Working Definition of a Net Zero Energy Building (NetZEB) approach

Defined by

strategic research centre for
ZERO ENERGY BUILDINGS

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1. Working Definition of a Net Zero Energy Building (NetZEB) approach

Conceptually, a Net Zero Energy Building is a building with greatly reduced energy demand that allows the energy demand to be balanced by an equivalent generation of electricity (or other energy carriers) from renewable sources. A NZEB is connected to one or more energy infrastructures; electricity grid, district heating and cooling system, gas pipe network, biomass and biofuels distribution networks. When the generation is greater than the building's loads, excess electricity and heat is exported to the utility grid. In this way excess renewable energy production can offset fossil fuel energy use. The definition of NZEB is therefore intrinsically connected to the energy infrastructure, which the buildings are part of.

The NZEB is a complex concept and so is a NZEB definition applicable for all situations. The following main topics are considered in the present NZEB working definition, see table 1:

- Unit of balance
- Balancing period
- Type of energy use included
- Requirements on energy efficiency
- Renewable energy options
- Requirements on indoor climate
- Specific requirements for renovation

Table 1 also includes a suggestion for a pragmatic approach for implementation of the definition by 2020.

Table 1. Definition of a Net Zero Energy Building approach for Danish conditions

Main Topics	Pragmatic Approach 2020	NZEB Definition
In net zero energy buildings all energy use on a yearly basis is covered by energy from renewable sources		
Unit of balance	Primary energy factors (Average values based on technical and political decisions)	Primary energy factors (dynamic (time-dependent) primary energy factors based on technical and local values)
Energy use included	Building related: Heating, cooling, ventilation, DHW, lighting and other technical installations User related: Appliances Construction related: Energy use on construction site (only drying out)	Building related: Heating, cooling, ventilation, DHW, lighting and other technical installations User related: Appliances Construction related: LCA of energy embodied in building materials and installations and energy use for building construction, maintenance, renovation and demolition
Balancing period	Yearly (standard calculations, documented by measurements, construction site energy use to be written off in a fixed period)	Yearly (standard calculations based on a fixed period eg. 40 years, construction site energy use to be written off in a fixed period, documented by measurements)
Renewable energy options	On-site and building connected (grid connected renewable energy is included in primary energy factors)	On-site and building connected (grid connected renewable energy is included in primary energy factors)
Requirements on energy efficiency	New Buildings: Primary energy demand / building area (kWh/m2 year and divided into building, user and construction related use) Renovation: Cost optimized demand reduction on primary energy use before installation of renewable energy	New Buildings: Primary energy demand / building area (kWh/m2 year) Renovation: Cost optimized demand reduction on primary energy use before installation of renewable energy
Requirements on indoor climate	Indoor environmental quality (standard calculations and quality evaluations, documented by measurements) (note: Termisk komfort (sommer/vinter), luftkvalitet, akustik/støjdæmpning, lys)	Indoor environmental quality (standard calculations and quality evaluations, documented by measurements)

2. Introduction

The purpose of the Research Centre is through the development of new integrated low energy building solutions entirely based on extensive energy savings and renewable energy supply to meet the society's demands of 2020 and beyond for zero energy buildings. This is an attempt to develop a working definition for Danish ZEB, which can be used by the participants in the Research Centre to focus their research and their development of new technologies. Secondly, the working definition might also be used as basis for a discussion of a Danish ”Near Zero Energy Building” definition for future energy regulations in Denmark that fulfills the recast of the EU Directive on Energy Performance of Buildings.

Recast of EU Directive on Energy Performance of Buildings

At European level the EU Commission and Parliament have in their recast of the Directive on Energy Performance of Building put "Near Zero Energy Building" a the future target for buildings. The recast states:

- Members States shall ensure that:
  - by 31 December 2020, all new buildings are nearly zero energy buildings as defined in Article 2(1a), and
  - after 31 December 2018, public authorities that occupy and own a new building shall ensure that the building is a nearly zero energy building as defined in Article 2(1a).
- Member States shall draw up national plans for increasing the number of nearly zero energy buildings. These national plans may include targets differentiated according to the category of building.
- Member States shall furthermore, following the leading example of the public sector, develop policies and take measures such as targets in order to stimulate the transformation of buildings that are refurbished into nearly zero energy buildings, and inform the Commission thereof in their national plans referred to in paragraph 1.
- The national plan referred to in paragraph 1 shall include inter alia the following elements:
  - the Member State's detailed application in practice of the definition of nearly zero energy buildings, reflecting their national, regional or local conditions, and including a numeric indicator of primary energy use expressed in kWh/m2 per year. Primary energy factors used for the determination of the primary energy use may be based on national or regional yearly average values and may take into account relevant European standards;
  - Member States may decide not to apply the requirements set out in (a) and (b) of paragraph 1 in specific and justifiable cases where the cost-benefit analysis over the economic lifecycle of the building in question is

negative. Member States shall inform the Commission of the principles of the relevant legislative regimes.

- For the purpose of this Directive, the following definitions shall apply:
  - "building": means a roofed construction having walls, for which energy is used to condition the indoor climate; a building may refer to the building as a whole or parts thereof that have been designed or altered to be used seperately;
  - "nearly zero energy building" means a building that has a very high energy performance, determined in accordance with Annex I. The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby;
  - "energy performance of a building": means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes inter alia energy used for heating, hot water, cooling, ventilation and lighting;
  - "primary energy": means energy from renewable and non-renewable sources which has not undergone any conversion or transformation process;
  - "energy from renewable sources" means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;

International Research on Zero Energy Buildings

International research on zero energy buildings is carried out in a project of the International Energy Agency (IEA) under the joint Solar Heating and Cooling programme (SHC) Task 40 and the Energy Conservation in Buildings and Community Services programme (ECBCS) Annex 52: “Towards Net Zero Energy Solar Buildings”. In this project the various definitions found in literature are revised, state of the art examples of zero or close to zero energy buildings are collected into a database, and a thorough analysis of a possible set of definitions is in progress. The ZEB definition in this discussion paper reflects this work.

3. Description of considered topics in NZEB working definition

Unit of Balance

Probably the most important for a NZEB definition is the issue of the unit of balance on which it should be based: final energy; primary energy; exergy; energy costs or maybe CO_2 emission?

The most obvious way to account for the energy demand and generation of a building would be to base it on the energy units itself. Such a balance would then look differently depending on where the energy is measured in the energy chain, i.e. delivered or primary energy. The delivered energy is the easiest unit to implement and understand, but has a major drawback, as the quality of the different kinds of energy is fully neglected. Delivered energy is therefore only useful, if the building is an all electric building. For calculating the energy use of a building, the most commonly used unit is the primary energy. This unit allows taking into consideration the difference in the generation and distribution of 1 kW of electricity and 1kW of heat or natural gas and thus express better the actual building energy use. The balance could also be given on the basis of **carbon equivalent emissions**. This implies the adoption of a ZEB definition based on primary energy, where the correspondence between energy and emissions can be calculated.

Other options could be to give credits on the basis of energy costs, or on exergy. The former option is likely to be a very unstable and imprecise definition due to energy price volatility and economic externalities; while the latter may be difficult to understand for anybody not acquainted with such a physical property as exergy, and it is even debatable whether exergy would actually be a good proxy of environmental performance of buildings.

Secondly, it is necessary to address the methodology to use. First of all it should be considered that the energy infrastructure will change, possibly even drastically, in the future. Especially with regard to electricity, the way it is produced and exchanged throughout Europe is going to be substantially different in the coming decades than how it is today. It may be useful to couple the definition of NZEB with the evolution of the future energy infrastructures of which the buildings are going to be an integral part. This evolution has to be captured in the definition to avoid a situation, where a building is designed and constructed to be a NZEB today, but it is no longer such after some years because electricity from the grid has got a higher share of RES in the generation mix, or lower GHG emissions due to nuclear and CCS technology, hence if based on the primary energy factor in the grid, the credits received by the building for its own electricity generation will be lower. An alternative approach could be to focus on the offset of fossil fuels and base the received credits for building renewable energy production on the primary energy factors for the fraction of energy produced by fossil fuels that has been offset. In this way the demand for building integrated renewable energy systems would be smaller for buildings connected to an energy production grid with a high share of renewable energy as well as the demand will decrease in time if the share of renewable energy in the grid increases. In either cases the evaluation of the credits needs to be continuously updated.

An option is to consider a **yearly static** evaluation method, in which the crediting values correspond to yearly averages of electricity (or heat) generation and are updated regularly (i.e. every, every second or every 5 years). However, the electricity (and heat) generation mix does vary both with the time of the year and the hours of the day, according to load levels (base or peak generation technology), availability of intermittent RES at local and regional level, storage capacity and trans-national power transmission. The opposite of a yearly static method is a **fully dynamic** evaluation method, based on hour-by-hour evaluation of the credits e.g. from the hourly clearing of the electricity market. This option is more meaningful because it would reflect nearly real time, what is the actual impact of the electricity consumption by the building. It is also more difficult to perform, yet possible because it is already standard procedure for the electricity market to operate on hourly prices, hence knowing hour-by-hour what the generation mix and technology are like.

A pragmatic and intermediate solution could be a **static weighted** evaluation method where average values are considered for a year (or a month or a season) but there is also an hour-of-the-day classification into different levels, i.e. corresponding to average load levels (from base to peak load) and/or average share of RES and/or average GHG emissions in the grid electricity generation mix. It shall be noticed that some of the energy carriers, i.e. electricity, should be evaluated at European level, while others like gas, biomass, biofuels and district heating/cooling should be evaluated considering the regional and local infrastructure.

Type of Energy Use

Another important issue to consider is the type of energy use to include in the balance. All energy use in the lifetime of the building includes the following types:

- Building related: Heating, cooling, ventilation, DHW, lighting, pumps and fans and other technical service systems
- User related: cooking, appliances, ligting
- Construction related: Energy use embodied in building materials and installations and energy use for building construction, maintenance, renovation and demolition

Today, energy requirements for buildings only include the building related energy use, but with the energy efficiency improvements and the tight energy requirements for the future this will only cover a minor part of the total energy use in buildings. User related energy use will be at the same level or higher than the building related energy use. To ensure a balanced approach with focus on the most important and cost effective solutions for energy reductions in buildings it is necessary to include all types of energy use in a NZEB definition.

A pragmatic and intermediate solution, until a common framework for calculation of embodied energy in building materials and installations is established, could only include building related energy use, user related energy use and energy use on the construction site (mainly for drying out the construction) in the building energy balance.

The long term goal must be to include embodied energy in the full life cycle of the building (cradle to cradle).

Balancing Period

The definition could focus just on the yearly balance of emissions related to the energy demand and energy generation during the normal operation of the building, considering only its **operating lifetime**. As an alternative the definition could consider the entire **life cycle** of the building, including also the emissions embodied in materials and technical installations, in the construction and demolition phases and eventually considering also waste management options (i.e. recycling).

This means that the yearly balance includes the yearly renewable energy production, the yearly operating energy use and a relative share of the embodied energy in building materials and installations and energy use for building construction, maintenance, renovation and demolition

Linked to the above discussion on the choice of crediting values, a **sub-yearly** period could be chosen, i.e. monthly or seasonal as an alternative. In the latter case one would avoid great disparity between, let's say, winter demand and summer generation and would capture variable availability of renewable energy. Another option would be to perform the balance over a period of several years to take into account the evolution of the future energy infrastructure.

A pragmatic and intermediate solution, until a common framework for calculation of embodied energy in building materials and installations is established is to only include the yearly renewable energy production, the yearly operating energy use and a relative share (for example 1/40) of the energy use for construction in the balance.

It is well known that prediction of future energy use in a building is very uncertain, especially due to the difficulties with regard to taking user behaviour into account properly. It is also well known that a new building needs a commissioning period before all systems work as intended. Therefore, it cannot be expected that all net zero energy buildings will reach the zero energy balance within the first year(s) of operation and time for commissioning and adaptation to actual performance should be allowed.

On the other hand it is important that an actual net zero energy balance is reached and it is therefore required in the definition that the energy balance is documented by measurements and actions are taken if a balance is not reached on a yearly basis.

Renewable Energy Options

A NZEB typically uses traditional energy sources such as the electric and natural gas utilities when on-site generation does not meet the loads. When the on-site generation is greater than the building's loads, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use.

In a NZEB definition it is necessary to define the supply-side of the renewable energy sources. By renewable energy sources can for example be understood: solar thermal, solar photovoltaic (PV), biomass and wind or wave energy. In principle two options consist for renewable energy supply: on-site supply and/or off-site supply. For the on-site supply it is often distinguished between supply within the building footprint and supply within the building site. For the off-site supply the building either uses renewable energy sources available off-site to produce energy on-site, or purchase off-site renewable energy sources.

The goal for the future is to increase the share of renewable energy in the energy system and in time fully offset the use of fossil fuels. The renewable energy sources can either be integrated in the building or in the energy production system and it is important that a definition encourages the most cost effective solution and continues development of renewable energy systems.

Renewable energy supply to the building is in the working definition, as it is in the present energy regulation, limited to supply from renewable energy sources available on the building site or directly connected to the building, e.g. a group of houses sharing a central solar heating system and the grid connected renewable energy sources is included in the primary energy factors for the grid. This definition works very well for buildings outside the district heating grid, while it might need modification in areas with district heating based on renewable energy.

Requirements for energy efficiency

In principle a net zero energy building can be a traditional building, which is supplied with very large solar collector and solar photo voltage systems. If these systems deliver more energy over a year than the use in the building it is a net zero energy building. On the other hand in order to be able to meet future needs for energy efficiency improvements (an average 50 % decrease in energy use in all buildings), new buildings must improve their energy efficiency considerably and relatively much more than the existing building stock.

In the analysis of many of the existing NZEB approaches a very similar path to achieve NZEB can be noticed. Firstly, the approach includes a reduction of energy demand using energy efficient technologies and secondly it includes utilization of renewable energy sources to supply the remaining energy demand. Energy efficiency is usually available for the life of the building; however, efficiency measures must have good persistence and should be “checked” to make sure they continue to save energy. It is almost always easier to save energy than to produce energy and the above strategy is the most logical approach to reach NZEB. In order to ensure that net zero energy buildings also are very energy efficient buildings a definition of a fixed value of maximum allowed primary energy demand / building area (kWh/m2 year) could be a good solution in combination with energy efficiency requirements for specific components and technologies. This requirement could include separate requirements for building related, user related and construction related energy use.

In building renovation the optimum economic relation between implementation of energy efficiency measures and renewable energy sources will be different than for new construction. Therefore cost optimized values for maximum allowed primary energy use could be considered for renovated buildings, while the energy efficiency requirements for specific components and technologies could remain the same. Specific requirements could also be set for buildings with architectural and/or historic value.

Requirements for Building Effectiveness and Indoor Climate

The term building effectiveness means the ability of the building to perform its task in an effective way. For example is the task of an office building to create suitable working conditions for a number of employees in an organization. So the density of occupants or the relation between indoor climate and productivity could be measures of effectiveness. This should also be taken into consideration, when the building energy efficiency is evaluated.

The topic of indoor environmental quality is almost fully neglected in the net zero energy building definitions, though it is an important issue. On the one hand, it would be very beneficial from general point of view, that all NZEB would use the same values. It would be much easier to evaluate and compare NZEBs from different location worldwide. On the other hand, giving so detailed criteria in the NZEB definition could significantly limit its usefulness in many cases. Since, different values can be used depending on building type, country, applied standard and local climate conditions.

In the definition of zero energy buildings it could be considered to include (minimum) requirements to occupancy density as well as guidance or suggestions to which minimum indoor environmental quality (temperature, IAQ, light, noise attenuation and acoustics) standards should be used. As with the energy balance of the building it is also very important to require that the indoor environmental quality is documented in the design phase by standard calculations and quality evaluations and in the operation phase is documented by measurements.

4. Supporting Conditions

The Net Zero Energy Building performance and wide scale acceptance as a future building concepts depends on its interaction with the community and the common energy supply grids. Table 2 illustrates the important considerations and requirements needed in this respect.

Table 2. Additional considerations and requirements for Danish conditions

ZEB Definition	Pragmatic 2020	Definition
Required preparations for ZEB? communities	Prepare grid for building interaction for both electricity and heat Strategic planning to ensure solar availability for NZEB buildings in urban developments	Prepare grid for building interaction for both electricity and heat Strategic planning to ensure solar availability for NZEB buildings in urban developments
Building/grid interaction	Possible to export more than consumed of both electricity and heat	Possible to export more than consumed of both electricity and heat
Primary Energy factors	Definition of average primary energy factors for different energy carriers and load conditions	Dynamic (time-dependent) primary energy factors based on technical and local values should be made available

A net zero energy building is connected to one or more energy infrastructures. Among these infrastructures a net zero energy building interacts with the electricity grid and the district heating and cooling system as the building both import and export electricity and heat. Even if the building may have a net zero energy input on an annual basis it can at the same time exchange huge amounts of electricity with the public grid. In order to exploit this interaction in an optimum way the energy supply grids must be prepared to utilize and benefit from this interaction.

The difference between demand and production on the individual building and the consequently interaction with the energy grid(s) has to be considered and dealt with. How much should be done to compensate for this within the building itself and how much should be left to the aggregated level to solve? Initial investigations show that it should mainly be dealt with at the aggregated level, but also that it on the short term is a limited problem. However, this might change in the future as the energy supply system changes and needs to be investigated further.

In relation to NZEB design measures of “flexible demand” should be carried out at the building level, but the aim should not be to level out the difference between production and demand of the individual building in question. Instead, flexible demand should aim at controlling the interaction with the grid according to the energy availability in the grid, i.e. increase the building demand when renewable energy production in the grid is high and decrease the demand when it is not the case.

Another issue that needs consideration in future planning of the urban environment is the availability of solar radiation for NZEB buildings. This is crucial for the performance both with regard to energy conservation (passive solar heating and dayligthing) and renewable energy production (solar thermal and PV).