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A review of Net Zero Energy Buildings with reflections on the Australian context

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ABSTRACT

A Net Zero Energy Building (NZEB) is a term, subject to ambiguity, that could be used to describe a building with characteristics such as equal energy generation to usage, significantly reduced energy demands, energy costs equalling zero or net zero greenhouse gas (GHG) emissions. Despite lacking an authoritative definition of NZEBs, this relatively new emerging concept in Australia provides significant opportunities to reduce GHG emissions, energy usage and operational energy costs for buildings owners. This paper aims to explore the existing NZEB models, assess the progression of NZEB literature, identify key policies encouraging NZEB development and recognise potential areas of NZEB research.

1. Introduction

The building sector is experiencing significant challenges in relation to the consumption of energy, climate change and energy poverty issues [1]. Additionally, the long-term trend of increasing energy prices has led to the emerging market of renewable energy and led to decreasing costs of renewable energy technologies such as solar PVs [2]. This has pushed the boundaries for new developments in the built environment. One such development would be to design more sustainable residential and commercial buildings and retrofit the existing building stock to achieve energy neutrality or a Net Zero Energy Building (NZEB) status. A sustainable building may be defined as a building that maintains structural integrity, considers the health, safety, and comfort of users, includes efficiency measures and considers environmental impacts [3] in another word “maximum energy gains and efficiency, minimizing loss” [4]. There are many examples of both commercial and residential buildings with zero energy status around the world however in Australia NZEBs are still uncommon, likely due to the anonymity of the concept to a mainstream audience.

A Net Zero Energy Building is a term, subject to ambiguity, which could be used to describe a building with characteristics such as equal energy generation to usage, significantly reduced energy demands, energy costs equalling zero or net zero GHG emissions. Since 2006, different terms have been adopted to name different building concepts such as; (net) zero (source/site) energy building [5], zero energy costs building [5], zero energy emissions building [5], nearly zero energy building [6], zero emission building [7], zero carbon building [8], net-zero exergy building [9]. Specifically, an International Energy Agency (IEA) Joint Solar Heating and Cooling (SHC) report [10] addressed the NZEB issue, and its “Subtask A” was specifically dedicated to provide a definition framework. The fact sheet developed by Buildings Performance Institute Europe (BPIE) [11] summarises the current status (as of April 2015) of different approaches and indicators used across Europe (member states and Norway) for the nZEB definition of new and existing buildings.

The time frame used to measure this energy neutrality is not well defined in the literature. However, the vast majority of the studies discuss NZEBs that met their goal on an annual basis Carrilho da Graça et al. [12]. Sartori et al. [13] and Voss et al. [14] were among the first to discuss the implication of shorter balancing periods.

From the evidence of research in the renewable energy sector and specifically on NZEBs, a considerable demand in the global market for NZEBs is apparent. In Europe, great effort and actions have been dedicated to the actualization of the nZEB concept. In

Abbreviations: ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers; BAU, business as usual; CSIRO, Commonwealth Scientific and Industrial Research Organisation, Australia; EUI, energy use intensity; HVAC, heating, ventilating and air conditioning; LEED, leadership in energy and environmental design; NABERS, National Australian Building Energy Rating System; nZEB, nearly zero energy building; NZEB, net zero energy building; PV, photovoltaic; MRET, mandatory renewable energy target (supported by Australian Government); ZEB, zero energy building.

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2015 EU Member States were required to provide national plans for nZEB that will become the reference standard for new public buildings by 2020 [15]. Despite this, it is rare to find a robust business model in Australia that can prove the feasibility of this idea in the mainstream community and hence current examples of NZEBs in Australia tend to be confined to either individuals or organisations (particularly universities) associated with research and design. Currently, a significant resistance against zero energy building construction is that many people perceive NZEBs to be subject to significantly high capital costs relative to the operating costs [16–18]. According to Boemi et al. [3] a typical payback period in terms of monetary savings in utilities for a NZEB could range between 7 to 23 years. Although some economic calculations such as those by Boemi et al. [3] exist, there is limited literature discussing a business model for NZEBs which may include concepts such as saleability, target markets, value propositions, key resources, partnerships and channels of communication [19].

The purpose of this paper is to assess existing different NZEB models, review the current literature on this topic and identify policies that encourage NZEB development, particularly in the context of Australia. From this review paper, NZEB 'generations' have been established in order to assess the past, current and hypothesised future NZEB models.

2. Existing definitions of NZEBs and other related terms

Hui [20] recognised that there are some related terms that often become associated with NZEBs such as autonomous houses, being self-sufficient buildings, and green buildings, referring to buildings that reduce the negative environmental impacts caused by a building. In this review, a NZEB is viewed as a futuristic iteration of a green building. In general, "green buildings" are structures designed to promote efficient use of resources (e.g., energy, water, and materials) and sustainability [21]. Early certification schemes include the Building Research Establishment Environmental Assessment Methodology (BREEAM) in the UK in 1990 [22], and Leadership in Energy and Environmental Design (LEED) in the United States in 1994 [23]. Other major programs include the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan [24], Deutsche Gesellschaft für nachhaltiges Bauen (DGNB) system in Germany [25], and the Green Star system in Australia [26]. At the time of writing this paper more than 31 green building certification programs are used in over 30 countries worldwide [27]. Considerations of green buildings include energy usage, water usage, indoor environment quality, material selection and the buildings effect on its site. By considering material selection as part of the definition of a green building, there is an implied consideration for embodied energy. Chastas et al. [28] have presented a comprehensive review on the embodied energy in residential buildings-towards the nZEB.

From the literature, one of the first accepted interpretations of NZEBs are those proposed by Lund-Andersen et al. [29], which includes Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Costs and Net Zero Emissions [29]. These models and a brief summary of potential advantages and limitations are discussed as follow.

A **Net Zero Site Energy** building (referred in this paper as NZ-site-EB) is characterised by a building whereby for every unit of energy consumed, the building must also generate a unit of energy. This refers to the energy consumed and generated at the site, regardless of the origin of the energy. This definition is practical for buildings connected to an electricity grid as it accounts for each unit of energy regardless of its source. Arguably, this model is easier to quantify than source or NZ-emissions-EBs because it is reliant on the on-site energy usage. Torcellini et al. [5] also argued that 'a NZ-site-EB has the fewest external fluctuations that influence the ZEB goal' of their four definitions and hence it is 'the most repeatable and consistent definition'. A limitation of this definition is that it does not consider the energy generation method or sources of fuels and therefore there is an assumption that every unit of energy is equivalent to another unit of energy, regardless of source. Furthermore, this model does not dictate the conservative use of energy by the end-user or consider the efficiency of appliances directly. Using this model may also result in difficulty identifying cost-saving opportunities, such as taking advantage of peak and off-peak energy tariff rates.

Like a NZ-site-EB, a **Net Zero Source Energy** building (referred in this paper as NZ-source-EB) accounts for each unit of energy used by creating a unit of energy, except this is quantified at the source of energy for a NZ-source-EB [5]. This definition is advantageous as it accounts for energy that may be lost or wasted in the process of generation, transmission and distribution. Again, like a NZ-site-EB, this definition may also lead to difficulty identifying cost-saving opportunities. When compared to the NZ-site-EB, the NZ-source-EB could be viewed as the inferior model as a NZ-source-EB implies that at least a portion of the energy generated is coming from an off-site source and hence implies an inability for the building to be close to self-sufficient.

A **Net Zero Emissions** building (referred in this paper as NZ-emission-EB) refers to a building that generates at least as much energy that is emissions-free as it uses emissions-producing energy [5]. This definition is relatively consistent with many government policies that are promoting reduced GHG emissions such as the Kyoto Protocol. A limitation of this definition is that it advocates emissions-producing energy as long as the same unit of energy is offset by emission-free energy. It is also largely dependent on the regional electricity generation techniques (i.e. coal-generated electricity use would require more emissions-free energy production to offset it than nuclear-generated electricity use).

The fourth definition identified by Torcellini et al. [5] is a **Net Zero Energy Costs** building (referred in this paper as NZ-cost-EB), whereby the building owner has utility bills of zero charges. An advantage of this definition is that it does not require technical knowledge about energy and hence could be viewed as the most relatable concept to a non-scientific audience. A limitation of this definition is that it is common that utility providers may charge a maintenance or connection fee regardless of usage and hence a NZ-cost-EB can be unachievable in some cases. Additionally, this model does not consider the energy generation method and is subject to variances in utility costs and credits. Furthermore, utility providers do not necessarily accurately value emissions-free energy in proportional terms to emissions-producing energy. Hence, it is difficult to compare NZ-cost-EBs globally as rates, tariffs, and other fees will differ significantly. Finally, achieving NZ-cost-EB may affect the ability of the utility companies to maintain their infrastructure and hence a NZ-cost-EB may be viewed as being inconsiderate to the wider community or alternatively, it may act as a motivator for utility companies to adapt their core business. In Euroupe a clear path has been assigned for Member States to achieve nZEB target, to this regard, within EPBD recast directive, a cost optimality procedure has been defined [30–35].

Other mainstream models for NZEBs are those as defined by government policies, such as the **Zero Net Energy Commercial Building** as defined in the United States Energy Independence and Security Act [36]. In design, construction and operation a Zero Net Energy Commercial Building requires 'a greatly reduced quantity of energy to operate', 'to meet the balance of energy needs from sources of energy that do not produce greenhouse gases' and 'in a manner that will result in no net emissions of greenhouse gases, whilst still being "economically viable" [36]. Advantages of this definition include the consideration of emissions-free energy