Zero-Energy Buildings-A Review

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ABSTRACT

A zero-energy building (ZEB), which is an autonomous building energy option, is defined as a building that produces as much energy as it uses from renewable energy sources at the site. Zero-energy buildings can exchange energy with the power grid as long as the net energy balance is zero on an annual basis.In terms of the thermal energy transfer and storage, zero-energy buildings can achieve annual energy consumption levels down to 0 kWh per square metre through the use of renewable energy sources, which compares favourably with the passive house energy criteria per square metre. Energy plus houses, in contrast with both the passive houses and zero-energy buildings, focus on producing more energy per year than they consume, which can lead to an annual energy performance of -25 kWh per square metre. Zero-energy buildings should have features like:

i) Enable building owners to be isolated from fluctuating energy prices through the on or off-grid renewable energy supply

ii) Help reduce peak electrical demand by self-supplying energy demands on site

iii) Go hand in hand with the transformation of energy infrastructure and market.

Zero-energy buildings can be achieved by incorporating energy efficiency measures and on-site renewable energy generation technologies and its energy efficiency measures include: creating a high-performance building envelope, installing energy efficient appliances and lights, increasing the use of passive solar cooling and heating techniques and installing high-efficiency mechanical systems that match the lower energy requirements of the home. On-site renewable energy generation systems can be available within a building's footprint by using PVs, solar hot water and wind located on the building or at the site by means of PVs, solar hot water, low impact hydro and wind located on-site not on the building.

Zero-energy building is still in the conceptual stage in the Asia-Pacific region. A few pilot projects have been applied to public buildings, such as research institutes, for demonstration purpose e.g., Sustainable Energy Technology Centre in China, Pusat Tenaga Malaysia's Zero Energy Office (ZEO) Building and National Institution of Environmental Research in Republic of Korea.

Key Words: *Zero Energy Building, Energy Conservation, PV.*

1. INTRODUCTION

Large-scale shifts in dominant technologies are the necessary components of a transition towards sustainability. Such shifts are difficult because, in addition to technological innovation, they require changes in the existing institutions, professional norms, belief systems and, in some cases, also lifestyles. One way to facilitate this type of learning is through experimentation with new technologies and services. Over the past decade, environmentally oriented innovations in technology and services have emerged

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in all areas of the economy, driven by governmental policies, professional experts, market opportunities and social movements. The building construction sector, where interest in high performance buildings has been on the rise, is a primary example. This interest manifests itself in diverse ways, including a growing number of so-called green buildings or zero energy buildings, mostly in the public and commercial sectors and on university campuses. Additionally, democratic and federal states, and local governments are increasingly adopting policies to encourage high performance buildings, through tax incentives and subsidies, expedited permitting, or through adopting minimum requirements in public construction. The Zero Energy Building (ZEB) concept is no longer perceived as a concept of a remote future, but as a realistic solution for the mitigation of CO2 emissions and/or the reduction of energy use in the building sector. The increasing number of ZEB demonstration projects [1–7] and research interest in the ûeld [8–11] internationally highlights the growing attention given to ZEBs.

2. ENERGY EFFICIENCY AS A STARTING BASE

Components of solar houses, passive houses or whole passive house concepts are a basis for the energy efficiency in many built examples. Approximately one third of the worldwide recognized Net ZEBs use this idea and lower the energy demand of the buildings in all typologies equally by nearly 60% in comparison to standard buildings which were build according to current building directives. This calls for very good insulation, use of passive solar heat gains and a high compactness. The average surface to volume ratio is around 0.6 in the residential sector and around 0.3 in the non-residential sector. On the average, a maximum height of 3 stories is present in the residential sector and fewer stories in the office building sector. The latter is due to the strong cost pressure of this more energy intensive real estate sector. Some measures promote in addition to a reduced energy demand also the user comfort. Mechanical ventilation systems, partially with heat recovery, advanced day lighting or solar shading devices are used nearly as often as solar-thermal domestic hot water processing or power saving HVAC technology. The latter reduces both the heat demand and electricity demand. In an international scope, this is only partially grasped by construction specifications or energy directives. Also, the load of e.g. household appliances or office equipment is not illustrated in these regulations; however, it is present in most of the Net ZEB balances. A restriction on partial sectors of the consumption prevents the continuous examination in practice and extracts essential parts of the consumption from its necessary optimisation. The consumption should be measured furthermore with renunciation of oversized meter equipment. The annual measurability of energy consumption is an excellent aspect of the net zero energy principle. By including the electricity consumption, the need to reduce the electrical demands is evident. Nevertheless, it is obvious that this is hard to achieve in practice. Sparing equipment in offices or flats, as well as LED lighting, have been realized only in cases in which users and owners are the same authority. In this consumption sector, further savings potential is present.

As mentioned, the ZEB concept is the future international goal, however in order to progress with this aim there is a genuine demand for a commonly agreed framework for definition and calculation methodology. This paper first gives an overview of existing ZEB definitions with highlighting the most important aspects which should be discussed before developing new ZEB definitions. And finally, the paper attempts to provide some recommendations on the direction the development of a future ZEB definition and calculation methodology should proceed.

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3. THE CONCEPT AND DEFINITIONS

In concept, a Net Zero Energy Building (NZEB) is a building with greatly reduced energy needs through efficiency gains such that the balance of the energy needs can be supplied by renewable technologies. A good NZEB 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 NZEB. Efficiency measures or energy conversion devices such as daylighting or combined heat and power devices cannot be considered on-site production in the NZEB 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.

A zero energy building can be defined in several ways, depending on the boundary and the metric. Different definitions may be appropriate, depending on the project goals and the values of the design team and building owner. For example, building owners typically care about energy costs. A building designer may be interested in site energy use for energy code requirements. Finally, those who are concerned about pollution from power plants and the burning of fossil fuels may be interested in reducing emissions. Four commonly used definitions are: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions.

Each definition uses the grid for net use accounting and has different applicable renewable energy sources. The definitions do apply for grid independent structures.

3.1 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.

3.2 Net Zero Source Energy

A source ZEB produces at least as much energy as it uses in a 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.

3.3 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.

3.4 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.

Torcellini, Pless, Deru, & Crawley [12] indicate that the unit applied in the ZEB deûnition can be inûuenced 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 diferent ZEB deûnitions: site ZEB, source ZEB, emissions ZEB and cost ZEB, respectively. The authors point out advantages and disadvantages of each of the deûnition i.e. easy implementation of 'zero site energy' and 'zero energy costs' deûnition, more international and not regional feature of 'zero source energy' definition and calculation complexity of 'zero energy emission' definition. The proposed distinction between different metrics is brought up and further discussed in a number of publications [4,13–16]. Kilkis [20] states that the metric of the balance in the ZEB definition should address both the quantity as well as the quality of energy, if we want to assess the complete building's impact on the environment. Therefore, he proposes a new definition for the term ZEB, 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'. Mertz et al. [17] and Laustsen [18] distinguish only two units of the balance: emissions and energy, however, without specifying delivered or primary energy. The definition of 'Near Zero Energy Building' from the EPBD [19] is clear and uses the primary energy as the metric for the energy balance.

Designing a building in such a way that energy efficiency and on-site production convert it from an energy consumer to an energy producer lies at the heart of the zero-energy building (ZEB) concept. The concept is being researched at the National Renewable Energy Laboratory (NREL) through Building Technologies Program (BT)-funded research. NREL selected photovoltaic (PV) power systems as the technology for on-site production because the roofs of virtually all commercial buildings are viable sites.

4. WORLDWIDE SURVEY ON NET ZERO ENERGY BUILDINGS

During the last 20 years more than 200 reputable projects with the claim of a net zero energy balance have been realized all over the world. The number of finished buildings per year has risen continuously. In the beginning, extreme pioneering examples were realized by researchers. Within a short time, the first small net zero energy residential buildings were being built by ecologically enlightened developers and architects. They were often inspired by funded solar electricity generation and demonstrated a direct advancement beyond the then recently developed passive house concept. With the increase in availability of efficient technical solutions, bigger and more energy intensive building typologies have been built as Net ZEBs since 1998. Private building owner alliances and house building societies have implemented Net ZEB apartment houses and small settlements. Their focus has been threatening resource shortage, climate protection as well as the avoidance of rising energy costs. In addition, architects used the concept of zero energy buildings to position themselves in the former niche and now current boom branch of "high performance buildings", "green buildings" and even "zero energy buildings". Medium-sized enterprises and real estate companies took up the increasing hype in the sector of "green" buildings. To improve the image of the company or to offer real estate's more attractive than its opposition, they have built Net ZEB factories, office buildings and apartment houses. Often these buildings are certificated and equipped with sustainable technologies or materials. Nearly every tenth Net ZEB is also distinguished with a LEED-, DGNB-, Minergie-P, BREEAM- or a similar certificate. This shows the marketing strategies of these companies. The first large scale enterprises to become involved (Burger King, WalMart) are not known primarily for sustainable buildings but hope for competitive advantages from a "green" image improvement. To date, most finished Net ZEB projects were realized and originate in northwesterly situated countries and climates. Availability of economic resources, a head start in the field of technologies and knowledge of their energy and climate problem force these kinds of projects, even if the climatic conditions in central Europe and North America seem less suitable than in milder climates. The distribution of U-values of existing Net ZEBs in different climates shows that much more expenditure must be raised for the building cladding

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because of comfort and physical needs in these areas. Beside the passive house concept, a big pool of single measures concerning energy conservation can be found. Isolated measures are combined in integral draughts due to special exigencies. Besides, not all these measures have direct influence on the architecture of the buildings. The objection that efficient material and technologies are often not compatible to original design draughts is valid only partially. A great variety in possibilities can be found in the yet built projects.

5. CONCLUSIONS

Energy efficiency improvements that use the best available technologies and practices and integrated, whole-building design approaches can, on average, reduce consumption by 43%. Reducing consumption through energy efficiency is important in the ZEB context because it requires much less PV to reach net-zero. The main reason buildings failed to reach zero in this study was that they had too little roof area to accommodate PV. Achieving the ZEB goal on a given building project depends on four characteristics: (1) number of stories; (2) plug and process loads; (3) principal building activity (PBA); and (4) location. Establish a formal and clear definition of a ZEB. This study used net site energy of zero or less (less in this context means that the building produces more energy than it consumes) within the building envelope. We favor this definition because it is verifiable and does not require complicated conversion factors to be developed and maintained or energy systems to be included outside of buildings. However, there are pros and cons for all the possible definitions of ZEBs, including net zero source energy, net zero energy costs, and net zero carbon emissions.

- Establish a strategy for selecting subsectors on which to focus based on two priority criteria: (1) how easily the ZEB goal can be met and (2) how much sector energy can be reduced. The warehousing subsector offers the best opportunity in both criteria because warehouses are often single-story buildings with low plug and process loads. Educational and office buildings represent a good opportunity to reduce overall energy use. The service and retail subsectors are the next biggest opportunity.
- Develop a targeting strategy for selecting technology areas on which to focus based on different priority criteria: (1) how significant the savings potential is for current practice and (2) how significant the savings potential is for ZEBs. For ZEB commercial buildings, current research programs for lighting and dynamic windows should be augmented with efforts to improve thermal insulation levels, increase the efficiency of appliances and HVAC components, and promote publication and adoption of aggressive energy standards such as BSR/ASHRAE/USGBC/IESNA Standard 189P. Daylighting technology should not be neglected because it has relatively low technical risk (compared to advanced lighting) and because it can have a powerful positive effect in some building types (daytime operating hours and much of the regularly occupied floor plate within 20 feet of an outside surface) and on productivity and health. Though not modeled directly in this study, attaining performance levels suggested by the modeling results will also depend on success in the areas of integrated design, controls, commissioning and operation.
- Develop and maintain a set of standardized benchmark building definitions and models that offer consistent methods for measuring progress. These buildings should focus on ZEB issues such as the solar resource (rather than just efficiency) and include a relatively small number of models to enable technologies and practices to be studied cost effectively at the national level.

- Improve the accuracy of input data on plug and process loads and schedules. The results show that in future ZEBs, plug and process loads are expected to be the largest energy end use; however, few hard data are available about them. Research is required to collect submetered data that go far beyond those obtained by CBECS.

The attention given to the Zero Energy Building concept increased during the last years. Many countries have already established ZEBs as their future building energy target. Among different strategies for decreasing the energy consumption in the building sector, ZEBs have the promising potential to significantly reduce the energy use and as well to increase the overall share of renewable energy. However, in order not to fall short of expectation, there is a need for commonly agreed ZEB definition framework and a robust 'zero' calculation methodology. This framework should allow for a variety of solution sets and not focus only on PV based solution sets, as this strategy is mainly addressing small and new buildings.

This paper presented a literature review of ZEB definitions and proposed energy calculation methodologies for ZEBs. The ZEB definitions are expressed with a wide range of terms and phrases in the literature whereas the calculation methodologies are more consistent and have a common framework. Based on the literature review, the paper identified and presented a set of parameters that differ between ZEB definitions and which should be elaborated before defining a harmonized ZEB understanding.

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