

Overview of Zero Energy Building

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ABSTRACT: This paper focuses on the basic information and definitions about Net-Zero energy buildings (NZEB). It also highlights the differences between NZEB and a Green building. What are the environmental apprehensions of adopting NZEB. Energy Efficiency of the building and its measurement and verification play a vital role in advancing ZNEB constructions. Recommendation for the adoption on NZEB buildings including design specifications and construction methodology have been elaborated. The authors high recommend promotion of NZEBs to make it environmental oriented and preserve nature with emphasis on cost controls.

KEY WORDS: Net-zero energy buildings, green building, environment, system boundaries, energy efficiency

I. INTRODUCTION

A zero-energy building, also known as a zero net energy (ZNE) building, net-zero energy building (NZEB), or net zero building, is a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site, or in other definitions by renewable energy sources elsewhere. These buildings consequently contribute less overall greenhouse gas to the atmosphere than similar non-ZNE buildings. Most zero net energy buildings get half or more of their energy from the grid, and return the same amount at other times. Buildings that produce a surplus of energy over the year may be called "energy-plus buildings" and buildings that consume slightly more energy than they produce are called "near-zero energy buildings" or "ultra-low energy houses". The zero net energy consumption principle is viewed as a means to reduce carbon emissions and reduce dependence on fossil fuels and although zero-energy buildings remain uncommon even in developed countries, they are gaining importance and popularity.

Most zero-energy buildings use the electrical grid for energy storage but some are independent of the grid. Energy is usually harvested on-site through energy producing technologies like solar and wind, while reducing the overall use of energy with highly efficient HVAC and lighting technologies.

II. HOW IT IS DIFFERENT FROM GREEN BUILDING

Green buildings are a very wide range of buildings which essentially have measures built in to reduce the energy consumption of the building when compared with a normal building of similar site and occupancy. This can be achieved through optimization of facade and wall materials, passive design features and other measures to reduce the energy consumption. NET zero energy buildings simply put are buildings which generate as much energy as they consume over a period. to put in practical terms they are green buildings which reduce their energy consumption through passive and active measures and then meet their energy needs through renewable sources of energy installed on site. such sources may include solar, wind and hybrid generation techniques. some smaller structures may actually go completely off grid but larger commercial buildings need to be connected to grid power. the power generation peak and the consumption peak may not coincide but the overall energy balance is zero.

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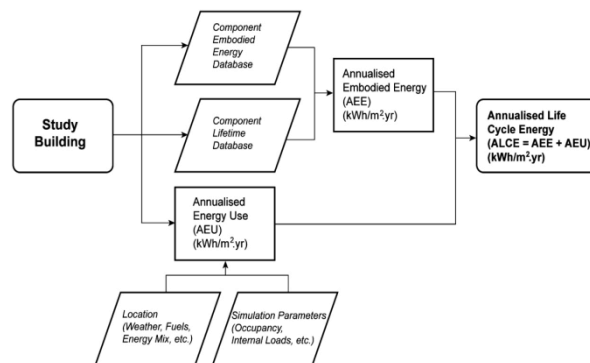
III. INTRODUCTION: THE CONCEPT OF 'NET ENERGY'

Within the built environment the term 'net energy' is often used to describe a balance between energy used by the building and its occupants and systems and energy produced by its renewable energy systems. The net energy analysis has been defined as a 'technique for evaluating which seeks to compare the amount of energy delivered to society by a technology to the total energy required to find, extract, process, deliver, and otherwise upgrade that energy to a socially useful form.

IV. DEFINITION OF ZERO ENERGY AND NET-ZERO ENERGY BUILDINGS

Historical definitions of zero energy are based mainly on annual energy use for the building's operation (heating, cooling, ventilation, lighting, etc.). The term 'net-zero energy' is frequently used to present the annual energy balance of a grid connected building but it does not consider the energy inputs to deliver the building and its components.

V. NET ENERGY AND THE BUILT ENVIRONMENT



Energy evaluation of buildings typically only considers the energy use in the form of electricity or fossil fuels for the operation of a building without considering the other energy inputs from building construction process as, for example, the manufacturing of materials. It can be argued that 'net energy' analysis is indirectly considered in these methods as, for example, reusing and recycling buildings and products (which effectively saves energy in the extraction, manufacturing, processes and transport industries) are rewarded by the rating method. The term 'net' is used in grid connected buildings to define the energy balance between energy used and energy sold, the term 'net-zero energy' being applied when the balance is zero. Net-zero site energy means that a site produces at least the same energy as it uses in a year, independent of the type of energy produced or used

$$ALCE = AEU + AEE \quad (1)$$

The sum of these two energy components gives a life cycle perspective of energy use and is defined as 'annualized life cycle energy' (ALCE), also expressed in primary energy units. A LC-ZEB can now be redefined as one whose annualized life cycle energy is zero.

Development of "smart grids" is ongoing to fully benefit from distributed generation with respect to reducing the grids primary energy and carbon emission factors, as well as operation costs. Within a least-cost planning approach, on-site options have to be compared with measures at the grid level, which take advantage of the economy of scale and equalization of local peaks.

It is clear that the mere satisfaction of an annual balance is not in itself a guarantee that the building is designed in a

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way that minimizes its (energy use related) environmental impact. Net ZEBs should be designed – to the extent that is in the control of the designers – to work in synergy with the grids and not to put additional stress on their functioning.

VI. BUILDING SYSTEM BOUNDARY

The boundary at which to compare energy flows flowing in and out the system. It includes:

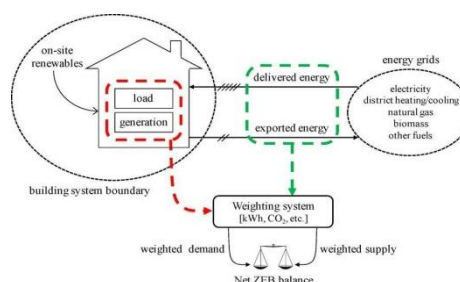
- Physical boundary: can encompass a single building or a group of buildings; determines whether renewable resources are ‘on-site’ or ‘off-site’.
- Balance boundary: determines which energy uses (e.g. heating, cooling, ventilation, hot water, lighting, appliances) are included in the balance.

Delivered energy

Energy flowing from the grids to buildings, specified per each energy carrier in (kWh/y) or (kWh/m² y). This is the energy imported by the building. However, it is established praxis in many countries to name this quantity ‘delivered energy’, see for example.

Load

Building’s energy demand, specified per each energy carrier in (kWh/y) or (kWh/m² y). The load may not coincide with delivered energy due to self-consumption of energy generated on-site.



Weighted demand The sum of all delivered energy (or load), obtained summing all energy carriers each multiplied by its respective weighting factor. **Weighted supply** The sum of all exported energy (or generation), obtained summing all energy carriers each multiplied by its respective weighting factor.

Net ZEB balance

A condition that is satisfied when weighted supply meets or exceeds weighted demand over a period of time, nominally a year. The net zero energy balance can be determined either from the balance between delivered and exported energy or between load and generation. The former choice is named import/export balance and the latter load/generation balance. A third option is possible, using monthly net values of load and generation and it is named monthly net balance.

The Net ZEB balance is calculated as in Eq

$$\text{Net ZEB balance} : |\text{weighted supply}| - |\text{weighted demand}| = 0 \quad (1)$$

where absolute values are used simply to avoid confusion on whether supply or demand is considered as positive. The Net

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ZEB balance can be represented graphically as in plotting the weighted demand on the x-axis and the weighted supply on the y-axis.

VII. FRAMEWORK FOR NET ZEB DEFINITIONS

The Net ZEB definition framework is organized in the following criteria and sub-criteria

Building system boundary

The building system boundary can be seen as a combination of a physical and a balance boundary. Only energy flows that cross the system boundary, i.e. both physical and balance boundaries, are considered for the Net ZEB balance.

1 Physical boundary

The physical boundary may be on a single building or on a cluster of buildings. In this paper the focus is mainly on single buildings, but the same framework would apply equally well to clusters of building. It is important to note though that a cluster of buildings implies a synergy between several buildings which are not necessarily Net ZEB as singles but as a whole. The physical boundary is useful to identify so called 'on-site' generation systems; so that if a system is within the boundary it is considered on-site, otherwise it is 'off-site'. If the boundary instead is set on the building's property or if the power meter is taken as the physical boundary, then the PV system would be on-site.

2 Balance boundary

The balance boundary defines which energy uses are considered for the Net ZEB balance. Operational energy uses typically include heating, cooling, ventilation, domestic hot water, fixed lighting and plug-loads. Other energy uses that do not occur in the operational phase, but in the life cycle of a building may be considered, such as embodied energy/emissions in materials and technical installations. More energy efficient and energy producing buildings are likely to deploy more materials (e.g. insulation) and technical installations (e.g. PV system) including materials whose manufacturing is energy intensive.

Boundary conditions

A consistent Net ZEB definition should allow a meaningful comparison between similar buildings in similar climates, as well as between the expected performance of a building from its design data and the measured performance revealed by monitoring data, see criterion §5: Measurement and verification. It is important to understand if any deviation from expected values is attributable to technical operating or design mistakes, or if it is simply due to different conditions of use. For this purpose it is necessary to explicitly specify a set of boundary conditions: functionality, space effectiveness, climate and comfort.

The functionality describes what type of uses the building is designed for, such as residential, office, school or hospital. In case of multi-functional buildings it is necessary to specify how the floor area is distributed between the different functions. The space effectiveness can be expressed in terms of people/m² or, consequently, of energy use per person. Variations from expected functionality and/or space effectiveness are important and should be taken into consideration before comparing the expected performance with the monitored one.

VIII. LOAD MATCHING

The temporal match between load and generation for an energy carrier gives a first insight on a building's ability to work in synergy with the grid. When there is a poor correlation between load and generation, e.g. load mainly in winter and generation mainly in summer, the building will more heavily rely on the grid. If load and generation are more correlated, the building will most likely have higher chances for fine tuning self-consumption, storage and export of energy in response to signals from the grid,

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IX. ENERGY EFFICIENCY

A Net ZEB definition may set mandatory minimum requirements on energy efficiency. Such requirements may be either prescriptive or performance requirements, or a combination of the two. Prescriptive requirements apply to properties of envelope components (e.g. U-values of walls and windows, air-tightness in pressurization test) and of HVAC systems (e.g. specific fan power, COP of heat pumps), while performance requirements apply to energy needs (e.g. for heating, cooling, lighting) or total (weighted) primary energy demand. For an overview of prescriptive and performance based energy efficiency requirements adopted in existing national or commercial certification systems. Mandatory requirements on energy efficiency may be determined on the basis of cost-optimality considerations as in the plans

of the EPBD such methodology is still under development for the time being. Alternatively, mandatory efficiency targets could simply require a demand reduction (e.g. 50%) compared to a reference building of the same category (e.g. detached house, office, school).

In absence of explicit requirements on energy efficiency it is left to the designers to find the cost-optimal balance between energy efficiency measures and supply options, eventually considering embodied energy too, if in the balance boundary.

X. MEASUREMENT AND VERIFICATION

As a minimum, an M&V protocol for Net ZEBs should enable the assessment of the import/export balance, as this is the core of the Net ZEB concept. Eventually, an M&V process could aim at evaluating also the temporal match characteristics, such as the load match or grid interaction indices. This requires setting the time resolution and selecting the duration of measurements, sampling and recording time.

As comfort is a mandatory requirement in buildings, an M&V protocol should also check the indoor environmental quality (IEQ).

The complexity can then increase significantly due to the large number of sensors likely required in several locations within a building. Nevertheless, to warrant indoor comfort is always the first priority in building design and the risk of designing Net ZEBs with poor IEQ shall be avoided; IEQ measurements would help to this respect. Furthermore it would help explaining possible deviations from the expected energy performance – in relation to the expected operating conditions the electricity use for plug-loads,

would require the installations of a separate meter—or possibly several—in addition those located at the interface with the grids (on the physical boundaries). This means moving from a whole building monitoring approach to sub-metering increasing the complexity of the monitoring system and jeopardizing the verifiability of the definition. For an easily verifiable definition, hence, it would be preferable to have all the energy carriers crossing the physical boundary included in the balance boundary as well.

XI. LITERATURE REVIEW

ZEB definition can be influenced by (1) the project goals, (2) the intentions of the investor, (3) the concerns about the climate and greenhouse gas emissions and (4) the energy cost. Therefore, they propose four different ZEB definitions: site ZEB, source ZEB, emissions ZEB and cost ZEB, respectively. The authors point out advantages and disadvantages of each of the definitions i.e. easy implementation of 'zero site energy' and 'zero energy costs' definition.

The issue of large storage capacity, backup generators, energy losses due to storing or converting energy and oversized renewable energy producing system in autonomous ZEB result in lack of global implication of the off-grid ZEB

(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' 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

- Domestic hot water: 14.4 kWh/m² (52 MJ/m²) per year

- Space heating: 13.7 kWh/m² (49 MJ/m²) per year

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- Electricity for operating the building: 7.6kWh/m² per year
- Electricity for household: 15.0kWh/m² per year
- PV electricity production: 22.6kWh/m² per year
- PV/T thermal production: 8.3kWh/m² (30 MJ/m²) per year
- Heat pump thermal output: 20.0kWh/m² (72 MJ/m²) per year

Thus, it is not included as renewable energy generation within the calculations. The BOLIG exchanges only electricity with the utility grid, however, as the building is still in the design phase and exact electricity flows between the building and the electricity grid are un-known, it is assumed to be 67% of the total electricity production. The only case for adopting this metric is for the ZEB using only one energy carrier e.g. full-electrical ZEB. Hence, most frequently applied unit is primary energy. It allows taking into consideration the difference in the generation and distribution of 1 kW of electricity and 1 kW of heat or natural gas and thus express better the actual building energy use. This approach may consider an outlook on the grid of the future (e.g. decreasing primary energy factor with time). Another option, not very popular within the building community, however, adopted by methodology, is the sub-yearly balance i.e. seasonal or monthly. By using these balancing periods the energy producing systems are dimensioned to better match the actual energy demand, but on the other hand they can be often oversized. Moreover, it is more difficult to achieve zero balance than in the case of annual balance, since the seasonal discrepancy between energy demand and renewable energy generation.

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 	<ul style="list-style-type: none"> • Need to develop site-to-source conversion factors, which require significant amounts of information to define.

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		efficiency technologies. • Does not consider all energy costs (can have a low load factor).	
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 non-energy 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.

XII. PERIOD OF THE BALANCE

The period of time over which the building calculation is performed can vary very much. It can be an exhaustive full life cycle of a building or the operating time of the building (e.g. 50 years) or very commonly used annual balance or applied in special situations a seasonal or monthly balance.

XIII. APPLIED METHODOLOGIES

Eleven out of twelve methodologies are based on the annual balance, which could be expected. Firstly, due to the fact that most of the building energy simulation programs as the final result give the annual energy use of a building, and secondly it is also the most preferred balancing period among the ZEB definitions in the literature.

Nevertheless, there is one – methodology – that uses a monthly balance with a special requirement that out of total onsite renewable electricity generation only the amount that is equal to electricity use can be accounted in the balance. Other energy carriers cannot be balanced.

XIV. RENEWABLE ENERGY SUPPLY OPTIONS

The renewable sources can either be available on the site e.g. sun, wind or need to be transported to the site e.g. biomass. Therefore, in principle two renewable energy supply options exist: on-site supply and off-site supply, respectively. 'The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby'.

For the on-site supply they distinguish between supply within the building footprint and supply within the building site. As for the off-site supply, they indicate that building either uses renewable energy sources available off-site to produce energy on-site, or purchases off-site renewable energy sources.

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XV. CONCLUSION

The choice of a proper balance metrics and weighting system should depend on targets in the political agenda and not being driven solely by feasibility of Net ZEB projects or minimization of investment cost; even though this may be a major target itself. However, it is important that authorities and competent national bodies and legislators are fully aware of the effect of the weighting factors when deciding upon the metrics to adopt for the Net ZEB definition they want to set in place. regards to metric, period and type of the balance, types of energy use included, renewable supply options, primary energy and CO2 factors and unique features.

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BIOGRAPHY



Prathamesh Vijay Bagare, is a B.E. Civil graduate M. H. Saboo Siddik College of Engineering. He is passionate about green buildings, sustainability and overall impact of construction industry on environment. Being a civil engineer, the author wants to work in the field of environmental sustainability for the betterment of society. He has presented multiple research papers in various conferences.



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Dhruv Desai, This is Dhruv Desai's life Mantra. Since his birth in Mumbai, India to months spent in Blacksburg, he has strived for his goals. His dream is to learn and grow in the field of construction. He aspires to build his father's construction company many more bounds further. As for now, he is studying Construction and Engineering Management (Department: Civil and Environmental Engineering) at the prestigious Virginia Tech, VA. Dhruv has earned his Bachelor's Degree in Civil Engineering from the University of Mumbai, India.