A review of definitions of Zero Energy Buildings

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Abstract
Zero energy buildings (ZEB) are regarded as an integrated solution of problems of energy saving, environmental protection, and CO_2 emission reduction in the building section. ZEB could be even possible with electricity production if enough renewable energy could be used. Moreover, various building-service systems with renewable energy sources have been widely considered for potential applications in ZEB. All of these new features extend the technical boundary of the conventional energy-efficient buildings, attach a more profound implication to the sustainable development of building technology, and therefore pose a challenge to evaluation works on ZEB performance.
The paper presents a review of ZEB definitions. It outlines discrepancies between different definitions and issues to be solved in order to develop a consistent and robust ZEB definition, which can facilitate the development of the energy calculation procedure.
The approaches concerning the units applied in ZEB definitions, the period of time over which the building calculation is performed, types of energy used, types of energy balances as well as renewable supply options are considered.
Key words: ZERO ENERGY BUILDING, NET ZERO ENERGY BUILDING, DELIVERED ENERGY, EXPORTED ENERGY, ENERGY BALANCE

Introduction

Commercial and residential buildings consume about one-third of world's energy. Owing to the energy crisis, increased emissions of wastes and the depletion of fossil fuels, research and development in building technologies and integrated processes have attained greater and renewed interest among stakeholders worldwide.

In order to reduce the dependence of the buildings on the primary energy, a number of studies on energy-saving technologies have been carried out worldwide. On the other hand, renewable energy utilization was regarded as reasonable solutions to global warming, air pollution, and energy security. Through integrating the technologies of energy-efficient and renewable energy utilization in building, zero energy buildings (ZEB), which are an innovative concept for high-performance building, are suggested. Zero energy building (ZEB) is a building with considerably reduced annual energy consumption by saving as much energy as possible via better heat insulation, solar shading, natural energy and high-efficiency equipment as well as creating energy (e.g., with photovoltaic (PV) power generation), while maintaining comfortable environments.

A zero energy building (ZEB) produces enough renewable energy to meet its own annual energy consumption requirements. There are a number of long-term advantages of moving toward ZEB, including lower environmental impacts, lower operating and maintenance costs, better resiliency to power outages and natural disasters, and improved energy security.

Reducing building energy consumption in new building construction or renovation can be accomplished through various means, including integrated design, energy efficiency retrofits, reduced plug loads and energy conservation programs. Reduced energy consumption makes it simpler and less expensive to meet the building energy requirements with renewable sources of energy.

Private commercial property owners are interested in developing ZEB to meet their corporate goals, and some have already constructed buildings designed to be zero energy.

However, nowadays definitions of ZEB differ from region to region and from organization to organization leading to confusion and uncertainty around the term.

The paper provides an overview of the different approaches to ZEB definitions with the emphasis on their similarities and peculiarities as well as considers the problems to be discussed further.

The zero energy/emission building is a complex concept, thus the development of one ZEB definition applicable for all case is not a simple task. There are many approaches to the ZEB definition and each of them spotlights different aspects of ZEB. Those issues have served to create a list of the main topics, which should be considered, when developing a new ZEB definition.

Review of literature on ZEB definitions

The study of the approaches concerning ZEB definitions shows that they differ on the applied unit for energy balance, period of the balance, type of energy use, type of balance, renewable energy supply options, connection with the energy infrastructure.

First and probably the most important is the issue of unit of balance between consumed and generated energy from renewables by the building.

The applied units for the "zero" balance can be the final or delivered energy, primary energy, CO_2 equivalent emissions, the cost of energy or some other parameters.

In [1], four types of metrics are considered: site energy (delivered or final energy), source energy (primary energy), energy costs and energy emissions.

According to [1], pluses and minuses of each metrics are as follows.

The use of *site energy* as metric has such advantages:

- Easy to implement;
- Verifiable through on-site measurements;
- Conservative approach to obtaining ZEB;
- No externalities affect performance, can track success over time;
- Easy for the building community to understand and communicate;
- Encourages energy-efficient building designs.

The shortcomings of the use of the *site energy* as metric:

- Requires more PV export to offset natural gas;
- Does not consider all utility costs (can have a low load factor);
- Not able to equate fuel types;
- Does not account for nonenergy differences between fuel types (supply availability, pollution).

The use of *source energy* as metric has such pluses as:

- Able to equate energy value of fuel types used at the site;
- Better model for impact on national energy system;
- Easier to reach ZEB.

Minuses of the use of the *source energy* as metric:

- Does not account for nonenergy differences between fuel types (supply availability, pollution);
- Source calculations are too broad (do not account for regional or daily variations in electricity generation rates);
- Source energy use accounting and fuel switching can have a larger impact than efficiency technologies;
- Does not consider all energy costs (can have a low load factor).

As an additional issue to be considered is the need to develop site-to-source conversion factors, which require significant amounts of information to define.

When energy is consumed on-site, the conversion to source energy must account for the energy consumed in the extraction, processing and transport of primary fuels such as coal, oil and natural gas; energy losses in thermal combustion in power generation plants; and energy losses in transmission and distribution to the building site. Source energy is calculated from delivered energy and exported energy for each energy type using source energy conversion factors.

Cost ZEB may be characterized as having such advantages:

- Easy to implement and measure;
- Market forces result in a good balance between fuel types;
- Allows for demand-responsive control;
- Verifiable from utility bills.

But, at the same time, such shortcomings are inherent to the *cost ZEB*:

- May not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid;
- Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges;
- Highly volatile energy rates make for difficult tracking over time.

As additional issues to be considered are:

- Offsetting monthly service and infrastructure charges require going beyond ZEB;

- Net metering is not well established, often with capacity limits and at buyback rates lower than retail rates.

Advantages of *emissions ZEB*:

- Better model for green power;

- Accounts for nonenergy differences between fuel types (pollution, greenhouse gases);

- Easier to reach ZEB.

At the same time, the *emissions ZEB* need appropriate emission factors.

Mertz, et al. [2] address the issue of net-zero CO_2 buildings and distinguish two approaches towards the ZEB: a net-zero energy building or a net-zero CO_2 (CO_2 neutral) building. They are the result of resource limitation and environmental impact, respectively. Mertz, et al. [2] describe the net-zero energy home as *"... a home, that over the course of year, generates the same amount of energy as it consumes"*. Furthermore, *"In a CO_2 neutral home, no CO_2 is added to the atmosphere due to the operation of the building"*. For the first time Mertz, et al. [2] has mentioned a possibility for a building to be a part of the CO_2 credits exchange market. Moreover, in the definition for net zero CO_2 building authors indicate, that net-zero energy building is at the same time a CO_2 neutral home; however, CO_2 neutral home does not necessarily have to be a net-zero energy home.

Other possible metrics are exergy and some others. So, Kilkis [3] states that the metric of the balance in ZEB definition should address both the quantity as well as the quality of energy, if the complete building impact on the environment must be assessed. He explains that: "*(...) although ZEB definition seems logical, it falls short recognize the importance of exergy in assessing the complete impact of buildings on the environment"*. Therefore, the author proposes a new definition for the ZEB concept, in particular a *Net-Zero Exergy Building* and defines it as "*a building, which has a total annual sum of zero exergy transfer across the building-district boundary in a district energy system, during all electric and any other transfer that is taking place in a certain period of time"*.

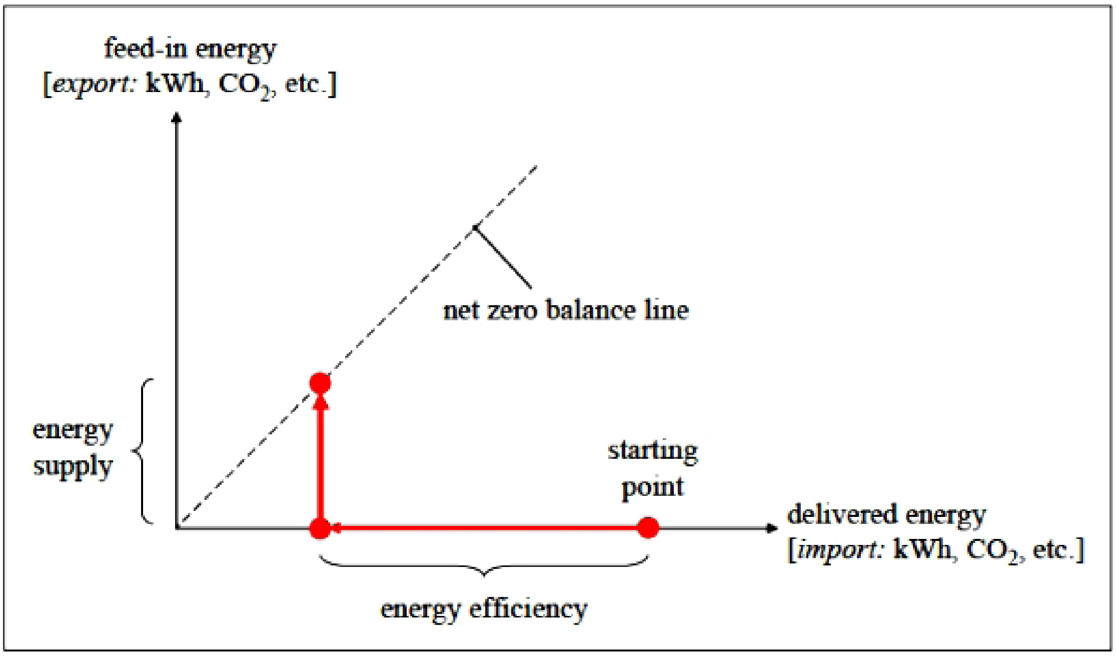

Figure 1. The net zero balance of a Net ZEB [9]

The primary energy is obviously the most favoured metric of the ZEB balance. This is in line with the latest EPBD recast [4] and common practice in many energy calculation methodologies.

The grid connected ZEB definitions from the existing literature are inconsistent in the type of balance that should be used. The most favoured is the balance between the energy needs or consumption and the renewable energy generation [1, 5, 6, 7]. However, in the papers of Lausten [8] and Mertz et. el. [2] the energy balance reflects the status of energy flows between the building and energy infrastructure, i.e. the overall energy delivered to the building from the utility grid has to be offset by the overall energy feed to the grid. Torcellini et al. [9] represent the net zero balance of a net ZEB (grid connected ZEB) graphically (Fig. 1), plotting the import (delivered energy) on the *x*-axis and the export (feed-in energy) on the *y*-axis.

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 for obtaining a Net ZEB consists of two steps: firstly, reduction in energy demand (x-axis) by means of energy efficiency measures; secondly, generation of electricity, or other energy carriers, by means of energy supply options to get enough credits (y-axis) to achieve the balance.

However, the study shows that the most accepted energy balance takes place between the energy use of building and the renewable energy generation.

The period of time over which the building calculation is performed can vary very much. In the existing literature on the issues considering ZEB definitions, the annual balance is the most favoured period of the balance [2, 10]. However, Hernandez and Kenny [11] states that the full life cycle of the building could be more appropriate period of time for the energy balance. Alternatively, a seasonal or monthly balance could also be considered.

The next important question is: what type of energy use should be included in the balance. Should it be only the energy required for operating the building i.e. building related (heating, cooling, ventilation, lighting, pumps and fans, other technical service systems) or user related (domestic hot water, cooking, appliances, lighting) or should also the embodied energy in the building construction and used technical equipment as well as in the construction and demolition of the building be accounted in the balance? This issue does not have an unambiguous answer and the opinions are divided as the countries practices are very different.

Based on the literature review, the most common approach is to include only the operating energy in the balance, and at this moment the embodied energy is not considered as the input for the balance. However, Hernandes and Kenny [11] suggest that the energy balance should not only be focused on the energy used by building in the operation phase, but as well include the energy embodied with building construction and systems. However, it should be noted that in the prevailing publications the type of energy use included in the balance is not specified [1, 4, 5, 6, 8]. The renewable energy sources (RES) can either be available on the site e.g. sun, wind or need to be transported to the site e.g. biomass. Therefore, there are two renewable energy supply options: on-site supply and off-site supply respectively. Thus, our attention is turned to the question: how and where the renewable energy is produced. Some of the proposed methodologies even do not address the issue of various supply options. The opinions are divided, one claim that only building footprint and site should be used, others accept the possibility of buying carbon credits in the carbon market in order to offset the energy use of a building. Even, the recent recast of the Directive on Energy Performance of Buildings [4] gives unclear answer to the above questions by stating: "(…) *energy should be covered to a very significant extent by energy from renewable sources produced on-site or nearby.'* Taking Torcellini's definition, the EPBD term "nearby" logically belongs to "off-site".

According to Torcellini, et al. [1] there are two options: on-site supply or off-site supply. Within the on-site supply authors distinguish building footprint and building site. Within the off-site supply, the building either uses RES available off-site to produce energy on-site, or purchase off-site RES. Tocellini, et al. [1] suggest ranking of preferred application of renewable energy sources (Table 1).

Table 1. ZEB Renewable Energy Supply Options [1]

Option number	ZEB supply-side options	Examples
0	Reduction of site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On-site supply options		
1	Use of renewable energy sources available within the building footprint	PV, solar hot water, and wind located on the building
2	Use of renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building
Off-site supply options		
3	Use of renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol or biodiesel that can be imported from off site, or waste streams from on-site processes to generate electricity and heat
4	Purchase of off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other 'green' purchasing options. Hydroelectric is sometimes considered

Moreover, Torcellini, et al. [1] indicate: "*Rooftop PV and solar water heating are the most applicable supply-side technologies for widespread application of ZEBs. Other supply-side technologies such as parking lot-based wind or PV systems may be available for limited applications.*"

Marszal et. al. [12] attempt to represent graphically the possible renewable energy supply options suggested in different energy calculation methodologies (Fig. 2).

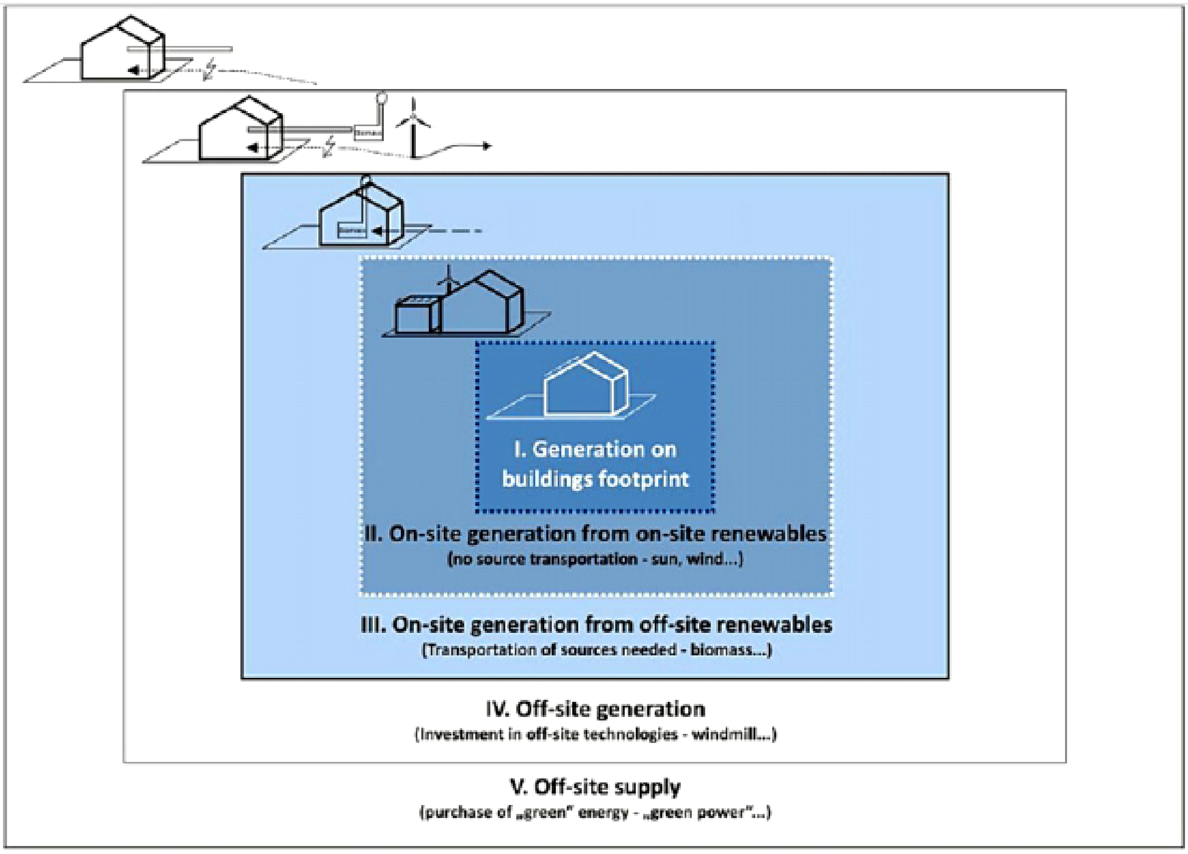

Figure 2. Overview of possible renewable supply options [12]

Next issue that requires clear answer is: if the ZEB definition should include specific requirements in terms of energy efficiency. In the review of existing ZEB approaches a very similar path to achieve ZEB can be noticed. Firstly, the reduction of energy demand using energy efficient technologies is applied, and afterwards the renewable energy sources to supply the remaining energy demand are utilized. The above strategy is the most logical approach to reach ZEB. Nevertheless, Laustsen, [8] points out that: "*In principle ZEB 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 zero net energy building.*" In order to avoid and eliminate this 'low-quality' ZEB a fixed value of maximum allowed energy use could be a good solution.

Moreover Torcellini, et al. [1] state: "*A good ZEB definition should first encourage energy efficiency, and then use renewable energy sources available on site. A building that buys all its energy from a wind farm or other central location has little incentive to reduce building loads, which is why we refer to this as an off-site ZEB.*"

Sartori at. al. [13] states that a Net ZEB definition may set mandatory minimum requirements on energy efficiency. Such requirements may be either prescriptive or performance requirements, or a combination of the two. Prescriptive requirements apply to properties of envelope components and of ventilation systems, while performance requirements apply to energy needs (e.g. for heating, cooling, lighting) or total (weighted) primary energy demand.

The paper [14] provides an overview of prescriptive and performance based energy efficiency requirements adopted in existing national or commercial certification systems.

Mandatory requirements on energy efficiency may be determined on the basis of cost-optimality considerations as in the plans of the Energy Performance of Buildings Directive [4]; such methodology is still under development [15]. Alternatively, mandatory efficiency targets could simply require a demand reduction (e.g. 50%) compared to a reference building of the same category (e.g. detached house, office, school). In absence of explicit requirements on energy efficiency it is left to the designers to find the cost-optimal balance between energy efficiency measures and supply options, eventually considering embodied energy too, if in the balance boundary.

However, the analysis of a large number of already existing ZEB underlines the priority of energy efficiency as the path to success.

In the ZEB definitions, the topic of indoor environment quality is almost fully neglected, though it is an important issue. On the one hand, it would be very beneficial from general point of view, that all ZEB would use the same values. It would be much easier to evaluate and compare ZEB from different location worldwide. On the other hand, giving so detailed criteria in the ZEB definition could significantly limit its usefulness in many cases. As different values can be used depending on building type, country, applied standard and local climate conditions. A good solution could be guidance or suggestion which standards or values should be used.

Monitoring procedure of ZEBs is an issue to be considered as well. Torcellini at.al. [9] address the issue about monitoring procedure: "*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.*"

Thus, as for the definition of ZEB, until now there is no consensus on a common expression, which can be satisfied by all participators in this research field. However, through research works, ideas exchange, and discussion during recent years, a common view is emerging that a widely-accepted definition of ZEB should be a definition framework which contains different elements, such as: boundary, metrics, criteria etc. Inside this common framework, various participators can choose elements in different levels to form a specific definition, based on individual considerations on cost, local climate, environmental protection demand, or the feasibility of on-site renewable energy source. In this way, the definition frame, which contains different levels of ZEB for different scenarios, can be helpful to put forward roadmap or guideline for countries, regions, associations or design groups based on their specific demands.

Through the definitional framework, a basis for legislations and action plans to promote ZEB development effectively can also be created.

Conclusions

While the concept of ZEB is understood, an internationally agreed definition is still lacking. From the information presented, it may be seen that a lot of discrepancies exist between the different approaches to ZEB definition.

The zero energy building is a complex concept thus the development of one ZEB definition applicable for all cases is not a simple task. There are many approaches to ZEB definition, and each of them spotlights different aspects of ZEB. Those issues have served to create a list of the main topics, which should be considered, when developing a consistent and robust ZEB definition.

The known approaches concerning the units applied in ZEB definitions, the period of time over which the building calculation is performed, type of energy use, type of balance as well as renewable supply options have been analyzed.

A lot of issues need to be discussed further. Among them are the issues connected with the determination of mandatory minimum requirements on buildings energy efficiency and what type of energy use should be included in the balance. In the ZEB definitions, the topic of indoor environment quality is almost fully neglected, though it is an important issue. These issues do not have an unambiguous answer and the opinions are divided.

A commonly accepted definition and corresponding methods of measurement for ZEB would have a significant impact on the development of design strategies for the buildings and spur greater market uptake of such projects.

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