Cost analysis of nZEB/Plus energy buildings

Buildings targeting nearly zero-, net zero- or plus-energy performance levels have proven technically feasible, though relatively expensive. In this article we analyse cost data from both EU-wide studies and surveys and from national case studies in Germany, Italy and Norway. We also discuss how to reduce the investment cost by 15%.

Keywords: Nearly zero-energy building, nZEB, zero emission building, net zero-energy building, Net-ZEB, plus-energy building, investment cost, global cost, cost analysis, cost reduction.

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In the last decade there has been a proliferation of building projects targeting a nearly zero, net zero or plus energy level of efficiency. Such buildings are often referred to under acronyms such as ZEB (Zero Energy/Emission Building) and Net-ZEB (Net Zero Energy Buildings). Here we refer to the range from nearly zero-energy buildings to plus-energy buildings with the abbreviation nZEB/Plus buildings. The map in **Figure 1** shows the worldwide distribution of nZEB/Plus buildings. Though examples of such buildings can be found in several countries and nearly any climate, there is a clear predominance of European examples.

Not surprisingly, this situation is mirrored by both the legislative and the scientific contexts of the EU. The Energy Performance of Buildings Directive (EPBD recast, 2012) makes it compulsory for all new buildings to be nearly zero-energy (nZEB) by 2020 – publicly owned and occupied buildings from 2018. The international scientific community, addressing the need to systematize and further advance knowledge on ZEBs, established the research project «Net Zero Energy Solar Buildings» under the umbrella of the International Energy Agency (IEA) programmes Solar Heating and Cooling (SHC) and Energy Conservation in Buildings (EBC). This research project ran from 2009 to 2013 with a major participation from European countries, contributing amongst other things to the collection of data for the cases shown in **Figure 1**.

The majority of nZEB/Plus projects realized worldwide and in Europe consist of small houses, either detached, semi-detached or row-houses, and have been constructed as single projects. This fact contributes to the notion of nZEB/Plus buildings as highly capital intense, since small houses present some economically unfavourable conditions for the achievement of the nZEB/Plus target. First, small houses have a high surface to volume ratio, meaning high heat dispersion through the envelope and the consequent need for extremely high insulation levels[1]. Second, technical installations for heating, ventilation and air conditioning (HVAC) such as mechanical balanced ventilation with heat recovery

[1] Cooling is usually not critical for this type of building because the cooling need can be minimized or eliminated by means of passive strategies such as solar shading of windows (incl. by roof overhang) and natural cross ventilation, which are relatively simple to implement in small houses.

Figure 1. Map of nZEB/Plus projects. Source: http://www.enob.info/en/net-zero-energy-buildings/map/.

and heat pumps are normally more expensive at small scale. Furthermore, technologies such as micro-CHP (in the order of few kW) are not yet mature for this market, leaving the more capital intensive PV as the sole *de facto* option for onsite electricity generation.

On the other hand, small houses present a technical advantage for the achievement of nZEB/Plus targets. The very same high surface to volume ratio also means larger surfaces available for harvesting solar radiation and RES (Renewable Energy Sources) in general. The roof area, often slanted, is sufficient to host the necessary PV capacity as well as solar thermal systems.

On the whole, it can be said that achieving zero or even plus energy performance levels in small houses is relatively easy from a technical viewpoint, though expensive. This statement is indeed confirmed by the evidence of small houses dominating the scenery of nZEB/Plus buildings realized so far, and their reputation as capital intensive. Additionally, it should also be noticed that a large part of nZEB/Plus buildings has been built as showcases, being first examples in a country or region, and sometimes as research objects, therefore deploying a multitude of technologies in the same building, for research and demonstration purposes. Such cases are surely, and unnecessarily, more expensive that what need to be delivered to the market in large scale.

Investment cost of nZEB/Plus buildings

There is limited open availability of cost data for the construction of nearly zero-energy and plus-energy buildings (nZEB/Plus). Additionally, since a large part of the existing nZEB/Plus has been built as showcases as mentioned, there is the challenge to select representative cases and/or to filter what are the costs actually attributable to the higher energy performance from what is attributable to the exceptional architectural qualities, such as materials used, or the use of redundant and/or experimental technologies. Finally, it should be reminded that in many cases what is documented and available are the design cost data, not the as-built cost data.

The data collected and presented here come from fundamentally two sources:

1. Study & survey conducted at EU level.
   The EU study is a parametric study performed within the project "Towards nearly zero-energy buildings" commissioned by DG-ENER (final report public[2]) where several predefined passive and active solutions were combined in thousands of combinations, and applied to reference buildings placed in four EU regions with different climate and economic background: West, North, South and East EU. The energy performance was simulated and cost estimated based on reference unit cost gathered within the same project.
   The EU survey has been conducted within the EPBD Concerted Action (EPBD-CA, results partially public available[3]), surveying 33 examples of nZEB from different EU countries.

[2] http://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings

[3] http://www.epbd-ca.eu/archives/946

2. National case studies in Germany, Italy and Norway. These are representative examples where the authors had got direct access to cost data and the breakdown of cost into categories (Envelope, HVAC, PV/RES and Design), for a total of 7 examples. These are all built examples with the only exception of the "Norwegian PH+PV". This is a reference passive house building whose construction cost are used as reference by the construction industry, with the addition of PV and related cost. The energy performance of the national case studies varies from nZEB to plus-energy.

The main characteristics of the case studies are presented in **Table 1**, while cost data are shown in **Table 2** for each case. The results for the EU study & survey are shown graphically in **Figure 2**. The total investment cost is the construction cost incurred by the construction company, inclusive of profit margins and design cost (normally outsourced to architecture and engineering offices), exclusive of VAT. The global cost, where reported, includes estimates of operation and maintenance cost, including eventual revenues from surplus electricity sold to the grid.

For the EU survey the extra cost for achieving the nZEB performance is given in relation to the cost of a building built according with the national standard. For the EU parametric study the extra cost range represents the "Pareto frontier" (=cheapest, bottom line cost) of the parametric combinations in the nZEB area, in relation to the cost-optimal level estimated in the same parametric analysis.

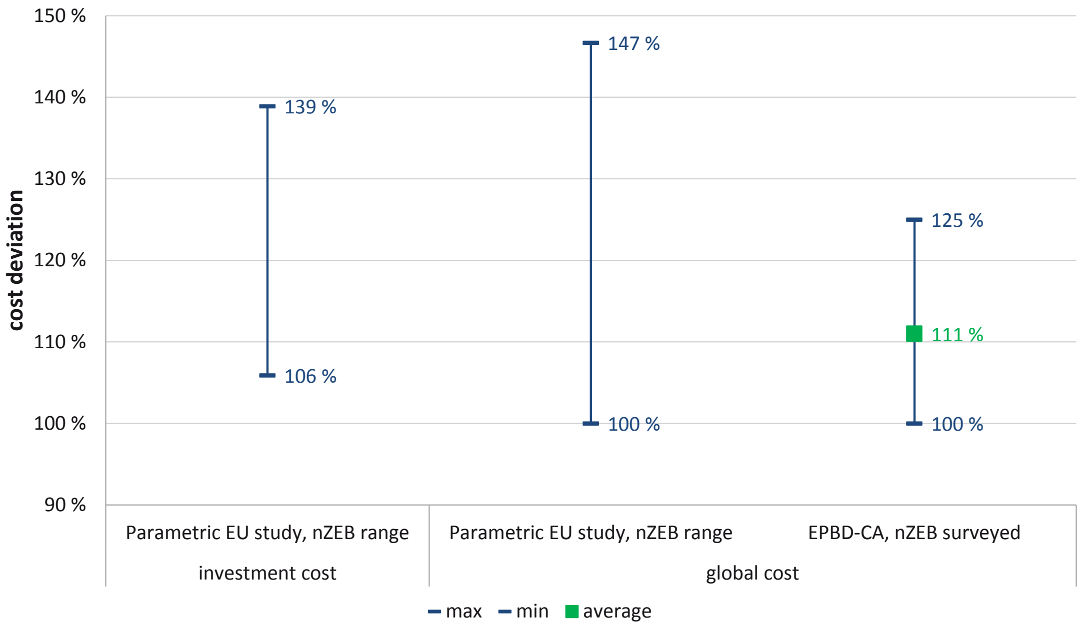

Figure 2. Investment and global cost for the nZEB/Plus from the EU study & survey case studies.

Table 1. Case studies – description.

Name	Location	Type	Energy Performance	Year	Mechanical balanced ventilation	PV	
						W/m² (floor area)	@ €/Wpeak installed
EU study & survey							
Parametric study EU	West EU	Single Family House	nZEB	2010	Yes	Yes, n.a.	2.8
	North EU				Yes	Yes, n.a.	3.6
	South EU				No	Yes, n.a.	3.0
	East EU				No, most	Yes, n.a.	3.0
Survey EPBD-CA	EU	mixed types	nZEB	< 2014	Yes, most	Yes, n.a.	n.a.
National case studies							
Rieselfeld	Germany	Row house	1999 passive house/ 2010 nZEB (+PV)	1999/ 2010	Yes	32	3.5
Solarsiedlung Freiburg	Germany	Neighbourhood	Plus energy	2005	Yes	69	5.0
CasaClima Viterbo	Italy	Multi Family House	nZEB	2012	Yes	10	2.5
Druso Ovest	Italy	Multi Family House	nZEB	2014	Yes	4	1.9
Norwegian PH+PV	Norway	Single Family House	nZEB	2014	Yes	30	2.3
Multikomfort	Norway	Single Family House	Plus energy	2014	Yes	100	2.3
Skarpnes	Norway	Cluster	Plus energy	2014	Yes	53	2.3

The results of the EU parametric study show that there can be, potentially, large variability in both investment and global costs for nZEBs. The results of the EU survey too, available only for the global cost, show large variability in the range 0–25%, with an average at 11%.

For the national case studies in **Table 2** and **Figure 3** the total investment cost for "standard typical" buildings is first compared with "high" and "low" standards. This refers to higher or lower overall qualities of the buildings (such as architectural features, use of materials, finishing) while the energy performance is the same as for "typical" buildings. This gives an appreciation of the cost variability normally found in the construction market, regardless of energy performance. It can be seen that nZEB/Plus buildings have an extra total investment cost, for the observed cases, between 9–27%, with an average of 15%. This is a comparable range of extra cost for higher standard buildings, which are in the range 15–35%.

The cost breakdown available for the national case studies conveys important information for identifying where it is reasonable to seek for investment cost reductions. In order to understand this it is necessary to have a look at the main technical characteristics of the standard buildings (built according to national standard) and the nZEB/Plus buildings, as shown in **Table 3**.

The nZEB/Plus breakdown of investment cost form **Table 2** and **Figure 3** shows how the extra cost arises from the contribution of all the cost categories:

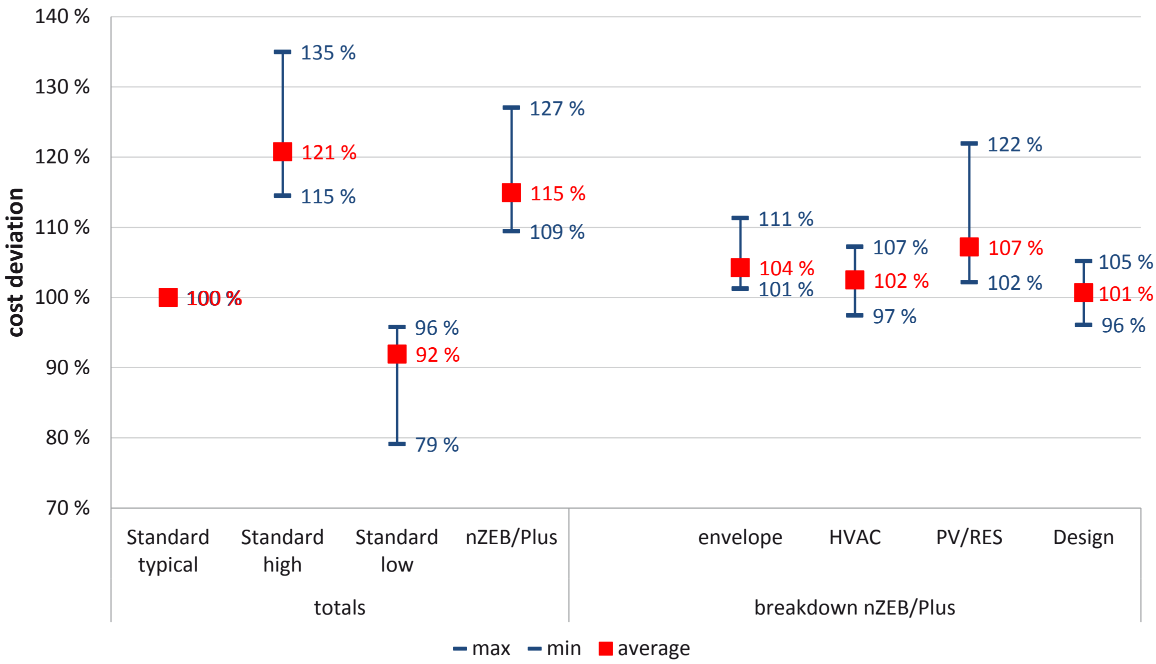

Figure 3. Total investment cost and breakdown per cost category for the nZEB/Plus from the national case studies.

Table 2. Case studies – total cost and breakdown per cost category.

Name	Investment cost								Global cost	
EU study & survey										
	Cost optimal* [€/m²]	Total [%] nZEB range							Total [%] nZEB range	
Parametric West EU	1 500	113%	127%						109%	126%
Parametric North EU	1 800	111%	139%						107%	147%
Parametric South EU	1 700	106%	124%						100%	123%
Parametric East EU	1 500	107%	130%						103%	143%
Survey EPBD-CA								Average 111%	100%	125%
National case studies										
	Standard typical [€/m²]	Total [%]			Breakdown nZEB/Plus [%]					
		Standard high	Standard low	nZEB/Plus	Envelope	HVAC	PV/RES	Design		
Rieselfeld	1 011	119%	79%	113%	102%	101%	111%	99%		
Solarsiedlung Freiburg	1 600	115%	89%	124%	101%	97%	122%	103%		
CasaClima	1 100	127%	91%	112%	107%	103%	102%	100%		
Druso Ovest	1 100	123%	91%	109%	102%	104%	102%	100%		
Norwegian standard	2 339	124%	96%	113%	105%	104%	103%	101%		
Multikomfort	2 339	124%	96%	122%	111%	104%	110%	96%		
Skarpnes	1 600	135%	94%	127%	105%	107%	107%	105%		

Table 3. Main technical characteristics of the national case studies (nZEB/Plus in grey shade).

Technical description		Germany	Italy	Norway
Envelope	Walls U-value [W/m²K]	0.30	0.34	0.18
		0.14 – 0.19	0.18	0.10 – 0.12
	Window U-value W/m²K]	1.6	2.2	1.2
		0.8 – 1.2	1.2	0.7 – 0.8
	Other	-	-	-
		Thermal bridges free & air-tight		
HVAC	Ventilation	Natural – Mech. Exhausted	Natural	Mech. Balanced η = 70%
		Mech. Balanced η = 80%	Mech. Balanced η = 80% Decentralized mech. Balanced	Mech. Balanced η = 80-85%
	Heat supply	Gas condensing boiler	Gas condensing boiler	Electric boiler, district heating
		District heating Solar thermal	Gas condensing boiler District heating Solar thermal	District heating Ground source heat pump Solar thermal
PV/RES	Electricity generation	-	-	-
		PV, CHP at district central	PV	PV

Envelope, HVAC, PV/RES and Design. There is no one single technology, or category of technologies, that in itself determines the extra cost.

The single most important category is the PV/RES, though this is chiefly due to the cost of PV installations, which used to be considerably more expensive just a few years ago. **Table 1** shows how the PV cost (normalized per m² of floor area) dropped vertically in just a decade from the 5.0 €/m² of 2005 (in Germany) to the 1.9 €/m² of 2014 (in Italy). This cost refers to an installed and functioning system, not only to the module cost. Furthermore, PV cost is expected to drop further at around 1.2 €/m² (German market) by 2020, thus reaching market parity with grid electricity in most EU countries, without any feed-in tariff[4]. The impact of PV on the total extra cost of nZEB/PV is therefore expected to decrease in the next years. Besides, the impact depends also on the amount of installed PV capacity, and as **Table 1** shows there can be large variations, chiefly determining if the building is nZEB or plus energy.

Extra costs for improving the envelope remain significant, especially in warmer climates (in %) where the existing standards are less stringent. However, a closer analysis shows that the additional insulation cost is not any longer the main contributor, at least in colder climates. The extra cost for making the envelope thermal bridge free and air-tight becomes predominant at a certain point, not because of the cost of materials but due to the additional work it requires to properly solve all the details, especially when constructing *in situ*.

The relative impact of HVAC technologies is somewhat lower, showing oscillations that even go on the savings side. However, this happened in the case of a neighbourhood development where a local heating system was installed. At single building level the impact of HVAC cost is higher, partly due to the installation of heat supply technologies such as heat pumps and solar thermal collectors, but chiefly due to the cost of a mechanical balanced ventilation system with heat recovery[5], whose cost is in the order of 80 €/m² (German market).

Last not least, the design cost can also increase considerably due to the deployment of solutions that are (not yet) mainstream and therefore require additional effort from the design team, such as thermal bridge and air-tightness architectural detailing, and proper dimensioning and engineering layout and integration of highly energy efficient HVAC and RES solutions. However, where integrated energy design has been systematic and involving all professional actors around the design table since the early design phase, extra design cost has been minimal or even negative.

Ambition: Investment cost reduction of 15%

The cost analysis of the nZEB/Plus buildings shows that there is no single technology or category of technologies able to deliver a 15% investment cost reduction.

4 EPIA (2012) Connecting the Sun – Solar Photovoltaic on the Road to Large-scale Grid Integration, *European Photovoltaic Industry Association (EPIA) report.*

5 With the exception of Norway and other Nordic countries where such a system is compulsory also in standard buildings.

The goal is therefore achievable by a combination of simpler and cheaper technologies in all categories, linked together by an integrated energy design.

Perhaps one of the most known examples of plus energy neighbourhood is the "Solarsiedlung Freiburg" in Germany, completed in 2005 (for cost data see **Table 2**). This development was conceived and realized by the architecture office Rolf Disch Solar Architecture, who is now driving the development a new Solarsiedlung (in English: solar estate) in Germany, whose construction is planned to be completed in 2018. The next graphs refer to the two neighbourhoods, with aerial view of the Solarsiedlung Freiburg in **Figure 4** and graphs showing the extra investment cost, total and breakdown, in comparison with standard buildings of the same period (**Figure 5** and **Figure 6**).

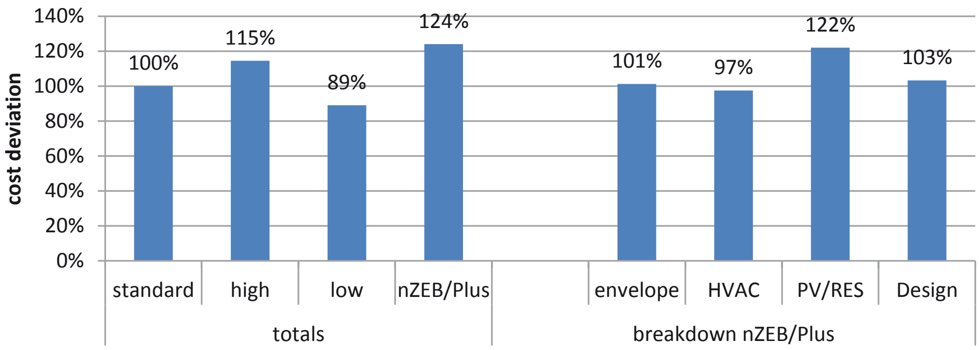

Figure 5. Total investment cost and breakdown per cost category for the plus energy neighbourhood "Solarsiedlung Freiburg" – 2005.

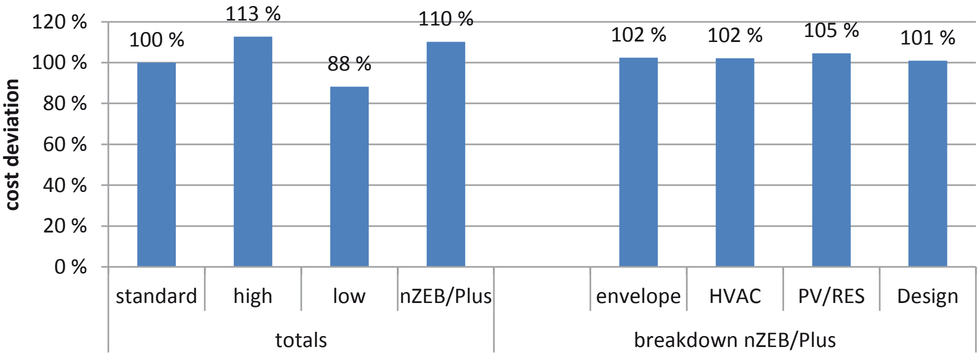

Figure 6. Total investment cost and breakdown per cost category for the plus energy neighbourhood "new settlement" – 2018.

The amount of PV installed is approximately the same in both cases, being 69 W/m² in Freiburg and 78 W/m² in the new development. **Figure 5** shows how the cost of PV was dominant in 2005, while in 2018 it is expected to remain significant though considerably lower, **Figure 6**. The cost for HVAC in Freiburg was lower than the reference because of the scale effect, since it served a larger area, which is not the case in the new development. Here it remains the challenge of making the HVAC solutions cheaper, especially regarding the ventilation system. Envelope cost is slightly higher in the new development since it achieves the passive house standard, which was not the case in Freiburg. Finally, design cost are contained thanks to the accumulated know-how by the two key actors (Rolf Disc and Fraunhofer), that will also drive the development of simpler and faster design methods and tools.

Figure 4. "Solarsiedlung Freiburg", Germany 2005. Photo: courtesy of Rolf Disch Solar Architecture.

The approach to investment cost reduction in the new development compared to Solarsiedlung Freiburg can be a roadmap also for other neighbourhood developments in Europe.

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