Nearly Zero Energy Buildings (NZEB). Status of implementation and selected examples in Europe

With the adoption of the recast Energy Performance of Building Directive (EPBD) in 2010 (Directive 2010/31/EU), the building industry and the European Member States (MS) faced new tough challenges. One of the most prominent among them is the progress towards new and retrofitted Nearly Zero-Energy Buildings (NZEB) by 2021 (2019 in the case of public buildings)

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Article 9 of the recast EPBD requires that "Member States shall 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". Member States 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

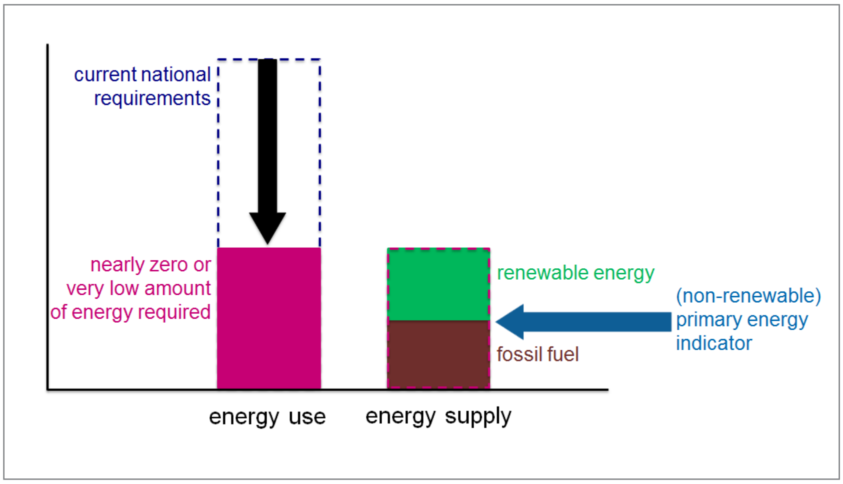

Fig. 1 Graphical interpretation of the NZEB definition according to Article 2 of the EPBD recast

the transformation of buildings that are refurbished into nearly zero-energy buildings".

A NZEB is defined in article 2 of the Directive 2010/31/EU as "a building that has a very high energy performance... . 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 presents the main elements of the NZEB definition of the EPBD, Directive 2010/31/EU Article 2.

The outcome of EU Concerted Action EPBD project

A major problem in the MS is the meeting point between the NZEB definition and the cost-optimal Energy Performance (EP) requirements. Several major parameters cannot be easily predicted for the coming 5 years. These parameters include future performances of new technologies and existing technologies that will be further improved in the next years, cost developments of technologies, future primary energy factors (mainly for electricity, as well as for district heating and cooling), due to changes in the infrastructure, cost developments of energy carriers, labour and planning, as well as boundaries like changing climate and lifestyle.

Figure 2 presents the planned timeline according to [1] for improving the energy performance requirements in the EU Member States, including the intermediate targets and the NZEB application according to Articles 2 and 9 of the EPBD.

According to the analysis within the EU Concerted Action (CA) EPBD project, which was reviewed by the national representatives of the participating countries, about 40% of the MS have not yet a detailed definition of the NZEB in place. Some of them state this clearly in their national plan for increasing the number of NZEBs. About 60% of the MS have fixed their detailed NZEB definition in a legal document, but a few of the documents include text passages that inform about the draft status of the definition or that the definition might be updated later on. The relevant legal documents are building regulations, energy decrees and official guidelines or the national NZEB plans.

The very high energy performance is expressed in at least 9 countries by requiring a top energy performance building class. Other countries give specific information about the ratio of the tightening of the (primary) energy requirement compared to the level of 2014 (in some cases of 2012). These tightening ratios are between 10-25% and 50-60%. Denmark states a tightening of even 75% but relates it to an earlier energy performance requirement (2006).

The very most countries (23 countries and one of the three Belgian regions) use a primary energy indicator in kWh/m²year either in their detailed NZEB definition or already in their current energy performance

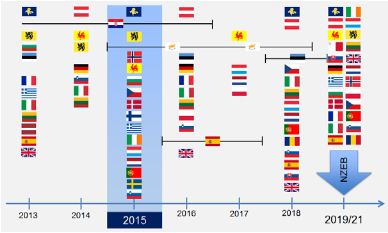

Fig. 2 Planned timeline for improving the energy performance requirements in the EU Member States, including the intermediate targets and the NZEB application according to Articles 2 and 9 of the EPBD recast [1]

requirements for new buildings. Two additional countries and the other two Belgian regions use either E-levels (a figure for the primary energy use divided by a reference primary energy use), or include the primary energy as calculation result, but not as indicator.

In most of the countries the limits for the nearly zero or very low amount of energy required are placed on more than primary energy only. The additional parameters include U-values of building envelope components, mean U-values of the building envelope, net and final energy for heating, cooling and possibly other energy uses and CO_2 emissions.

While about 1/3 of the countries have only indirect requirements for the "very significant extent of renewable energy", those with direct requirements set them mostly as energy share of the primary energy use. The required renewable energy share varies from > 0% to > 50%. A few other countries set specific minimum renewable energy contributions in kWh/m²year. 'Indirect'

By April 2015 about 60% of the Member States have fixed their detailed NZEB definition in a legal document. While many Member States require a renewable energy share of the primary energy or a minimum renewable energy contribution in kWh/m²year, others use indirect requirement such as a low non-renewable primary energy use that can only be met if renewable energy is part of the building concept.

Fig 3 Austria: Messequartier, Graz

requirements means that due to the low maximum value of primary energy use allowed for NZEBs the use of energy generated from renewable energy sources is implied.
The national applications of the NZEB definition need to show a clear direction, although the exact values might still have to be adjusted by the MS at a later stage, when costs and the other influencing factors become predictable with a higher degree of certainty. However, a clear indication of the tightening range (e.g., 30-50% better EP compared to the current requirements) is necessary for the building industry, investors and planners, in order to stimulate timely technology innovations and developments.

International examples of NZEBs

One of the most recently released publications of CA EPBD is the report "Selected examples of Nearly Zero-Energy Buildings" [2], which compiles 32 examples of buildings that implemented in EU the set (or envisaged) NZEB national requirements. The examples have been selected and provided by CA EPBD national delegates.
Pilot projects of nearly zero-energy buildings are built to show the public, as well as the involved industry and planners, that buildings of this kind are already possible, what they look like, what costs are implied, which technologies can be used and what are the user experiences. The examples, which are presented in the report in a structured way, have been contributed by the Member States delegates of 20 countries in total. They include residential and non-residential buildings, new buildings, as well as renovations to the NZEB level. In the following pages a few of the case studies are shortly described to show the rather different approaches.
This newly built housing complex is, with a net floor area of about 21.000 m², the largest of the collected NZEB examples. The multi-family house has been constructed with a thermal building envelope that meets Passive House requirements, including triple-glazed windows. The complex is heated by a district heating system, while the domestic hot water demand is mainly covered by a 700 m² solar thermal collector installed on the roof. Part of the energy concept is a mechanical ventilation system with 75% heat recovery. The total final energy use for heating, domestic hot water and ventilation amounts to 30.1 kWh/m²/year and includes 52% renewable energy contribution. The overall performance goes beyond the current Austrian energy performance requirements by 43%.
The architectural approach, with a variety of shared spaces including a swimming pool on the terrace, combined with the extensive infrastructure results in a very high residents' satisfaction level. The building costs were 57 million EUR for the entire estate which amounts to about 2,700 EUR/m², partly subsidised by the Styrian government.
The Bulgarian case study proves that very low energy consumption can be achieved with moderate renovation measures at the building envelope level (insulation of the walls to reach a U-value of 0.35 W/m²K, 10 cm mineral wool insulation between the ceiling and the unheated space under the roof to reach 0.26 W/m²K, and new double-glazed windows), combined with a comprehensive improvement of the building service systems. The heating and cooling of the research centre is now achieved

by an ambient-based variable refrigerant flow heat pump in connection with the ventilation. Hot water is provided by local electrical heaters and the building now also features a low-energy lighting system. The total final energy use includes heating, domestic hot water generation, cooling, ventilation, and lighting amounts to 48 kWh/m²/year. This is an improvement of 78% compared to the national requirements in Bulgaria. Sixty-three percent (63%) of the final energy is provided by renewable energy sources. The measures have required up to 38 EUR/m² for the renovated building envelope and 92 EUR/m² for the Heating, Ventilation and Air-Conditioning systems and 130 EUR/m² for the lighting. Total costs were 423,900 EUR (for 1,630 m²).

The Croatian NZEB example was a pilot project to specifically demonstrate that the national energy performance class A (foreseeing less than 15 kWh/m²/year for heating) can be met. It is a three-storey, multi-family house with 28 apartments. The walls have been insulated with 20 cm stone wool, the roof with 30 cm XPS and the windows are triple-glazed. Heating and cooling are provided by an underfloor system connected to a reversible heat pump and a gas boiler. A ventilation system with a high recuperation factor ensures good indoor air quality. The domestic hot water is generated by solar thermal collectors in combination with the gas boiler. The total final energy includes heating, domestic hot water, cooling, ventilation and lighting and amounts to 66 kWh/m²/year, which is 78% lower than the national building energy performance requirements. Twenty-two percent (22%) of the final energy is provided by the solar thermal collectors. The most impressive factor about this pilot project is that it was built without any additional costs compared to a regular building fulfilling the national requirements. The total costs amounted to 912 EUR/m². One area found lacking was the insufficient experience of the workforce concerning the application of new technologies, especially the mounting of the windows, which should meet a

Fig. 4 Sweden: single-family house in Vallda Heberg

quality control scheme used in Germany (RAL). Further information about the national status and possibilities of training the workforce can be found under BUILD UP Skills.
This Swedish example is one of many high performance single-family houses presented in the report, several of which aimed much further than the national NZEB requirements (plus energy or net zero energy), and thus also proved much more expensive (e.g., the German efficiency house plus in Berlin). The single-family house in Vallda is highlighted as one example where the additional costs, compared to a regular Swedish single-family house, are only 10% higher – with the total cost reaching 4,360,000 EUR or 2,450 EUR/m². It is a building in an area where all buildings have to aim for the Swedish passive house standard. The timber stud walls have been insulated with 29 cm mineral wool and 8 cm glass wool (U=0.11 W/m²K), while the roof includes 60 cm blowing wool (U=0.07 W/m²K) and the house has triple-glazed windows. There is a supply and exhaust ventilation system with a rotating heat exchanger and a heating element. The bathroom floor heating system is connected to the domestic hot water system. Both heating and domestic hot water are supplied by a local district heating system with 40% of the energy generated by solar thermal energy and 60% by a central wood pellet boiler. The measured total final energy use amounts to 56 kWh/m²/year and is 100% renewable. The improvement compared to the national energy performance requirements is 51%. The project shows a very good conformity with the calculated values at the planning stage and the residents are very satisfied with the indoor climate.
The Italian case study, a newly built house, has minimised energy needs due to a well-insulated building envelope. The remaining energy needs are covered by innovative and efficient systems and integrated renewable sources. The external walls are made of autoclaved aerated concrete blocks with external thermal insulation (EPS and cellulose fibre) so that they result in a U-value of 0.18 W/m²K. The ground slab is created with disposable formwork for ventilated underfloor cavities. The roof has a wooden structure and is insulated with wood fibre (U-value 0.18 W/m²K). The windows have triple glazing and wooden frames with aluminium-cladding on the outside. Thermal bridges have been minimised. The heating system is based on a gas-condensing boiler which can modulate between 5 and 25 kW and provides support to the domestic hot water as well. Radiant wall panels supply heat to the rooms. Four solar thermal collectors of 9.32 m² and a 500 litre storage contribute to the heating as well. A mechanical ventilation system with heat recovery ensures a good indoor air quality. PV panels with a peak power of 2.94 kWp are installed on the roof. The renewable energy covers 67% of the total final energy (heating, hot water and lighting). The improvement compared to a traditional new house is 80%. The CASACLIMA A classified house was built with about 25% higher costs than a traditional house.

Cross analysis of the applied strategies and technologies

Two-thirds (22) of the gathered buildings concern residential and 11 non-residential buildings, whereby 25 are newly built and 7 renovated to the NZEB level. Building sizes vary considerably between 98 m² and 21, 000 m². The construction types include brick, concrete and timber walls with U-Values between 0.065 and 1.97 W/m²K and an average of 0.29 W/m²K. Roof U-values are generally lower with 0.06 to 0.55 W/m²K and an average of 0.14 W/m²K. Twenty (20) buildings have low-e-coated, triple-glazed windows and 8 buildings, mostly located in Southern Europe, have double-glazed windows.
Forty-one percent (41%) of the examples are heated by heat pumps; other heat generators often used are gas boilers, district heating and biomass boilers. Only 32% of the buildings include cooling systems which often use activated building components. The domestic hot water system is nearly always combined with the space heating system, but four buildings use decentralised electrical domestic hot water generation. About 77% of the buildings use mechanical ventilation systems with heat recovery, and only 3 buildings rely solely on natural ventilation.
As regards the renewable energy sources, PV panels have been installed in 69% of the examples and solar thermal systems in 53% of the buildings. Geothermal energy contributes via heat pumps in 31% of the buildings, while six additional buildings use air-to-air heat pumps (ambient energy). The district heating systems that are connected to the buildings often show a high share of renewable energy and therefore low non-renewable primary energy factors.
Measured energy values are available for 8 of the 32 buildings; in the remaining cases, values have been

calculated usually with the national energy performance calculation method. Nine buildings achieve a positive annual primary energy balance, the so-called 'plus energy buildings'. For seven of them, this includes also the equipment, e.g. household energy, etc. The average renewable energy ratio related to the total final energy is as high as 70%, and the average improvement of the presented examples over the current national requirements is also very high at 74%.

Cost data has been difficult to compare as the buildings differ in the aimed energy levels, size, building type, and, most importantly, country of origin. For several buildings (in particular those that are privately owned) costs are not available; for others, costs are expressed in different ways, e.g. total costs, additional costs for achieving the high energy performance, total EUR, or percentages. The costs may also include different cost items. However, a first analysis of cost data, based on nine example buildings each, shows that the additional construction and technology costs for NZEBs compared to buildings fulfilling the national energy performance requirements are between 0% (0 EUR/m²) and 25% (473 EUR/m²), with an average of 11% (210 EUR/m²). Two-thirds of the buildings have received special funding to cover part of the planning, construction or monitoring costs.

Documented experiences with the buildings include high owner satisfaction, monitored energy use that meet the calculated predictions, advices on how to further increase the energy efficiency or comfort in the buildings, and experiences with certain building materials. Many of the buildings received architectural or energy efficiency awards. The CA EPBD report gives insights into all 32 inspiring examples and more details on the cross analysis.

Conclusions

The CA EPBD catalogue on selected examples of NZEBs shows that there are pilot projects for NZEBs and demonstration projects of even more ambitious energy performance levels in at least 20 Member States. Since most of them are residential buildings, it can be assumed that many countries started the with NZEB applications in the domestic sector but will continue with demonstrations buildings in non-residential buildings within the next years. The decrease in energy consumption compared to the current national energy performance requirements for buildings (74% in average) and the ratio of the renewable energy use (70% in average) is more than impressive. The used building envelope quality and applied building service technologies depend on the countries but some main approaches can be reported such as generally low U values at the roof (average is 0.14 W/m²K), in Central and Northern Europe mostly triple-glazing at the windows, heat generation by heat pumps, gas boilers or district heating systems with high ratios of renewable energy, ventilation systems with heat recovery and PV and solar thermal systems. Costs can be as low as zero additional Euro compared to a standard building and as an average amount to 10% additional costs.

In the upcoming years all countries will have fixed their national application of the NZEB definition and this will open the way for further pilot and demonstration buildings with different technical approaches and more experiences with costs and user satisfaction. An overview of the status of the national NZEB definitions will be soon published by CA EPBD as well as an update of the country reports on the EPBD implementation status.

REFERENCES

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