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Criteria for Definition of Net Zero Energy Buildings

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Abstract

The idea of a Net Zero Energy Building (Net ZEB) is understood conceptually, as it is understood that the way a Net ZEB is defined affects significantly the way it is designed in order to achieve the goal. However, little agreement exists on a common definition; the term is used commercially without a clear understanding and countries are enacting policies and national targets based on the concept without a clear definition in place. This paper presents a harmonised framework for describing the relevant characteristics of Net ZEBs in a series of criteria. Evaluation of the criteria and selection of the related options becomes a methodology for elaborating sound Net ZEB definitions in a formal, systematic and comprehensive way, creating the basis for legislations and action plans to effectively achieve the political targets. The common denominator for the different possible Net ZEB definitions in the harmonised framework is the balance between delivered and feed-in energy and associated credits. Additionally, other indicators than the mere balance over a period of time may be given in order to add qualified information on the overall "goodness of design" of a Net ZEB. Finally, the monitoring procedure is considered as an integral part of the definition.

1. Introduction

The topic of Zero Energy Buildings (ZEBs) has received increasing attention in recent years, until becoming part of both EU and US policies on energy efficiency in buildings. In the recast of the EU Directive on Energy Performance of Buildings (EPBD) it is specified that by the end of 2020 all new buildings shall be "nearly zero energy buildings" [1]. For the Building Technologies Program of the US Department Of Energy (DOE), the strategic goal is to achieve "*marketable zero energy homes in 2020 and commercial zero energy buildings in 2025"* [2]. However, despite the emphasis on the goals the definitions remains generic and are not yet standardised. The EPBD, for example, states that "nearly zero energy building means a building that has a very high energy performance" and that "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".

In general, there is a plurality of approaches in defining what a ZEB is. Relevant work can be found in literature on the survey and comparison of case studies and existing and proposed definitions [3 – 7]. It emerges from these analyses that little agreement exists on a common definition that is based on scientific analysis. Recurrent issues concern the metric (i.e. primary energy, carbon emissions, etc.)

and the items to be considered in the balance (i.e. energy use in the operation of a building, energy embodied in materials and technical installations, etc.) . In turn, the different definitions end up suggesting different optimal design strategies, influencing the choices on insulation levels, HVAC system performance, PV or cogeneration system dimensioning, etc.

The term ZEB is used commercially without a clear understanding and countries are enacting policies and national targets based on the concept without a clear definition in place. Commercial definitions may be partial or biased in their scope, for example including only some loads in the balance, or allowing for energy inefficient buildings to achieve the status of ZEB thanks to oversized PV systems, but without applying any energy saving measure. For these reasons such definitions are not suitable as a basis for regulations and national policies. Furthermore, in order to be environmentally friendly in a broader view ZEBs should be designed – to the extent that is in the control of the designers – in a way that do not put additional stress on the energy supply grids.

Indeed, the focus of this paper is on buildings that are connected to an energy infrastructure, i.e. electricity grid, district heating and cooling system, gas pipe network, biomass and biofuels distribution networks, and not on autonomous buildings. To this respect the term *Net ZEB* can be used to refer to buildings that are connected to the energy infrastructure, while the term ZEB is more general and may include as well autonomous buildings. The wording 'Net' underlines the fact that there is a balance between energy taken from and supplied back to the energy grids over a period of time, nominally a year. Net ZEBs are the focus of this paper.

The work done so far in the IEA Task40/Annex 52 [8], including the comparison of calculation methodologies adopted or suggested by the participating institutes in their home countries [9], has confirmed that the idea of Net ZEB is understood conceptually. Conceptually, it is understood that a Net ZEB is a building with greatly reduced energy demand that can be balanced by an equivalent on-site generation of electricity, or other energy carriers, from renewable sources. It is also understood that the definition may affect significantly the way buildings are designed to achieve the goal. What is missing is a formal, comprehensive framework that considers all the relevant aspects characterising a Net ZEB definition. This paper builds upon concepts found literature and expands the analysis identifying a series of criteria that characterise a sound Net ZEB definition.

2. Terminology and balance concept

The term *criterion* is here meant as a standard or a test by which to evaluate, decide about or deal with something. The word *requirement*, instead, refers to a condition that must be satisfied. The criteria presented later describe significant aspects or characteristics of Net ZEBs that would eventually affect how the building is designed to achieve the given definition. Within each criterion different choices or options are available; some of them may be to comply with specific requirements.

The sketch shown in Fig. 1 gives an overview of relevant terminology addressing the energy use in buildings and the connection between buildings and energy grids. The sketch is not an energy balance graph.

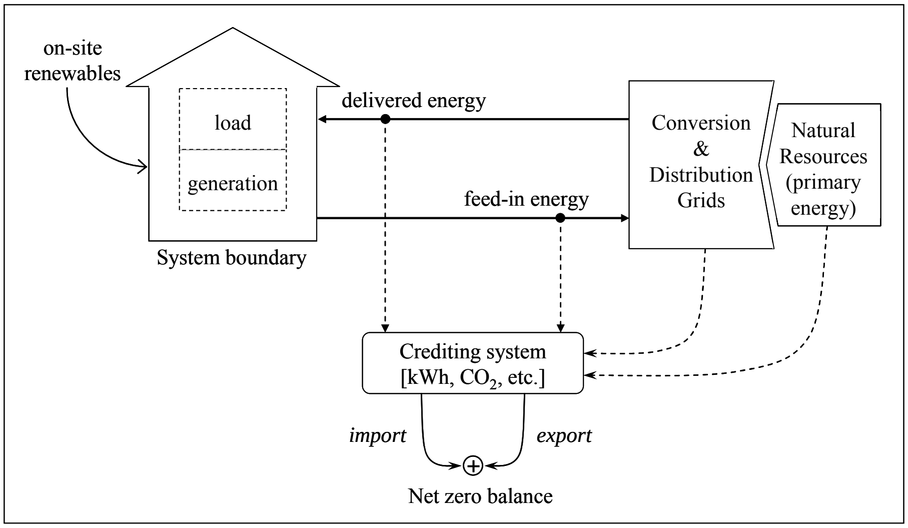

Fig. 1. Connection between buildings and energy grids.

A building or a cluster of buildings, depending on where the *system boundary* is put, is characterised by a certain load, but also by some sort of energy generation in case of Net ZEB. The *load* includes the efficiency of technical installations, not only the net energy demand. The *generation*, likewise, includes storage and conversion losses. A building is assumed to be in steady state over a year – no net accumulation of energy within the system boundary – regardless of the balance between load and generation. Renewable energy sources available on-site are used passively (e.g. solar gains through windows) and actively (e.g. atmospheric or ground source heat pump) to partially satisfy the building's load. These *on-site renewables* are also used to generate energy carriers (e.g. electricity) that in part cover the load and in part are fed back into the grid, depending on the temporal matching between generation and load and the available storage possibilities.

These various supply systems to which a building may be connected are named with the generalised term of energy grids, or simply *grids*. Buildings and grids exchange energy in the form of energy carriers that have been converted from natural resources. The convention is to name *delivered energy* the energy supplied by the grids to the buildings; while the energy flowing from the buildings to the grids is named *feed-in energy*.

The concept of balance between delivered and feed-in energy, together with any form of interaction with the grids, is central in the definition of Net ZEBs. However, these two quantities are normally not evaluated directly in their physical units but by means of some crediting system. A *crediting system* converts the physical units into other metrics, e.g. primary energy or equivalent carbon emission, in order to evaluate the effect of the entire energy chain, including the properties of the natural sources, the conversion processes and the distribution grids. Other metrics than those mentioned are also possible, as discussed later. Hence, the *import* and *export* shown in Fig. 1 can be expressed as follows:

$$import = \sum_i \text{delivered\_energy}(i) \times \text{credits}(i) \tag{1}$$

$$export = \sum_i \text{feed-in\_energy}(i) \times \text{credits}(i), \qquad \text{where } i = \text{energy carriers} \tag{2}$$

For a Net ZEB the balance between import and export over a period of time must be zero, or even positive, i.e. in case also embodied energy or embodied emissions in materials have to be balanced off. The following balance inequality is then a minimum requirement for a Net ZEB:

$$\text{Net ZEB:} \qquad |\,export\,| \; - \; |\,import\,| \; \geq \; 0 \tag{3}$$

The balance can be represented graphically as in Fig. 2, plotting the import (delivered energy) on the *x*-axis and the export (feed-in energy) on the *y*-axis.

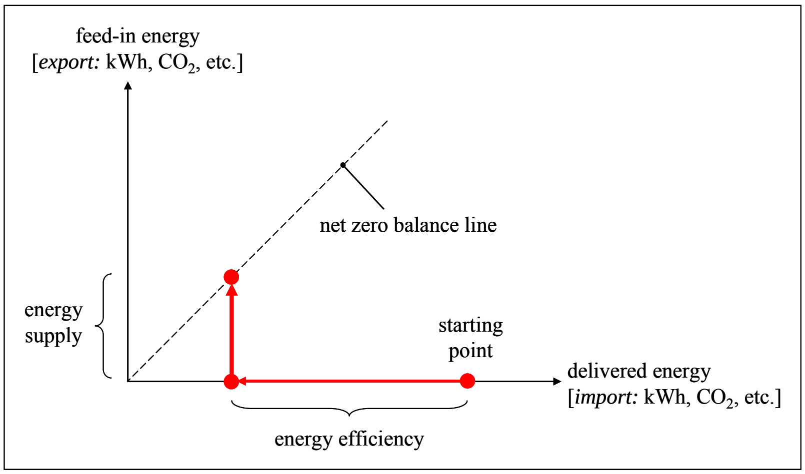

Fig. 2. Graph representing the net zero balance of a Net ZEB.

The starting point may represent the performance of a new building built according to the minimum requirements of the building code or the performance of an existing building prior to renovation work. The general pathway to achieve a Net ZEB consists of two steps: first, reduce energy demand (*x*-axis) by means of energy efficiency measures. Second, generate electricity, or other energy carriers, by means of energy supply options to get enough credits (*y*-axis) to achieve the balance.

3. Criteria for Net ZEB definitions

The balance of Eq. (3) represents the core of a Net ZEB definition. However, for it to be meaningful and of practical use a number of aspects have to be evaluated and some explicit choice made, e.g. the metrics adopted for crediting. Furthermore, other indicators than the mere balance over a period of time may be desirable to add qualified information on the overall "goodness of design" of a Net ZEB.

These issues are described and analysed in a series of criteria. For each criterion different options are available on how to deal with that specific characteristic. The criteria and the respective options have emerged from literature review and the personal experience of the participants in the IEA Task40/Annex52 [8], and have come into the form presented here after thorough analysis and discussions within the same Task/Annex.

The aim is to create a harmonised framework for describing the relevant characteristics of Net ZEBs, recognising that different definitions are possible, depending on the preferred options. Therefore the Net ZEB definition can be tailored to be consistent with the purposes or the political targets that lay behind the promotion of Net ZEBs. However, evaluation of the criteria and selection of the related options becomes a methodology for elaborating sound Net ZEB definitions in a formal, systematic and comprehensive way. The authors' auspice is that this will create the basis for legislations and action plans to effectively achieve the political targets.

The criteria are:

1 Boundary conditions *(what is behind the net zero balance?)*

1.1 System boundary

Is the boundary on a single building or on a group of buildings? In the latter case a local district heating system would be internalised within the boundary, with the consequence to internalise also its efficiency and the actual mix of fuels used.

Which energy grids are two-ways, only electricity or others too, e.g. district heating/cooling system or (in future) hydrogen grid?

1.2 Functionality and effectiveness

What type of building is it: detached house, apartment, office, school, etc.? and what is the energy/person used? What is the effectiveness of the building in terms of people/m^2? This information is useful for comparison with other similar buildings, but also for checking monitored vs. design data because higher/lower people density causes different energy demand.

1.3 Climate and Comfort

What is the reference climate? What comfort standards have been followed to calculate the load? This information is useful for comparison with other similar buildings, but also for checking monitored vs. design data because hotter/colder years and different user behaviour cause different energy demand.

2 Crediting system *(what is in the axes of the balance graph?)*

2.1 Credit metrics

What metrics is used? As mentioned, this is a major characteristic where Net ZEB definitions can differentiate. In [3] four types of metrics are considered: site energy (final energy), source energy (primary energy), energy cost and energy emissions, discussing advantages and disadvantages of each choice and showing, for example, how the choice would affect the required PV installed capacity. Other possible metrics are exergy, see [10], environmental credits or even politically decided factors. For an analysis of the details and the implications for design of each choice reference is made to the mentioned literature [3 – 7, 10].

2.2 Credit accounting

How are the credits accounted for? Due to the complexity of the energy infrastructure, it is often feasible to estimate the credits only as average values for a period of time and this would be a static accounting. At least, this is the case for primary energy and carbon emission factors. On the other end, energy prices can be available on hourly basis, therefore leading to a fully dynamic accounting. As an intermediate option a semi-dynamic accounting would have seasonal/monthly average values and/or daily bands for base/peak load. Dynamic and semi-dynamic accounting, where possible, would help the design of buildings that optimise their interaction with the grid.

In the evaluation of electricity, and perhaps also district heating, credits it is also important to distinguish between average and marginal production and specify which choice is made.

Credits will vary over time and space. Certain energy carriers, e.g electricity, may be evaluated for a large regions; e.g. the EU, considering that the EU electricity grid and market will eventually become fully integrated. Other energy carriers, e.g. district heating or biomass, may be credited according to the national or local context, according to the actual availability of resources in the area. In any case the evaluation of credits should be updated at regular intervals to reflect the development of the grids. To this respect it is possible to consider different forecast scenarios on the evolution of credit values.

3 Net Zero Balance

3.1 Items of the balance

This is another critical point for a Net ZEB definition. What loads are included in the balance? Only loads typically considered related to the building, i.e. heating, cooling, ventilation and auxiliary energy or also loads typically considered related to the user, i.e. domestic hot water, lighting, cooking, plug loads, etc.? National and commercial standards on energy performance may consider different combinations of the above mentioned loads and the user load may be standardised in different ways.

Are other energy services that would have a positive environmental impact included in the balance, as for example treatment of rain water or charging of electric vehicles? Electric vehicles are not a building related load but charging their batteries may be used as a way to reduce the interaction with the grid.

Is the embodied energy in materials and technical installations included? Or is a complete Life Cycle Assessment (LCA) analysis performed, including construction and demolition phases, waste treatment and recycling options? Moving towards more energy efficient and energy producing buildings increases the demand for materials and technical installations, including materials whose manufacturing is energy intensive. Consequently, the importance of embodied energy increases and including it into the balance broadens the scope of Net ZEBs as environmental friendly and sustainable buildings.

3.2 Balancing period

What is the basis for calculating the balance? The most common and often implicit choice is the yearly balance. Another choice is a balance upon many years, e.g. a reference period of 30-50 years after which the building is likely to undergo major renovation works and significantly change its characteristics. An analysis over a long period would allow simulating the building performance with stochastic input data on climate, user behaviour and evolution of credit values.

Alternatively, a seasonal or monthly balance could also be considered; of course this would have significant consequences on the optimal balance between energy efficiency measures and energy supply options.

3.3 Energy efficiency *(what measures are used to decrease the energy demand?)*

Are there mandatory minimum requirements on energy efficiency? Set by national or commercial standards, such as EPBD labels A or B, Energy Star, low energy, passive house? Or cost-optimal energy performance levels calculated on the economic life-cycle, as proposed by the EPBD recast [1]? Or with reference to similar conventional buildings (or pre-renovation conditions), such as < 50%? See [11] for an analysis of recommended energy performance for Net ZEB in different climates.

Note that if the metric is on non-renewable energy use, i.e. the non-renewable part of primary energy, then using biomass/biofuels or purchasing green electricity may be virtually seen as equivalent to energy efficiency measures (the effect is to move down along the *x*-axis in the balance graph).

3.4 Energy supply *(what options are used to get enough credits for the balance?)*

Is there an explicit hierarchy of supply options? In [3] a hierarchy of supply options is proposed as the pathway for design of Net ZEB, where on-site supply options, e.g. PV and on-site wind, are prioritised over off-site supply options, e.g. import of biofuel for cogeneration or purchase of green electricity. This is meant to add an additional indication to the mere balance, similarly to what is the intent of the temporal energy match indices (see below).

Is electricity from gas fuelled cogeneration and fuel cells also credited? Such electricity is not generated from renewable sources, but in areas with poor performance of the grid (high share of fossil fuels and high carbon emission in the generation mix) it may be reasonable to reward technologies that make a very efficient use of natural gas, especially if the gas grid is already in place.

Is it possible to resource to "soft options", as purchase of green electricity or investments in green projects or funds? For example, the new definition of zero carbon home in the UK forces new houses to reduce their carbon emissions by at least 70% (compared to 2006 regulation), but allows house builders to mitigate the rest with investment (through a national investment fund) in low- and zero-carbon energy projects off-site in order to abate costs [12]. Stretching the concept of soft options to its extreme, also trading of carbon emission or green certificates may become an option, but this is not regarded as consistent because completely independent from the characteristics of the building.

Because of the possibility to resource to soft options (at least to a certain extent) it is more correct to talk about "supply options" rather than energy generation, which would have a stricter meaning.

4 Temporal energy match *(what is beyond the balance?)*

As grid connected buildings are investigated, it is useful to define some indicators which can evaluate the impact on the energy carrier exchange between the building and the energy infrastructures. The mere satisfaction of a balance over a period of time (such as a year) is not in itself a guarantee that the building is designed in a way that minimises its environmental impact. In particular, Net ZEBs should be designed to work in synergy with the grids and not to put additional stress on their functioning, namely the power grid. Quantitative indicators are proposed and analysed in [13].

5 Monitoring procedure

Is the definition based only on design data and simulations or a monitoring procedure is mandatory to check the effective balance? The meters displaced should allow to measure the effective balance, the temporal match indices and preferably also the actual separate loads, e.g. heating, cooling, plug loads etc. The monitoring procedure should also check the comfort to avoid that a Net ZEB is mistaken for a not consuming building due to a low fulfillment of comfort requirements. Furthermore, it should be possible to assess if deviations from calculated performance are due to technical operational problems or different characteristics than assumed, or if the deviation are due to different comfort, climate, functionality or effectiveness than designed for (see point 1.2). Due to stochastic variation in the climate, occupancy, etc. there should be tolerance limits within which the building can be said to satisfy the Net ZEB definition.

5. Conclusions

The term Net ZEB refers to buildings that are connected to the energy infrastructure. While the concept of Net ZEBs is understood, an internationally agreed definition is still lacking. It is recognised that different definitions are possible, in order to be consistent with the purposes and political targets that lay behind the promotion of Net ZEBs. A harmonised framework for describing the relevant characteristics of Net ZEBs in a series of criteria has been presented. For each criterion different options are available on how to deal with that specific characteristic. Evaluation of the criteria and selection of the related options becomes a methodology for elaborating sound Net ZEB definitions in a formal, systematic and comprehensive way. This can create the basis for legislations and action plans to effectively achieve the political targets.

The common denominator for the different possible Net ZEB definitions in the harmonised framework is the balance between delivered and feed-in energy and associated credits. The general pathway to achieve a Net ZEB consists of two steps: first, reduce energy demand by means of energy efficiency measures. Second, generate electricity, or other energy carriers, by means of energy supply options to get enough credits to achieve the balance.

Additionally, other indicators than the mere balance over a period of time may be desirable, in order to add qualified information on the overall "goodness of design" of a Net ZEB. In existing literature an example of such additional information is given by a hierarchy of supply options. In the work of the IEA Task40/Annex 52 this qualified information is added by means of temporal energy match indices. Finally, the monitoring procedure is viewed as an integral part of the definition.

6. Acknowledgements

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