applied sciences

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Zero Energy in the Built Environment: A Holistic Understanding

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Received: 17 July 2019; Accepted: 13 August 2019; Published: 16 August 2019

Abstract: International pressures through global agreements such as the recent Paris agreement in 2015 have put stress on governments and industries to find lasting solutions for the built environment. The built environment was recognized as an important factor in reducing global emissions for the first time at the Conference of Parties (COP) 21 meeting in Paris through a dedicated 'Buildings Day.' The Global Alliance for Buildings and Construction (GlobalABC) was also launched at COP 21 as a network to globally support zero emission, efficient and resilient buildings and construction sector. The Paris Agreement brought all nations to collectively combat climate change with a view to limit temperature increases to no more than 2 degrees Celsius (°C). Nations agreed to report their efforts through the monitoring program. In most countries, residential and commercial buildings spend a large proportion of their energy in lighting, heating, ventilation, air conditioning and in various appliances requiring energy for operation. This paper takes a broad understanding of zero energy. Starting with buildings, the definitions also consider understanding zero energy and from a carbon perspective, considering going from beyond buildings to include precincts and cities. The paper brings an understanding of zero energy, its importance, and its urgency with respect to global commitments to reduce the impact of the building and construction sector and the role of governments and industries in supporting the lowering of emissions in the built environment now and in the future.

Keywords: ZEB (Zero Energy Building); ZCB (Zero Carbon Building); zero energy; zero carbon; buildings; built environment

1. Introduction

The Sustainable Development Goals (SDGs), New Urban Agenda (NUA) and attendant global agreements such as the recent Paris agreement [1] bring back the focus to buildings and the built environment. For the first time, the role of the built environment was acknowledged in the Conference of Parties (COP) 21, which invited nations to put forward their best efforts through nationally determined contributions (NDCs), expressed as the 'Intergovernmental Panel on Climate Change to provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways' (para 21). COP 21 also saw the launch of the Global Alliance for Buildings and Construction (GlobalABC) as a voluntary network supported by the French government and United Nations Environment Program comprising organizations from all levels of government, businesses, inter-governmental organizations, peak industry bodies, networks and think tanks contributing to lowering our carbon emissions arising from the building and construction sector [2]. The building and construction sector accounts for 39% of energy-related carbon dioxide emissions when upstream power generation is included. The sector needs to improve by at least 30% by 2030 [3].

In 2016, an estimated 235 billion square meters of total floor area had been constructed, and in the next 40 years, an additional 230 billion square meter buildings will be constructed [3], doubling existing built stock. Most of the building and construction are expected to occur in developing countries, particularly those countries that lack mandatory building codes. In the context of expected increases in the building and construction industry, this paper queries the significance of the role of energy use in the built environment.

In most countries, residential and commercial buildings spend a large proportion of their energy in lighting, heating, ventilation and air conditioning (HVAC), as well as in appliances. In the new growth regions of the world such as the Asia-Pacific and Latin America, cities are undergoing rapid building and construction, and, therefore, it is even more important in these countries that the new buildings cater to designs that support energy efficiency in buildings and the use of equipment and appliances in buildings [3,4].

The aim of this paper is to develop a better understanding of how emissions may be reduced using a zero energy buildings approach. The objective is to present an understanding to support decision making as a response to international pressures such as the Paris Agreement and to support the vision of organizations as the GlobalABC.

This paper takes a broad understanding of zero energy. Commencing with buildings, definitions are provided that also consider carbon and go beyond buildings to include precincts and cities from a planning perspective. The paper brings the discussions together by also considering the role of governments and industries in supporting and lowering emissions in the built environment sector.

The paper uses secondary literature to explain fragmented information currently existing to understand the role of zero energy in buildings and the built environment to lower emissions. Peer reviewed literature and internet sources are used to present a case to take a holistic approach. By incorporating examples as appropriate, the paper presents an understanding of reducing emissions in the built environment through the zero energy platform in a logical and simple manner.

2. Zero Energy

There are several definitions in the literature on zero energy. A zero energy building (ZEB) has greatly reduced energy loads such that renewable energy can supply the remaining energy needs of the building. Like sustainability, there are a number of definitions, and the devil is in the details when claims regarding a ZEB are made. There are no international agreed definitions of a ZEB yet. A ZEB can be considered to be a progression from passive sustainable building design, and the energy requirements of the building should be balanced between active and renewable technologies.

The US Department of Energy was among the first to consider a ZEB. The EU (European Union) was among the first regions in the world to mandate its use. Article 9 (1) of the Energy Performance of Buildings Directive requires member states to “ensure that: (a) By 31 December 2020, all new buildings are nearly zero-energy buildings; and (b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings” [5]. According to Article 2 (2) of the EPBD (Energy Performance Buildings Directive) a net zero energy building (NZEB) “means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby” [5].

According to Fokaides [6], a ZEB is a building that has net zero energy consumption and zero carbon emissions annually. A true ZEB does not exist in reality. It is actually the concept of net zero where the sum of energy use and the energy generated in the building balance each other. Energy also has different meanings [7]:

- Source energy
- Site energy

- Energy cost
- Emissions as a result of using energy

Each of these are explained in some detail below.

2.1. Source Energy

Net zero source energy refers to a building that produces as much energy compared to the energy generated at the source. If the system boundary is drawn around the building, the transmission of the energy to the building, inclusive of the fuel source to and from the power plant, needs to be considered. In other words, the embodied energy needs to be considered until it reaches the site boundary to service the building/s under consideration. It also means that if the source energy is generated from renewables such as solar or hydro, the impact through the use of the energy—that is the embodied energy—will be lower. A physical boundary can encompass a single building on site or a group of buildings depending on which building/s are considered to be part of the site.

Energy supply mandatory requirements may need to be set [8]. This may be in the form of a hierarchy of renewable energy supply options. The supply options may be prioritised on the basis of emissions-free and reduced transportation, transmission and conversion losses; availability over the lifetime of the building and be highly scalable, widely available, and have high replication potential for future net ZEBs.

2.2. Site Energy

Zero site energy buildings produce energy on site and ideally consume as much as they produce on site. In urban areas in particular, they may use the grid for back up, assuming that the grid is two-way where energy can be delivered to and received from (most grids are two-way). To understand energy use on site, monitoring is required; also, such buildings, if well designed, will make use of their passive designs to ensure that the building itself uses as little energy as possible for operations. If there is more than one building on site, it is important to measure the sub metering for each of the buildings separately, especially if different sources of fuel are used; for example, solar and geo thermal fuel sources will need to be separated. Another important factor to be considered in this case is also what constitutes site for the building: Is it just the footprint of the building or the entire property, including car parking? For example, parking areas covered with photovoltaics (PVs) were used in a ZEB in Singapore built by the Building and Construction Authority [9]. Energy uses are usually for heating, cooling, ventilation, hot water, lighting and plug load for various appliances.

Crawley and others [10] expanded further from Torcellini and others' [11] definitions to include categories from A to D in relation to zero energy buildings. They stated that a ZEB A uses renewable energy from the building footprint, ZEB B uses sources available on site, and ZEBs C and D consider offsite options. ZEB C uses energy sources off-site to generate energy on site. Basically, this would involve importing materials that can generate electricity and heat to the site. In a ZEB D, renewable energy is purchased off site; in other words, green energy is used on site.

Other researchers [12,13] have distinguished two units of the balance: Emissions and energy, though they have done so without specifying delivered or primary energy. To understand the impact of the building on the environment, Kilkis [14] stated that the metric of the balance in the ZEB definition should address both the quantity as well as the quality of energy. In this context, his proposal is a definition for a ZEB where the building has zero exergy. He states that a net zero exergy building is one:

> 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.

Exergy is defined as the 'maximum available work that can be extracted from a system during a process that brings the system into equilibrium with its environment' [15,16]. Exergy can be destroyed and, therefore, provides a better concept for understanding which components of a system can account for irreversibility's [16]. According to Kilkis, exergy is the available amount of energy to be used; if the exergy is zero, then, the building qualifies as a zero-exergy building. If the building draws exergy from the surroundings, then there are associated emissions that need to be considered. Shukuya [17] also used exergy rather than energy for understanding how different components of a system use energy and where emissions occur in a system. His argument for the use of exergy hinged on understanding 'what is consumed in what manner, how much and where.' According to him, exergy may be used to understand how a system may work thermodynamically. Shukuya [17] used exergy for understanding the environmental planning and design of the built environment, whereas Sangi and Muller [16] used exergy for the dynamic understanding of systems at a building scale.

The exchange between the building and its surroundings or the grid makes more sense when using green or renewable energy during peak demands. A net zero energy building connected to the grid when compared to an autonomous house [18] offers a better solution if renewable energy is used to capture energy. The Vales [18] defined an autonomous house as:

> The autonomous house on its site is defined as a house operating independently of any inputs excepts those of its immediate environment. The house is not linked to the mains services of gas, water electricity or drainage but uses the income-energy sources of the sun, wind and rain to service itself and process its own wastes.

This is because electric storage systems are avoided, which adds to the embodied energy of the building. At a domestic scale, this may not be economically and environmentally feasible due to the nature of domestic dwellings. It may work better at a precinct scale or in the commercial sector where the energy through renewable generation (particularly solar) is used when the occupants need it most. Particularly in the domestic sector, most of the energy is used in the evening and weekends.

The selection of primary energy for a ZEB is critical because it allows for the differentiation between electricity and fossil fuel use and also includes an indication of the efficiency for delivering other energy needs of the building such as heating, hot water, and plug in loads. In a life cycle ZEB approach where life cycle implications are considered, boundary definitions are critical, and, therefore, the forms of energy used are also critical. Sometimes, carbon dioxide may be used as an indicator, in which case conversion factors from primary energy to carbon dioxide can be easily integrated within the proposed methodologies and definitions of energy use in most countries [19]. On an annual basis, energy use can then be calculated using both actual performance and also through energy simulations. Needless to say, to find exactly how much energy is being used actual calculation is required.

The selection of renewable energy is also important. Renewable energy such as biomass, wood pellets, ethanol or biodiesels may be produced offsite and used on site [20]. While transportation costs need to be considered for these fuel types, it may be better from an overall cost and embodied energy perspective to use these types of renewables than from a grid that may be green from a far off solar or wind plant due to transmission losses.

Energy alone need not be the only resource considered. Water is another resource used in building construction and operation. Resulting emissions from using water may also be considered in the net zero equation for the net-zero concept. Net-zero waste likewise balances the input and outputs related to waste [21].

2.3. Energy Cost

Net zero energy cost refer to the cost of the energy consumed by the building. Most building owners, particularly in urban areas, see this as a primary concern. The cost of energy often includes infrastructural elements and peak demand costings by utility providers. Therefore, cost does not necessarily reflect the energy consumed vs. the energy produced by the building or on site. For instance, in Australia, current feed-in tariffs do not encourage on site production because if the energy is fed back to the grid, the costs of feeding back to the grid are much lower than the costs of energy drawn from the grid. The incentives for building owners to support energy production on site are almost non-existent because they pay more to draw energy from the grid than the cost to sell back to the grid. However, examples of early feed-in tariff in grids around the world show that they are not just delivering energy—they are also receiving energy, predominantly through solar panels where solar energy is abundantly available, particularly in tropical and some temperate regions in the world. Energy generated on site is usually consumed on site before being exported to the grid. This has implications for the peak demand of energy consumption, as supporting local on-site production for energy consumed in buildings puts less load on the grid infrastructure.

2.4. Emissions as a Result of Using Energy

Net zero emission buildings consider only the emissions produced by the energy needs of the building. The definition, therefore, supports renewable sources because their emissions are often lower than standard fossil fuel emissions, particularly when embodied energy is considered. Authors such as Satori and others [22] also discussed the importance of energy infrastructure, climatic conditions and building typology. Each country needs to adopt its own definition of what a ZEB means to them as the primary energy, carbon emission factors for various energy carriers, energy efficiency and supply chain technologies vary from country to country.

An energy-positive building or an energy plus building: As the name suggests, these produce more energy from renewable sources on-site than required or typically consume from the grid and therefore have excess 'energy' to feed back into the grid where grid connections occur. This may be achieved by using a combination of passive solar building designs, the use of insulation and other passive techniques, and the use of renewable sources of energy such as solar or wind.

3. Zero Carbon

In addition to a ZEB, zero carbon may also be used as a measure in place of zero energy. A building with zero net energy emissions is also known as a zero carbon building (ZCB) or a zero emissions building. As a ZCB, the carbon emissions generated from on-site or off-site fossil fuel should be balanced by the amount of on-site renewable energy production. One of the early examples in the Asia-Pacific is Hong Kong's ZCB, in operation since 2013 [23].

In the UK, the Zero Carbon Home policy [24,25] for new residential buildings has two options for meeting this requirement: Carbon compliance and allowable solutions. The former is a mix of mandatory energy efficiency measures and a selection of on-site options to be implemented. Allowable solutions are a set of further supply options, including extended on-site options, near site options, and off site options. Such options take the option of energy supplies beyond the site boundary.

4. The Role of Government and Industry

While governments may consider responses to zero energy or zero carbon from a regulatory or policy perspectives, the role of industry in pushing the boundaries for industry engagement is yet another viable option to support the intent of net zero in the built environment.

A total of 185 countries (as of October 2016) signed the Paris Agreement that entered into force on 4 November 2016 [26]. By February 2019, the total number of countries signing the Agreement increased to 194 states with the further addition of the European Union [27].

Table 1 provides a list of some countries that have buildings or built environment related policies and programs. The EU has not been included here because the EU has led the development in NZEB policies and is well ahead of the rest of the world. While the ratified countries have all agreed to report on actions to reduce greenhouse gas emissions, not all the countries include the buildings and construction sector in their NDCs. It is clear from the table that not all countries that have signed the Paris Agreement have policies and programs supporting lowering emissions from the built environment. For instance, among the developed countries, though the US has withdrawn from the Paris Agreement, the states of California and New York have signed up drafting stringent building codes and regulations to support reduced emissions. Canada revised its previous NDC with new targets for the buildings sector—specifically a 'net-zero energy ready' building code to be adopted by 2030 [28].

Other developed countries such Australia have NZEB policies in addition to making changes to their building codes, sustainable construction practices, supporting low emission indoor environments through thermal comfort, enhancing the performance of appliances and equipment used in buildings including high efficiency lighting programs, the use of solar energy, and energy efficiency programs. However, other emerging economies such as India and Indonesia need to go well beyond these considerations.

A fact remains, though, that many of the developing countries are the ones that need the most support in the transition to low carbon economies. Countries such as El Salvador in Latin America and Lesotho in Africa are lower middle-income countries (as of 2019) [29] that have recognized the role of the building sector in their NDCs.

Table 1. Selected country/state status in relation to the Paris Agreement and built environment policies/programs.

Country	Paris Agreement	NZEB Policies/programmes	Building Codes & Regulations	Retrofitting policies/programmes	Sustainable/Innovative Construction Practices	Thermal comfort policies/programmes	Enhancing the energy performance of appliances and equipment policies/programmes	Energy efficiency programmes	Alternative building materials and technology policies/programmes	High-efficiency lighting technology policies/programmes	Solar photovoltaic (PV) policies/programmes
Australia	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y
Azerbaijan	Y						Y	Y			
Bangladesh	Y										
Bhutan	Y						Y				
Brazil	Y										
Burkina Faso	Y										
Canada	Y	Y	Y	Y			Y				
Chile	Y										
China	Y										
Colombia	Y		Y								
Egypt	Y										
El Salvador	Y				Y	Y					
Ethiopia	Y										
EU	Y	Y	Y								
Fiji	Y										
Ghana	Y										
India	Y		Y								
Indonesia	Y										
Japan	Y		Y								
Kenya	Y										
Korea	Y						Y				
Lao	Y										
Lesotho	Y		Y	Y			Y	Y	Y		
Malawi											
Mexico	Y		Y			Y					Y
Morocco	Y										
Nepal	Y										
New Zealand	Y										
Nigeria											
Rwanda	Y										
Singapore	Y	Y	Y								
South Africa	Y										
South Korea	Y										
Sri Lanka	Y										
Tanzania	Y										
Thailand	Y										
Uganda	Y										
United Kingdom	Y	Y									
Uruguay	Y										
USA											
Vietnam	Y		Y								
Zambia											
Sample Canadian and American states											
British Columbia (Canada)	Y	Y	Y	Y	Y	Y		Y		Y	
California (USA)	Y	Y	Y				Y	Y	Y	Y	Y

Y: Countries where programme/polices are in effect. Sources: [30–33].

Global organizations have risen to the 2 °C Scenario (2DS) challenge set out in the Paris agreement. Architecture 2030, a peak industry body in the US has issued the Architecture 2030 challenge, in which a combination of good design strategies, use of technologies and systems and off-site renewable energy all support the goal for reaching carbon neutrality. They state on their website that all new buildings, developments and major renovations shall be carbon-neutral by 2030 [34].

Architecture 2030 issued The 2030 Challenge, asking the global architecture and building community to adopt the following targets [34]:

- "All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG (greenhouse gas)-emitting, energy consumption performance standard of 70% below the regional (or country) average/median for that building type.
- At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70% of the regional (or country) average/median for that building type.
- The fossil fuel reduction standard for all new buildings and major renovations shall be increased to:
    - 80% in 2020
    - 90% in 2025
    - Carbon-neutral in 2030 (using no fossil fuel GHG emitting energy to operate)."

These targets may be accomplished by implementing innovative sustainable design strategies, generating on-site renewable power and/or purchasing (20% maximum) renewable energy. Architecture 2030 support the use of fossil fuels along with highly efficient buildings to ultimately move towards being carbon neutral, largely through the use of renewable energy.

The World Green Building Council (WGBC) has developed the Advancing the Net Zero project. This project supports the idea that every building should produce zero carbon emissions by 2050. This is being supported by and undertaken by the green building councils in various countries: Australia, Brazil, Canada, France, Germany, India, the Netherlands, South Africa, Sweden, and the United States. The outcome of the project is an expectation that all new and existing buildings will not produce any emissions by 2050. The means to do this will be developed by the green building councils in these different countries [35].

In Australia, the federal government announced a national carbon offset standard to seek certification under the carbon neutral program in 2015. The objective of the standard is to provide a benchmark for organizations in Australia which are voluntarily seeking to be carbon neutral for their operations, products, services and events. The intention is to support clients in making decisions about purchasing and encouraging more businesses to reduce and offset their emissions, thereby impacting overall greenhouse gas emissions. As part of the process of using these standards to make claims, there must be a good understanding and a measure of the organizations' carbon footprints, their ability to reduce emissions where possible, their ability to offset the emissions, their ability to have their carbon footprint or account individually audited, and their ability to publicly report key information about the carbon neutral claim [36].

These standards are now being expanded to include buildings and precincts in an announcement made by Minister Hunt in 2016 [37]. In support of this, the Green Building Council of Australia (GBCA) has also been working on a '2020 carbon neutral buildings' challenge [38]. Along the lines of Architecture 2030, the GBCA supports good design, using technology including on site renewable generation where possible, and the use of green power for offsets.

5. Discussions

The importance of defining a ZEB is particularly critical when developing policy regulations. As Visscher and others [39] have noted, if buildings are to be compared for understanding how they perform, a common set of considerations and understanding consequences are essential. In addition, along with clear measurements of building energy use, feedback on building performance and its operation relative to weather conditions, indoor environmental quality, and such factors need to be clarified. New forms of legislative and regulatory requirements are essential to ensure energy reductions in new as well as existing building stock. Thus, not only is the future building stock to be considered, particularly in the new growth regions of the Asia-Pacific, Latin America and Africa [40] but also how existing building stock may be converted to reduce their energy use in support of low carbon lifestyles. Without clear and effective compliance mechanisms, the best intentions of de-carbonization may simply be laudable goals without presenting clear evidence-based support for the further development of policy and increasing stringency in the future. In a similar vein, a lack of general understanding of ZCB principles, insufficient and inconsistent practices, unclear and uncertain ZCB policies, and conflicting priorities in management have been highlighted [41,42].

As buildings do not exist in isolation but are part of the wider built environment where most populations reside, it is essential to consider the broader context. Beyond buildings and examining the role of precincts and cities of a NZEB is also important. It is particularly critical because NZEB policies are increasingly encapsulating not just buildings but also precincts. The role of energy sources beyond the building footprint, including for transportation needs, are also considered. The larger the building footprint on the site and the taller the building, the greater the chances are that the building overshadows other buildings nearby, thus compromising the ability of its neighbors to solar access.

In the move towards achieving a true ZEB, both existing building stock and cost need to be taken into consideration. However, before doing that, there is still a way to be traversed to truly understand the meaning of a ZEB. As Marszal and others [43] stated:

> Firstly, the reduction of energy demand using energy efficient measures and secondly the utilization of renewable energy sources to supply the remaining energy demand. Energy efficiency is usually available for the life of the building; however, efficiency measures must have good persistence and should be "checked" to make sure they continue to save energy. It is almost always easier to save energy than to produce energy, and the above strategy is the most logical approach to reach ZEB. In order to ensure that zero energy buildings also are very energy efficient buildings, a fixed value of maximum allowed energy use could be a good solution in combination with energy efficiency requirements for specific components and technologies. Mowing [sic] towards more specific criteria, the indoor climate requirements could also be part of the ZEB definition. On the one hand, it would be very beneficial from a general point of view that all ZEB would use the same requirements with regard to energy efficiency and indoor climate and thus it would be much easier to evaluate and compare ZEBs from different locations worldwide. On the other hand, giving so detailed criteria in the ZEB definition could significantly limit its usefulness in many cases. Since, different values can be used depending on building type, location, applied standard and local climate conditions.

A consistent point that has been raised by a range of researchers [44] is that it is essential to be clear on what the definitions are, as accounting practices could be different if there is no clarity in the definitions. This would also assist in measuring and benchmarking like for like in various countries—particularly in similar climatic conditions.

The split incentive concept in the building industry often makes it difficult to consider a holistic and cohesive approach to design, construction and operation. The main underlying drivers for various stakeholder groups such as developer, builder, owner and occupier may not all be the same. For instance, a developer does not want to take risks in the use of innovative technologies for energy efficiency, as it may cost more and the results do not benefit the developer but the occupier because they pay less for building operations. A developer wants to spend the least amount of time in building to recover costs. Builders want to also finish projects quickly for profits, as more time on projects means more money is lost, and they too do not want to innovate if the returns on their investment are passed onto the occupier. Owner-occupiers typically have more leverage for energy efficiency as they can put pressure back on the developer and builder to make decisions that impacts ongoing use of the building.

Industry responses to support the built environment community encourages a collaborative approach needed by all actors to move in the direction of overall GHG reductions. However, what this does not take into account is the cost of continuously upgrading the technologies to reduce energy efficiency in the building and an assumption that technologies alone will be sufficient to move buildings towards high performing buildings. The role of building occupants has not been considered in this equation. This approach also does not consider situations where the dominant source of grid energy may be 100% from renewables. In such situations, the focus of the buildings should be on achieving greater energy efficiency leading to very low energy use with the support of both technology and occupants.

As can be seen from the various definitions of a ZEB, one very difficult area to regulate is user behavior. The role of the people also impinges on cultural expectations and diversity. For example, setting higher indoor temperatures in summer above the standard 'norms' encourages building users to dress appropriately, and, like-wise, a lower setting in winter supports putting on additional clothing to make occupiers more comfortable. In some cultures, these are a bit difficult to accept, and education/cultural change becomes very critical support for acceptance.

A key factor to be considered in this is the process of design itself. The standard design process is concept and architectural design, with HVAC designs undertaken by the relevant experts and then the process of construction by builders and relevant contractors. This is a linear process whereas what is now being expected by industry is an integration of the design and the various consultants involved in energy modelling and façade and systems design [8]. This fundamentally changes the traditional role of the architects and the consultants (usually engineers). This recognition in practice is not being recognized in the education of architects, engineers and other built environment professionals. When extended from buildings to precinct scales and even larger into cities, it is equally important for planners to also get involved in the planning of cities to ensure maximum solar orientation to support passive design and renewable energy options.

Feedback with the experience in the use of technology is also important. For example, in the design of the Council House 2 building [45] in Melbourne, the wind mills placed on the building do not work, and this has now been publicly acknowledged.

6. Conclusions

Definitions are important, as they assist in creating briefs that are clear and transparent to all stakeholders concerned in design, build and operation of buildings. The role of good design cannot be highlighted enough, though. Good design and planning are critical to ensure that more passive and less active systems support the operation of the buildings and precincts, leading to less energy use on active systems. It is also important to measure the performance of the building or beyond the building as the case may be, particularly in the first year of commissioning because many changes are made as fine tuning occurs to optimize efficiencies. That is not to say that the performance of the building or beyond the building should not be made on an ongoing basis, as ongoing performance ensures that feedback loops are closed between design intent and actual performance in reality. Particularly where new technology is used, ongoing performance enables understanding of the use of new technologies, as well as their risks and benefits to wider stakeholders in the building industry.

The fact is that increased building and construction activities will impact environmental damage unless serious efforts are made to curb associated emissions. This is where international agreements such as the Paris Agreement and the networks such as the GlobalABC have a critical role to play. As noted, in some parts of the world, rising emissions are expected to mature to the middle or the end of this century. The very act of building requires energy for construction, but if good design and planning may be used as a way to mitigate ongoing emissions through zero energy in operation, the overall trajectory for the future seems more optimistic. As indicated, the considerations and consequences of a ZEB are important, as they set up the underlying parameters of building operation and disassembly at the end of life or when renovations or refurbishments occur. They also support emerging ideas such as circularity in the built environment.

Funding: This research received no external funding.

Acknowledgments: My thanks to Priyanka Erasmus for developing the end note library for this paper.

Conflicts of Interest: The author declares no conflict of interest.

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