Hui, S. C. M., 2010. Zero energy and zero carbon buildings: myths and facts, In *Proceedings of the International Conference on Intelligent Systems, Structures and Facilities (ISSF2010): Intelligent Infrastructure and Buildings*, 12 January 2010, Kowloon Shangri-la Hotel, Hong Kong, China, pp. 15-25. (www.aiib.net)

Zero energy and zero carbon buildings: myths and facts

Dr. Sam C. M. Hui

Department of Mechanical Engineering, The University of Hong Kong
Pokfulam Road, Hong Kong
E-mail: cmhui@hku.hk, Tel: (852) 2859-2123, Fax: (852) 2858-5415

ABSTRACT

Zero energy building (ZEB) and zero carbon building (ZCB) are general terms applied to a building with zero net energy consumption and zero carbon emissions, respectively. In recent years, ZEB and ZCB have attracted much attention in many countries because they are considered as an important strategy to achieve energy conservation and reduce emissions of greenhouse gases. In some countries, the strategy for moving by regulation to ZEB/ZCB has generated a lot of debate as to whether it is currently feasible.

This research paper explains the myths and facts of ZEB and ZCB, with the aim to enhance understanding and avoid misleading statements. The definitions and key concepts of ZEB and ZCB are described. To investigate the practical considerations and real meanings of ZEB and ZCB to our society, some of the pilot projects in the world are reviewed and the local conditions in Hong Kong are studied. The critical issues for achieving ZEB and ZCB are discussed from both engineering and architectural points of view. Important factors affecting the feasibility of ZEB and ZCB are examined.

Keywords: Zero energy building, zero carbon building, Hong Kong.

1. Introduction

To combat the climate change issue, developing the city into a low carbon society is a global trend worldwide (DCLG, 2007; Loper, *et al.*, 2008; NIES, 2009). Low or zero carbon design is essential to achieve the carbon reduction target. Among all sectors, building industry is identified as the major contributor on carbon emission (DCLG, 2006). There is a growing interest in the development of zero energy, zero carbon and carbon neutral buildings in the world (ECEEE, 2009; Marsh, 2002; NIES, 2009; NSTC, 2008).

Zero energy building (ZEB) and zero carbon building (ZCB) are general terms applied to a building with zero net energy consumption and zero carbon emissions, respectively (Torcellini, *et al.*, 2006). In recent years, ZEB and ZCB have attracted much attention in many countries because they are considered as an important strategy to achieve energy conservation and sustainability as well as reduce emissions of greenhouse gases. Pilot ZEB/ZCB projects were proposed and built in recent years (BioRegional, 2003; Frechette III and Gilchrist, 2009; Iqbal, 2004; ISE, 2000; Pogharian, *et al.*, 2008; Tang, 2005; Wang, 2009; Wang, Gwilliam and Jones, 2009). It is believed that ZEB/ZCB can help reduce energy consumption and costs, carbon emissions, as well as dependence on fossil fuels.

To put ZEB and ZCB into reality and promote wider application, it is important to enhance people's understanding and develop effective policy. This research paper explains the myths and facts of ZEB and ZCB, with the aim to enhance understanding and avoid misleading statements. The definitions and key concepts of ZEB and ZCB are described. To investigate the practical considerations and real meanings of ZEB and ZCB to our society, some of the pilot projects in the world are reviewed and the local conditions in Hong Kong are studied.

The critical issues for achieving ZEB and ZCB are discussed from both engineering and architectural points of view. Important factors affecting the feasibility of ZEB and ZCB are examined.

2. Definitions and Basic Concepts

What do people mean by zero energy or zero carbon performance? To evaluate the concepts clearly, it is necessary to know if they are talking the same language and making the same assumptions.

In general, the terms 'zero energy', 'zero carbon' or 'zero emission' are applied to buildings that use renewable energy sources on-site to generate energy for their operation, so that over a year the net amount of energy generated on-site equals the net amount of energy required by the building (Australian Government, 2008).

2.1 Definitions of ZEB

ZEB can be defined as a building that produces as much energy on-site as it consumes on an annual basis. Torcellini, *et al.* (2006) provided four definitions of ZEB: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. A classification system based on renewable energy supply options is also used to distinguish different types of ZEB. Table 1 shows a summary of the terms and definitions.

Table 1. Terms and definitions of ZEB and ZCB [adapted from Torcellini, *et al.* (2006)]

Terms	**Definitions/Meanings**
Zero energy building (ZEB) or net zero energy building (NZEB)	A building that produces as much energy on-site as it consumes on an annual basis
Net zero site energy building (site ZEB)	Amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building
Net off-site zero energy building (off-site ZEB)	Similar to previous one, but consider purchasing of energy off-site from 100% renewable energy sources
Net zero source/primary energy building (source ZEB)	It produces as much energy as it uses in a year, when accounted for the source. For electricity, only around 35% of the energy used in a fossil fuel power plant is converted to useful electricity and delivered. Site-to-source conversion multipliers are used to calculate a building's total source energy
Net zero energy cost building (cost ZEB)	The cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site
Net zero energy emissions building, zero carbon building (ZCB), zero emission building	The carbon emissions generated from the on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production

Usually, common ZEB definitions only include the energy to operate the building and not other carbon emitting areas associated with the building, such as the manufacture and transportation of building materials and energy used during construction. Stricter definitions of ZEB may consider the energy used in the construction and eventual decommissioning.

In Europe, the ZEB definition specifies the overall annual primary energy consumption since this is closer to the policy to reduce carbon emissions (ECEEE, 2009). In USA, NAHB Research Center (2006) has investigated the potential impact of zero energy homes (ZEHs) and indicated that a ZEH should combine state-of-the-art, highly energy-efficient designs and equipment with on-site renewable energy generation (which typically includes a solar hot water production system and a rooftop photovoltaic system) to return as much energy to the utility as it takes on an annual basis. These ZEHs are designed to perform well, be comfortable, require only standard maintenance, and look no different from an ordinary home.

ASHRAE (2008) pointed out that the only way to measure if a building is a ZEB is to look at the energy crossing the boundary. Other definitions, including source, emissions, and cost, are based on this measured information and include weighing factors and algorithms to get to the metric of interest. A ZEB can exchange energy with the power grid to achieve net energy balance while maintaining an acceptable level of service and functionality.

2.2 Related Concepts

There are also other terms which are similar or closely related to ZEB/ZCB. Table 2 describes these terms and their meanings. For instance, an autonomous house is a building that can produce power from the sun and get drinking water from the rain (Vale and Vale, 2000). It is a house that is kind to the planet and liberates its owner from utility bills. However, achieving a ZEB without the grid is very difficult, as current storage technologies is limited and off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses. Thus, for energy balances in ZEB, usually grid connection is allowed and necessary.

Table 2. Related concepts of ZEB and ZCB

Terms	Definitions/Meanings
Autonomous or self-sufficient building	A building designed to be operated independently from infrastructural support services e.g. electricity grid, municipal water systems, sewage treatment systems, storm drains, communication services
Energy-plus/-positive building (E+B)	A building that produces a surplus of energy during a year
Green building (GB)	A building that reduces the environmental impact while improving environmental sustainability
Low energy building (LEB)	Building developments that facilitate or use low levels of energy (than regular buildings)
Off-the grid building	A building that is completely self-sufficient and stand-alone. It is not connected to an off-site energy utility facility. It requires distributed renewable energy sources AND energy storage capability
Passive (energy) building	Passive house (passivhaus in German); passive solar building; ultra low energy, through passive design; does not include active systems e.g. mechanical ventilation or photovoltaics

ZEBs set out to use renewable electricity generated on-site. Although obtaining electricity from the grid through accredited green electricity providers should be used and could be considered as having net zero carbon emissions, the intention of ZEBs is that they are relatively self-contained (Australian Government, 2008). This provides occupants with a full understanding of how much space and cost is required to provide renewable energy solutions on-site and the benefits of energy efficiency.

A building approaching zero energy is called “near-zero energy building” or “ultra low energy building”. It is believed that most ZEBs are very “green”, however, very few green buildings use zero energy. ZEB and green building (GB) have many similarities since both aim to reduce energy bills and greenhouse gas emission to achieve high-performance energy-efficient buildings. The goal of GB is to use resources more efficiently and reduce a building's negative impact on the environment. ZEB may or may not be considered "green" in all areas, such as reducing waste, using recycled building materials, etc. Also, ZEB does not consider the embodied energy of the structure, energy for construction of the building and energy for transport or commuting. Table 3 shows a brief summary of the comparison of low energy, zero energy/carbon and green buildings.

Table 3. Comparison of low energy, zero energy/carbon and green buildings [adapted from ECEEE (2009)]

	Pros	Cons
Low energy building (LEB) (e.g. passive house)	Cost optimal; well established principles with thousands of buildings constructed	Does not achieve greatest energy/carbon saving potential
Zero energy building (ZEB)/ Zero carbon building (ZCB)	Greatest energy/carbon saving	More expensive; limited practical experience
Green Building (GB)	Takes account of wider sustainability and resource use issues	May not be realistic across all new buildings

2.3 The Meaning of Zero Carbon

In UK, the definitions of zero carbon performance have attracted much concern in recent years (Fulcrum, 2009; UK-GBC, 2008). According to DCLG (2006), a zero carbon home is one with zero net emissions of carbon dioxide from all energy use in the home. The definition encompasses all energy use in the home (including energy for cooking, TVs, computers and other appliances) rather than just those energy uses that are currently part of building regulations (space heating, hot water, ventilation and some lighting). It means that over a year there are no net carbon emissions resulting from the operation of the dwelling. This could be achieved either through steps taken at the individual dwelling level or through site wide strategies. So it will not be necessary for each dwelling to have its own microgeneration capacity where development level solutions would be more appropriate.

At the same time, the *Code for Sustainable Homes* in UK (DCLG, 2008a) specifies true zero carbon dwelling as one where net carbon dioxide emissions resulting from all energy used in the dwelling are zero or better. This includes the energy consumed in the operation of the space heating/cooling and hot-water systems, ventilation, all internal lighting, cooking and all electrical appliances. The calculation can take account of contributions from onsite renewable/low carbon installations. Off-site renewable contributions can only be used where these are directly supplied to the dwellings by private wire arrangement.

To clarify the situation, DCLG (2008b) tried to develop a practical definition of zero carbon homes and non-domestic buildings. It was proposed that the definition for zero carbon homes should be based on high energy efficiency, on-site carbon reduction measures, and a list of allowable solutions (mainly offsite) for dealing with the remaining emissions. Here, zero carbon means that, over a year, the net carbon emissions from all energy use in the home would be zero. In a related study, DCLG (2009) recommended allowable solutions could include large scale off-site (and potentially unconnected) renewable energy facilities, investment in local energy efficiency measures and the installation of energy efficient white goods or building control systems. In addition, Fulcrum (2009) argued that a single, sensible, universally applicable definition of ZCB could cope with innovation while driving the building industry toward a coherent vision for a sustainable built environment. They also believe the metrics used should be outcome-based and the criteria should be widened to include new renewable energy generation installations in the vicinity of the development as per the 'on- or near-site' suggestion in the report UK-GBC (2008).

3. Major Initiatives and Pilot Projects in the World

In the past few years, the political desire for ZEB/ZCB and much tougher energy performance requirements in buildings has considerably gathered pace and momentum. A brief summary of the major initiatives and pilot projects in the world is described as follows.

3.1 The Goals in Europe

The UK has set an aggressive goal to require all the houses built on its territory after 2016 to be carbon neutral (DCLG, 2007). That is to say, the new energy consumption for each of these houses will be zero. All energy necessities will be covered by renewable power sources, such as biomass boilers, wind and solar converters on roofs, better insulation in the walls and windows and so on. More stringent Building Regulations and relevant planning policy will be developed to set a framework for the zero carbon development (DCLG, 2006). The government has also introduced a time-limited stamp duty land tax relief in 2007 for new homes built to a zero carbon standard set in Her Majesty's Treasury (HMT) regulations. The ZCB idea will be extended to other types of buildings. Table 4 shows a summary of the zero carbon agenda of UK.

Table 4. Zero carbon agenda of UK

Year	Target
2010	25% improvement in the energy/carbon performance set in Building Regulations
2013	44% improvement in the energy/carbon performance set in Building Regulations
2016	Zero Carbon Homes and Zero Carbon Schools
2018	Zero Carbon Public Buildings
2019	Zero Carbon Buildings

The European Parliament has also called for amending the 2002 Energy Performance of Buildings Directive (recast) to make ZEBs mandatory for new buildings and impose zero energy standards to a certain percentage of refurbished buildings by 2019 (ECEEE, 2009). This means that primary use of energy will require energy to be produced on site, within the building. The drive towards zero energy/zero carbon and even positive energy buildings is led by Western European nations (France, Germany, The Netherlands, UK) and Hungary. The impact of the zero energy standards will necessarily call attention to, and investment, into energy efficiency within buildings to meet the guidelines.

To promote better understanding and education of ZEB/ZCB, the IEA SHC Task 40 and ECBCS Annex 52 Joint Project: Towards Net Zero Energy Solar Buildings (NZEBs) was initiated in 2008 (Voss and Riley, 2009). Its objective is to study current net-zero, near net-zero and very low energy buildings and to develop a common understanding, a harmonized international definitions framework, tools, innovative solutions and industry guidelines.

3.2 The Initiatives in USA

In USA, the concern for creating the technology and knowledge base for cost-effective ZEBs is growing steadily. Table 5 shows examples of major initiatives in USA for ZEBs. Strategies and policies for high-performance ZEBs have been studied (NSTC, 2008). A Zero Energy

Buildings Database (http://zeb.buildinggreen.com) has been set up by the US Department of Energy to highlight ZEB projects in USA (Crawley, Pless and Torcellini, 2009).

Table 5. Examples of the major initiatives in USA for ZEB and ZCB

Initiatives	Description
Architecture 2030 (www.architecture2030.org)	The goal is to achieve a dramatic reduction in the greenhouse gas (GHG) emissions of the building sector by changing the way buildings and developments are planned, designed and constructed.
AIA (American Institute of Architects) 2030 Carbon Neutral Design Commitment (www.aia.org)	It is a voluntary program for AIA member firms and other entities in the built environment. It asks these organizations to make a pledge, develop multi-year action plans, and implement steps that can advance AIA's goal of carbon neutral buildings by the year 2030. The AIA 2030 Challenge calls for incrementally reducing energy use, starting with a 50% reduction over existing buildings' energy use and increasing savings up to 2030, when new buildings will be carbon neutral.
ASHRAE Vision 2020 (ASHRAE, 2008)	It sets out requirements for developing the tools by 2020 to enable commercially viable net zero energy buildings by 2030.
Net-Zero Energy Commercial Building Initiative, by U.S. Department of Energy (Crawley, Pless and Torcellini, 2009)	Its aim is to achieve marketable net-zero energy commercial buildings by 2025. It supports the goal of net zero energy for all new commercial buildings by 2030, and specifies a zero-energy target for 50% of U.S. commercial buildings by 2040 and net zero for all U.S. commercial buildings by 2050. www1.eere.energy.gov/buildings/commercial_initiative/
Zero Energy Homes research initiative, by U.S. Department of Energy	The U.S. Department of Energy has partnered with building professionals and organizations to further develop the Zero Energy Homes concept. www.energysavers.gov/your_home

3.3 Pilot Projects

To illustrate the practical planning and design considerations of ZEB/ZCB, some examples of pilot projects are shown in Table 6 and Figure 1. They represent different approaches to ZEB/ZCB. The major features and characteristics of these buildings can be found in the relevant references and sources.

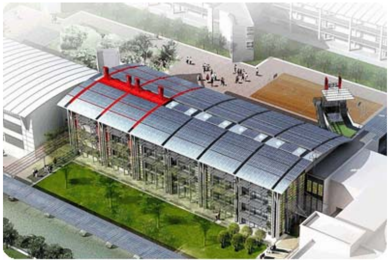
Table 6. Examples of pilot projects of ZEB/ZCB

Country	Project Name [Year of completion]	References/ Sources
China	Pearl River Tower, Guangdong [2010]	Frechette III and Gilchrist (2009)
Germany	A self-sufficient solar house in Freiburg [1992]	ISE (2000)
Malaysia	Pusat Tenaga Malaysia's ZEO Building (Zero Energy Office) [2007]	Tang (2005); www.ptm.org.my/PTM_Building
Singapore	Building and Construction Authority (BCA) Academy [2009]	Wang (2009) www.bca.gov.sg
UK	Beddington Zero Energy Development (or BedZED) in London [2002]	BioRegional (2009 & 2003); Dunster, Simmons and Gilbert (2008); Marsh (2002)
UK	The Barratt Green House in Watford (Level 6 Code for Sustainable Homes) [2008]	Ickeringill (2009); www.barrattdevelopments.co.uk

Pearl River Tower, Guangdong, China

Self-sufficient solar house, Freiburg, Germany

Pusat Tenaga Malaysia's ZEO Building, Malaysia



BCA Academy, Singapore

Beddington Zero Energy Development (BedZED), London

The Barratt Green House in Watford, UK

Fig. 1 Examples of ZEB/ZCB projects in the world (see Table 6 for the references/sources)

4. Discussions

ZEB is not a single product or technology; but rather a combination of closely-integrated evolving technologies. The technical concept of ZEB depends on climate and usage of building, therefore, detailed analysis is needed to optimise the building performance. Effective system integration to minimise the whole-building energy-consumption requires careful planning and computer modelling in order to make all the subcomponent parts work together cost effectively.

4.1 Myths and Facts

When describing the 10 big energy myths, Goodall (2008) pointed out a myth that zero carbon homes are the best way of dealing with greenhouse gas emissions from buildings. In fact, making a building genuinely zero carbon is extremely expensive, and just focusing on the about 1% of the housing stock that is newly built each year has no effect on the remaining 99% existing buildings. In Germany a mixture of subsidies, cheap loans and exhortation is succeeding in getting hundreds of thousands of older properties eco-renovated each year to very impressive standards and at reasonable cost.

Some people have commented that the UK and European goals have imposed an extraordinarily ambitious target which is difficult to achieve (Menon and Porteous, 2008; Osmani and O'Reilly, 2009; Williams, 2009). It is argued that the priority should be the energy performance of existing buildings, since new buildings account for less than 2% of the stock and ZEBs would therefore only have a marginal impact on the overall energy efficiency of the building stock for many years to come. From an economic point of view it would be more effective to reach out for "low energy buildings", which may save 70-90% of energy requirements at substantially lower costs. Thus, it is believed that it would be more rational to set out more stringent energy performance standards for new and existing buildings.

Major benefits of creating zero energy, zero carbon or zero emission buildings come from the increased energy efficiency strategies that are necessary to make on-site renewable energy sources viable and the immediate awareness and better understanding of energy use they encourage for their occupants. It is possible to reduce carbon emissions from energy use down to zero in the majority of new non-domestic buildings, as long as onsite, near-site and offsite renewable solutions are employed. Moreover, to cut emissions growth from the buildings sector to nearly zero, additional policies on the supply side will be required, such as policies to reduce the carbon intensity of electric generation, promote investments in onsite renewable energy and slow growth in demand for energy services (Loper, *et al.*, 2008).

4.2 Design Strategies for ZEB/ZCB

Designing a ZEB or ZCB can be complex, as each design solution must be tailored to the specific location (Australian Government, 2008). This includes designing to the features and qualities of the site, designing for the requirements of the building's use, designing with an understanding of how to incorporate renewable energy sources on-site and designing with consideration of actual energy use (CIBSE, 2004). The basic design strategies for ZEB/ZCB are summarised in Table 7.

Table 7. Design strategies for ZEB and ZCB

Design strategies
Incorporate energy efficiency strategies with renewable energy options from the outset of the project
Choose a site or location that allows for renewable energy opportunities and reduces transportation and food production needs
Maximise passive design strategies in the design of the home to reduce energy demand
Reduce water use in conjunction with reducing the demand for hot water
Select materials use appropriately, by incorporating materials that enhance the passive design strategy and have a low embodied energy
Reduce energy use in all areas of the building
The balance between energy efficiency and renewables is an important issue. It is essential not to apply excessive renewables to buildings with poor energy efficiency

A good ZEB should first encourage energy efficiency, and then use renewable energy sources available on site. Reduction of energy demand must be the first goal. Passive solar design is often more cost effective than adding expensive photovoltaic (PV) to a conventional inefficient building. Common energy efficiency (EE) features include daylighting, EE lighting, EE office equipment, EE ventilation, controls and sensors, orientation, insulation and energy management. Figure 2 shows the strategies for net zero energy building. A balance between energy conservation and energy generation should be considered carefully.

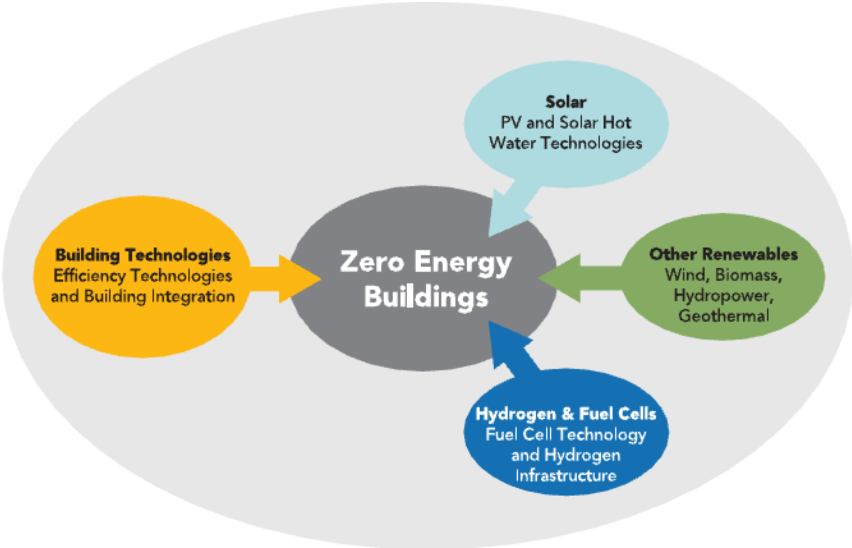


Fig. 2 Strategies for net zero energy building [Source: NSTC (2008)]

4.3 Shifts in Dominant Technologies

Brown and Vergragt (2008) pointed out that large-scale shifts in dominant technologies are necessary to a transition toward sustainability. However, such shifts are difficult because, in addition to technological innovation, they require changes in the existing institutions, professional norms, belief systems and, in some cases, also lifestyles. They found that higher order learning on a scale ranging from individuals to professional and business communities, to the society at large, is needed. This learning is especially crucial in the types of innovations that depend mainly on synthesis of existing technologies and know-how to achieve radical reductions in energy and material consumption, as is the case with high performance buildings. One way to facilitate this type of learning is through experimentation with new technologies and services. ZEB/ZCB can provide opportunities for such experimentation.

Menon and Porteous (2008) found that low-carbon and zero-carbon scenarios would require radical changes of funding/fiscal and building cultures. It is noteworthy that setting a medium term challenging target in the UK has proved a real driver for change in the home building industry. The UK Government's decision to set a deadline for zero carbon homes had been a brave one and had led to a sea change in the way the industry looked at emissions. Where before there had been a series of gradual increments to steadily improve energy efficiency over time, this had made people think about what the eventual aim was instead.

The demands for buildings that can reduce carbon emission related to building energy usage are growing. Climate change mitigation requires assigning monetary values to societal values and changing building owner's financial performa through societal investments.

4.4 Cost Implications

As reported in UK-GBC (2007), there is a cost associated with building to zero carbon. The cost varies widely with both the form and the use of the building. However, preliminary modelling suggested that the premium could range from over 30% down to as low as 5 or 10% of current baseline costs. In practical applications, ZEB/ZCB is often seen as too expensive or as requiring too much change in design and construction practices. Many people believe that economies of scale will bring down costs of environmental technologies; pilot projects and R&D will provide a testing ground and information to overcome the industry resistance in practices.

Jennings (2009) pointed out that efficiency level above 30% is not economically viable for today's office building market. Industry need to consider what is technically achievable and also need to take into account what is cost-effective for owners and society.

4.5 ZEB in Use

Care must be taken to the operation and management of ZEBs in actual use. Nowadays, building managers often do not include energy efficiency when vetting the performance of buildings. And they tend to over-operate the system, for instance setting the air-conditioning at cold temperatures, so as to avoid complaints. Normally, it takes a year to fine-tune any building but the ZEB could be more complicated because of its many innovations.

It is recommended that ZEB status be reviewed and tracked each year through utility bills or submetering. Realistically, a building may be designed to achieve one or more ZEB definitions but may not achieve a net zero energy position in actual operations every year. Any ZEB may fall into the near-NZEB category in a given year, depending on weather, the condition of the building, operations, and other factors. A well-operating ZEB also may become a near ZEB during abnormal weather years that have above-average cooling and heating loads, with below-average solar and wind resources.

For example, some people have asked if BedZED, the best known eco-village in UK really achieved the target. BioRegional (2009) found that the combined heat and power (CHP) doesn't work and the original onsite water treatment system was decommissioned. Despite post-construction analyses revealing the development is not actually zero fossil energy (due to problems with the renewable energy technologies that were incorporated), there have been significant CO_2 savings per resident, the homes are improvements above typical UK homes standards and there are many valuable lessons that have and can be learnt.

4.6 Situations in Hong Kong

The city of Hong Kong is compact with high urban densities and many high-rise buildings (Hui, 2001). It is much more difficult, if not impossible, to make zero-energy or zero-carbon high-rises than houses. Fortunately, Hong Kong has a very efficient transport system that has greatly reduced our energy consumption in transport. This is reflected in the fact that our building stock accounts for a very significant part of the total energy consumption in the territory.

Although ZEB/ZCB is not an immediately achievable objective for most of the buildings, Hong Kong should adopt a more proactive role to reduce energy consumption in existing buildings and explore more renewable energy sources. The mandatory building energy codes, to be legislated soon, and the recent energy/carbon audit subsidies for building owners, will help cut energy demand, but the supply side remains unclear. If energy certificate and energy labels for buildings can be developed and implemented, it would provide greater market force and better building information for energy efficiency (Hui and Lee, 2009).

To promote sustainability and innovation in Hong Kong, more creative ideas and practical innovations are needed. For example, Bağcıa (2009) has investigated the concept of “zero energy island” and indicated the potential application of the available natural and alternative energy resources in Peng Chau Island, Hong Kong. The results showed that some of the mentioned resources can be used very efficiently to supply the required electricity of the island whereas others are not very suitable.

5. Conclusions

Buildings are the largest end-users of energy in a society and the building sector is of fundamental importance to strategic carbon emissions policy. To stimulate the market to innovate and adapt to low carbon technologies, measures to promote zero energy and zero carbon building projects are useful.

It is believed that ZEB and ZCB can demonstrate what is possible when resources are combined with high ideals and green design. To overcome the resistance and barriers to better energy efficiency, much of the need for change involves the better use of known technology, and some involves changing behaviour.

We must think of innovating in ZEB/ZCB as both a process and a product, and that both must be considered in the future efforts to replicate this building. If zero energy or zero carbon is pragmatically defined as a directional goal, rather than as being fixed quantitatively, then the strategies and policies to improve the energy/carbon performance can be designed and implemented in a more effective way.

In the coming future, builders may go beyond energy efficiency and strive to qualify their buildings as carbon neutral or net zero energy. It is hoped that energy self-sufficiency in buildings can be achieved in our society and ZEB/ZCB will also become economical and socially acceptable in the near future.

References

ASHRAE, 2008. *ASHRAE Vision 2020*, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.

Australian Government, 2008. *Your Home Technical Manual*, 4th ed., Department of the Environment, Water, Heritage and the Arts, Commonwealth of Australia, Canberra ACT, Australia, www.yourhome.gov.au/technical.

Bağcıa, B., 2009. Towards a zero energy island, *Renewable Energy*, 34 (3): 784-789.

BioRegional, 2009. *BedZED Seven Years On: The Impact of the UK’s Best Known Eco-village and Its Residents*, BioRegional Development Group, Surrey, UK.

BioRegional, 2003. *BedZED: Toolkit Part II, A Practical Guide to Producing Affordable Carbon Neutral Developments*, BioRegional Development Group, Surrey, UK.

Brown, H. S. and Vergragt, P. J., 2008. Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building, *Technological Forecasting & Social Change*, 75 (2008): 107–130.

CIBSE, 2004. *Energy Efficiency in Buildings: CIBSE Guide F*, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.

Crawley, D., Pless, S. and Torcellini, P., 2009. Getting to net zero, *ASHRAE Journal*, 51 (9): 18-25.

DCLG, 2009. *Costs and Benefits of Alternative Definitions of Zero Carbon Homes: Project Report*, Department for Communities and Local Government (DCLG), London.

DCLG, 2008a. *Code for Sustainable Homes: Technical Guide*, Department for Communities and Local Government (DCLG), London.

DCLG, 2008b. *Definition of Zero Carbon Homes and Non-Domestic Buildings: Consultation*, Department for Communities and Local Government (DCLG), London.

DCLG, 2007. *Building a Greener Future: Policy Statement*, Department for Communities and Local Government (DCLG), London.

DCLG, 2006. *Building a Greener Future: Towards Zero Carbon Development: Consultation*, Department for Communities and Local Government (DCLG), London.

Dunster, B., Simmons, C. and Gilbert, B., 2008. *The ZED Book: Solutions for A Shrinking World*, Taylor & Francis, Abingdon, Oxon.

ECEEE, 2009. *Net Zero Energy Buildings: Definitions, Issues and Experience*, European Council for an Energy Efficient Economy (ECEEE), Stockholm, Sweden.

Frechette III, R. E. and Gilchrist, R., 2009. Seeking zero energy, *Civil Engineering*, 79 (1): 38-47.

Fulcrum, 2009. *Fulcrum's Dream Definition of Zero Carbon Buildings*, Fulcrum Consulting, London, www.fulcrumfirst.com.

Goodall, C., 2008. The 10 big energy myths, *The Guardian*, Thursday, 27 November 2008, www.guardian.co.uk.

Hui, S. C. M. and Lee, R. K. H., 2009. Development of energy labels for residential buildings in Hong Kong, In *Proceedings of the 10th Asia Pacific Conference on the Built Environment: Green Energy for Environment*, 5-6 November 2009, Kaohsiung, Taiwan, 8 pages.

Hui, S. C. M., 2001. Low energy building design in high density urban cities, *Renewable Energy*, 24 (3-4): 627-640.

Ickeringill, A., 2009. Can a home be environmentally sustainable and a fun place to live? *Building Engineer*, 84 (4): 20-21.

Iqbal, M. T., 2004. A feasibility study of a zero energy home in Newfoundland, *Renewable Energy*, 29 (2004): 277–289.

ISE, 2000. *The Solar House in Freiburg: From A Self-sufficient Solar House to A Research Platform*, Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany.

Jennings, J., 2009. The bleeding edge of green, *Consulting-Specifying Engineer*, 45 (5): 48.

Loper, J., *et al.*, 2008. *Reducing Carbon Dioxide Emissions through Improved Energy Efficiency in Buildings*, Alliance to Save Energy, Washington DC.

Marsh, G., 2002. Zero energy buildings: Key role for RE at UK housing development, *Refocus*, 3 (3): 58-61.

Menon, R. and Porteous, C. D. A., 2008. Materials, specification and economic implications of moving to carbon-neutral housing, *Open House International*, 33 (3): 48-59.

NAHB Research Center, 2006. *The Potential Impact of Zero Energy Homes*, National Renewable Energy Laboratory, Golden, CO.

NIES, 2009. *Japan Roadmaps towards Low-Carbon Societies (LCSs)*, National Institute for Environmental Studies (NIES), Tsukuba, Ibaraki, Japan.

NSTC, 2008. *Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings*, Subcommittee on Buildings Technology Research and Development, Committee on Technology, National Science and Technology Council (NSTC), Washington, DC.

Osmani, M and O'Reilly, A., 2009. Feasibility of zero carbon homes in England by 2016: A house builder's perspective, *Building and Environment*, 44 (9): 1917-1924.

Pogharian, S., *et al.*, 2008. Getting to a net zero energy lifestyle in Canada: the Alstonvale Net Zero Energy House, paper presented to *the 23rd European PV Solar Energy Conference*, Valencia, Spain, September 2008, 7 pages.

Tang, C. K., 2005. Pusat Tenaga Malaysia's ZEO Building (Zero Energy Office), presentation at *Sustainable Buildings Conference 2005*, 27-29 September 2005, Tokyo, Japan, www.sb05.com.

Torcellini, P., *et al.*, 2006. Zero energy buildings: a critical look at the definition, In *Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings*, August 14−18, 2006, Pacific Grove, CA, 12 pp.

UK-GBC, 2008. *The Definition of Zero Carbon*, Zero Carbon Task Group Report, UK Green Building Council (UK-GBC), London, available at www.ukgbc.org.

UK-GBC, 2007. *Report on Carbon Reductions in New Non-domestic Buildings*, UK Green Building Council (UK-GBC), for Department for Communities and Local Government, London, available at www.communities.gov.uk.

Vale, B. and Vale, R., 2000. *The New Autonomous House: Design and Planning for Sustainability*, Thames & Hudson, New York.

Voss, K. and Riley, M., 2009. *IEA Joint Project: Towards Net Zero Energy Solar Buildings (NZEBs), Task/Annex Text*, SHC Task 40 and ECBCS Annex 52 Joint Project, International Energy Agency Solar Heating and Cooling Programme, CanmetENERGY, Natural Resources Canada, QC, Canada.

Wang, E. E., 2009. Singapore's first "Zero Energy Building" launched, *Channel NewsAsia*, 26 October 2009, www.channelnewsasia.com.

Wang, L., Gwilliam, J, and Jones, P., 2009. Case study of zero energy house design in UK, *Energy and Buildings*, 41 (11): 1215-1222.

Williams, J., 2009. Zero carbon homes - myth or reality?, *IOP Conference Series: Earth and Environmental Science*, 6 (2009) 262015.