt} is the interest rate for the alternative case.

3.16 Increased financing from bank loan

General description

During the user phase of the building, the requested loans for construction or renovation entails costs in the form of interest payments and repayments. During the user phase, other costs related to operation occur, such as costs for heating, cooling and electricity. **If measures are carried out to decrease the energy demand, resulting in lowered costs during operation, this will result in a possibility to have higher loans as there is room for higher costs in form of interest rates and repayments**.

This benefit occurs during the operation phase and, in case of proper building management and maintenance, can be continuous, and can last until the end of life of the building.

This co-benefit has an influence at single building level and have an impact on the economic revenues of the stakeholders who invest in buildings.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Quantitative	Operation	Investors

Quantification techniques

Depending on whether the stakeholder will amortise the bank loan the quantification will differ. Regardless of method, the quantification results in a monetary term, increased bank loan, which corresponds to the increased investment opportunity.

For both cases, the following equation may be used:

$$IL=\frac{(OC_{\alpha}+MC_{\alpha})-(OC_{alt}+MC_{alt})}{i}-A$$

where *IL* is the increased bank loan, OC_a is the operational costs for the base case, MC_a is the maintenance costs for the base case, OC_{alt} is the operational costs for the alternative case, MC_{alt} is the maintenance costs for the alternative case, *A* is the amortisation and *i* is the interest rate given for the loan. If the specific bank loan does not require amortisation, A=0.

It should be noted that cost included in *OC* and *MC* should only be the costs which are affected by the alternative case. E.g. costs for interior repainting will be the same regardless if a building/projects choose to install PV-panels or not.

3.17 Prefabricated building – cost, time and quality control

General description

The use of prefabrication hybrids the construction sector with the manufacturing processes. It takes advantage of the opportunities from new digital technologies that allow to keep together the different parts of the building process from design to its management over time.
The industrial process guarantees the reliability of the goods produced in the factory, according to a detailed production program, subject to direct and continuous control and finally each product is associated by a Declaration of Performances (DoP).
The high energy efficiency of a prefabricated building is guaranteed by the performance of the single element constituting the building envelope, but also by the precise and controlled construction. In fact it requires an extremely detailed design that highlights the need to resolve any weak points in advance.
In fact, prefabricated building activities are carried out using lean approaches, paying attention to the analysis of costs and performance throughout the entire life cycle of the building.
The stabilization of production processes and the consequent reduction of the uncertainties linked to the construction, allows an enhanced compliance with the planned cost and timing. In addition, the use of a prefabricated system allows a considerable reduction in construction time: the resources used during the production phase in the factory, allow the construction of prefabricated structures while the preparatory works on site are still in progress.
Thanks to the extended design up to the assembly phase and to the construction logistics, the possibility of detecting problems during the execution phase is excluded. Avoiding these problems, which could cause delays, poor execution and unforeseen costs, the costs of realization are clear and defined from the beginning
This benefit mainly occurs during the construction phase, having an influence for the increased quality control during the operation. It has an influence at single-building level.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
Qualitative	Planning, Construction, Operation	Designers, people living in the building, maintainers, investors

3.18 Prefabricated building – structural performances and façade integration

General description

Prefabricated parts and components being made in a sophisticated production centre are highly more efficient than the traditional ones.
Prefabricated elements allow to reach excellent performances in terms of structural resistance (they can reach large spans without intermediate supports), ant seismic criteria, fire resistance, acoustic and at the same time they guarantee thermal insulation and solutions for details and critical nodes both in the design and construction phase.
The prefabricated concrete structures are made with raw materials that can be variously combined to obtain different characteristic. Concrete products have a high durability and require low maintenance. Thanks to its structural properties and performance characteristics that industrialized concrete construction ensures, is registered, over the life of the business, you save on insurance premiums. This is even more evident in areas of high seismic risk, of flood and fire. The fact that the individual elements prefabricated into concrete can be easily disassembled means that a building can be easily expanded by inserting new structural elements and / or reusing existing ones. Moreover, it is possible to integrate structure and other components in one module.
With the prefabricated elements it is possible to integrate architectural, static, physical and plant design to reach the realization of a multifunctional product.

In fact, such prefabricated building elements can provide different functionality such as integrated renewable energy generation, ventilation ductwork, insulation and transparent components - all in one prefabricated wall-element.

This benefit occurs during the planning, construction and operation phase and, in case of proper building management and maintenance, can be continuous, and can last until the end of life of the building.
This co-benefit has an influence at single building level.

CO-BENEFIT TYPE	PHASE OF LCC	STAKEHOLDERS
qualitative	Planning, Construction, Operation	Designers, construction company, people living in the building, maintainers, investors

3.19 Conclusion

The previous overview shows that, in some cases, quantifying the impact on the revenue stream of the co-benefit can be very challenging. In fact, the complexity of the factors affecting the evaluation usually undermine the possibility to have a unique assessment approach, with defined indices and equations. Nevertheless, this report provides an initial overview of a set of co-benefits that covers all the phases of the life cycle, with the main general aspects and, where possible, a reference for quantitative evaluation.
To conclude the overview of the co-benefits as selected by CRAVEzero partners, an analysis of the connection between the actions as analysed within D3.1 *Guideline I - nZEB Processes* and the co-benefits has been carried out. We classified each action according to the number of co-benefits that can be influenced, from 1 (i.e. one action influence only one co-benefit) to 5 (i.e. one action influence 5 co-benefits). Table 13 summarizes the results of the analysis.

Table 13: Summary of the results of the analysis

ACTION (AS DESCRIBED IN D3.1)	NUMBER OF INFLUENCED CO-BENEFITS	CO-BENEFITS DEPENDING ON THE ACTIONS
Apply Strategy towards efficient use of land	1	Increased value of land
Assessment of the Potential for Decentralized renewable power generation	1	Increased energy security
Consideration of Seasonal Storage on District Level	1	Increased energy security
Consideration of Thermal / Electrical Microgrids on District Level	1	Increased energy security
Definition of Integrative Design Team	1	Aesthetics and architectural integration
Funding schemes for nZEBs	1	CO_2 emission savings
Hydraulic Balancing	1	Health benefits
Installation renewables	1	Increased reputation and good publicity
Optimize Insulation	1	Prefabricated buildings - quality control
Optimize Solar Access in Urban Layout	1	Aesthetics and architectural integration
Tenant Design and Construction Guidelines	1	Faster rental of a building
Thermal Activated Building Elements	1	Health benefits
Urban Masterplanning Allowing highly compact buildings	1	Aesthetics and architectural integration
User Information on Energy Expenditure	1	Increased reputation and good publicity
Air tightness	2	Prefabricated buildings - facade integration/quality control
Assessment of the energy efficiency and renewable energy potentials	2	Increased energy security, increased reputation and good publicity
Building Automation	2	Health benefits, increased reputation and good publicity
Construction checklists	2	Prefabricated buildings - on-site work, cost and time efficiency control
Construction Details - Heat Bridges	2	Prefabricated buildings - facade integration, quality control
Cooling strategies	2	Reduced vacancy of nZEB, health benefits
Green Power and Carbon Offsets	2	Increased reputation and good publicity, increased value of land
Regional efficiency improvement targets supporting nZEB	2	CO_2 emission savings, increased value of land
Renewable Energy - Photovoltaics	2	Prefabricated buildings - facade integration, Reduced vacancy of nZEB
Efficient Space Design	3	Prefabricated buildings - quality control, structural performances, facade integration
Problem Advanced Energy Metering	3	Increased productivity, Lower staff turnover, Reduced sick leaves
Extended producer responsibility	3	Prefabricated buildings - quality control, facade integration, structural performances
Flexibility & Adaptability	3	Prefabricated buildings - facade integration, quality control, structural performances
Energy performance calculation ' energy performance certificate	4	Faster rental of a building, increased energy security, increased financing by lower interest rate, increased financing from bank loan

ACTION (AS DESCRIBED IN D3.1)	NUMBER OF INFLUENCED CO-BENEFITS	CO-BENEFITS DEPENDING ON THE ACTIONS
BIM systems	4	Prefabricated buildings - facade integration, quality control, structural performances, cost and time efficiency control
Efficient use of materials	4	Aesthetics and architectural integration, Prefabricated buildings - facade integration, quality control, structural performances,
Optimize Solar Gains / Solar Control	4	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs
Definition of Allowed Thermal comfort ranges	5	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs, Prefabricated buildings - quality control
Improve Daylight Factor	5	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs, health benefits
Improve Window to Wall Ratio	5	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs, Prefabricated buildings - facade integration
Indoor Air Quality Assessment	5	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs, health benefits
Mechanical Ventilation	5	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs, health benefits
Natural Ventilation	5	Lower staff turnover, increased productivity, reduced sick leaves, reduced vacancy of nZEBs, health benefits
Optimize Building Envelope (Compactness and Insulation)	5	Aesthetics and architectural integration, prefabricated buildings - quality control, facade integration, structural performances, CO_2 emission savings
Prefabrication of multifunctional Building Elements	5	Aesthetics and architectural integration, prefabricated buildings - quality control, facade integration, structural performances, cost and time efficiency control
Tenant Design and Construction Guidelines	5	Aesthetics and architectural integration, prefabricated buildings - quality control, facade integration, structural performances, cost and time efficiency control
Energy performance guarantee	5	Increased reputation and good publicity, Increased reputation and good publicity and quality control, increased financing by lower interest rate, increased financing from bank loan
Operations and Maintenance Plan	5	Prefabricated buildings - facade integration, quality control, structural performances, increased financing by lower interest rate, increased financing from bank loan

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5 APPENDIX

Cost Benefit analysis of nZEBs for project developers

In the course of the CRAVEzero project, an Excel tool was developed in addition to many other tools and assistance, which shows the influences of the various co-benefits with regard to project costs. For this purpose, the formulas explained in the previous chapter were used to provide well-founded results. With the help of this tool it is possible to show savings potentials especially due to different Co-Benefits.

The dashboard consists of three tabs for the project details and a rider for the results.

1. The first tab "Reference Building" asks for general information about the building. These are subdivided into Financial and Energy.
2. The second tab "High quality nearly zero energy building" deals specifically with information concerning the quality of the building. A distinction is made between several factors:
    - Financial
    - Energy
    - Added Values
    - Added Values (only of office buildings)
3. General information about the location and the conditions can be given in the grey area "Global Parameters - General".

Figure 29: Use of the dashboard

http://www.cravezero.eu/pinboard/Developer/Developercalc.htm