Joint Project - Task 40/Annex 52
Net Zero Energy Buildings

# Zero Energy Building definition – a literature review

## A technical report of subtask A

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# Contents

Results of this literature review are presented in two parts. First part presents key publications that significantly contribute to the discussion on ZEB definitions, and finally the discussion itself. In the second part, Appendix, the ZEB definitions from the literature are divided into the groups in order to give the reader an overview of the wide variety of ZEB definitions.

# 1 Introduction

The worldwide CO2 emission mitigation efforts, the growing energy resource shortage and the fact that buildings are responsible for a large share of the world's primary energy use drives research towards new building concepts, in particular Zero Energy/Emission Buildings (ZEBs). Unfortunately, the lack of a common understanding for this new type of building results in misunderstandings, endless discussions, and moreover number of unique approaches often applicable for a single ZEB project.

The ZEB concept is not a new idea. Literature exists from 1970's, 80's and 90's which describes zero energy/emission buildings; Esbensen and Korsgaard (1977), Gilijamse (1995). It was the time when the consequences of the oil crisis became noticeable and the issue of fossil fuels sources and energy use started to be broadly discussed. Over the decades, in many articles and research projects number of ZEB's were described and evaluated; however, almost for each case the ZEB was defined differently or no exact definition was adopted. Moreover, often the path for achieving the 'zero goal' affected significantly the ZEB definition. Yet, just a few years ago this concept attracted the attention of a wide international audience and a worldwide discussion began.

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 literature, various approaches towards ZEB definitions are differentiated.

# 2 Key existing Net-Zero approaches from the literature

With the ZEB concept gaining in popularity the literature on zero energy/emission buildings is also hasty growing. Most of the publication focuses on documenting different ZEB demonstration projects; however, a number of documents have significantly contributed to the discussion of understanding and defining ZEB concept. One of those milestones is the report written by Torcellini, et al. in 2006. The authors point out that despite the exciting phrase of 'zero energy', ZEB definition often lacks a clear and commonly understandable explanation of what this term actually means. Torcellini, et al (2006) indicate that the definition of ZEB concept 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 highlight 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.*

Table1. ZEB Definitions Summary by Torcellini, et al. (2006)

| Definition | Pluses | Minuses | Other Issues |
|---|---|---|---|
| Site ZEB | • Easy to implement.<br>• Verifiable through on-site measurements.<br>• Conservative approach to achieving ZEB.<br>• No externalities affect performance, can track success over time.<br>• Easy for the building community to understand and communicate.<br>• Encourages energy-efficient building designs. | • Requires more PV export to offset natural gas.<br>• Does not consider all utility costs (can have a low load factor).<br>• Not able to equate fuel types.<br>• Does not account for nonenergy differences between fuel types (supply availability, pollution). | |
| Source ZEB | • Able to equate energy value of fuel types used at the site.<br>• Better model for impact on national energy system.<br>• Easier ZEB to reach. | • Does not account for non-energy differences between fuel types (supply availability, pollution).<br>• Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates).<br>• Source energy use accounting and fuel switching can have a larger impact than efficiency technologies.<br>• Does not consider all energy costs (can have a low load factor). | • Need to develop site-to-source conversion factors, which require significant amounts of information to define. |
| Cost ZEB | • Easy to implement and measure.<br>• Market forces result in a good balance between fuel types.<br>• Allows for demand-responsive control<br>• Verifiable from utility bills. | • 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.<br>• Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges.<br>• Highly volatile energy rates make for difficult tracking over time. | • Offsetting monthly service and infrastructure charges require going beyond ZEB.<br>• Net metering is not well established, often with capacity limits and at buyback rates lower than retail rates. |
| | | | |

| | | | |
|---|---|---|---|
| Emissions ZEB | • Better model for green power.<br>• Accounts for nonenergy differences between fuel types (pollution, greenhouse gases).<br>• Easier ZEB to reach. | | • Need appropriate emission factors. |

The distinction between different ZEB definitions made by Torcellini, et al. (2006) is further discussed in various publications "The Potential Impact of Zero Energy Homes", (2006), Torcellini, et al. *(2006), "Centerline", (2008), Noguchi, et al. (2008), Kilkis, (2007), Voss, (2008).

Kilkis, (2007) in his review on ZEB definitions, takes slightly another direction then Torcellini, et al. (2006). He indicates that in balancing the 'zero' both quantity and quality (exergy) of energy should be taken into consideration. Kilkis 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, 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".*
Moreover, Kilkis points out that taking into consideration the exergy balance instead of energy balance, enable to quantify the compound carbon emissions of a building, and thus accurately rate building impact on the environment. By compound $CO_2$ emissions author understands the direct carbon emission from the building and avoidable secondary carbon emission that is the consequence of the exergy mismatch. He states that "(*…) 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 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. (2007) describe the 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".* Furthermore, *"In a $CO_2$ neutral home, no $CO_2$ 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 $CO_2$ credits on a carbon trading market form some who has $CO_2$ credits to sell. In addition, the home could generate all of its energy on-site like a net-zero energy home".*
For the first time Mertz, et al. (2007) has mentioned a possibility for a building to be a part of the $CO_2$ credits exchange market. Moreover, by the last statement in the definition for net-zero $CO_2$ building authors indicates, 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.

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". H*owever, at the same time he emphasizes its weak points by stating: "*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 unit of 'zero' Lausten, (2008), similarly as Mertz, et al. (2007), mentions two approaches:

- ***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.*

Recently, the EU Commission and Parliament have in their recast of the Directive on Energy Performance of Building put 'Near Zero Energy Building' a the future target for buildings and defined it as: *"(…) a building that has a very high energy performance, determined in accordance with Annex I. The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby."*

# 3 Discussion of new net zero approach

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, see Appendix, 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 unit of balance. Should it be final/delivered energy; primary energy; exergy; energy costs or maybe $CO_2$ emission? When looking at the general practice the most obvious way to account for the energy demand and generation of a building would be base it on the energy units itself. Such a balance would then look differently depending on where the energy is measured in the energy chain, i.e. final/delivered or primary energy. The final/delivered energy is the easiest unit to implement and understand but it has a major drawback as quality of the different kinds of energy is fully neglected. Therefore, 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. Hence it expresses better the actual building energy use. The balance could also be given on the basis of carbon emission; however, for a second separate definition of Zero Emission Building. Other options for the unit could be the energy prices or exergy. However, as the cost unit would create very unstable and imprecise definition due to energy price volatility and economic externalities, the exergy as unit may be difficult to understand for anybody not familiarized with the 'term' exergy.

The second important question is: what type of energy use to include in the balance. Should it be only be the energy required for operating the building i.e.:

- building related: heating, cooling, ventilation, lighting, pumps and fans, other technical service systems
- 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, in the recent publication of Hernandez et al. (2010) the authors indicate that accounting embodied energy in the balance would allow to estimate the true environmental impact of a building.

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 mostly applied 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 building-grid interaction should be well describe, because this connection ought to be beneficial for both sides. Unfortunately, at this moment most of the studies focus only on describing how positive this connection is for the building neglecting fully the gird situation.

Next issue that requires clear answer is: if the ZEB definition should include specific requirements it 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, 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 'low-quality' ZEB a fixed value of maximum allowed energy use could be a good solution.

- minimum indoor environment quality (temperature and IAQ)

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 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. As 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.

- type and application of renewable energy sources?

In prevailing ZEB cases descried 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, 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 should the ZEB definition impose a certain type of RES?

The second issue of renewable energy sources is, in particular the possible supply options of RES. Based on the existing literature most of the ZEB definition do not specify where the renewable energy is generated. Possibly, due to the fact that in the majority of the cases the energy renewable sources are used within building footprint or on-site. However, some countries i. e. United States distinguish also other options i.e. purchase of off-site renewable energy sources, and propose a whole hierarchy of supply options. Therefore, to be able to develop a worldwide applicable ZEB definition this issue has to be consider.

When the above mentioned questions are answered, then there is an issue of: if this one general definition is enough to include all cases? Focusing only on a single building brings already ambiguity. There are different buildings types with different purposes and requirements; therefore, one definition will probably not capture all this diversity. 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 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.

## 4.1 Energy focus

Total energy demand in the building is a sum of thermal and electricity demand; however, many studies focus only on one demand 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 1970's and 80's, when large part of energy use in the buildings was mostly due to the heating (space heating and domestic hot water) in publications the zero energy buildings were actually zero-heating buildings, since only heating demand was accounted into a zero balance. 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 some papers the 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 ambiguous. 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"*.

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 majority of the ZEB definitions authors avoid specification of demands included in the balance. The best examples of such type of definition can be find in i.e.: the NREL report "The Potential Impact of Zero Energy Homes" from 2006: "*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."* 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."*

In few ZEB projects and publication the focus is put on the operating energy demand as well as on energy embodied in the building construction and/or materials and/or technical systems. Hernandez et al. (2010) propose even an separate definition for this type of ZEB, in particular the life cycle zero energy building (LC-ZEB) and define it as: "(…) *one where the primary energy used in the building in operation plus the energy embodied within its constituent materials and systems, including energy generating ones, over the life of the building is equal to or less than the energy produced by its renewable energy systems within the building over their lifetime."* Another example of such approach can be the 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."*

## 4.2 Energy Supply system

The scientific publications focus either on off-grid ZEBs or on-grid ZEB. The main difference between those two approaches is that, the off-grid ZEB does not have any connection to the energy infrastructure, thus it does not purchase energy from any external sources, and the boundaries for the balance calculations are within the building. The on-grid ZEB, in the literature also named "net zero" or "grid connected", is the energy producing building connected to one or more energy infrastructures; electricity grid, district heating and cooling system, gas pipe network, biomass and biofuels distribution networks. Therefore, it is has a possibility for both buying and selling energy from/to the utility grid. This division is also well 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 in these publications. The authors 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."*

The papers in which clear definition for the off-grid ZEB are i.e.: 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."* and 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 without including a clear definition of 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): *"(...) 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 publications 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 also become a topic for 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"*

## 4.3 Renewable energy options

In a ZEB definition it is necessary to define 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. 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. |

Moreover 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."*

## 4.4 Type of renewable sources

Conceptually, a zero energy building is a building with greatly reduced energy demand, such that the energy demand can be balanced by an equivalent generation of electricity (or other energy carriers) from renewable 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, based on the literature analysis 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)Karmer, (2007), Mertz, et al. (2007), Parker, et al. (2001), Rosta, et al. (2008), "Riverdale NetZero Project-Edmontom, 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)."*

## 4.5 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 that when the scientific studies of zero energy concept are not describing any 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)."*

### 4.6 Single or Community

If one building can be ZEB, then crating a zero energy community should be just a matter of merging 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 know 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 – minimising residents' use of fossil-fuel cars and the need to commute to work."*

Finally, Morbitzer 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), 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."*

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