CONCERTED ACTION
ENERGY PERFORMANCE OF BUILDINGS

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1. Introduction

In 2010, the adoption of the Energy Performance of Buildings Directive - EBPD (Directive 2010/31/EU) presented both the building industry and Member States (MSs) with new challenges. One of the most prominent among them, as far as new buildings are concerned, is the progress towards Nearly Zero-Energy Buildings (NZEBs) by 2021 (or, in the case of public buildings by 2019). Thus, since 2010 and also during the current working phase, the Concerted Action EPBD (CA EPBD) has been discussing the issues related to NZEB, promoting dialogue and the exchange of best practices among MSs, and thereby contributing to a more effective implementation of the EPBD.

The work of the CA EPBD under the Central Team New Buildings & NZEBs focuses on practical challenges and experiences with the early implementation of NZEBs in the MSs by collecting case studies and discussing how to integrate renewable energy systems (RES) and other innovative technologies, as well as the indoor climate issue, into the energy performance assessment methods.

This report summarises the main outcomes of the work of the CA EPBD under the Central Team New Buildings & NZEBs on these topics from October 2015 to February 2018. The work is based on the active participation of the national delegates (representing national authorities in charge of implementing the EPBD), and includes information gained from questionnaires, national studies and poster presentations.

2. Objectives

The aim of this Central Team's work is to support the implementation of policies on new buildings, particularly including requirements for new buildings, NZEB and the inclusion of RES as part of the energy performance of new buildings, as laid out in the EPBD Articles 6, 9, 2(2) and Annex I.

Article 6 of the EPBD requires MSs to "*ensure that new buildings meet the minimum energy performance requirements*" set in accordance with the calculated cost-optimal level and that "*the technical, environmental and economic feasibility of high efficiency alternative systems*" are "*considered and taken into account*".

In 2019/2021, the minimum energy performance requirements for new buildings will be defined by the national application of the NZEB definition[1,2]. MSs shall furthermore "*draw up national plans for increasing the number of nearly zero-energy buildings*" and "*following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings*".

A NZEB is defined in Article 2(2) of the EPBD as "*a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*".

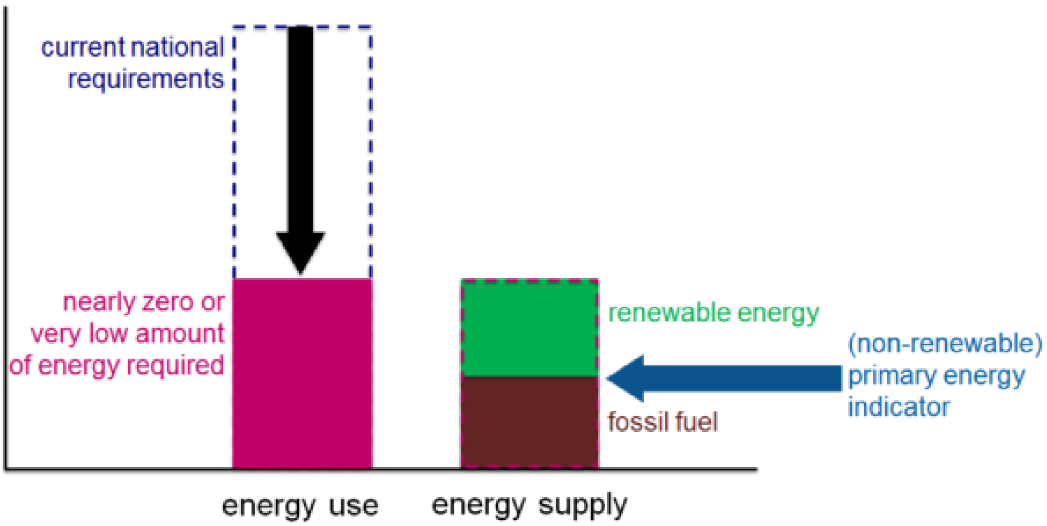

Figure 1: Graphical interpretation of the NZEB definition according to EPBD Articles 2 and 9.

The discussion topics of the Central Team New Buildings & NZEBs included the following:

- different national applications of the NZEB definition;
- suitable and innovative building and service system solutions;
- their impact on indoor comfort;
- national and European calculation methods; and
- demonstration buildings for raising awareness among the general public.

A particularly important objective has been the integration of RES into the NZEB national implementation strategies. This is part of the EPBD requirements, but it also links to the requirements of the Renewable Energy Sources Directive (Directive 2009/28/EC – RESD). In accordance with the RESD (Article 13(4)), by 31 December 2014, MSs must require the use of minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation. This requirement must be implemented in MSs' building regulations and codes, or by other means with equivalent effect.

The CA EPBD Central Team New buildings & NZEBs collaborates closely with the Cross-Cutting Team Technical Elements concerning innovative service systems and calculation methods, especially concerning the CEN EPB standards (Mandate 480). The discussions organised by both teams include the possible adoption and implementation of the CEN standards by the MSs. The outcome of this work is summarised in the Report of the Cross-Cutting Team Technical Elements.

3. Analysis of Insights and Main Outcomes

3.A. Analysis and insights

3.A.1 National applications of the NZEB definition

Although the target dates in Article 9(1) of the EPBD are in the future, the deadline for transposition of Article 9 was 9 January 2013. By that date, all the NZEB provisions of Article 9 had to be reflected in national transposition measures. Such a lengthy run-up was considered necessary given how long it takes to plan, acquire permission for and construct a building. While the date of NZEB implementation is approaching, the development of national applications of the NZEB definition is continuously being followed by the CA EPBD. The latest complete overview of the national NZEB definitions is presented in the report "Nearly Zero-Energy Buildings: Overview and outcomes" as part of the Concerted Action EPBD report "Implementing the Energy Performance of Buildings Directive (EPBD)" of August 2016. This overview and the definitions summarised therein, contributed also to the "Commission Recommendation on NZEB"[3].

Updates of the national NZEB definitions have been the focus of work at the end of CA EPBD IV. For the overview at hand the following five main points have been analysed per country:

1. Is there a detailed NZEB definition available?
2. How is the "very high energy performance" expressed?
3. Where are the limits defined for "a very low amount of energy required"?
4. Is there a requirement for "covered to a very significant extent by energy from renewable sources"?
5. Is a "primary energy indicator in kWh/m².year" in use?

Table 1 was developed based on the detailed information provided by MSs' delegates in February 2018.

With the deadlines end of 2018 (new public buildings) and end of 2020 (all new buildings) approaching more and more MSs have their national application of the NZEB definition in place. By February 2018 a total of 76% of the countries have defined detailed NZEB requirements in legal documents. The remaining countries have mostly drafts available that are based on studies. They foresee to conclude the work on the NZEB definition within 2018.

Main points of the national NZEB definition (as reported by the CA EPBD delegates)			Austria	Belgium: Brussels	Belgium: Flanders	Belgium: Walloon	Bulgaria	Croatia	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg *	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovak Republic	Slovenia	Spain	Sweden	United Kingdom
Detailed definition	Included in a legal document	Government decree/law		■	■	■	■		■				■				■		■	■		■	■			■			■	■		■	
		Technical regulation						■		■	■	■		■				■	■		■								■				
		National NZEB plan	■					■																				■		■			
	Not yet included in a legal document														■	■						■		■	■		■				■		■
	Draft available														x							x		x							x		
Very high energy performance	Tighter requirements compared to current values for	General												■												■					x		
		Mean U-value of building envelope								■																							
		Reference technologies								■																		■					
		Heating energy demand																												■			
		Final energy	■																														
		Primary energy				■	■	■		■			■						■									■	■	■			
		(Primary) energy performance coefficient			■	■																		x									
	Top building class						■		■			■					■	■		■	■	■ x	■						■				x
	Specific new building class										■																						
	Passive house (building envelope) level			■																													
	KfW efficiency house 55/70														x																		
Nearly zero or very low amount of energy required. Limits on:	Component U-values				■	■			■								■	■	■					x		■			■	■	x		
	Thermal bridges																	■															
	Mean U-value of building envelope				■	■	■			■					x									x						■		■	
	Heat transfer coefficient/heat loss of building envelope																		■		■												
	Air permeability																	■															
	(Net) heat demand		■	■					■						x		■					■ x											
	Installed lighting power								■																								
	System efficiencies						■										■	■	■														
	Heating energy demand																		■	■										■	x		
	Cooling energy demand																		■												x		
	Total energy efficiency		■																														
	Electrical input																															■	
	Final energy (total or divided into energy uses)		■							■																■			■				x
	Primary energy			■	■	■	■	■	■	■	■	■	■	■	x		■	■	■	■	■	■ x	■	x		■		■	■	■	x	■	
	CO_2 emissions		■															■										■					x
	Summer overheating																■		■														
Very significant extent of renewable energy	Direct	Minimum share in %	■		■		■	■	■						x		■	■	■	■	■		■					■	■	■			
		Minimum contribution in kWh/m².yr			■									■				■															
		(Choice of) exemplary RES measures	■		■						■								■														
	Indirect **			■		■				■	■	■	■									■ x		x		■					x	■	x
Primary energy indicator in kWh/m².yr	Included		■	■		■	■	■	■	■	■	■	■	■	x		■		■	■	■	■ x	■			■		■	■	■	x	■	
	Other main indicator, but PE as additional/interim result. Main indicator:	CO_2																															x
		Primary EP coefficient			■	■												■						x									

* At the time of the overview Luxembourg had a national NZEB definition for residential buildings in place, but not yet a NZEB definition for non-residential buildings
** Indirect: RES contribution required in order to achieve the minimum energy performance requirement
X Details based on drafts are marked with "X"

Table 1: Status of the detailed national application of the NZEB definition in practice in the CA countries as of February 2018.

CA EPBD has analysed not only the status of work of the NZEB definition in the countries, but also the political, economical, technical and procedural barriers that prevent or delay MSs from fixing their NZEB definition. The CA also supported MSs in their work through detailed discussions and exchange between delegates. More detailed information can be found in a CA EPBD factsheet[4].

National NZEB definitions differ significantly from each other. This is documented in the tabular overview that deals with the four main points of the general NZEB definition in the EPBD. Limits for the energy performance are, for example, set in addition to primary energy on many different characteristics. Further deviations that prevent from comparing the national NZEB definitions among MSs are: different calculation methods, building culture, climate, investment and energy costs, etc.

During the CA work on the national NZEB definitions, it also became apparent that some of the definitions underwent changes since the first publication. Further revisions are planned. Reasons for this include the use of new calculation methods (including the change towards the new CEN EPB calculation standards), the new cost-optimal reports submitted by MSs taking into account the situation in 2020, and reduced required RES contributions, as studies showed that the earlier ones are difficult to achieve in the urban context.

Highlights of 3.A.1	CA EPBD has continuously followed up on the national applications of the NZEB definition. As of February 2018, a great deal of progress in this work has been recognised, since more than 70% of the MSs currently have a detailed NZEB definition in place.

3.A.2 Use of renewable energy systems in urban NZEBs

The overview of national applications of the NZEB definition in CA EPBD III showed that countries use different approaches to RES requirements. Some MSs request a direct RES contribution (share in percentage, or minimum amount of kWh/m² per year); others have only included an “indirect” RES requirement by setting very low primary energy requirements that can only be met with RES contributions. Earlier CA EPBD work on national applications of the NZEB definition has shown that MSs see a specific challenge in how to include RES contributions to the energy supply of multi-family houses in city centres, where roof areas and other areas suitable for the installation of RES technologies (e.g., the ground around the buildings) are limited in comparison with the buildings’ floor area and are often shaded by other buildings.

In order to investigate these barriers and to present possible solutions, CA EPBD analysed which RES technology contributions can generally be assessed with the national energy performance calculation method, and which ones can fulfil possible direct RES requirements as part of national NZEB definitions. The result is an overview with information on the applicability of RES technologies across 24 countries. Large differences exist across countries regarding those RES solutions which can be included in their energy performance calculations, and those which can be used to fulfil direct NZEB RES requirements. Some technologies (e.g., solar thermal panels for domestic hot water generation and for heating, PV for self-use[5] as well as biomass boilers and heat pumps coupled to external air/exhaust air/ground or ground water) can in general be accounted for in the energy performance calculation in all 24 countries that took part in the evaluation. Other RES technologies (e.g., PV for feed-in, RES as part of district cooling, micro-wind turbines (self-use or feed-in) and local hydro power for self-use) can be accounted for in the energy performance calculation in about half of the countries that took part. The RES technologies that can most rarely be accounted for in energy performance calculations are RES electricity via the grid (with a specific contract) and local hydro power for feed-in (see Table 2).

The evaluation whether the RES technologies can fulfil direct RES requirements as part of NZEB requirements (currently required in 11 of the 24 countries) resulted in a similar order as above. Solar thermal panels for domestic hot water and PV for self-use are accepted in all 11 MSs, and solar thermal panels for heating support, biomass boilers, micro wind-turbines for self-use, and PV for heating input are accepted in 10 MSs. RES electricity via the grid with a specific contract, RES as part of district cooling and local hydro for feed-in are accepted in only a few countries. A follow-up session is planned in order to investigate reasons for differences in the national approaches.

A discussion of specific RES solutions for multi-family houses showed that most countries allow systems to be installed on associated buildings such as garages, as long as they are under the same ownership and/or on the same building plot. Most also allow the use of community systems as long as there is a direct connection to the building. Some countries allow the use of waste heat from industry or from heat pumps based on sewage water, but others do not have calculation methods to account for these. The use of higher insulation levels as an alternative to RES is only applicable in a few countries. Additional RES solutions for urban multi-family-housing identified during the discussions were heat recovery from showers, purchase of green certificates and participation in RES projects.

Solution \ Country	BE-BR	BE-FL	BE-WA	BG	CY	DE	DK	EE	GR	ES	FI	FR	HR	HU	IT	LT	LV	MT	NL	NO	PL	PT	SE	SK	SL	UK
RES as part of district heating	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y		Y	N	Y	Y	Y
RES as part of district cooling	N	N	N	Y	Y	Y	N	Y	Y	N	Y	Y		N	Y	N	N	N	Y	Y	N	Y	N	N	Y	N
Solar thermal panels for DHW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar thermal panels for heating support	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV for self-use	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV for feed-in	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	N
PV for heating (input to heat storage)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV/T hybrid solar collectors for self-use	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV/T: PV for feed-in, T for self-use	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N
Micro wind-turbine for self-use	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Micro wind-turbine for feed-in	N	N		N	Y	Y	N	Y	Y	N	N		N	N	N	Y	Y	Y	Y	Y	N	N	N	Y	N	N
Local hydro for self-use	N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Local hydro for feed-in	N	N	N	N	N	N	N	Y		N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N
Biomass boiler	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Biomass CHP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y/N	Y/N	Y	Y	Y	Y/N	N	Y	Y	Y	Y		Y	N	Y	Y	Y
HP coupled to external or exhaust air	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
HP coupled to ground / ground-water	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Direct geothermal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Direct ground water cooling	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
RES electricity via grid (specific contract)	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	Y	N	N	N	Y	N	N	N	N	N	N
Alternative: higher insulation level	Y	Y	N	Y	N	Y	N	Y	Y/N	Y/N	N	N	N	N	Y	N	N	N	Y	Y	Y	N	Y/N	N	Y	N

Table 2: Accountable RES solutions in the MSs' energy performance calculations.

Figure 2: The Solar Active House in the city centre of Frankfurt features a heat pump coupled to the sewage water and PV modules on the roof and the façade (source: HHS Architekten).

Differences in calculations for RES in the MSs were investigated. The discussions resulted in a greater understanding of the countries' reasons for following specific approaches. Calculations in some MSs do not account for certain RES technologies (e.g. PV/T[6], local hydro power). Some of the technologies (both PV/T and local hydro power) are not covered by CEN standards. Additionally, there is no or very little local use of some of the technologies and therefore no need to develop procedures. In some MSs there are additional procedures to deal with technologies for which there is no standard calculation defined. Some MSs impose limits on the amount of locally-generated energy that can be accounted for and some do not allow any exported electricity to be accounted for in order to avoid double-counting in the EPC and grid primary energy factor.

Some MSs have (different) ways of limiting the accountable amount of generated electricity, and have already partly implemented changes based on their experiences. Other MSs do not have limits, and some of these MSs have separate energy performance requirements for the building envelope instead.

The main advantages of having limits for the accountable amount of generated electricity were identified as:

- reducing probability of grid problems (e.g., too much PV in one region causing the grid to become unstable);
- making designers think harder about reducing energy demand;
- avoiding double counting of RES.

The main advantages of not having limits were identified as:

- encouraging RES and positive energy buildings;
- making renewable electricity available for more uses (e.g., e-mobility).

In most countries, RES are found mainly in single-family houses or public buildings. For buildings containing multiple dwellings, specific arrangements are needed so as to distribute or assign locally-generated energy to different users. Examples of such arrangements from Germany were given:

- A simple solution is for a collective of users (e.g., owners of the dwellings in the building) to own the renewable energy systems. The electricity generated might then be divided between the users according to a specific private contract, with any surplus fed into the grid and remuneration divided between the owners.
- In a building owned by a housing company, electricity generated is given as a gift to tenants (i.e., costs are included in the rent), who can decide to refuse the gift and use electricity from another supplier.
- In a building owned by a housing cooperative, a PV system is financed by a fund of the city's energy supply company only available to the tenants. Tenants pay into the fund and receive electricity at an attractive price.

In Denmark, a pilot building has been constructed to demonstrate how electricity can be distributed within a building which has multiple tenants, a PV installation, a storage battery and a grid connection. There are local sub-meters for the PV production, battery output, apartment usage, and a main meter for the grid connection. Smart meters allow the definition of an order of priority for energy use so that locally-produced electricity is used before locally-stored energy and that both of these are used before grid energy. The building is energy-neutral on an annual basis.

Highlights of 3.A.2	Countries differ greatly with regard to RES solutions that have been included in their energy performance calculations and in which solutions can be used to fulfil foreseen direct NZEB RES requirements. The collection of practical solutions for the use of RES at inner-city buildings presented approaches that can be applied in other MSs as well.

3.A.3 Best practice examples of NZEBs

EPBD (Directive 2010/31/EU) Article 9 states "*MSs shall ensure that after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings."* With this date approaching, MSs and/or municipalities in the MSs have started to design and construct pilot projects for public NZEBs. Some MSs have set up research or financial support programmes for (types of) high-performance public buildings. These form the basis of the collection of NZEB-like educational buildings that has been compiled within CA EPBD.

In total, 17 examples of educational buildings have been collected and compared, of which three are kindergartens, eight are schools (mostly primary schools), two are combined kindergartens and schools, and four are university buildings. The main results of the comparison are:

- Concrete/masonry construction was the most commonly used, although several of the buildings are of lightweight construction. The windows are triple-glazed in ten of the buildings and double-glazed in four of the buildings. U-values were found within the following ranges:
    - Walls: 0.09 – 0.40 W/m²K (average: 0.16 W/m²K)
    - Windows: 0.60 – 1.76 W/m²K (average: 0.97 W/m²K)
    - Roof: 0.06 – 0.30 W/m²K (average: 0.13 W/m²K)
    - Ground/cellar ceiling: 0.06 – 0.56 W/m²K (average: 0.19 W/m²K)
- For space heating, heat pumps are used in nine of 17 examples, gas boilers in two examples, biomass in one example, district heating in six examples and a combined heat and power unit based on wood pellets in one example. Hot water is mostly generated in combination with the space heating but some buildings have additional water heating features like electrical top-up and solar thermal panels. One example uses decentralised electric water heating.

• Twelve of the buildings include cooling systems with five of them using a reversible heat pump, one using a district cooling system, three using free cooling, one using adiabatic cooling, two using night ventilation and one having cooling built into the ventilation system.
• All buildings include elements of demand controlled mechanical ventilation, 14 with heat recovery and three without heat recovery. Controls are based on CO_2 emissions, occupancy, humidity or temperature.
• Lighting controls are based on manual control (four examples) or occupancy control (six examples). Daylighting control is included in five schools. One building uses DALI (Digital Addressable Lighting Interface) controls.
• Four buildings have no RES system included. PV systems are installed in ten of the buildings. Three buildings have solar thermal panels on the roof. RES (waste heat and/or biomass) are also included in the district heating systems used in three of the buildings, one of which also uses water from a nearby lake for cooling.
• The average final energy use for the buildings is 50.5 kWh/m².year but includes partly differing energy demands. The average primary energy use is 55.3 kWh/m².year.
• The improvement compared to current requirements is on average 68%. The average renewable energy contribution rate is 49%.
• The documented additional costs compared to conventional new educational buildings are on average 603 €/m² floor area (17% of total costs). The average is reduced down to 204 €/m² (11% of total costs) if an outlier (by far the most expensive example building) is not accounted for.

The variety in the thermal quality of the building envelope and the used service system technologies shows the impact of the different climatic conditions, regional building culture, user expectances and specific aims of the pilot projects.

Highlights of 3.A.3	The collection of NZEB-like educational buildings showed that many countries are using public pilot projects in order to gain experiences with the building standard and to motivate builders and planners of private and commercial buildings to develop and realise NZEBs in advance of the 2019/2021 deadline. The analysis of the case studies showed however that the additional investment costs, with an average of 11% (or about 200 € per m² floor area), are still substantial.

3.A.4 Cost-efficient technologies, strategies or processes for NZEBs

The additional costs for NZEBs compared to conventional buildings are assumed to be a barrier for increasing the number of NZEBs for the time being. An earlier collection of NZEB-like case study buildings in CA EPBD III has shown that the additional costs were on average about 10% of the total costs, or roughly 200 €/m². The European Commission has financed and is financing several projects[7] dealing with cost-effective technologies and strategies for NZEBs which were introduced to the CA members.

A CA EPBD survey identified the following technologies that are considered to offer the best potential for being cost-efficient in NZEBs: heat pumps, PV, insulation, heat recovery and renewable energy sources in general. Eight countries have guidelines for cost-efficient buildings and some countries use the cost-optimal EPBD analysis as guidance for cost-efficient buildings.

Lessons learned in the MSs concerning the building envelope, the technical building systems, and the design and construction processes are:

- Improving U-values of the building envelope with insulation and/or double or triple glazing is often cost-effective, but there is a need to balance decreases in heating demand and increases in cooling demand. Shading devices can be either outside the building or integrated into the building, and measures outside the building might also include the use of trees to provide shading. Taking into account factors such as positioning and orientation is often cost-efficient.
- Differences in cost-efficiency of technical building systems between countries tend to depend on climate, energy supply mix, existing infrastructure, subsidy policies and consumer perceptions. PV and heat pumps are popular and electric heat pumps are often combined with PV. Solar thermal systems may be cost-effective, but they are losing market share to PV. Mechanical ventilation systems with heat recovery are cost-effective in colder climates, and direct electric infrared heating is becoming popular in countries with low prices and low primary energy factors for electricity. Control and automation systems can be cost-effective, but are often not optimally operated, although LED lighting with presence and daylight control is generally cost-effective.
- Concerning the design process, architects and engineers are now working more closely together than they did 10 years ago, and it was suggested that BIM can help to further avoid unnecessary iterations. It is important to focus on the wider benefits of NZEBs and on achieving the best quality for the budget available instead of focusing only on the additional costs.
- It is important to include the energy specialist at each stage of the construction process. The use of Building Information Modelling (BIM) can help with quality control and effective communication between different teams. Cost, time available and quality are closely interlinked, but a problem arises when improved quality does not increase financial value. Copying solutions from other countries is difficult.

Highlights of 3.A.4	The additional costs of NZEBs compared to current new buildings are regarded as a barrier for an increased number of early NZEB buildings. The CA EPBD has exchanged experiences regarding technologies and strategies that can contribute to more cost-efficient NZEB buildings. The technologies considered most cost-efficient are heat pumps, PV, insulation, heat recovery and renewable energy sources in general.

3.A.5 Innovative technologies

The developments towards NZEBs in the MSs lead to more and more innovative technologies being introduced into the MSs' building market over the last few years. The CA EPBD collected and exchanged first experiences with new technologies in the MSs. Information was also gathered on how MSs handle these technologies in their calculation methods or other assessment procedures. The work concentrated on the following technologies:

1. demand controlled ventilation;
2. building automation systems;
3. reversible heat pumps (for cooling in summer);
4. advanced solar shading systems.

The discussion around innovative technologies shows that there are large differences among MSs in the used system variations and how commonly they are used in different types of buildings. According to the assessment of the CA participants, demand controlled ventilation (based on either humidity control, CO_2-control or temperature control) is used in the majority of new buildings in France and Belgium, is often used for non-residential buildings in Denmark, and is more rarely used in the Eastern EU MSs.

Building automation systems can be classified as defined in EN 15232. The more advanced building automation systems are currently mainly used in new non-residential buildings in Sweden, Italy, Portugal, France and Norway. However, the cost and time necessary for maintenance and repair was in general considered to be high, and it was thought that few people have a good understanding of the systems. These issues make it difficult to estimate the benefits of building automation systems. Reversible heat pumps can be based on different energy sources and are only rarely used in a few countries, and mainly in the context of residential buildings. In Norway, the use of reversible air-to-air heat pumps in residential buildings is more common, while reversible ground-to-water heat pumps are most commonly used in non-residential buildings. Use of advanced solar shading systems such as inter-pane shading devices, semi-transparent PV, switchable solar-protection glass and bio-shading remains rare in the EU MSs.

The methods of calculating the systems' impacts on the building energy use also vary across the different countries and technologies. Further information on the calculation approaches for these innovative systems can be found in the Report of the Cross-Cutting Team Technical Elements. An exchange between the countries and CEN might help to encourage broader use of the innovative technologies.

Highlights of 3.A.5	Innovative technologies are entering the building market in most MSs, but the handling of these technologies in assessment procedures differs between the countries.

3.A.6 Indoor climate in high performance buildings

Inadequate design or execution of building energy efficiency improvement measures on the construction site can have negative consequences on the quality of the indoor climate in high performance buildings. Problems may include overheating due to increased thermal insulation (such as highly efficient windows) and increased airtightness, which can also result in lower indoor air quality if this is not complemented by a suitable ventilation solution. Other problems include emissions coming from the use of inappropriate materials, noise problems caused by ventilation systems, insufficient heating and poorly functioning installations. Work in the CA EPBD on the topic included the presentation of experiences from real buildings and the identification of key success factors to ensure a good indoor climate.

The main success factors identified were:

- correct installation and commissioning of ventilation and air-conditioning systems;
- in-use monitoring of the performance of building service systems;
- regulatory requirements setting targets (e.g., for minimum ventilation rate) or specifying measures to be used (e.g., solar shading, openable windows for night ventilation);
- quantitative indicator(s) of discomfort based on duration/intensity and the inclusion of comfort/discomfort indicator(s) in EPCs;
- education of users regarding behaviour, expectations of systems and possible lifestyle adaptations.

Indoor climate influence factors, such as the heat capacity of the building, outdoor CO_2 levels, ventilation rates etc., need to be further investigated. In general, calculation methods and energy performance requirements need to include indoor comfort issues. Different usage patterns can influence indoor comfort and therefore assessment methods need to take them into account.

Highlights of 3.A.5	High performance buildings, including NZEBs, benefit from reduced energy use but some of the commonly applied measures can also have a negative influence on indoor climate. In consequence, indoor climate requirements are increasingly being integrated into energy performance assessment and control procedures. Technical, regulatory and user dependent influence factors for good indoor comfort have been identified and discussed within CA EPBD.

3.B. Main Outcomes

Topic	Main discussions and outcomes	Conclusion of topic	Future directions
National applications of the NZEB definition	The development of national applications of the NZEB definition is continuously followed by the CA EPBD.	The CA EPBD factsheet "National Applications of the NZEB Definition – The complete Overview" gives a detailed overview of the status of the national applications of the NZEB definition by February 2018.	CA EPBD will continue to follow up on the NZEB transposition process in the MSs.
Use of RES systems in urban NZEBs	Countries differ greatly in the RES solutions that can be assessed by their energy performance calculations and in which solutions can be used to fulfil foreseen direct NZEB RES requirements.	The collection of practical solutions for the use of RES in inner-city buildings showed potential for MSs to further learn from each other.	MSs have to solve legal and financial barriers such as how to distribute PV electricity generated on multi-family houses to the tenants.
Best practice examples of NZEBs	Seventeen examples of NZEB-like educational buildings have been collected and compared.	Many countries use public pilot projects to gain experience and to motivate private and commercial builders to develop and realise NZEBs in advance of the 2019/2021 deadlines.	Further work should include a focus on the renovation of existing buildings to NZEBs.
Cost-efficient technologies, strategies or processes for NZEBs	The CA EPBD has exchanged experiences with technologies and strategies that can contribute to more cost-efficient NZEBs.	The technologies considered most cost-efficient are heat pumps, PV, insulation, heat recovery and renewable energy sources in general.	Several EU Horizon 2020 projects are investigating this issue and will publish outcomes in 2019/2020.
Innovative technologies	Innovative technologies are entering the building market in most MSs.	The handling of these technologies in assessment procedures differs among the countries.	Exchange between the countries and CEN might be helpful for a broader use of innovative technologies.
Indoor climate in high performance buildings	Indoor climate requirements are becoming part of the national energy performance assessment procedures.	Technical, regulatory and user dependent influence factors for good indoor comfort have been identified and discussed within CA EPBD.	Further influencing factors such as the heat capacity of the building, outside CO_2 level, ventilation rates etc., need to be further investigated.

4. Lessons Learned and Recommendations

While most EU MSs have set out their national application of the NZEB definition in legal transposition measures or in national plans on NZEB, some are still in the last phase of this development; in practice, this usually means a consultation process with stakeholders. The exchange of information in the CA EPBD has proven to be very helpful for experts responsible for the implementation of the EPBD in MSs.

According to the national CA EPBD delegates, the major challenges for tightening minimum energy performance requirements centre around the cost-optimality of the energy performance requirements, especially when one takes into consideration the following points:

- the unknown future direction of energy prices;
- the performance of new technologies;
- the investment costs of these technologies; and
- primary energy factors (mainly for electricity, district heating and cooling).

A specific difficulty lies in the integration of RES in buildings within a dense urban context. The work of the CA EPBD has shown that countries differ greatly in the RES solutions that can be included in their energy performance calculations, and in which solutions can be used to fulfil foreseen direct NZEB RES requirements. For buildings containing multiple dwellings, specific arrangements are needed to distribute or assign locally-generated energy to different users.

The majority of countries have built pilot NZEB projects, often using public buildings as pioneering examples, in order to gain experience with suitable technologies, costs, reliability and user-acceptance that might prevent rebound effects. However, in order to kick-start the roll-out of NZEBs throughout the EU, a significant reduction is needed in the additional costs compared to standard building regulations, from a current level of about 11% to about 5%. This development would be supported by national and EU programmes for the development of cost-efficient NZEBs. Several Horizon 2020 projects are currently developing relevant solution sets. Future approaches should also include NZEB solutions for new and existing buildings on a district level.

Experts from various countries strongly suggest combining energy performance requirements with indoor comfort requirements, not only for NZEBs but also in general in the building legislation (for both new buildings and renovations). Several countries have integrated indoor comfort indicators into their energy performance assessment procedures and requirements. The work on similar approaches in other countries will be accelerated by the information exchange within the CA EPBD. This corresponds to the "Commission Recommendation on NZEB" which highlights that to avoid deterioration of indoor air quality, comfort and health conditions in the European building stock, the stepwise tightening of minimum energy performance requirements resulting from the implementation of NZEB across Europe should be done together with appropriate strategies dealing with indoor environment.

For the next decade, new ambitious building energy performance targets need to be set which go beyond minimising the energy use and aim, as is the case with plus-energy houses, at (over)compensating the remaining low energy needs with renewable energy (produced on-site or off-site). Together with the implementation of the national long-term renovation strategies, this will be necessary for a highly energy efficient and decarbonised building stock by 2050 and for achieving the EU energy and climate goals.

Endnotes

1. See Article 9 of the EPBD that requires MSs to ensure that (a) by 31 December 2020 all new buildings are nearly zero-energy buildings; and (b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.

2. See also Commission Recommendation (EU) 2016/1318 of July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings.

3. See endnote 2.

4. Erhorn-Kluttig, H.; Erhorn, H.: National Applications of the NZEB Definition – The complete Overview. Status February 2018. Factsheet of the Concerted Action EPBD, 2018.

5. I.e. without using the national grid as buffer; this may include a battery.

6. Hybrid solar photovoltaic thermal panels

7. Within the Horizon 2020 programme the EU is financing the following projects dealing with cost-efficient technologies and strategies for NZEBs:

    - ZERO-PLUS (GA no. 678407): Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology;
    - InDeWaG (GA no. 680441): Industrial Development of Water flow Glazing;
    - CHESS-SETUP (GA no. 680556): Combined HEat SyStem by using Solar Energy and heaT pUmPs;
    - CoNZEBs (GA no. 754046): Solution Sets for the Cost reduction of new Nearly Zero-Energy Buildings;
    - CRAVEzero (GA no. 741223): Cost Reduction and market Acceleration for Viable nearly zero-Energy buildings;
    - A-ZEB (GA no. 754174): Affordable Zero Energy Buildings;
    - NERO (GA no. 754177): Cost reduction of new Nearly Zero-Energy Wooden buildings in the Northern Climate Conditions.

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