Energy and Buildings 158 (2018) 616–628

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

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

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ARTICLE INFO

Article history:
Received 7 November 2016
Received in revised form 27 August 2017
Accepted 16 October 2017
Available online 18 October 2017

Keywords:
Net zero energy building
NZEB
Building energy policy
Global policy

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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https://doi.org/10.1016/j.enbuild.2017.10.055
0378-7788/

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 sources and it considers economic feasibility. This definition does not specifically imply that on-site renewable energy should be considered before sourcing energy from other sources. Using this definition also may result in difficulty identifying cost-saving opportunities (i.e. taking advantage of peak and off-peak tariff rates).

A closely aligned concept to the NZEB is the **nearly Zero Energy Building** (nZEB) as defined in the European Performance of Buildings Directive [37]. A nZEB is a very high-performance building, determined based on annual energy consumption associated with typical use, including indoor temperature control to maintain a predetermined temperature. The 'nearly zero' amount of energy required should be sourced to a 'very significant extent' by renewable energy sources on-site or nearby. One of the benefits of this model is that under "Annexe I" of the European Performance of Buildings Directive there is a large emphasis on HVAC systems and consideration of climate, positioning, and orientation of buildings. Like the U.S. model, the European Union's nZEB also focuses on optimising cost. The life cycle analysis (LCA) of nZEB is used to assess if a design strategy is sustainable [38–40].

Table 1 summarises some of the key considerations of each NZEB or related concept model. It is apparent that the NZEB concept lacks a holistic, quantifiable and widely accepted definition. Some of the risks associated with a lack of a common definition are that NZEBs could be poorly executed and risk becoming a status symbol for building owners rather than a practical goal in alleviating environmental, social or ethical issues.

Marszal et al. [41] in their article highlighted the lack of a single definition for the term 'Zero Energy Building' and the inconsistencies in the way this term is applied. As an extension of this, they compares the differences in the ways in which the calculations of a ZEB are carried out. The main differences was identified as the inconsistencies in the source of energy generation (on-site vs. off-site), the inclusion of embodied energy and the inclusion of GHG emissions.

3. The NZEB concept

Given that about one-third of GHG emissions can be attributed to buildings [42] and given that buildings are estimated to account for around 40% of energy usage globally [43], ZEBs provide significant opportunities to reduce GHG emissions and to reduce energy usage. Singh and Verma [44] estimated that more than 200 examples of legitimate NZEB projects exist worldwide, with recent fast growth in NZEB projects fuelled by the better availability of energy-efficient and renewable energy technologies. According to Singh and Verma [44], those interested in NZEBs tend to be from research or design background, or individuals or organisations wanting to decrease their energy costs, improve their image or give their organisation a competitive advantage (such as Burger King and Walmart). Although examples of NZEBs exists worldwide, NZEBs are most notably concentrated around North America and Europe, arguably due to factors such as more advanced research, greater availability to technologies, availability of funding for investment and high energy costs (particularly heating costs) due to extreme climates.

Hyde et al. [45] identified that the concept of a NZEB has a broad, general definition as achieving net zero energy consumption through energy efficiency measures to reduce energy demand, with the remaining energy demand generated using renewable energy technologies. The uncertainty presented in this definition is that this does not consider the specific balance between passive building design, renewable energy technologies and the building operator or management behaviour.

Despite the Torcellini et al. [5] definition being accepted by Hyde et al. [45], this definition seems to be somewhat obsolete given that Torcellini et al. [5], would define a NZEB as a building relying on off-site energy sources due to limitations in energy storage systems. Furthermore, Hyde et al. [45] argued that the NZEB concept should be considered in terms of an overall objective such as 'to eradicate GHG pollutants from the operation of buildings'. When considering NZEBs using this objective, it is logical to consider that eradicating GHG pollutants is not just the responsibility of new buildings owners but rather all building owners and hence the definition of a NZEB should be adapted to consider retrofitting buildings to achieve net zero energy as well as new buildings. Other definition distinctions to be made when considering NZEBs include on-site or off-site supply, grid-dependent or independent and whether the building is considered a NZEB measured across the lifespan of the building or over a smaller period (i.e. annually) [29]. It would also be possible to consider a NZEB by considering that emissions could be commoditised or offset.

In defining the concept of a NZEB, Torcellini and Crawley [46] identified several definitions that could be considered NZEBs and identify that building owners can be selective in the way they define a NZEB, based on their requirements. By taking a pessimistic mindset, it could be argued that building owners and researchers in this area could select less self-sufficient or sustainable methods to achieve some form of a NZEB. Pless and Torcellini [47] in another study classified four different types of NZEBs (Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Costs and Net Zero Emissions) in order of preference in terms of self-sufficiency and sustainability. Using this classification system, an ideal NZEB would offset all energy requirements within the footprint of the building (confined to the extent of the physical structure) using energy efficient practices and renewable energy resources [47]. Conversely, the least preferable NZEB would purchase renewable energy credits from an off-site source to offset their energy usage. This classification system is useful as it recognises that the concept of net-zero energy is subject to different interpretations and that although many different strategies can be used to offset or minimise energy, the ideal NZEB would aim to reduce as much energy usage as possible and supplement the remaining energy using renewable energy technologies.

To determine if commercial NZEBs are realistic, Torcellini and Crawley [46] consider the 1999 energy usage patterns of 5375 commercial buildings. According to the 1999 Commercial Building Energy Consumption Survey, these 5375 buildings averaged an energy use intensity (EUI) of 956 MJ m^{-2} [41]. Firstly, a base scenario was applied to these buildings which considered the energy usage of all buildings, assuming that they had been rebuilt to meet ASHRAE Standard 90.1-2004 [48]. Using this design standard resulted in a 41% reduction in EUI to 564 MJ m^{-2}. Next, additional criteria were simulated that assumed 50% of all roof areas were covered by solar PVs and this resulted in an EUI of 407 MJ m^{-2}. By incorporating energy-efficient measures, the EUI was reduced to 176 MJ m^{-2}. Finally, by making a number of assumptions about advancements in technology and the impacts of future research in an additional 20 years, it was concluded that the EUI was likely to be in the vicinity of −28 MJ m^{-2} (implying that buildings following this strategy would produce excess energy relative to their usage). Additionally, this research also showed that the ability to achieve a NZEB was dependent on the number of the building stories due to factors including daylighting potential and the load density per building footprint. Although this research shows promising potential to achieve the US Government's Department of Energy's NZEB goals, there is no explicit consideration in this paper of retrofitting existing buildings. Even if new buildings can feasibly be NZEBs by 2025, existing building stock must also be considered in NZEB research to take a more holistic approach to the overarching issues such as GHG emissions, self-sufficiency, and sustainability.

Table 1
Summary of NZEB considerations per model.

	Green Building	NZ-site-EB	NZ-source-EB	NZ-emissions-EB	NZ-cost-EB	Zero Net Energy Commercial Building	nZEB
Applies to new buildings	Y	?	?	?	?	?	?
Applies to retrofitted buildings	Y	?	?	?	?	?	?
Consideration of climate change	N	N	N	N	N	N	N
Encourages energy efficiency measures	Y	N	N	N	N	Y	Y
Consideration of the energy generation method/fuel source	N	N	N	Y	N	Y	Y
Consideration of energy storage	N	N	N	N	N	N	N
Consideration of embodied energy	Y	N	N	Y[a]	N	N	N
Recognition of cost-saving opportunities	N	N	N	N	Y	N	N
Grid connection	?	Y	Y	Y	Y	?	Y
Ease of measurement for end-user	?	Y	N	N	Y	N	N
Consideration of economic viability	N	N	N	N	Y	Y	N

Y = Yes, N = No.
[a] Norwegian definition.

Similar to Lund-Andersen et al. [29], Hui [20] defined ZEBs as buildings generating an equal amount of energy to their usage requirements to achieve goals such as reduced energy consumption or emissions, reduced energy costs and reduced dependence on fossil fuels. Hui [20] noted that often ZEB definitions neglect to consider the embodied energy required for manufacturing building materials and renewable technologies as well as the energy required to construct, maintain and decommission a building. Hui [20] discussed that achieving a ZEB is often ‘extremely expensive’ as they are customised to the climate and usage of the building, and existing ZEB policies are often highly ambitious. Around this period, ZEB policy trends seemed to be focusing on a small portion of new buildings, which had minimal impacts on the overall GHG emissions generated by buildings however this is progressively changing, particularly in Europe. Hui [20] suggested that it may be more feasible for governments and policy makers to consider offering incentives for energy efficient measures and creating targets for reduced energy in new and retrofitted buildings. By considering ZEBs as a progressive target and creating accessible ways for most building owners to consider reducing energy demand, Hui [20] believes that the impact in terms of reduced emissions or dependence on fossil fuels will be far greater than the result of current policies.

Like other papers reviewed, Sartori et al. [49] agree that no specific, universal definition for a NZEB exists and however the basic principle of reducing energy requirements and supplementing the remaining energy using renewable technologies is commonly agreed upon within academia and design fields. Sartori et al. [49] identified that a potential risk of this lack of definition is that building could be over-engineered, in turn, oversupplying the energy requirements and being inefficient. Sartori et al. [49] discussed energy performance standards in relation to the level of comfort provided by a building and argue that these two factors must coexist for a NZEB to be sustainable. Like Jagemar et al. [50], this paper also discusses the importance of characterising buildings by a climate zone and understanding that a NZEB in a cooler zone will significantly differ from a NZEB in a warmer zone, given that heating and cooling generally dominates energy usage. Sartori et al. [49] implied that although NZEB models and definitions should be consistent in terms of their goals, each NZEB should be customised to maximise efficiencies based on locational factors, such as climate.

Although encouraged by the growth in the NZEB industry, Singh and Verma [44] suggested that without standardisation in NZEB practices and a robust definition of a NZEB, there will continue to be very few legitimate examples of NZEBs. Given that examples of NZEBs are still sparse and that there is a lack of well-established definitions and assessment methods, it is still difficult to assess cost-effectiveness of NZEBs [51]. Although there is still scepticism surrounding their feasibility, it seems reasonable to consider NZEBs as alternatives to standard buildings due to issues such as increasing energy demand with growing population and usage, decreasing non-renewable energy resources, elevated energy costs and climate change issues.

4. Design strategy

When considering the inconsistency of NZEB models, Lund-Andersen et al. [29], pose two questions to be considered to calibrate design goals for a NZEB. These questions involve determining the methodology by which ‘net zero’ is defined and determining the subsequent limitations for the energy generation options. In the context of designing a NZEB under current NZEB models, it would be relatively easy to adopt a definition of NZEB that is less holistic to make a business model more feasible and more attractive to investors.

Li et al. [52] discussed two main strategies to consider when designing ZEBs. The first strategy is to minimise energy usage by limiting the amount of heat gain and loss (i.e. appropriate insulation), considering internal energy-efficient design and building services systems such as heating, cooling and utilities. Like Li et al. [52], Singh and Verma [44] agree that good examples of NZEBs tend to use energy efficiency and passive design as a base for their NZEB, which can be used to support both lower energy requirements and increased comfort of the building users through maintaining desirable temperatures and supplying sufficient daylighting. Secondly, the use of renewable energy technologies should be considered to supplement the energy usage needs that cannot be minimised. Well-established renewable energy technologies such as PVs, wind turbines, solar thermal, heat pumps and district heating and cooling are discussed as possible avenues.

Aelenei et al. [51] presented a similar design approach to NZEBs relative to Li et al. [52] and Singh and Verma [44], using three prioritised principles. These design principles, in order, are passive design approaches to reduce current energy usage associated generally with heating, cooling, lighting and appliances, followed by active design approaches to implement energy efficient systems and finally the implementation of renewable energy systems. This originally 3 step processes is known as 'Trias Energetica', more recently an expansion to a 5-step process was proposed by Gvozdenović et al. [53].

Although lacking specific detail, it is generally accepted that a ZEB should prioritise energy efficiency strategies followed by implementing renewable energy technologies to account for the energy deficit [5]. Torcellini et al. [5] believe that a NZEB should account for their energy demands from 'low-cost, locally available, non-polluting, renewable sources'. Also, the unpredicted nature of renewable energy resources needs to be considered during the design [54]. Although doing away from the electricity grid is often perceived as desirable, Torcellini et al. [5] believe that a grid connection is a useful tool in balancing energy, assuming that excess energy can be always utilised by the grid, which may be inaccurate during times of high market saturation. Similar to Torcellini et al. [5], Carrilho da Graça et al. [12] explained that although potentially desirable, a grid disconnection is not generally feasible as technologies are unable to cope with the 'seasonal mismatch' of energy demand versus supply [12]. This idea could be increasingly outdated to an extent with advancements and additional availability in energy storage technologies. Additionally, this problem of grid disconnection could potentially be alleviated by implementing renewable, district energy generation systems (i.e. at a city scale) using a wide range of renewable energy generation methods.

When considering renewable energy technologies to be implemented into NZEBs, Torcellini et al. [5] recommended a set of priorities to be considered that rank technologies by their ability to reduce environmental impacts, reduce transportation and conversion losses, consider the longevity of the technology in terms of a building's lifespan and the availability of the technology (favouring widely available technologies). Using these criteria for renewable energy technologies, implicitly would be prioritising on-site energy generation methods within the project boundary. This project boundary or footprint could lead to uncertainty in some contexts however Torcellini et al. [5] suggested that this area is clarified by increased regulation, such as solar access ordinances, giving property owners explicit rights to solar energy.

Good et al. [55] studied PV technology and their impact on emission balances in buildings net zero emission buildings. This research was limited to residential buildings types only. The research analysed how orientation of PV systems along with materials used can

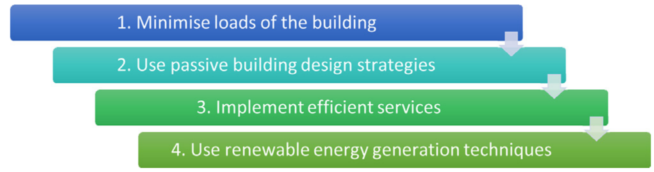

Fig. 1. Hierarchical design strategy for NZEBs.

affect the energy efficiency of a building. Four PV system configurations were considered which are all positioned on a flat roofed home. Four different PV technologies were also considered which were made up of different materials. Each system configuration was modelled using each of the different PV technologies (16 cases altogether) to establish the energy yield and subsequently which one is more efficient. Embodied emissions, avoided emissions, greenhouse gas payback and return on investment and the net emissions balance were also modelled for each case. The results show that the system with the largest area of high-efficiency Si-mono modules achieves the best lifetime emission balance.

In terms of load reduction strategies, Gagliano et al. [56] and Evola et al. [57] discussed strategies that result in high value in terms of financial investment. When considering a multi-storey apartment building in Sicily, Italy, Gagliano et al. [56] found that some of the most effective methods to achieve an 'enhanced saving' building includes optimising the external wall insulation, reducing thermal bridging, using low-E and reflective windows, ventilated façades and green roofs. Similarly, Evola et al. [57] stated that some techniques to reduce loads with minimal financial efforts in a Southern Italian terraced house may include increasing the insulation, using a very-low emissive coating on the inner side of the windows, implementing movable shading devices and tilt-and-turn opening devices for natural ventilation. Despite providing useful guidance, Evola et al. [57] inferred that these strategies are not a one-size-fits-all solution and particularly local climate must be considered to adjust individual design strategies accordingly. Further research into passive design and energy load reduction strategies is catalysed in Europe by programs such as Horizon 2020, an initiative of the European Commission [58].

Based on the literature, Fig. 1 offers a prioritised list of broad design steps that should be used to create a NZEB. Although net zero energy consumption could be achieved by reordering these principles, it is argued that this hierarchy will create a sustainable NZEB.

5. Case studies

Using the LEED Volume Prototype Restaurant as a baseline, Ramirez Millan et al. [59] explored the feasibility of creating a net zero energy restaurant in Chicago, USA for McDonalds. The LEED Volume program has been adopted by large organisations such as McDonalds and Marriott hotels and involves creating a LEED design prototype that can be applied to multiple locations [60]. This program allows large organisations to save time and money when compared to achieving one-off LEED certifications, estimated to be around $100,000 per hotel owner in the case of Marriott hotels [60]. Using technological and design improvements on this prototype, Ramirez Millan et al. [59] were able to reduce the building's energy load by 21%, with the most significant energy savings in HVAC and exterior lighting. The main renewable energy source considered in this example was solar PVs. Taking into consideration the US Federal Investment Tax Credit which subsidises 30% of expenditures on eligible solar energy properties and assuming a 25-year lifetime of the solar PVs, it was deduced that this system could result in a lifetime revenue of around US $1,400,000 when connected to the existing electricity grid. This figure could be increased as the State

Table 2
Samples of established NZEBs#.

	Building		#	Building	
1	Nikini Building, Colombo, Sri Lanka	 [65]	6	Adam Joseph Lewis Center for Environmental Studies, Oberlin College, Ohio USA	 [66]
2	Institute of Technology Building, Cork, Ireland	 [67]	7	Zion National Park Visitor Center, Utah, USA	 [68]
3	CSIRO Energy Centre, Newcastle, NSW, Australia	 [69]	8	Mosaic Centre, Edmonton, Alberta, Canada	 [70]
4	H-1 Home, Lebanon, New Jersey, USA	 [61]	9	Efficiency House Plus, Berlin Germany	 [71]
5	P-1 Home, Charlotte, Vermont, USA	 [61]	10	SOLAR XXI, Lisbon, Portugal	 [72]

of Illinois also offers a property specific incentive for solar energy systems, as determined on a case-by-case basis by a chief county assessment officer. The most economical model found showed that 22% of the energy usage could be offset by using energy efficiency measures, 11% via more efficient HVAC systems, 49% by capturing solar energy and 18% energy demand would be a remaining deficit. Ramirez Millan et al. [59] recommended a number of strategies to potentially reduce this deficit to zero including future technological advances, water conservation techniques and increasing the efficiency of McDonald's standard kitchen appliances.

Hoque [61] presented a study that compares two net zero energy homes (based on annual energy consumption) in New Jersey and Vermont, United States. The home in New Jersey is powered mainly by solar and the Vermont example is mainly powered by wind. In this region of the United States, a major emphasis in NZEB design is placed on reducing the heating load of the homes, given the colder climate. Furthermore, net zero energy homes can be attractive to homeowners in this region as the United States government incentivises NZEB design with tax breaks and incentives. Although there are notable advantages to choosing net zero energy homes some of the potential barriers encountered by homeowners may include high design and construction costs (implying potentially long payback periods), lack of knowledge about sustainable design concepts, difficulty claiming tax benefits and lack of designer and builder expertise in this field. The two homes considered in the study are both constructed of mainly timber, are open plan, use foam insulation to maintain a humidity of around 40–45% and are oriented south to maximise solar heating and daylight. Hoque [61] concluded that although both homes are well designed to significantly reduce energy usage, the success of both of these examples is reliant on the homeowners also being aware and conservative about their energy usage.

Sánchez et al. [62] compared 12 low-energy office buildings in Spain to conclude design solutions for future NZEBs. Low-energy is diversely defined by Sánchez et al. [62] with various buildings claimed to have features such as reduced energy consumption by more than 80% of a conventional building in the region, 'integration of solar technologies' and buildings using renewable technologies in conjunction reduced energy demand. In undertaking this study, Sánchez et al. [62] realised that despite relatively specific net zero energy goals as set out by the European Building Performance Directive, no office building in Spain could technically be considered net zero energy and therefore they considered low-energy consumption buildings in their study. In this study Sánchez et al. [62] verified previous research that showed that as a building height increases, the feasibility of a NZEB decreases, as all buildings were relatively low rise with a maximum of 5 stories [46]. Other consistent design features identified in the studied buildings included glazed windows, adequate insulation and passive cooling and heating strategies. The most commonly used renewable energy technology was solar PVs. The construction costs per area of the studied buildings were budgeted around 40% higher than a standard Spanish office building and generally actual construction costs were 25% higher than budgeted. This high construction cost and the fact that none of the studied buildings technically were NZEB, indicates that the NZEB industry needs significant advancement before NZEB is more realistic and feasible.

Ingeli and Čekon [63] evaluated the energy consumption and design features of a Slovakian example of a net zero energy house. By analysing the thermal insulation used in this house, Ingeli and Čekon [63] determined that the air tightness plays an important

Table 3
Assessment of how each example matches common NZEB definition factors.

#	Year of construction	Description	Cost	Number of storeys	Built to NZEB (or similar) specification or retrofitted	Project aim	Consideration of climate	Energy efficiency measures	Renewable energy generation	Storage	Consideration of embodied energy	Other factors considered	Source
1	2008	948 m^2 commercial office building	Cost of solar panels only INR 28,000,000 [65]	3 (and basement)	New	NZ-site-EB	?	√ Natural ventilation, daylighting, shading provided by a courtyard	√ Solar PVs	√ Battery storage	?	N/A	[45,65]
2	1974	233 m^2 section of 24,000 m^2 concrete university buildings	Unknown	2	Retrofit	Emissions ZEB	?	√ Natural ventilation, daylighting, additional insulation	√	?	?	N/A	[45,73]
3	Unknown	10,000 m^2 research facility featuring laboratories and offices	AU$3400/$m^2$ [74]	Unknown	New	3.5 star using the NABERS Energy rating with goal of regaining 5 stars	?	√ Natural ventilation, use of shading	√ Solar PVs, Micro Gas Turbines	√ Thermal storage	?	√ Transport (electric vehicles)	[64,74]
4	Unknown	390 m^2, 4 bedroom, 2.5 bathroom colonial, detached farmhouse	Unknown	2	New	NZ-site-EB	√ Heating dominated climate	√ South oriented, passive solar heating, daylighting	√ Solar PVs	√ Thermal mass element	√ Timber walls chosen to reduce embodied energy	√ Local materials for minimised transport energy	[61]
5	2006–2007	260 m^2, open plan, detached house	US $2110/$m^2$ [75]	2	New	NZ-site-EB	√ Heating dominated climate	√ South oriented, daylighting	√ Wind power	?	√ Minimised material usage	√ Local materials for minimised transport energy	[61]
6	2001 [66]	1263 m^2 college building featuring classrooms, auditorium and offices	US $5759/$m^2$ [76]	2	New	NZEB	√ Climate dominated by both extreme heating and cooling demands	√ Daylighting, passive solar heating, treated glass panels to reduce heat loss, natural ventilation	√ Solar PVs, Closed-loop groundwater heat pump system	?	√ 'Low environmental impact' materials [77]	N/A	[5,78,77]
7	2000	818 m^2 main visitor center and 256 m^2 comfort station	'The Zion Visitor Center cost 30% less to build than a comparable National Park Visitor Center'	1	New	nZEB	?	√ Daylighting, passive heating, treated glass panels to reduce heat loss, natural ventilation, sufficient insulation	√ Solar PVs	√ Battery storage	?	√ '20% of materials, including stone, concrete, and paving, were manufactured within 500 miles (800 km) of the site'	[5,78,79]
8	2015	2787 m^2	CA$3767/$m^2$	3	New	NZEB	√ Heating dominated climate	√ South oriented, daylighting	√ Solar PVs Geothermal heating and cooling	√ Geothermal energy	√ Use of timber to reduce embodied energy	N/A	[80,70]
9	2011	130 m^2 two storey single-family house	1,080,000€	2	New	Annual positive energy balance	√ Heating dominated climate	√ Triple glazed windows, minimised thermal bridges	√ Photovoltaic roof and façade, heat pump	√ 40 kWh battery storage	√ Use of timber panels	√ Consideration of electric vehicles within the building envelope	[71,72]
10	2006	1200 m^2 office building	800€/m^2 (including taxes)	3	New	Low energy building	√ Designed to diminish all cooling load	√ South oriented, glazed areas of façade	√ Photovoltaic roof and façade	?	?	N/A	[71,81]

role in low heat losses. The house researched in this paper is powered by a combination of solar and electric energy. Although the solar system is productive in the summer months and far exceeds the energy usage of the house, the most significant energy usage is during winter with around 10 times more energy used in winter than summer. Ingeli and Čekon [63] suggested that although this house has a net zero energy usage when unused energy is commoditised in the summer months, the designer of this property could implement further measures such as batteries and other renewable technologies to further reduce electric energy consumption and to better customise the renewable energy production for the winter conditions. This example demonstrates that although a building is considered a NZEB, it doesn't necessary mean that the building is capable of sustaining the human activities off-grid. It also emphasises that the consideration of the climate is vital to a sustainable NZEB.

As well as considering the passive design and the implementation of current technologies, Wall et al. [64] indicated that other factors that require consideration for ZEBs include building occupant behaviour, future unpredictability in energy demand and the integration of future renewable and energy storage technologies. In this study, an assessment is undertaken to determine solutions to retrofitting an existing commercial building in Newcastle, NSW, Australia to achieve a net zero energy target. The building, used by the CSIRO, consumes 63% of its total electricity use to maintain consistent temperature control in order to meet laboratory safety requirements. Using the NABERS star ratings as a baseline, it was determined that the site was achieving an average of a 3.5-star rating (equivalent to 207 kg CO_2-e per m^2). As part of this assessment, the CSIRO aimed to gain a 5-star NABERS rating and potentially exceed it. By creating a GHG abatement cost curve it was determined that carbon neutrality is a realistic goal for this building, corresponding to achieving between a 6-star and 7-star NABERS rating. The proposed solution to achieving this goal would include implementing advanced technological solutions including fault detection systems and optimised control of renewable energy resources.

6. Case studies of existing buildings working towards a NZE status

Table 2 shows samples of the existing NZEBs that have achieved or are working towards a NZE status.

Table 3 shows that in the cases studied, there are several different terms to describe the zero energy status of buildings and many authors define their zero energy term slightly differently. Table 3 considers how each of the case studies meets a number of factors that have been identified throughout various literature in relation to defining a NZEB, such as energy efficiency measures and renewable technologies. Generally, most buildings seem to follow these basic factors to an extent.

Embodied energy is not often explicitly included in most definitions of NZEBs however Table 3 illustrates that most of the examples consider embodied energy. The most common consideration for embodied energy tended to be accounted for in the choice of building material and transport energy. Consideration of the embodied energy created by manufacturing and transporting renewable technologies such as solar PVs is not explicitly considered in the case studies considered. This suggests that perhaps consideration for embodied energy is in some cases not explicit but rather a consequence of which materials are most economical based on their local availability.

Analysing Table 3 highlights the difficulty is comparability of the NZEB examples. This highlights that without clear definitions, policies and design framework, NZEBs will continue to rise to varying standards and achieving varying levels of success in terms of ongoing NZEB goals such as reducing GHG emissions or freeing end-users from rising electricity prices.

7. Human-building interaction

Hausman [82] presented a number of observations about human energy-related decision-making. Firstly, an economic model is presented that shows that energy demand is a factor of available capital, required utility, possible substitutions and decisions in regards to conservation. In theory, if energy prices are rising, consumers should be making trade-off decisions such as considering higher-cost, more efficient appliances in return for lower operational energy demand. The reality is that energy is not necessarily the only consideration for consumers and often consumers are shown to devalue the operating costs of appliances in relation to initial investment costs [82]. In the context of NZEBs, there is a risk that building owners will deem a NZEB, energy efficient appliances or renewable technologies unfeasible due to high initial costs as they might devalue the ongoing operation costs.

In the time leading up to the report by Hausman [82] being published, there was an oil availability shortage and this led to increasing electricity prices in the USA. Public awareness and concern about energy prices and availability were generally escalated at this time. Meanwhile, it was common practice for appliance manufacturers to supply product information that had the sufficient data required to make economic calculations to show which product would be most economical in the long-term. Despite this, only a portion of consumers made long-term economic calculations and considered which appliances were most efficient for them [83].

Arguably, this research is dated and may not be fully representative of current energy decision-making practices however, it does illustrate that human behaviour can be somewhat illogical and hence it cannot be assumed that humans will choose the most efficient appliances, renewable technologies or building type. Hausman [82] recommended that a potential solution to this could be governments providing education programs for consumers to think about initial costs in relative terms to ongoing energy costs or by governments implementing efficiency standards to ensure that appliances with poor efficiency are not available in the market.

In terms of NZEBs, without social support of sustainability measures and governments setting minimum standards, building owners may make decisions that result in poor efficiencies. The research conducted by Hausman [82] reinforces a study conducted by Li et al. [52] which stresses the importance of the general public having a positive attitude towards renewable energy initiatives and sustainable development so that ZEBs are favoured over less environmentally friendly options. Social behaviour in energy decision making and the reliance of human behaviour on the success of NZEBs provides scope for future research.

The operational performance of NZEBs during full occupancy has been studied by Zhou et al. [84]. They noticed that the annual operational energy consumption was more that the onsite energy generation. Three main elements were identified as the main causes for this discrepancy, the installed equipment varies in type, quantity and time of use with the design stage. The unregulated user behaviour was identified and the second case, and lastly the predicted energy generation by solar PV was not achieved due to significant reduction in efficiency due to haze weather.

Robert and Kummert [85] in their work examined the use of the downscaling method known as "morphing" to generate weather data profiles in order to assess the energy performance of Net-zero energy buildings (NZEBs). Morphing is applied to typical "horizon years" (for 2020 & 2050) representative of future climate and on a month-by-month and year-by-year basis. It was suggested that climate-sensitive buildings such as NZEBs should always be

Table 4
Notable policies supporting energy and sustainability initiatives and NZEBs.

Country	Notable policies supporting energy and sustainability initiatives and NZEBs		
	City-wide/Local	State/Regional	Country-wide
Australia	Zero Net Emissions by 2020 (City of Melbourne)	Energy Technology Innovation Strategy (ETIS)	Renewable Energy Target
			Commercial Building Disclosure (CBD) Plan
Canada	Greenest City 2020 Action Plan (City of Vancouver)	British Columbia Clean Energy Act 2010	ecoENERGY Innovation Initiative (funding for research and development in energy efficiency, clean electricity and renewables, bioenergy, electrification of transportation and unconventional oil and gas) [96].
		Pacific Coast Action Plan on Climate and Energy (applies to British Columbia, Canada and California, Oregon and Washington, USA) [95]	
European Union member states	(See UK section)	–	2010 European Performance of Buildings Directive
			2012 Energy Efficiency Directive
UK	The London Plan, specifically Chapter 5 [97]	–	National Renewable Energy Action Plan [98]
New Zealand	Wellington 2040 plan [99]	–	New Zealand Energy Strategy (New Zealand Government)
	Christchurch City Council's Sustainable Energy Strategy		
Japan	Tokyo Initiative of Smart Energy Saving [100]	–	2014 Strategic Energy Plan [101].
United Nations countries	–	–	Kyoto Protocol
USA	San Francisco Climate Action Strategy [102]	California Energy Efficiency Strategic Plan [104].	2007 Energy Independence and Security Act Department of Energy's Solar America Initiative (SAI) [106]
	GoSolarSF (initiative of the San Francisco Climate Action Strategy) [103].	New Residential Zero Net Energy Action Plan [105]	Solar Decathlon [107]

designed using multi-year simulations with weather data that take climate change into account.

8. Notable national and international policy support for promoting NZEBs

Policies and incentives for catalysing NZEB progress in Australia are not readily publicised. There are however, a number of policies in regards to renewable energy technologies and energy efficiency. A predominant energy policy in Australia is the Renewable Energy Target. This target is made up of two separate schemes, the Large-scale Renewable Energy Target and the Small-scale Renewable Energy Scheme. The Large-scale Renewable Energy Target has a goal of creating an additional 33000 GWh of renewable electricity by 2020 [86]. This target is supported by the creation of large-scale generation certificates for eligible power stations. The Small-scale Renewable Energy Scheme incentivises renewable energy generation by offering small-scale technology certificates to individuals or small businesses with eligible systems [87]. For both large-scale and small-scale renewable generation certificates, Renewable Energy Target liable entities are required by law to buy these certificates and hence the individual or organisation can recoup some financial incentive for their system [88].

The Commercial Building Disclosure (CBD) program is an initiative of the Australian Federal Government which enforces the disclosure of energy efficiency information for large commercial office space that is for sale or lease [89]. Although not directly supporting NZEB growth, this mandatory disclosure program could act as an incentive for building owners to improve their energy efficiency in order to increase saleability and marketability of their building. As well as offering benefits to the building owner, this program has also been successful in overall improvement in average energy ratings since mandatory disclosure was introduced [90]. At a Victorian state level, the Energy Technology Innovation Strategy (ETIS) is an initiative of the Victoria Government that funds low-emission energy technology projects [91]. Government grants totalling AUD$370 million have been available for projects in areas such as clean brown coal, renewable and sustainable energy, greenhouse reduction technologies and automotive research [91].

In 2014, the City of Melbourne introduced the Zero Net Emissions by 2020 strategy. This strategy sets out targets that focus on the City of Melbourne council operations, commercial buildings, residential buildings, energy supply, transport and waste [92]. In terms of commercial buildings, this strategy outlines plans to increase the average NABERS rating to '4' by 2018 [92]. The goals set out by this strategy for residential buildings are far vaguer, with the strategy stating that long-term targets will be founded on a yet-to-be-developed baseline.

Worldwide, there is relatively advanced policy support for NZEBs in regions such as North America and the European Union. Notable policies include the 2007 Energy Independence and Security Act in the USA and the 2010 European Performance of Buildings Directive, which both actively promote NZEB goals [36,37,93]. Initiatively, these regions with relatively good policy support coincide with more advanced research and progression towards creating NZEBs. Vasquez et al. [94] indicated that although the existing regulations might lead to the 20% energy efficiency goal by 2020, but they are not sufficient for the 2050 energy and GHG-emission goals, showing that further research and development is still required. Table 4 summarise some of the notable policies supporting NZEBs in different countries.

9. Discussion

During the last decade, substantial developments have been made in the field of building energy saving through recovering waste to energy and utilising various energy conservation measures. This trend has been carefully investigated and crafted into a schematic diagram as presented in Fig. 2. The first generation of green buildings emerges due to increasing concern about the neg-

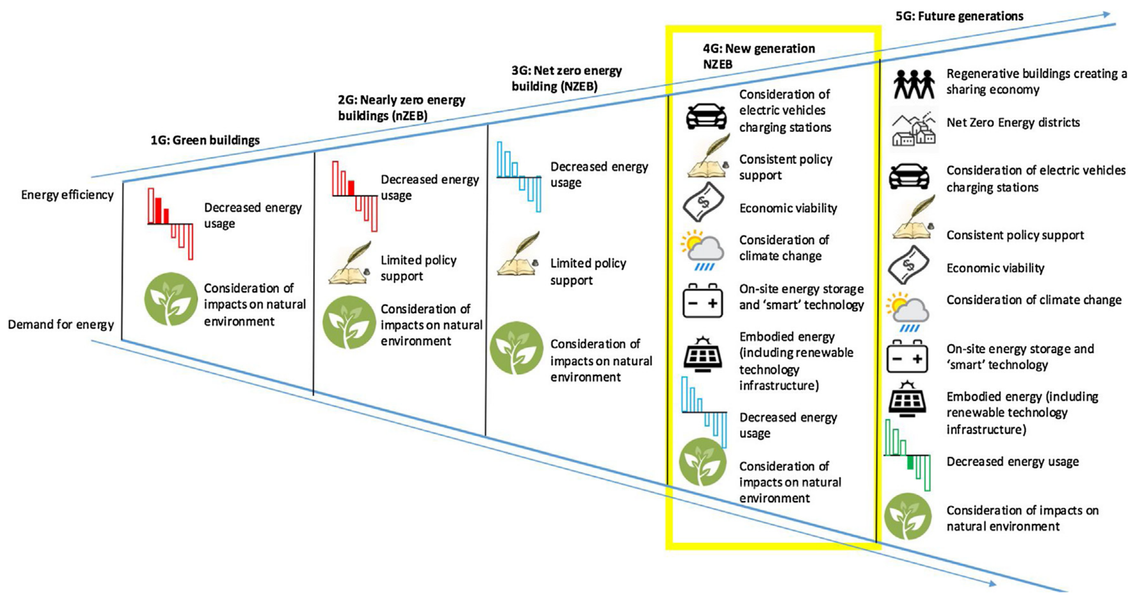

Fig. 2. One interpretation of generations of NZEBs. (The figure was designed by the first author using open source clipart).

Table 5
Summary of government policy support for NZEBs.Country.

	NZEB-specific Policies	Renewable Energy Polices	Other related targets (i.e. emission targets)	Research and development funding
Australia	N	Y	Y	Y
Canada	Y	Y	Y	Y
European Union Member States	nZEB	Y	Y	Y
New Zealand	N	Y	Y	? (refer to 'Note')
Japan	Y	Y	Y	? (refer to 'Note')
USA	Y	Y	Y	Y

Y = Yes, N = No.
Note: Funding initiatives for research and development programs in these countries were not considered to be readily publicised in the research conducted. This may not be a reflection of each of the countries willingness to fund research programs in the area of NZEBs. This is likely to be attributed to the way that each country disperses funds for grants (i.e. some countries appear to predominately use public campaigns to gather research proposals before providing monetary grants whereas other countries appear to be more discretely funding research organisations).

ative impact of building to the natural environment in the 1990s after the introduction of long standing certification schemes such as BREEAM and LEED. Historically, one of the first attempt to conceive a Net Zero Energy House was done in 1977 by Esbensen and Korsgaard "Dimensioning of the solar heating system in the zero energy house in Denmark". Ever since then the trend towards reducing the energy consumption of the building started with a rapid pace, in European Union the concept of nZEB was proved after several success stories and eventually caused changes in building codes in 2010 to push builders out of their traditional practices. The third generation of NZEB was emerged in US and Japan, mainly followed by improvement of Solar PV technology and reduction of cost of PV modules.

The fourth generation (4G) as defined in this paper is formed by the introduction of battery storage technology into the building that would allow demand management in ways that were not achievable before. The fourth generation is more economic viable thanks to the drop in the cost of Solar PVs and control systems. However, the high cost of battery storage is still a major challenge.

The authors envision the fifth generation (5G) having more holistic approach, which includes consideration of electric vehicles within the building premises, consistent policy support, economic viability, consideration of climate change, on-site energy storage, implementation of 'smart' technology and the internet of things (IoT) [108], consideration of embodied energy, neutral energy usage and general consideration of the impacts on the natural environment. The future generations of NZEB could incorporate regenerative energy strategies and have the ability to be scaled-up or/and integration to a district level.

Marique and Reiter [109] applies the NZEB concept to a neighbourhood scale (single urban block surrounded by streets) to determine the feasibility of a net zero neighbourhood taking into consideration possible on-site renewable technologies and transportation energy consumption. This is a response to the growing interest in NZEBs and policies set by the European Performance of Buildings Directive (EPBD) and the United States Energy Independence and Security Act of 2007 that promote ZEBs.

The neighbourhood NZEB accounts for both building, transportation and public amenities. Although recent studies suggest that energy used by public amenities such as street lights can be neglected compared to energy used by buildings and transportation [109]. The renewable energy technologies considered for neighbourhood NZEB are combination of solar PVs, wind turbine and geothermal power. The geothermal electricity might not be an obvious choice for singular NZEB, but for the neighbourhood NZEB it would assure availability for the baseload power. Also, technologies such as thermal energy storage and seasonal energy storage systems could bring more balance between generation and demand where a seasonal variation of renewable energy supplies is an issue.

Although countries like Australia and New Zealand show limited support of NZEB initiatives [110], the existence of related policies proves that there is potential for adoption of these policies to accommodate NZEB goals. Table 5 summarises the policy support of various countries analysed.

Marszal et al. [41] in their review work, identified the most important metrics that defines a NZEB, such as the period and the types of energy included in the energy balance, potential renewable energy sources, the local network infrastructure, indoor climate control, and the building–grid interaction. Moving forward, additional research investigations on topics related to NZEBs are required. These deficiencies in our current understanding include a universally acceptable definition of NZEBs and increasing our knowledge of climate change and social change to predict future energy demand better. All new buildings should integrate and optimise all major high-performance building attributes (energy efficiency, durability, whole life-cycle performance and occupant health, wellbeing and productivity) and beyond. Meanwhile, the major challenge is on the existing buildings which were built based on the building codes and regulations at the time. Although the energy efficiency and energy conservation measures through various energy performance contracting are reducing the energy consumption rates, a more radical action such as deep refurbishment might be the only answer. Ultimately, the NZEBs and regenerative buildings would reverse the pattern towards reducing the overall energy consumption.

10. Conclusions

The operation of buildings accounts for a substantial portion of the electricity demands worldwide, providing significant opportunities to reduce demand through NZEBs. The NZEB concept could be potentially considered for new buildings as well as existing buildings in order to have a tangible impact in terms of overarching issues such as GHG emissions, sustainability and freedom for consumers from rising electricity prices.

Given the opportunities presented by NZEBs, it is initiative to ask why you would not design every building to be a NZEB. An immediate response might be to discount NZEBs due to the perceived cost of the building. However, evidence of NZEB progression may suggest that this is an excuse rather than a justifiable response. Therefore, the question that requires answering is 'What is required to ensure that every building is a NZEB?'. This paper identifies some commonly documented limitations of the current research and development that may be considered the drivers for future NZEB growth. These common themes are listed as followed.

1 A lack of a universally agreed, holistic definition of a NZEB is evident. Various ways to achieve a NZEB under current broad definitions leads to difficulty in comparability of NZEBs and difficulty determining best practices. The examples of buildings achieving or working towards a net-zero energy status shown in this paper demonstrate the diversity of strategies used to achieve net-zero energy goals.

2 Inconsistent governance of energy efficiency standards worldwide is an issue. Governments are believed to be a crucial driver in creating policies to encourage net zero energy targets and providing the public with awareness of energy issues. Generally, the research indicated that the USA, Canada, Japan and the European Union Member States are arguably the most advanced countries in creating public policies relating to ZEBs and general public awareness of ZEBs.

3 Public acceptance and government encouragement of NZEBs is considered to play a major role in their success. This area is not well documented in the current literature and provides scope for future research.

4 There is a notable lack of research about holistically accounting for embodied energy, particularly accounting for the energy usage in manufacturing building materials and manufacturing devices for renewable energy technologies such as solar PVs. This could potentially be an area of development in further research on this topic.

5 Although it is clear that a NZEB is likely to be realistic given the current state of building design and energy technologies available, there is little discussion of economic feasibility and hence an opportunity exists to validate the economic feasibility of NZEBs.

6 In terms of the Australian context, it is explained that very little support for NZEBs has been demonstrated in Australia, particularly in mainstream community. This is reinforced by a lack of specific policy support as discussed in Section 8. Although there is a lack of Australia NZEBs, reviewing the literature in the international community proves that there are significant challenges, particularly in regards to a universal definition, that may need to be developed before countries such as Australia can develop clear policies to support NZEBs.

7 The authors came to the conclusion that in Australia separate sets of targeted policies are required for residential and non-residential buildings. The policies should advocate stronger building code and ensure much higher levels of compliance. Given that Australia has already had a high penetration of renewables, better codes could likely get it to near zero energy residential buildings.

Acknowledgements

The authors would like to thank Mr. Chris Buntine, ESD Leader, Victoria, Aurecon (Australia) for providing initial discussions and reviewing the manuscript.

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