Defining Zero Energy Buildings from a Cradle to Cradle Approach

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ABSTRACT: Several bodies including the DOE, ASHRAE and the IEA SHC Task 40 are working on developing definitions for Net Zero Energy Buildings (NZEBs). Most existing definitions are based on setting a performance metric (quantity and quality) such as site energy, source energy, energy costs, or emissions, and a boundary for the energy source. However, the problem of most existing definitions is that they neglect the energy use during the whole building lifecycle, neglect the climatic context, neglect the urban or city scale, derive from a 'zero' or neutralizing notion, link the energy use to area separately from occupants and do not specify the intended definition audience they address e.g. policymakers or building developers or construction professionals. On the other hand, the cradle to cradle approach encourages the creation of ecologically positive footprint buildings where buildings are very efficient by design and by using suitable technologies to become energy positive. The cradle to cradle approach allows us to examine broader criteria including the embodied energy, environmental impact, energy storage and the management of plus energy. Therefore, in this paper, we discuss those problems and suggest a necessary shift to approach NZEB definition, from a cradle to cradle approach rather from a balance approach. This paper provides an overview of existing definitions and compares their impact toward cradle to cradle NZEBs. Finally, the paper sets three principles for defining NZEBs and suggests a definition, metric and calculation method from a cradle to cradle approach.

Keywords: definition, net, near, zero energy, buildings, cradle to cradle

1. INTRODUCTION

Many scholars and committees are analysing and discussing various definitions of 'zero energy buildings' [1-5]. However, there have been debates on the effectiveness of the 'zero energy' or 'net zero energy' concept on the long term decision making. One of the reasons of controversy is due to the difficulties of setting boundaries. Different methods and levels of accuracy have been used for energy analysis over the years and results have been expressed in different terms including energy cost, energy source, energy site and energy emissions. Moreover, the existing definitions potentially mislead the application because they do not take into account the total energy input during the whole building life cycle. They are trapped by the charm of the phrase 'zero energy'. Despite that the NZEB objective has raised the bar for sustainable development in the building industry, it still remains theoretical and is only considered as a short term goal that limits the innovation and creativity of achieving a long term vision for sustainable building. In fact, most these definitions are based on balance approaches that aim to reach energy neutrality and emerge from an ecological footprint reduction paradigm. Existing definitions do not account for wider perspective than annual energy during the operation of building. Some voluntary environmental rating systems including BREEAM, LEED and CASBEE include issues such as material choice, transportation and reusing buildings but do not directly approach the embodied energy and building life cycle.

However, the environmental and resource limitations provide increased motivation for design of plus energy buildings. The world energy outlook is expecting an increase of about 60% of energy consumption worldwide. In fact, we cannot achieve fossil free buildings without setting a comprehensive definition from a Cradle to Cradle a (C2C) approach. A definition that includes all energy inputs during a building's life will reveal where the potential lies for maximum impact of environmental decisions on the overall life cycle of buildings. We need a definition that takes into account the energy use before, during and after the building and provide a framework that allows comparison, analysis and a perspective on opportunities that optimize the use of energy resources.

1.1. Objective:

Therefore, this paper aims to examine and refine this issue, particularly by comparing existing definitions and reviewing them in light of a more comprehensive NZEB definition. Our goal is to provide a defensible and realistic definition of innovative NZEBs that cater to the cradle to cradle (C2C) philosophy [6]. The need for clarity and accuracy has become increasingly important as the NZEB concept has become more widespread. Yet without a universally accepted definition of what zero impact entails, the issue has become confused. Without consistent parameters to determine NZEB compliance there is no way to achieve our sustainable objectives. Without the performance indicators and boundaries, the end result is predictable: buildings will continue to be produced on the basis of the same practice that has produced our existing built environment.

2. EXISTING DEFINITIONS AND PERSPECTIVES

In the field of the built environment the concept of 'net zero energy' was first introduced in the 1970s when ecologist Howard Odum, stated that '*the true value of energy to society is the net energy, which is that after the costs of getting and concentrating that energy are subtracted'* [7].However, 40 years later the concept of 'net zero energy' has not been clearly defined or introduced in the main stream certification, calculation and standardisation methods.

The following chapter reviews the different definitions of 'near zero', 'zero' and 'net zero' energy buildings. We should note that determining if a building is truly 'zero energy' or 'net zero energy' is a complex task. Definitions by default are constricting because they are static, while the reality is that buildings and their life cycles are dynamic.

2.1. NEAR ZERO ENERGY DEFINITION

There are several early examples for attempts towards '*near zero*' energy including the 1939 MIT Solar House I, using solar thermal collectors and water storage and the 1955 Bliss House using solar air collector and rock mass. Examples include the Vagn Korsgaard Zero Energy Home in Denmark Saskatchewan House in Canada [8]. Most examples are based on heavy insulation, good air tightness and heat recovery. This approach allowed the reduction of solar collection surface and solar storage when compared to previous attempts. Those buildings used some features that apparently work well and became mainstream in low energy constructions. Also these early examples contributed to the upgrade of voluntary and obligatory standards towards '*near zero*' energy including the Passivhaus in Germany and the R-2000 scheme in Canada [9]. Also the EU Directive on Energy Performance of Buildings (EPBD) specifies that by the end of 2020 all new buildings shall be "*nearly zero energy buildings*". The EPBD, for example, states that "*nearly zero energy building means a building that has a very high energy performance*" and that "*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*" [10]. Thus the term ' *near zero*' is used for reduction demand and increasing efficiency.

2.2. ZERO ENERGY DEFINITION

The term '*zero energy*' refers to autonomous off-grid buildings. The idea of autonomous buildings is to use energy storage system that stabilizes the energy availability. The earliest example, the Dymaxion House, was built in the USA in 1950. Examples include the Ark Bioshelter in 1970s and development of Earthships in the 1990s. The design '*zero energy*' buildings require large roof area for mounting solar collectors and PV arrays. Due to the seasonal and annual climatic variations, the criteria of sizing the collection and storage systems dictate large size costly storage systems [11]. If 'zero energy' buildings are analyzed from a life cycle approach they will have a heavier energy and environmental impact compared to 'near' and 'net' zero energy buildings [12].

2.3. NET ZERO ENERGY DEFINITION

The term '*net zero*' is used for calculating the annual energy use for the building operations including cooling, heating, ventilation, lighting and plug loads. The term 'is based on using the electricity grid both as a source and a storage medium thus avoiding the onsite electricity storage. Since the revival of the 'net zero' concept in the 1970s in the field of the environment there has been an agreement to connect a domestic renewable system to the electricity grid. This argument has been adopted widely due to the better life cycle performance of NZEBs versus autonomous buildings [12]. The 1988 Chanelle zero energy house in Norway and the 1996 Freiburg self sufficient house in Germany were the earliest attempts in Europe. Since then several concrete classifications and calculation methodologies for zero energy building or net zero energy buildings (NZEB) unfolded [13, 14].

One of the earliest classifications for four primary definitions found in literature was the study by Paul Torcellini, Shanty Pless and Michael Deru with the National Renewable Energy Laboratory (NREL) set one. The authors highlighted the influence of the definitions on project design and success in achieving the zero energy goal [15]. The four definitions are based on the site energy, source energy, energy costs, or emissions. All four definitions assume a grid connected building where the annual export and import is equalized during the term of one year. The '*net zero site energy*' definition assumes producing at least as much energy as used in a year, when accounted for at the site. The '*net zero source energy*' assumes producing at least as much energy as used in a year when accounted for at the source, referring to the primary energy used, using site-to source conversion factors. The '*net zero energy costs*' assumes that the money paid by the utility to the building owner for energy exported to the grid is at least equal to the amount the owner pays the utility over a year. Finally, the 'net zero energy emissions' assumes producing at least as much emissions-free renewable energy as used from emissions-producing energy sources. The authors suggest that buildings should first reduce energy use overall, and produce electricity within the building footprint.

Another study by Kilkis [16] highlighted the importance of balancing the neutrality of energy regarding the quantity and quality (exergy) of energy. He stressed on the exergy as an optimal metric that can assess the complete impact of the building on the environment. Therefore, the author suggests a new definition for ZEB namely the Net Zero Exergy Building (NZXB) 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". On the other hand, Mertz, et al. [17] describes a method of performing and comparing lifecycle costs for standard, CO_2-neutral buildings. The authors emphasize on the costs of source energy to be calculated based on the cost of photovoltaic systems, tradable renewable certificates, CO_2 credits and conventional energy.

Moreover, a number of authors focused on finding a common definition for electricity dominated buildings. For example, Gilijamse [18] defines a ZEB as building where no fossil fuels are consumed, and annual electricity consumption equals annual electricity production. The author considers the electrical grid as a storage buffer with annual imports and exports. Iqbal [19] defines ZEB as buildings that does not consume fossil fuels and produces an equal amount of electricity over the term of one year.

Among the variety of definitions, in practice many practitioners have opted to meet the site ZEB goal, as with this approach there is no need to adjust for grid generation and transmission losses, utility emission rates, or utility cost structures. As these values can vary greatly by location, the site ZEB goal simplifies energy calculations and provides a more level playing field.

3. THE PROBLEM OF EXISTING DEFINITIONS

Thus far the definitions for achieving zero energy have been reviewed from a conceptual perspective. To a large extent most of these definitions aim to reach a balance by setting energy metrics (kWh or MJ), boundary balance (net zero) and balance period (monthly, seasonally or yearly). However, there are major problems with most definitions. To face those problems, the joint team of the IEA SHC Task 40 is developing criteria for NZEB definition [20]. Figure 1 illustrates a summary of the scope of questioned criteria among the task activities. This chapter discusses the major faults of existing definitions from a technical standpoint along with an examination of the relevant characteristics of the zero energy building philosophy.

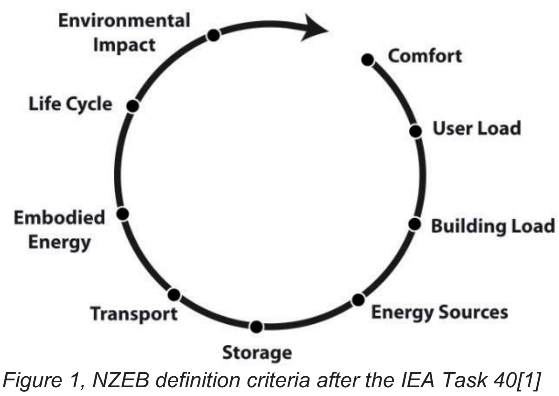

Figure 1, NZEB definition criteria after the IEA Task 40[1]

The primary problem that has weakened previous attempts to define a zero energy use of resources is the tendency of researchers to deal energy only during operation, regardless of the total life cycle and associated CO_2 emissions. The energy used in the building has a history of energy consumption behind it: the energy of manufacturing, transporting and processing the resource. The 2002 Beddington Zero Energy Development model, in the UK, followed later as a revolutionary attempt to associate carbon emission to energy variously referred to as zero carbon, carbon neutral, or fossil free development [21]. However, the existing definitions ignore those important aspects. Therefore, in order to truly achieve zero energy, we need to be willing to see and deal with all the life cycles and to pursue a more integrated approach that takes this into account. Additionally, it would be beneficial to create a CO_2 index so that we have a consistent understanding of the energy consumption impact within the building process and during the life cycle.

Secondly, the existing definitions derive from the notion of neutralizing the resource consumption and define this as zero energy consumption. In fact, the "break even" approach is very limiting. Restricting the boundaries to 'zero' or 'net zero' is misguided. The 'zero' goal limits innovation and creativity in achieving long-term sustainable building practices. If energy generated on site prove to be abundant resources, why then should we limit our objectives to zero? Moreover, it discourages the potential to research how buildings can in fact become fossil fuel independent. The decline in the availability of oil, gas and coal means that the cost of fossil fuels will become increasingly volatile. Peak oil will have a huge impact throughout the economy. The existing definitions seek to reach zero energy buildings within a black fossil fuel paradigm. Thus, a C2C definition of NZEBs should emphasize the viability of harnessing renewable resources.

Thirdly, most definitions focus on linking resource consumption efficiency to building area regardless of occupants. In fact, taking into consideration the needs of occupants is equally as important as building area in achieving consumption efficiency. For example, Switzerland is considering a resource efficiency measurement per capita. The Swiss 2000-Watt Society proposes defining energy consumption relative to the number of occupants [22]. Similarly, the United Kingdom is proposing a Personal Carbon Allowance (PCA). The PCA concept is based on setting tradable domestic quotas at around 5 tonnes of CO_2 per capita per year [21].

Fourthly, most perspectives neglect the urban context as a factor of influence and its implications on the relation with energy grids. Researchers have worked to define universal parameters that do not always correspond with urban context or seasonal variations. Definitions should address the energy quality (primary), type (solar, wind, CHP), storage, grids and transmission in relation to urban density. For example, in community and city scale it will be difficult to generate renewable energy on the building scale. It becomes very important to match renewable energy profile to the urban typology and scale and maximize building integrated micro generation and exchange within urban plots boundaries [23]. Thus NZEBs should be defined as context-sensitive, thereby allowing for diversity and flexibility in buildings relative to their context.

Fifthly, most perspectives neglect the climatic context as a factor of influence and its impactions on the relation with comfort. The study of Sartori et al. showed that achieving the NZEB differs from country to another according to its considerations of climate-adapted indoor comfort criteria [24]. For example, the application of adaptive model of ASHRAE Standard 55:2004 or EN 15251:2007 can differ significantly from applying the Predicted Mean Vote (PMV) model of Fanger. None of the discussed definitions addressed the implications of comfort criteria choice n the building energy requirements and ability to achieve the NZEB goal.

In brief, existing definitions for NZEB are theoretical and require more refinement to reflect the reality of our future. Up to now, most definitions have not been comprehensive enough to tackle the zero energy objectives from a C2C approach. A NZEB should mean that a building's energy efficiency is maximized while taking into account the embodied energy, grid generation and transmission losses, utility emission rates, and utility cost structures. There is a certain urgency to set a definition for zero energy buildings, one that considers energy during all life cycles simultaneously. Also any definition should seek simplicity and consistency in order to facilitate comparison and provide effective design guidelines. The energy definition should have standardized metrics and benchmarks that are debated and agreed upon. A conceptual shift in how to effectively approach NZEB objectives is therefore necessary. This requires a further discussion of the core subject in this research: the C2C approach.

4. TOWARDS A C2C COMPATIBLE DEFINITION

This chapter brings us back to the core issue behind this paper: how to define NZEBs from a cradle to cradle perspective and attain a consistency and precision of definition that allows performance comparison and achieves a sustainable built environment in a feasible manner. The following procedure is to define the parameters of the definition of a NZEB by choosing a metric and setting a boundary limit.

From the discussion above we can conclude that there are three important criteria that should converge in a C2C compatible NZEB definition. Firstly, the definition must incorporate maximizing on the viability of harnessing renewable resources and become fossil energy independent. In this way, we avoid cradle to grave processes and supplant them with cradle to cradle metrics. Secondly, the definition must be based on primary energy, embodied energy and associate carbon dioxide emissions related to the energy use. Thirdly, the definition must include life cycle aspects of the energy use. In order, to achieve positive building footprint we must move from the cradle to grave paradigm that aims to reduce, avoid, minimize or prevent the use of fossil energy to a C2C paradigm that aims to increase, support, and optimize the use of renewable. As shown in Figure 2, the previous definitions are operating within a carbon negative or neutral approach that will never reach a positive and beneficial building footprint. The existing net balance approach assumes a fundamental dependence on fossil fuels. Therefore, we propose a definition that is based on renewable self efficiency. Whilst addressing the problems previously discussed, a new definition is as follows:

A cradle to cradle compatible net zero energy building seeks the highest efficiency in the management of combined resources and a maximum generation of renewable resources. The building's resource management emphasizes the viability of harnessing renewable resources and allows energy exchange and micro generation within urban boundaries.

Figure 2: clear line drawings are essential

The following units are suggested as universal metrics for communicating the resource management efficiency among all stakeholders involved in the building industry. The suggested metrics in Equation 1 and 2 conform to other international units as closely as is compatible with self-consistency comprehensive, and, in large part, already employed in practice.

$$\textbf{Energy Use} = \frac{\textbf{primary energy}\ (\text{kWh})^{*}\textbf{CO}_2\ \textbf{Index}}{\textbf{area}\ (\text{m}_2)\cdot\textbf{year}\cdot\textbf{capita}}$$

$$\textbf{Embodied Energy} = \frac{\textbf{primary energy}\ (\text{kWh})^{*}\textbf{CO}_2\ \textbf{Index}}{\textbf{area}\ (\text{m}_2)\cdot\textbf{year of total life cycle}}$$

5. DISCUSSION

The purpose of constructing a C2C based definition is to create a common framework that can be built upon in the future. Exposing the definition to for the long future will allow new ideas and tighter constructions to be added. The definition is only the beginning of a further process of definition, which the building design community must pursue. The definition of what makes a NZEB fits into C2C perspective. Our goal here is not to advocate a fixed, one-size-fits-all approach to defining NZEBs, but to rethink our goals and responsibilities for a consistent long-term approach. We believe that definitions for

NZEBs could be successful concepts if they integrate all aspects of building design and construction practice and are supported by transparent evaluation methodologies.

A C2C compatible definition recognizes synchronous cycles in resources during the building life cycle. Despite that the life cycle assessment is ill defined terrain; energy is interconnected in various ways in NZEBs. Therefore, a proper definition should focus on an overall balance, diverting resources where appropriate and giving them back to nature so that buildings are in equilibrium with their resources. Any zero energy metric should measure the carbon impact of energy consumption as a whole. The usage of energy reviewed is understood in a specific way and makes a specific and unique contribution in relation to carbon emissions. Designers should embrace the proposed standardized metrics and calculation methods as a means towards integrated design. Researchers should also build on existing knowledge and link their findings to back into the definition of NZEBs.

Furthermore, the net balance concept is fundamental for the proposed definition. The difficulty of matching the daily and seasonal demand with the onsite energy generation profiles will require always a buffer for energy storage. The difficulty of onsite storage and the severity of its environmental impact necessitate the dependence on micro or macro grids. Especially that we already invested in the nationwide grids and potential onsite generation in dense cities is low. Therefore, the concept of 'net' balance is valid but requires operating within fossil free balances. We have to prepare our built environment for decentralized on-site energy generation that is combined with centralized energy generation. Then we will have positive NZEBs.

It would be futile to assert that the proposed energy positive definition of NZEBs should take precedence over all others since the C2C philosophy is already so influential and broad in scope. There is also an emerging trend to create ecologically positive building footprints where the building design is very efficient and through suitable technologies energy become positive resources. There is a need to create buildings that imitate nature so that the footprint is ecological, healthy and beneficial. For example, buildings that support life and generate energy or are flexible to host PV panels with higher efficiency in the future. Our role as human beings is to contribute to the health of the planet and this we must pursue with vigour.

In fact, we are far away from '*near zero*' energy buildings in the current practice and legislative framework. For example, the European Commission decreased its ambition to set in the recast of EPDB to NZEB because the houses cost will increase between 7 to 15% based on an undertaken impact assessment [3]. Therefore, a softer approach was recommended. However, the key barrier to NZEBs is not technology related. The major barriers are legislative and economical. Therefore, the research community should not wait and restrict itself to the term of '*near zero*' or '*net* zero'.

Finally, a NZEBs life cycle and performance should be better monitored and documented in databases so that these can help us understand how buildings perform over their lifetime. Vast volumes of information can help establish real-world efficiency benchmarks and help in informing future building energy policies and design decisions.

6. CONCLUSION

The proposed definition, described in this paper, promotes a sustainable design model leading to zero energy buildings. The value of these definitions lie in their use as a metric for designing NZEBs, particularly in regards energy. We must understand that the various resources are merely individual components in the approach to zero energy buildings. These metrics are intended to facilitate zero energy designs so that the management of resources becomes measurable. Combined, they provide a framework that can guide design decisions not only in terms of carbon emissions but also in terms of the impact within other life cycles relevant to materials. They have the potential to guide future building energy policies. Redefining the NZEB from a C2C approach has the potential to make clearly visible the long term environmental impact of the design decisions.

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