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A literature review of Zero Energy Buildings (ZEB) definitions.

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by

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1. Introduction

It is difficult to find a building, which can be named the first Zero Energy/Emission Building (ZEB). One of the reasons could be that maybe ZEB is not a new concept for a building, it is just a modern name for buildings, from times before district heating and electricity, heated with wood or straw and lighted with candles and domestic animals? Nevertheless, in the late seventies and early eighties appeared few articles, in which phrases '*a zero energy house*', '*a neutral energy autonomous house*' or '*an energy-independent house*' were used. It was the time when the consequences of the oil crisis became noticeable and the issue of the fossil fuels sources and the energy use started to be discussed. However, those papers were mainly focused on the energy efficient technologies and passive solutions implemented in the building. Furthermore, only energy demand for space heating, domestic hot water and cooling were accounted in the 'zero', hence were they in fact buildings with zero energy use?

In the literature, over the decades, different ZEB's were described and evaluated, however almost in every paper the ZEB either was defined differently or no exact definition was used. Very often, the ways the zero energy goal was achieved have significantly affected the ZEB definition. Recently, the lack of common understanding and common definition for ZEB became noticeable, since this building concept is thought to be an effective solution for decreasing the energy use and greenhouse gas emissions from the building sector.

The main objective of this report is to give an overview of existing ZEB definitions. The review has shown that Zero Energy Building is a complex concept described with the wide range of terms and expressions. Based on the similarities and differences of the definitions from the existing worldwide literature, various approaches for ZEB definitions are differentiated.

2. Key existing Net-Zero approaches from literature

In the literature dedicated to Zero Energy Building the authors frequently emphasize the lack of common understanding of what should be equal to 'zero'. This issue has been widely discussed in numerous publications however, the question: should "zero" refer to the energy, the exergy or the CO₂ emissions or maybe energy costs, still has not been unambiguously answered.

In the report, Torcellini, et al. (2006), authors use the general definition for ZEB given by The U.S. Department of Energy (DOE) Building Technologies Program: "*A net zero-energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies.*" However they also point out clearly undefined

‘zero’: “Despite the excitement over the phrase “zero energy,” we lack a common definition, or even a common understanding, of what it means.”

Furthermore, in the paper authors indicate that the definition of Zero Energy Building can be constructed in several ways, depending on the project goals, intentions of the investor, concern about the climate changes and greenhouse gas emissions or finally the energy costs. Taking into consideration all the above mentioned scenarios Torcellini, et al. (2006) distinguish and point out advantages and disadvantages of four most commonly used definitions:

- **Net Zero Site Energy:** A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.
- **Net Zero Source Energy:** A source ZEB produces at least as much energy as it uses in year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building’s total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.
- **Net Zero Energy Costs:** In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
- **Net Zero Energy Emissions:** A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

Table 1.ZEB Definitions Summary by Torcellini, et al. (2006)

Definition	Pluses	Minuses	Other Issues
Site ZEB	<ul style="list-style-type: none"> • Easy to implement. • Verifiable through on-site measurements. • Conservative approach to achieving ZEB. • No externalities affect performance, can track success over time. • Easy for the building community to understand and communicate. • Encourages energy-efficient building designs. 	<ul style="list-style-type: none"> • 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). 	

Source ZEB	<ul style="list-style-type: none"> • Able to equate energy value of fuel types used at the site. • Better model for impact on national energy system. • Easier ZEB to reach. 	<ul style="list-style-type: none"> • Does not account for non-energy differences between fuel types (supply availability, pollution). • Source calculations too broad (do not account for regional or daily variations in electricity generation heat 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). 	<ul style="list-style-type: none"> • Need to develop site-to-source conversion factors, which require significant amounts of information to define.
Cost ZEB	<ul style="list-style-type: none"> • Easy to implement and measure. • Market forces result in a good balance between fuel types. • Allows for demand-responsive control • Verifiable from utility bills. 	<ul style="list-style-type: none"> • 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. 	<ul style="list-style-type: none"> • 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.
Emissions ZEB	<ul style="list-style-type: none"> • Better model for green power. • Accounts for nonenergy differences between fuel types (pollution, greenhouse gases). • Easier ZEB to reach. 		<ul style="list-style-type: none"> • Need appropriate emission factors.

Torcellini, et al. (2006) state that in all definitions grid connectivity is accessible, however the definitions also apply for grid independent structures. Finally, in the paper authors conclude: “*Consistent ZEB definitions are needed for those who research, fund, design, and evaluate ZEBs.*”

The distinction among the ZEB definitions made by Torcellini, et al. (2006) is further discussed and applied in various publications “The Potential Impact of Zero Energy Homes”, 2006, Torcellini, et al. (2006), “Centerline”, (2008), Noguchi, (2008), Kilkis, (2007), Voss, (2008).

Kilkis, (2007) in his work refers to Torcellini, et al. (2006) however, his review on ZEB definitions, takes slightly another direction. Kilkis indicates that in balancing the 'zero' both quantity and quality (exergy) of energy should be taken into consideration. Kilkis, (2007), 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. For example if a ZEB is connected to a district energy system and receives high temperature heat as well as electrical energy and provides heat in the same quality at a lower temperature and at the same quantity of electrical energy to the district, the building is not balancing the exergy of heat it receives and provides. This ZEB is still impacting the environment because the negative exergy balance must be made up by the district at a cost of additional fuel spending and harmful emission even though energy amounts of the heat and power flow across the building-district boundary are balanced... If the district generates power in the thermal power plant, and the ZEB generates electric power in a micro-combined heat and power (CHP) unit, and or by using wind turbine, all have different environmental impacts and exergy"*.

Therefore, author proposes a new definition for the ZEB 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"*.

Moreover, Kilkis, (2007) points out, that taking into consideration the exergy balance instead of energy balance enable to quantify the compound carbon emissions of a building, thus accurately rate building impact on the environment. By compound CO₂ emissions author understands the direct carbon emission from the building and avoidable secondary carbon emission that is the consequence of the exergy mismatch. According to Kilkis, (2007): *"... engineers, architects, decisions makers must recognize that the harmful emissions and global warming issues cannot be fully addressed by simple net zero energy building concept. Exergy dimension of the balance must be absolutely taken into account in order to fully reveal the magnitude of the problem and at the same time draw solution roadmaps"*

At the same time Mertz, et al. (2007) distinguish two definitions for ZEB: a net-zero energy building or a net-zero CO₂ (CO₂ neutral) building. They are the result of resource limitation and environmental impact, respectively. Mertz, et al. (2007) describe a net-zero energy home *"... as a home, that over the course of year, generates the same amount of energy as it consumes. A net-zero energy home could generate energy through photovoltaic panels, a wind turbine, or a biogas generator. The net-zero energy home consider in this paper uses photovoltaic panels (PV) to offset electricity purchased from the grid."*

"In a CO₂ neutral home, no CO₂ is added to the atmosphere due to the operation of the building. This could be accomplished by purchasing tradable renewable certificates (TRC's) generated by solar, wind, or biogas. It could also be accomplished by purchasing

CO₂ credits on a carbon trading market from some who has CO₂ credits to sell. In addition, the home could generate all of its energy on-site like a net-zero energy home”.

Mertz, et al. (2007) mention for the first time, the possibility for a building to be a part of the CO₂ credits exchange market. Moreover, by the last statement in the definition for net-zero CO₂ building authors indicates, that net-zero energy building is at the same time a CO₂ neutral home, however CO₂ neutral home does not necessarily have to be a net-zero energy home.

In the International Energy Agency (IEA) report written by Jens Laustsen in 2008, the issue of different interpretation the ZEB definition is further discussed. Laustsen, (2008) gives the general definition for ZEB: *“Zero Energy Buildings do not use fossil fuels but only get all their required energy from solar energy and other renewable energy sources”* however, at the same time emphasize its weak points by saying: *“Compared to the passive house standards there is no exact definition for the way to construct or obtain a zero energy building. In principle this 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.”* When focusing on the issue of what zero refers to Laustsen, (2008), similarly as Mertz, et al. (2007), mentions two definition:

- **Zero Net Energy Buildings** are buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid.
- **Zero Carbon Buildings** are buildings that over a year do not use energy that entails carbon dioxide emission. Over the year, these buildings are carbon neutral or positive in the term that they produce enough CO₂ free energy to supply themselves with energy.

Zero Carbon Buildings differ from Zero Energy Building in the way that they can use for instance electricity produced by CO₂ free sources, such as large windmills, nuclear power and PV solar systems which are not integrated in the buildings or at the construction site.

3. Discussion of new net zero approach

The Zero Energy Building is a complex concept thus the development of one ZEB definition applicable for all case is not a simple task. As presented in the literature review, 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 net ZEB definition.

First and probably the most important is the issue of the balance:

- what are the units of the balance (final energy; primary energy; exergy; energy costs or maybe CO₂ emission)
- which energy demands are in the balance: only the energy required for operating the building, or also the energy use connected with occupants behavior (cooking, appliances, lighting etc.) is included?
- if the embodied energy in the building construction, used technical equipment should be accounted in the balance?

When looking at the general practice 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. Since the energy prices not only change in time but also differ worldwide, using the energy costs, as unit could make it almost impossible to design a building, which would be a ZEB through its entire lifetime. Thus a building could be ZEB only at the time when it is design. The final energy is the easiest unit to implement and understand, but on the other hand quality of the different kinds of energy if fully neglected. CO₂ emission could be a unit, however for a second separate definition of Zero Emission Building.

The second question regarding the energy demands should not be difficult to answer, because if a building is named zero energy building, then total energy use should be included. In order to evaluate total building environmental impact embodied energy should be taken into account in the balance. However, it can be difficult, since in early design phase many data, values needed for including embodied energy in the calculations are yet unknown.

Another point for the discussion is the question: if net zero approach is only focus on grid connected cases or not? From the literature review it can be noticed that the term 'net' is more often used in the definitions for grid connected ZEB to emphasize the interaction with the utility grid. Assuming, that net zero approach includes only on-grid ZEB, in the newly developed definition the regulations of the building-grid interaction should be well described, since this connection ought to be beneficial for both sides. Unfortunately, the studies describe mostly how positive it is for the building neglecting the grid situation.

Furthermore, one more topic for the analysis is: if the ZEB definition should include specific requirements it terms of:

- maximum allowed energy use,
- minimum indoor environment quality (temperature and IAQ)
- type and application of renewable energy sources?

In number of publications devoted to ZEB, similar path to achieve ZEB can be noticed. Firstly, the reduction of energy demand using energy efficient technologies and afterwards utilization of renewable energy sources (RES) to supply remaining energy. This is the most logical approach to reach ZEB. Nevertheless, as Laustsen, (2008) 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 kind of ZEB a fixed value of maximum allowed energy use could be a good solution. In the literature the topic of indoor environment quality is almost fully neglected in the ZEB definitions, 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 ZEBs from different location worldwide. On the other hand, giving so detailed criteria in the ZEB 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. A good solution could be a guidance or suggestion which standards or values should be used. In prevailing ZEB cases described in the literature solar energy (solar thermal and photo voltaic – PV) is mostly common used RES. It follows from the fact that, firstly it can be easily implemented in the building construction (no extra space besides building footprint is needed) and secondly it is the best developed RES technology for small-scale application. However, there are cases, in which another RES than solar energy would be more beneficial or easier to use, so why the ZEB definition should impose a certain type of RES?

When the above mentioned questions, mostly related to general ZEB definition, are answered, then comes the matter if this one general definition is enough to include all cases? Focusing only on a single building brings already difficulties. There are different buildings types, which have different purpose and requirements and this diversity may not be covered by one definition. Thus, while developing the ZEB definition it should be considered that maybe it will be more suitable to develop separate definition for residential and non-residential buildings. The same issue appears when taking into consideration a single building and a community situation. Is one general definition sufficient for a building and at the same a group of buildings?

Finally, a question of different climates and thus different design criteria can be posed, if it is feasible to design and construct ZEB all over the world according to the same definition?

Those topics are the key issues/questions, which should be solved while developing a new ZEB definition.

4. Key points for definition of Net-Zero Energy Building

In this section are listed key points, which should be included in the definition.

- Primary energy – units of the balance.
- Total energy demand = for operating the building + associated with occupancy.

- Fixed maximum energy use. Developed at the meeting, since it should be a value achievable in all countries. A starting point, could be the energy use for a low-energy buildings.
- Distinguish between residential and non-residential
- Application all types of renewable energy sources.
- Regulations of the grid-building interaction.

Appendix: Literature Review

The following is a review of literature related to ZEB definitions and research projects. The reviewed literature is divided into a number of main important topics for the discussion of ZEB definitions.

1. Energy focus

Total energy demand in the building is a sum of thermal (heating, cooling) demand and electricity demand (appliances, lighting), however many studies focus only on one neglecting the other. This issue is raised by Able, (1994): *“Many low-energy building projects seem to have been based on the idea 'decrease heat supply at any cost'. In some cases, this has resulted in 'zero-energy buildings' which, it is true, do not need any heat supply but do, instead, indirectly need electricity, e.g., to operate the heat pump included in the system.”*

In the seventies and eighties, when large part of energy use in the buildings was mostly due to the heating (space heating and domestic hot water) in publications devoted to Zero Energy Building, in the definitions only heat was accounted in the zero.

Esbensen, et al. (1977) describe an experimental ZEB house in Denmark and point out: *“With energy conservation arrangements, such as high-insulated constructions, heat-recovery equipments and a solar heating system, the Zero Energy House is dimensioned to be self-sufficient in space heating and hot-water supply during normal climatic conditions in Denmark. Energy supply for the electric installations in the house is taken from the municipal mains.”*

Saitoh, (1984) and Saitoh, et al. (1985) in their studies present a Natural Energy Autonomous House in Japan. According to authors: *“... a multi-purpose natural energy autonomous house will meet almost all the energy demands for space heating and cooling as well as supply of hot water for standard Japanese house in 10-15 years. For this purpose, solar energy, the natural underground coldness and sky radiation cooling are utilized.”*

On the other hand, in number of papers total energy demand of a building is fully dominated by electricity demand, thus in the ZEB definition only electricity is considered. One of the reasons for this situation is simply the lack of district heating in many countries. However this issue is not commonly mention in the definition, which makes it imprecise.

Gilijamse, (1995): *“A zero energy house is defined here as a house in which no fossil fuels are consumed, and the annual electricity consumption equals annual electricity production. Unlike the autarkic situation, the electricity grid acts as a virtual buffer with annually balanced delivers and returns”*

Parker, et al.(2001): *“During times of peak demand, a Zero Energy Home generates more power than it uses, thereby reducing power demand on the utility provider. During times of power outage, the home generates its own power, allowing the homeowner*

essential energy security. In a Florida study, a prototype Zero Energy Home outperforms a conventional model by providing almost all of its own power needs throughout the year”

Iqbal, (2003): *“Zero energy home is the term used for a home that optimally combines commercially available renewable energy technology with the state of the art energy efficiency construction techniques. In a zero energy home no fossil fuels are consumed and its annual electricity consumption equals annual electricity production. A zero energy home may or may not be grid connected”*

Nevertheless, in the scientific publications exist ZEB definitions including both heating and electricity demand in total energy demand.

In the NREL report “The Potential Impact of Zero Energy Homes” from 2006, authors use as basis for the ZEB description the definition given by The U.S. Department of Energy (DOE) Building Technologies Program: *“a net zero energy building is a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies.”* and later extend it by saying: *“A Zero Energy Home combines state-of-the-art, highly energy-efficient designs and equipment with on-site renewable energy generation (which typically includes a solar hot water production system and a rooftop photovoltaic, or PV, system) to return as much energy to the utility as it takes on an annual basis. Zero Energy Homes are designed to perform well, be comfortable, require only standard maintenance, and look no different from an ordinary home.”*

According to Lausten, (2008), *“Zero Net Energy Buildings are buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid.”*

Voss, (1996): *“...Its entire energy demand for heating, domestic hot water, electricity and cooking is supplied solely by solar energy.”*

In some ZEB projects focus not only on the operating energy demand but also on energy embodied in the building construction and materials. One of example of such a project can be BedZED - neutral carbon eco-community near London. Morbitzer, (2008) points out: *“...where possible, BedZED is built from natural, recycled or reclaimed materials. All the wood used has been approved to be sourced from sustainable resources, and construction materials were selected for their low embodied energy and were sourced within 35-mile radius of the site if possible.”* Another example is a Rivendale NetZero Project (“Project Profile: Riverdale NetZero Project—Edmonton, Alberta”, 2008) in which, except energy efficient technologies and renewable energy production, resource conservation is taken into consideration: *“Sustainable, regional materials are used extensively in the building. The decorative exterior window trim is made from salvaged, clear cedar bevel siding. The glulam beams in the living room are recycled from a liquor store. The hardwood flooring is recycled from a school gymnasium. Other flooring is*

Marmoleum, cork and sustainably manufactured tile. The building envelope is constructed primarily of locally grown spruce. Most of the insulation is made of recycled newspaper.”

2. Energy Supply system

In the prevailing literature is the strict distinguish, between off-grid ZEB and on-grid ZEB. The main difference between those two approaches is that, the off-grid ZEB does not have any connection to the utility grid, thus it does not purchase energy from the external sources. In other words the building offset all required energy by producing energy from RES. The on-grid ZEB is also energy producing building, but there is a possibility for both purchasing energy from the grid and feeding it back to the grid. This division is also noticeable in the ZEB definitions.

The off-grid ZEB commonly also called autonomous or self-sufficient building has been presented in many publications: Stahl, et al. (1994), Voss, et al. (1996), Kramer, (2007), Platell, et al. (2007), however there is no clear definition of off-grid ZEB. The authors usually set the goals for the projects, which indirectly can be understood as the ZEB definition, or give the definition which can be used exclusively for described study case.

Stahl, et al. (1994): *“The goals of the project can be summarized as follows:*

- use of solar energy to replace other, environmentally damaging energy carriers*
- demonstration of new concepts of solar architecture integrated into an energetically optimized structure*
- utilization of advanced technologies for energy conservation*
- demonstration of new solar energy systems.*

The intention of the project is to show the technical potential of solar energy to replace all environmentally damaging energy carriers in a dwelling.

Kramer, et al. (2007): *“... objective is to demonstrate solar-hydrogen energy system that allows the building to operate without any connection to the electrical grid.”*

Voss, et al. (1996): *“The Fraunhofer Institute for Solar Energy Systems has built an energy self-sufficient solar house (SSSH) in Freiburg, Germany. Its entire energy demand for heating, domestic hot water, electricity and cooking is supplied solely by solar energy. The combination of state-of-the-art energy-saving technologies with highly efficient solar systems minimizes the mismatch between the solar radiation input and the building energy demand in winter. The remaining seasonal energy storage is accomplished by electrolysis of water during summer with electricity from a photovoltaic generator.”*

Nevertheless, there are studies, in which clear definition for the off-grid ZEB is given. According to the report written by Laustsen in 2008 for International Energy Agency (IEA) (Laustsen, 2008): *“Zero Stand Alone Buildings are buildings that do not require connection to the grid or only as a backup. Stand alone buildings can autonomously supply themselves with energy, as they have the capacity to store energy for night-time or wintertime use.”*

Iqbal, (2003): *“Zero energy home is the term used for a home that optimally combines commercially available renewable energy technology with the state of the art energy efficiency construction techniques. In a zero energy home no fossil fuels are consumed and its annual electricity consumption equals annual electricity production... An off-grid zero energy home has an arrangement for large energy storage usually in the form of batteries. In an off-grid zero energy home, depending upon the battery storage, a part of the load may be un-served.*

Similar, as for the off-grid ZEB, there are publications, describing the on-grid ZEB projects, however not including a clear definition for the on-grid ZEB. Naturally, somewhere in the paper it is mentioned that ZEB is exchanging energy with the utility grid, nevertheless it is not obvious from the beginning.

According to Rosta, et al. (2008): *“Ideally, a ZEH produces as much energy as it consumes in a year’s time”*. The definition is not saying much about the building and its interaction with the grid, however later in the paper can be read that: *“Accounting for the electric energy generated by the PV system on the ZEH, and defining electric energy used by the utility grid as positive and electric energy used by the grid as negative, a plot of the net electric energy usage of the houses is obtained”* which indicates, that there is building-grid interaction.

Noguchi, et al. (2008): *“In this paper, a net zero-energy home (NZEH) is defined as a house that consumes as much energy as it produces over a year”* and after few pages authors describe: *“The BIPV/T system is an on-grid application accompanied with an inverter for the AC/DC conversion. The system allows for redirection of the locally generated electricity surpluses to the grid.”*

The studies with clear grid-connected ZEB definition belong to: Gilijamse, (1995), Parker, et al. (2001), Iqbal, (2003), Laustsen, (2008).

Gilijamse, (1995): *“A zero energy house is defined here as a house in which no fossil fuels are consumed, and the annual electricity consumption equals annual electricity production. Unlike the autarkic situation, the electricity grid acts as a virtual buffer with annually balanced delivers and returns”*

Parker, et al. (2001): *“During times of peak demand, a Zero Energy Home generates more power than it uses, thereby reducing power demand on the utility provider. During times of power outage, the home generates its own power, allowing the homeowner essential energy security. In a Florida study, a prototype Zero Energy Home outperforms a conventional model by providing almost all of its own power needs throughout the year.”*

Iqbal, (2003): *“Zero energy home is the term used for a home that optimally combines commercially available renewable energy technology with the state of the art energy efficiency construction techniques. In a zero energy home no fossil fuels are consumed and its annual electricity consumption equals annual electricity production... A grid-connected zero energy home may generate more power than it uses supplying excess generated power to the grid. During times of power outage, using the energy stored in*

batteries, a grid-connected zero energy home can generate its own power, allowing the homeowner essential energy security. A zero net energy home is designed and constructed to generate all of the energy it requires through a combination of energy efficiency and renewable energy generation technologies.”

Laustsen, (2008): “Zero Net Energy Buildings are buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid”

The issue of large storage, energy losses either in storing or converting energy and oversized renewable resources in autonomous ZEB compared to grid-connected ZEB become a public discussion.

Torcellini, et al. (2006) indicate: “A ZEB 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. Achieving a ZEB without the grid would be very difficult, as the current generation of storage technologies is limited. Despite the electric energy independence of off-grid buildings, they usually rely on outside energy sources such as propane (and other fuels) for cooking, space heating, water heating, and backup generators. Off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses. As a result, the energy production from renewable resources must be oversized. In many cases (especially during the summer), excess generated energy cannot be used.

According to Voss, (2008): “While the energy systems used in off-grid buildings have to be over-dimensioned, especial in term of storage, in order to provide energy at all times [Goetzberger 1994], in grid-connected projects the goal is simply to have the total amount of energy consumed in the building over the course of year offset by the total amount produces.... The connection to the power grid therefore plays a decisive role as a sort of storage battery for electricity, especially in Europe across seasons”

3. Single or Community

If one building can be ZEB, then crating a zero energy community should be just a matter of combining those building into communities, villages or even towns. However, should also the definition for one ZEB be multiplied by the number of the buildings creating the community or should zero energy community has a separate definition.

In the scientific publications the prevailing definitions are focus only on one building/house/home only Laustsen, (2008) in the ZEB definitions uses plural: “Zero Net Energy Buildings are buildings... Zero Carbon Buildings are buildings...etc” Though, later in the paper author indicates “Compared to the passive house standards there is no exact definition for the way to construct or obtain a zero energy building.”

Nevertheless, few case studies ZEB communities are described. The best known eco community also called the largest UK eco village is the Beddington Zero Energy Development (BedZED). *“BedZED has been designed to address environmental, social and economic needs. It brings together a number of proven methods – most of which are not particularly high tech - for reducing energy, water and car use. Crucially, it produces affordable, attractive and environmentally responsible housing and workspace”* [1].

According to General Information Report 89, (2002): *“BedZED’s zero-carbon ‘total energy strategy’ is achieved via:*

- *energy-efficient design of the buildings – reducing heat losses and utilising solar gain, to the point where it is feasible to eliminate conventional central heating systems altogether*
- *energy-efficient and hot-water-saving appliances to reduce demand – this sets the capacity for the CHP system*
- *use of renewable energy sources – wood-fuelled CHP (trees absorb CO₂ as they grow, and return it to the atmosphere when burnt); PV power integrated into the sunspace roofs means that BedZED will become a net exporter of renewable energy*
- *a green transport plan (see Section 6) –minimising residents’ use of fossil-fuel cars and the need to commute to work.”*

Finally Morbitzer, (2008) emphasizes: *“...a strength of BedZED is certainly the variety of environmental issues it addresses. It does not only focus on energy demands of a building, but also by considering aspects such as transport energy, embodied energy, water consumption, ecology, or social housing”*.

Not exactly the ZEB community is defined by Clark, et al. (2008), though in the paper authors describe the agile sustainable communities with this words: *“Agile sustainable communities are primarily the result of different infrastructures that interact together or in tandem... Agile means that within a geo-political city, state or region, the local communities generate their energy from local on-site renewable power resources such as solar, water, waste, wind, geothermal, and biomass, etc. These renewable energy supplies can also be backed by storage technologies, the central grid or other means so that the community always has power or a firm base load.”*

Bağcı, (2008), based on the studies introduces a new term of zero energy island and explains it as: *“ In the context of this study, the focus was on production of electrical energy only. Analog to the existing term ZEB (Zero Energy Building), a new term ‘Zero Energy Island’ is introduced to name the same concept for islands.”*

4. Building type

The ZEB definitions can be also divided according to the building type. In the prevailing literature there is almost no difference between the ZEB definition for a commercial building and a residential building. Commonly in the publications three

phrases are used: zero energy building, zero energy house and zero energy home. As the first term is the most comprehensive and includes both residential and commercial building, the two others typically are used for the residences.

Generally, there is this tendency, when the scientific studies of zero energy concept are not devoted to one, specific study case (building) the authors tend to use the phrase zero energy building: Torcellini, et al. (2006), Kilkis, (2006), Voss, (2008), Laustsen, (2008). The U.S. Department of Energy (DOE) Building Technologies Program (NREL, 2006) uses one ZEB definition for both building types *“a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies.”*

Though, when the paper is dedicated to an exact type of building, usually the residence, phrase zero energy house exchangeable with zero energy home is employed in the definition: Esbensen, et al. (1977), Parker, et al. (2001), Gilijamse, (1995), Iqbal, (2003), Mertz, et al. (2007), Rosta, et al, (2008), Noguchi, et al. (2008), Pogharian, et al. (2008).

In the Griffith, et al. (2006) the technical potential to achieve ZEB for commercial building is investigated, though the authors do not create any special ZEB definition, Griffith, et al. use the net-site ZEB definition described by Torcellini, et al. (2006): *“For this research, we used a net site energy definition. A net site ZEB produces as much energy annually as it uses when accounted for at the site (natural gas energy use is offset with on-site electricity generation at a 1:1 ratio).”*

5. Application of renewable energy sources.

Good ZEB definition should also indicates, what is the supply-side of the renewable energy sources. According to Torcellini, et al. (2006) there are two options: on-site supply or off-site supply. Within the on-site supply authors distinguish building footprint and building site separately. 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. (2006) propose a ranking of preferred application of renewable energy sources:

Table 2. ZEB Renewable Energy Supply Option Hierarchy Torcellini, et al. (2006)

Option Number	ZEB Supply-Side Options	Examples
0	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On-Site Supply Options		
1	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
2	Use 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 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 that can be used on-site to generate electricity and heat.
4	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other “green” purchasing options. Hydroelectric is sometimes considered.

Torcellini, et al. (2006) 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. Renewable energy resources from outside the boundary of the building site could arguably also be used to achieve a ZEB. This approach may achieve a building with net zero energy consumption, but it is not the same as one that generates the energy on site and should be classified as such. We will use the term “off-site ZEB” for buildings that use renewable energy from sources outside the boundaries of the building site.”*

“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. Efficiency measures or energy conversion devices such as daylighting or combined heat and power devices cannot be considered on-site production in the ZEB context. Fuel cells and microturbines do not generate energy; rather they typically transform purchased fossil fuels into heat and electricity. Passive solar heating and daylighting are demand-side technologies and are considered efficiency measures. 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.”

6. Type of renewable sources

The main concept of zero energy building is the independence of fossil fuels, thus the utilization of the renewable energy sources. By renewable energy sources can be understood: solar thermal, solar photovoltaic (PV), biomass and wind or wave energy. In the prevailing literature ZEB definitions are not focus on one particular renewable technology.

According to ASHRE (Kilkis, 2007): *“ZEB is a building, which on annual basis, uses no more energy than is provided by the building on-site renewable energy sources”.*

The U.S. Department of Energy (DOE) Building Technologies Program (NREL, 2006) defines ZEB as: *“a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies.”*

Torcellini, et al. (2006) in ZEB definitions do not spotlight specific renewable source, however in the paper authors emphasize that: *“Rooftop PV and solar water heating are the most applicable supply-side technologies for widespread application of ZEBs.”*

Laustsen, (2008) includes in the ZEB definition all RES, however emphasizes solar energy: *“Zero Energy Buildings are buildings that do not use fossil fuels but only get all their required energy from solar energy and other renewable energy sources.”*

Mertz, et al. (2007) distinguish three RES: *“A net-zero energy home could generate energy through photovoltaic panels, a wind turbine, or a biogas generator”*

Iqbal, (2003): *“Zero energy home is the term used for a home that optimally combines commercially available renewable energy technology with the state of the art energy efficiency construction techniques. In a zero energy home no fossil fuels are consumed...”*

Nevertheless, among the studies can be noticed that most commonly applied technologies in the ZEB projects are solar thermal and photovoltaic: Esbensen, et al. (1977), Saitoh, (1984), Saitoh, et al. (1985), Stahl, et al. (1995), Voss, et al. (1996), Gilijamse, (1995) Kärner, (2007), Mertz, et al. (2007), Parker, et al. (2001), Rosta, et al. (2008), *“Riverdale NetZero Project-Edmonton, Alberta”*, (2008), Noguchi, et al. (2008) etc.

Charron, (2005) gives even a definition for zero energy solar homes: *“Homes that utilise solar thermal and solar photovoltaic (PV) technologies to generate as much energy as their yearly load are referred to as net-Zero Energy Solar Homes (ZESH).”*

Other renewable energy sources are not as popular as solar energy, though there are studies describing ZEB projects in which biomass and wind or wave energy are taken into consideration as a possible RES.

Iqbal, (2003): *This paper presents a feasibility study of a wind energy conversion system based zero energy home in Newfoundland... Energy for space and water heating, cooking, lighting and electrical appliances can be provided by a wind turbine system assuming that exchange of electricity with the grid is possible.”*

Bağcı, (2008): *“The potential of different alternative energy resources was considered, such as solar, wind, tidal, wave, energy crops and MSW (municipal solid waste).”*

General Information Report 89, (2002) indicates that BedZED’ s carbon neutrality is achieved inter alia by: *“use of renewable energy sources – wood-fuelled CHP (trees absorb CO₂ as they grow, and return it to the atmosphere when burnt); PV power integrated into the sunspace roofs means that BedZED will become a net exporter of renewable energy”*.

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