SOLAR NET ZERO ENERGY BUILDINGS: A REVIEW

I.P. Udayanga, S.D.A. Soorige* and N.H.C. Manjula

Department of Building Economics, University of Moratuwa, Sri Lanka

ABSTRACT

Commercial and residential buildings account for almost 40% of the world total energy demand. In order to fulfil that energy requirement, large amount of fossil fuels are used and it has made a greater impact on the environmental sustainability and the economic stability of the society. Therefore, the industry gives more concern to create an environmentally friendly and economically viable renewable energy (RE) solution since last few decades. A number of environmentally friendly building design concepts have been established to promote the renewable energy (RE) usage in the building sector. Solar Net Zero Energy Building (Solar NZEB) can be identified as one such environmental friendly building design concept which has gained a significant global attention in the last decade. This study is focussed on reviewing the Solar NZEB concept and its applicability based on the literature. First the approaches to achieve zero energy balance in a building is explained in terms of energy efficiency measures and onsite renewable energy sources. Further, the design considerations of Solar Net Zero Energy Buildings are identified and following identification of the enablers and barriers for the Solar NZEB, the research concludes with a conceptual framework for Solar NZEB.

Keywords: *Enablers and Barriers; Energy Efficiency Measures; Net Zero Energy Building (NZEB); Renewable Energy (RE); Solar Energy.*

1. INTRODUCTION

Cuce *et al.*(2016) revealed that nowadays buildings are accountable for 40% of the total energy consumption of the world. The major part of that (80-90%) is consumed during the operation stage of the buildings and the rest (10-20%) inherent with the construction stage (Ramesh *et al.,* 2010). Since the costs of resources are frequently increasing, the energy efficiency, resource efficiency and the energy cost saving approaches have become vital in present. Maistry and Annegarn (2016) cited that the best possible way to bring down the energy cost of a building is to reduce the energy demand in operational stage and need to discover more potential methods to reduce operational energy in the building. As an energy efficient building approach, the Net Zero Energy Building (NZEB) concept is rapidly growing since last few years in the world and some of the developed countries have included NZEB concept as their main goal of the energy policy as well (Sartori *et al.*, 2012).

Sartori *et al.* (2010) defined the NZEB as "a building with greatly reduced energy demand that can be balanced by an equivalent on-site generation of electricity, or other energy carriers, from renewable sources". According to the ASHRAE (2008), NZEBs produce as much energy from renewable energy sources to balance the consumption on the annual basis. NZEB is a building design concept which is used for both commercial and residential buildings to achieve the great reduction of energy consumption through efficiency gains in a way that total energy requirement of the building get supplied by on-site renewable energy sources (Torcellini *et al.,* 2006 ; Deru and Torcellini, 2007). As per the investigations of Castro-Lacouture and Roper (2009), solar, wind and geothermal can be used as the primary renewable sources in NZEBs. In addition to that, low impact hydro, biofuels and biogas also can be used as renewable energy sources at the site in NZEBs (Carmichael and Managan, 2013; Deng *et al.*, 2014).

*Corresponding Author: E-mail - dumindu.soorige@gmail.com

Athienitis *et al.* (2010) specified that solar power is the most promising RE solution for the NZEBs to fulfil the energy requirements while reducing the environmental impact. Use of other primary RE sources like wind power for NZEBs are limited due to different wind directions, noises and structural considerations (Torcellini *et al.,* 2006). NZEBs can use the solar energy both in form of electricity and heat which produced by solar PV (photovoltaic) modules and thermal collectors (Good *et al.,* 2015). According to the Department of Energy (2015), there are numbers of benefits are incorporated with the zero energy buildings in the global context which enable the NZEB concept in the world including technical, environmental and social enablers. Nevertheless, some of the barriers are decelerated the growth of NZEB concept and need to find proper solutions to overcome those barriers. This research paper is aimed to develop a literature based framework for the implementation of solar NZEB. In achieving that aim literature review was carried out mainly in the areas such as energy efficiency measures to achieve NZE, Renewable Energy potentials in NZEBs, design considerations of solar NZEB, Enablers of Solar NZEB and Barriers to Solar NZEB. The literature review started with the general NZEB and then gradually narrowed down to the solar NZEB since the solar is the most potential renewable energy source in buildings as per the literature.

2. LITERATURE REVIEW

2.1. CONCEPT OF NET ZERO ENERGY BUILDING (NZEB)

As cited by Sartori *et al.* (2012), NZEB is a building which has a great reduction of energy demand that can be balanced by on-site energy generation using renewable energy sources (Sartori *et al.*, 2012). Similarly, Hyde *et al.* (2012) stated that NZEB approach is comprised of building energy demand reduction using energy efficient techniques and increase energy supply through renewable sources like solar energy. According to Torcellini *et al.* (2006), there are four types of NZEB approaches which are commonly used in the world including, Net Zero Site Energy, Net Zero Source Energy, Net Zero Cost Energy and Net Zero Emission Energy. Each type of NZEB uses the grid for exchanging energy and has diverse applications of renewable energy sources.

2.2. APPROACH OF ZERO ENERGY BALANCE

A study by Jadhav (2015), zero energy balance of a building can be obtained by mainly 3 steps includes on site demand management, on site supply options and off site supply options. Similarly, Pless and Torcellini (2010) have developed this hierarchy to address the approach of achieving NZE status which is illustrated in Figure 1. First, it is focused to reduce the energy demand and then generate the balance energy demand through RE supply options.

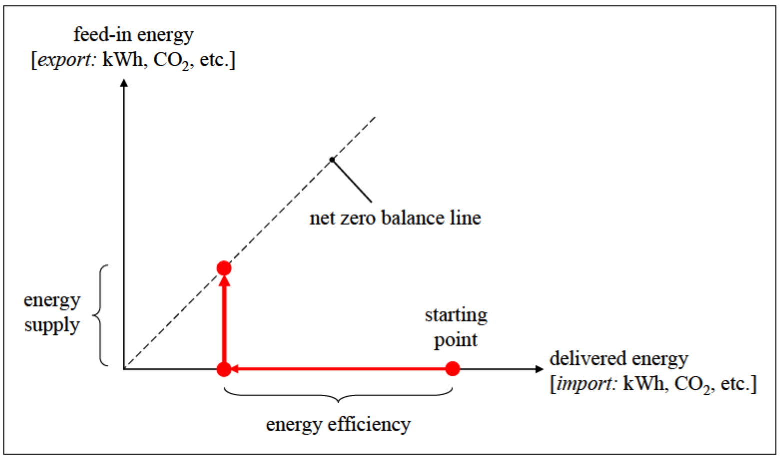

Figure 1: Method of Achieving NZE Status in Buildings

Source: (Sartori et al., 2010)

Here, starting point indicates the energy demand of building which is built according to the minimum requirements of building codes. The first step is to reduce energy demand through energy efficiency techniques (y-axis). Then feed the balance demand using renewable sources (x-axis).

2.2.1. USE OF ENERGY EFFICIENCY MEASURES

According to a study by Pless and Torcellini (2010), reduce the site energy using energy efficiency measures and building technologies is the first step of the NZE concept. There is a great potential for building energy saving through effective operation even without changing the structure of the building (Guan *et al.,* 2010). Further, nowadays energy saving potentials and energy efficiency measures have become top research topics in the world. There are numbers of factors may affect for the performance of NZEBs including form of the building structure, envelope, construction materials, location, orientation, climate changes and proper ventilation of the building (Russell *et al.,* 2008; Chan *et al*., 2010 and Liu *et al*., 2013). Table 1 presents the energy efficiency measures available as per the literature.

Table 1: Energy Efficiency Measures in Buildings

Energy Efficiency Measures		
1	High efficient HVAC system	(Hyde *et al.*, 2012), (Jadhav, 2015), (Kneifel, 2010)
2	Natural ventilation	(Patil *et al*., 2015), (Hyde *et al.*, 2012), (AlAjmi *et al.,* 2016), (Jadhav, 2015), (Russell *et al*., 2008)
3	Thermal insulation	(Pless and Torcellini, 2009), (Jadhav, 2015), (Banerjee, 2015), (Cellura *et al.,* 2014), (Kneifel, 2010)
4	Evaporative cooling	(Hyde *et al.*, 2012), (Pless and Torcellini, 2009)
5	Ground source heat/cool pumps	(Pless and Torcellini, 2009), (Jadhav, 2015), (Banerjee, 2015), (Russell *et al.,* 2008), (Cellura *et al.*, 2014),
6	Ocean water cooling	(Pless and Torcellini, 2009)
7	Shading on windows	(Hyde *et al.,* 2012), (AlAjmi *et al.,* 2016), (Deng *et al.*, 2014), (Banerjee, 2015), (Aelenei and Gonçalves, 2014), (Cellura *et al.,* 2014), (Kneifel, 2010)
8	High performance glazing and windows	(Hyde *et al.,* 2012), (AlAjmi *et al.,* 2016), (Jadhav, 2015), (Banerjee, 2015), (Cellura *et al.,* 2014), (Kneifel, 2010)
9	Proper orientation of the building	(Deng *et al.*, 2014), (Russell *et al.,* 2008)
10	Energy efficient lighting	(Deng *et al.,* 2014), (Russell *et al.*, 2008)
11	Natural day lighting	(Patil *et al.,* 2015), (Hyde *et al.*, 2012), (AlAjmi *et al.*, 2016), (Pless and Torcellini, 2009), (Jadhav, 2015), (Banerjee, 2015), (Russell *et al.*, 2008), (Aelenei and Gonçalves, 2014), (Kneifel, 2010)
12	Motion sensitive lighting system	(Hyde *et al.,* 2012)
13	Equipment zoning and scheduling	(AlAjmi *et al.*, 2016), (Cellura *et al.,* 2014)
14	Energy Management System (EMS)	(Hyde *et al.*, 2012), (Deng *et al.,* 2014)
15	Building automated systems	(Jadhav, 2015), (Banerjee, 2015), (Russell *et al.,* 2008), (Cellura *et al.*, 2014)

2.2.2. ON-SITE RENEWABLE ENERGY GENERATION

In a net zero energy building (NZEB), the total energy demand of the building is fulfilled by renewable energy which is generated on-site. NZEB supply options are included with solar PV, solar hot water, wind, hydro power and biofuels (Pless & Torcellini, 2009). Classification of the onsite renewable energy sources is given in Table 2.

Table 2: Renewable Energy Potentials in NZEBs

Renewable Energy Sources		
1	Solar PV	(Patil *et al.*, 2015), (Hyde *et al.,* 2012), (AlAjmi *et al.,* 2016), (Pless and Torcellini, 2009), (Deng *et al.,* 2014), (Jadhav, 2015), (Banerjee, 2015), (Russell *et al.,* 2008), (Aelenei and Gonçalves, 2014), (Cellura *et al.*, 2014)
2	Solar thermal	(Patil *et al.*, 2015), (Hyde *et al.,* 2012), (AlAjmi *et al.*, 2016), (Pless & Torcellini, 2009), (Jadhav, 2015), (Banerjee, 2015), (Russell *et al.,* 2008), (Aelenei and Gonçalves, 2014), (Cellura *et al.,* 2014)
3	Wind power	(Patil *et al.,* 2015), (Hyde *et al.,* 2012), (AlAjmi *et al.,* 2016), (Pless and Torcellini, 2009), (Deng *et al.,* 2014), (Jadhav, 2015), (Russell *et al.,* 2008)
4	Low impact hydro	(Patil *et al.,* 2015), (Pless and Torcellini, 2009), (Marszal *et al., 2*011)
5	Biomass	(Hyde *et al.,* 2012), (Pless and Torcellini, 2009), (Deng *et al.,* 2014),
6	Biodiesel	(Pless and Torcellini, 2009), (Russell *et al.,* 2008)
7	Biogas	(Deng *et al.,* 2014), (Marszal *et al.,* 2012)

2.3. SOLAR ENERGY AS A SOLUTION FOR NZEB

As per the study by Kalogirou (2004) identified that in past century the fossil fuels provided the larger portion of energy supply as it is much cheaper than renewable energy sources while giving less concern for environmental pollution. Since, the requirement of a reliable alternative renewable energy source became a crucial concern in last few decades due to the environmental issues, climate changes and global warming as a result of growing energy demand (Mekhilef *et al.,* 2011). Many researchers were discussed on the potential of solar energy solutions as one of the best RE approach (Patil *et al., 2*015; Russell *et al*., 2008). As Kalogirou (2004) further mentioned that, solar energy is more suitable than the other renewable solutions as it supplies clean and pollution-free energy. Singh (2013) stated that solar energy can be used basically in two ways; solar thermal and solar electricity; Solar thermal energy can be directly used to heat water to supply hot water for residential purposes and the light energy of solar can be converted to electricity using solar photovoltaic cells. Integration of solar PV in buildings mainly can be done in two different ways, includes building applied photovoltaic (BAPV) and building integrated photovoltaic (BIPV) (Zomer *et al.*, 2013).

2.4. DESIGN CONSIDERATIONS OF SOLAR NET ZERO ENERGY BUILDINGS

According to the Shi and Chew (2012), there two types of factors to be considered when installing a solar PV system such as geometric conditions and design factors. Geometric conditions include local weather conditions, longitude and latitude and designing factors includes system collection, the orientation of the building, installation area, PV panel area and the tilt angle. Table 3 summarises the design considerations of Solar Net Zero Energy Buildings.

Table 3: Factors to be Considered before Implementing Solar Energy Solutions

Design Considerations		
Geometric conditions		
1	Location of the building	(Shi and Chew, 2012), (Roos, 2009)
2	Solar radiation	(Gomes *et al.,* 2014)
3	Local weather condition	(Shi and Chew, 2012)
4	Altitude and latitude	(Shi and Chew, 2012)
5	Ambient temperature	(Gomes *et al.,* 2014)
Design factors		
6	Building orientation	(Shi and Chew, 2012), (Sun *et al.,* 2012), (Lan *et al.,* 2015), (Roos, 2009)
7	Roof type	(Shi and Chew, 2012), (Roos, 2009)
8	System selection	(Shi and Chew, 2012), (Meral and Dinçer, 2011), (Sun *et al.,* 2012)
9	Install location of PV	(Shi and Chew, 2012), (Roos, 2009)
10	Area of PV	(Shi and Chew, 2012), (Roos, 2009)

Design Considerations		
11	Tilt angle	(Shi and Chew, 2012), (Lan *et al.*, 2015), (Roos, 2009), (Handoyo *et al*., 2013)
12	Shading effect	(Shi and Chew, 2012), (Roos, 2009), (Gomes *et al.,* 2014)
13	Power quality of grid connection	(Meral and Dinçer, 2011)
14	Effect of solar system sub components	(Meral and Dinçer, 2011)

2.5. *ENABLERS OF SOLAR NET ZERO ENERGY BUILDING CONCEPT*

Zero energy buildings have become popular in last few years since the industry has given more concern on the limitations of the energy supply options and energy sources and the increase of energy cost and environmental impact (Aelenei et al., 2015). As per the literature finding of different authors, some key factors which enable the Solar NZEB in the global context were identified and Table 4 shows the review of the findings.

Table 4: Enablers of Solar Net Zero Energy Buildings

Enablers of Solar Net Zero Energy Buildings		
Technical Enablers		
1	Great reduction of energy demand	(Patil *et al.,* 2015), (Habash *et al.,* 2014), (Sartori *et al.,* 2010), (Lindkvist *et al.*, 2014)
2	Independence energy supply	(Aelenei et al., 2015), (Habash *et al*., 2014)
3	Improve occupant comfort level	(Aelenei *et al*., 2015), (Sartori *et al*., 2010)
Economic Enablers		
4	Less energy cost	(Aelenei *et al*., 2015), (Deng *et al*., 2014), (Lindkvist *et al., 2014)*, (Patil *et al*., 2015)
5	Earn profit through excess energy generation	(Jadhav, 2015)
Organizational Enablers		
6	Reduce carbon footprint	(Jadhav, 2015)
7	Increase the reputation of organization	(ASHRAE, 2008)
8	Increase business opportunities	(Koo *et al.,* 2014)
Political and Administrative Enablers		
9	Government policies	(Sartori *et al.,* 2010)
10	Tax deductions	(Aelenei *et al*., 2015)
11	Low interest loans by government	(Aelenei *et al*., 2015)
Environmental Enablers		
12	Environmental friendly building design	(Sartori *et al*., 2010), (Deng *et al.,* 2014)
13	Promote sustainability	(Sartori *et al.,* 2010)
14	Reduction of GHG emission	(Dean and Turnbull, 2014), (Jadhav, 2015)

2.6. *BARRIERS TO SOLAR NET ZERO ENERGY BUILDINGS*

There are numbers of barriers to implement solar energy solutions in NZEB both in the residential and commercial sector (Brostrom *et al.,* 2008). However, Lindkvist *et al.* (2014) described that there are five various dimensions which makes a great impact on the implementation of zero energy concept including technical, economic, social, environmental, organizational and legal. According to the literature findings, barriers to Solar NZEB concept were summarized using aforementioned dimensions as shown in Table 5.

Table 5: Barriers to Solar Net Zero Energy Buildings

Barriers to Solar Net Zero Energy Buildings		
Technical Barriers		
1	Inadequate work skills, training and awareness of workers	(Margolis and Zuboy, 2006), (Owen, 2006), (Sovacool *et al., 2011)*, (Aelenei *et al.*, 2015), (Barton, 2003), (Kraljevska, 2014)
2	Lack of innovations	(Lindkvist *et al.,* 2014)

Barriers to Solar Net Zero Energy Buildings		
3	No proper method of performance evaluation and verification	(Aelenei *et al.,* 2015), (Deng *et al.,* 2014)
4	Performance barriers to solar system equipment	(Sovacool *et al.,* 2011), (Brostrom *et al.,* 2008)
5	Building design errors to utilize solar	(Dean and Turnbull, 2014), (Brostrom *et al.,* 2008)
6	Lack technical solutions in maintenance	(Lindkvist *et al.,* 2014)
Economic Barriers		
7	High initial cost	(Margolis and Zuboy, 2006), (Owen, 2006), (Sovacool *et al.*, 2011), (Painuly, 2001), (Kraljevska, 2014), (Marszal *et al.*, 2011), (Brostrom *et al.*, 2008)
8	Uncompetitive market price for solar systems	(Owen, 2006), (Kraljevska, 2014)
9	Lack of financial sources	(Sovacool *et al.,* 2011), (Painuly, 2001), (Aelenei *et al.,* 2015), (Kraljevska, 2014)
10	Long payback period	(Painuly, 2001), (Aelenei *et al.,* 2015), (Kraljevska, 2014)
Socio Cultural Barriers		
11	Inadequate information dissemination	(Margolis and Zuboy, 2006), (Lindkvist *et al.,* 2014)
12	Architectural and cultural values of structures limit the technical solutions	(Lindkvist *et al.,* 2014), (Barton, 2003)
13	Unfamiliarity of society	(Sovacool *et al.,* 2011), (Kraljevska, 2014)
14	Impracticable expectations	(Sovacool *et al.,* 2011)
Political and Administrative Barriers		
15	Deficiency of government policy supporting	(Margolis and Zuboy, 2006), (Sovacool *et al.,* 2011), (Painuly, 2001), (Barton, 2003)
16	Lack of codes and standards	(Margolis and Zuboy, 2006), (Lindkvist *et al.,* 2014), (Brostrom *et al.,* 2008)
17	Poor participation of stakeholders	(Margolis and Zuboy, 2006), (Painuly, 2001)
18	Deficiency of legal and regulatory frameworks	(Painuly, 2001), (Kraljevska, 2014)
Environmental Barriers		
19	Environmental friendly material usage	(Lindkvist *et al.,* 2014)
20	Hazardous free innovations	(Painuly, 2001), (Yuosoff and Kardooni, 2012)

3. THEORETICAL FRAMEWORK FOR SOLAR NZEBS

Theoretical framework for Solar NZEB concept was developed based on the key literature findings as shown in Figure 2. It demonstrates how all the key factors are linked together to gain the ultimate objective of Solar NZEB concept which achieves the zero energy balance in a building using solar energy.

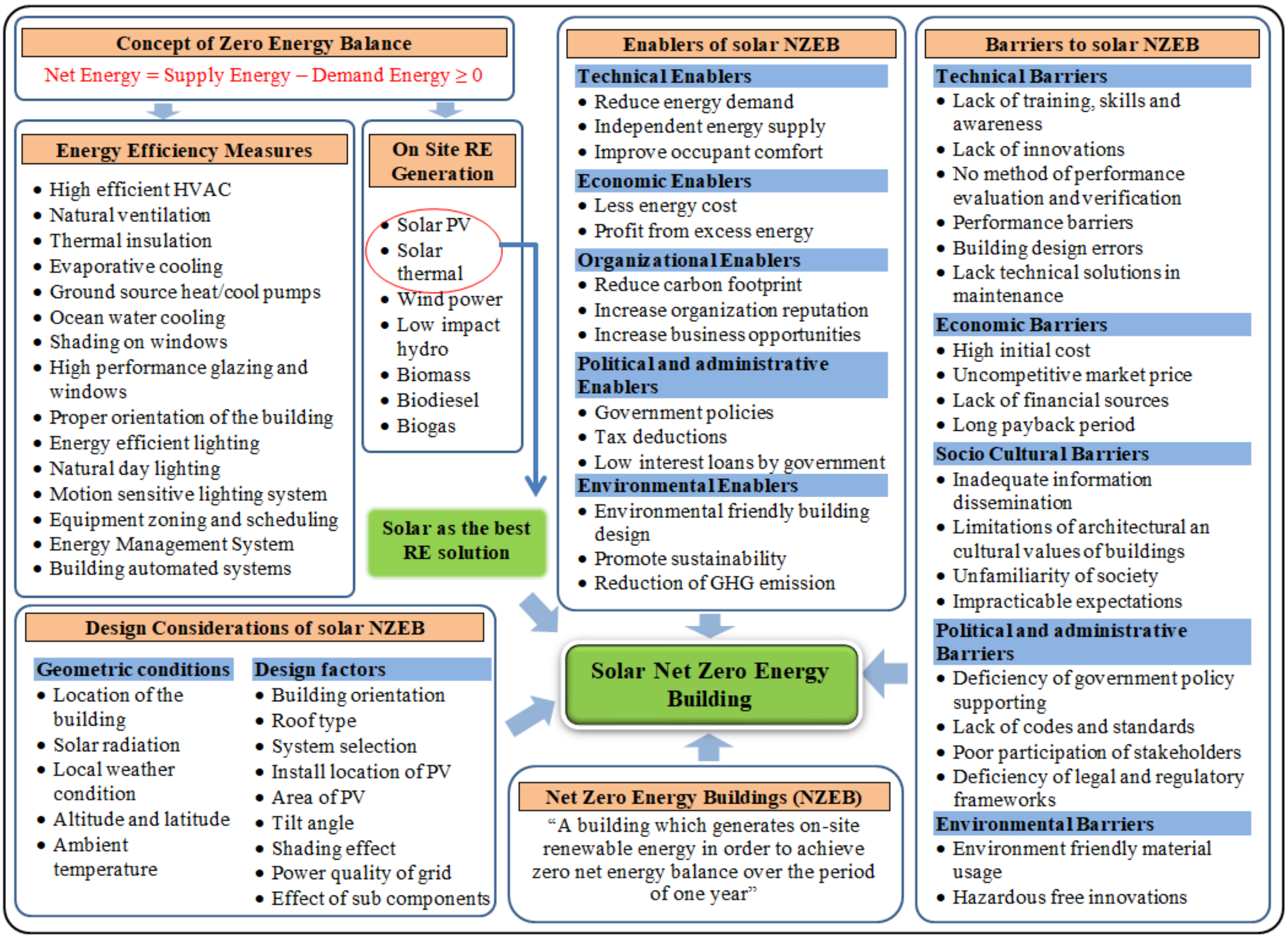

Figure 2: Theoretical Framework for Solar NZEBs

4. Conclusions and Recommendations

The theoretical framework which is shown in Figure 2 illustrates key aspects of Solar NZEB concept and it will assist for the professionals to learn about the concept and researchers for the further researches. The identified enablers and barriers in the global context may vary in different regions and each and every factor may not account the same weight. Hence, it is proposed to carry out further research on evaluating the enablers and barriers for solar NZEB and to develop strategies to overcome barriers considering different contexts.

5. References

Aelenei, L. and Gonçalves, H., 2014. From solar building design to net zero energy buildings: performance insights of an office building. *Energy Procedia, 48*, 1236–1243.

Aelenei, L. Petran, H. Tarrés, J. Riva, G. Ferreira, A. Camelo, S., … Gonçalves, H., 2015. New challenge of the public buildings: nZEB findings from IEE RePublic_ZEB Project. *Energy Procedia, 78*, 2016–2021.

AlAjmi, A. Abou-Ziyan, H. and Ghoneim, A., 2016. Achieving annual and monthly net-zero energy of existing building in hot climate. *Applied Energy, 165*, 511–521.

ASHRAE., 2008. ASHRAEVision 2020 Providing - Producing Net Zero Energy Buildings. Technology.

Athienitis, A. Torcellini, P. Hirsch, A. O'Brian, W. Cellura, M. Klein, R., … Carlucci, S., 2010. Design, optimization, and modelling issues of net-zero energy solar buildings. *In EuroSun,* 145–153.

Banerjee, R., 2015. Importance of Net Zero Energy Building. International Journal of Innovative Research in Advanced Engineering, 2(5).

Barton, D., 2003. Social and technical barriers and options for renewable energy on remote developed islands. Case study: Norfolk Island.

Brostrom, M. Eng, P. and Howell, G., 2008. The Challenges of Designing and Building a Net Zero Energy Home in a Cold High-Latitude Climate. *3rd International Solar Cities Congress,* Adelaide-South Australia.

Carmichael, C. and Managan, K., 2013. *Reinventing existing Buildings: eight steps to net ZeRo eneRgy.* Institute for Building Efficiency an Initiative of Johnson Controls: Milwaukee, WI, USA.

Castro-Lacouture, D. and Roper, K. O., 2009. Renewable energy in US federal buildings. *Facilities*, *27(5/6*), 173–186. https://doi.org/10.1108/02632770910944916 [Accessed 15 January 2018].

Cellura, M. Guarino, F. Longo, S. and Mistretta, M., 2014. Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study. *Energy and Buildings*, *72*, 371–381.

Chan, H.Y. Riffat, S. B. and Zhu, J., 2010. Review of passive solar heating and cooling technologies. *Renewable and Sustainable Energy Reviews*, *14(2),* 781–789.

Cuce, E. Cuce, P. M. and Riffat, S., 2016. Novel glazing technologies to mitigate energy consumption in low-carbon buildings: A comparative experimental investigation. *International Journal of Energy Research*, *40(4)*, 537–549

Dean, E. and Turnbull, P., 2014. Zero Net Energy Case Study Buildings Written by Foreword

Deng, S. Wang, R. Z. and Dai, Y. J., 2014. How to evaluate performance of net zero energy building–A literature research. *Energy*, *71*, 1–16.

Department of Energy., 2015. *A Common Definition for Zero Energy Buildings* [online]. Retrieved from http://energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf%5Cnhttp://energy.gov/eere/buildings/downloads/common-definition-zero-energy-buildings [Accessed 18 January 2018].

Deru, M. P. and Torcellini, P. A., 2007. *Source energy and emission factors for energy use in buildings*. National Renewable Energy Laboratory Golden.

GhaffarianHoseini, A. Dahlan, N. D. Berardi, U. GhaffarianHoseini, A. Makaremi, N. and GhaffarianHoseini, M., 2013. Sustainable energy performances of green buildings: A review of current theories, implementations and challenges. *Renewable and Sustainable Energy Reviews*, *25*, 1–17.

Gomes, J. Diwan, L. Bernardo, R. and Karlsson, B., 2014. Minimizing the impact of shading at oblique solar angles in a fully enclosed asymmetric concentrating PVT collector. *Energy Procedia*, *57*, 2176–2185.

Good, C. Andresen, I. and Hestnes, A. G., 2015. Solar energy for net zero energy buildings–A comparison between solar thermal, PV and photovoltaic–thermal (PV/T) systems. *Solar Energy*, *122*, 986–996.

Guan, X. Xu, Z. and Jia, Q.-S., 2010. Energy-efficient buildings facilitated by microgrid. *IEEE Transactions on Smart Grid*, *1(3)*, 243–252.

Habash, G. Chapotchkine, D. Fisher, P. Rancourt, A. Habash, R. and Norris, W., 2014. Sustainable Design of a Nearly Zero Energy Building Facilitated by a Smart Microgrid. *Journal of Renewable Energy*, 2014.

Handoyo, E. A. Ichsani, D. and Prabowo., 2013. The optimal tilt angle of a solar collector. *Energy Procedia*, *32*, 166–175.

Hyde, R. Rajapaksha, U. Rajapaksha, I. Riain, M. O. and Silva, F., 2012. A Design Framework for Achieving Net Zero Energy Commercial Buildings. *Proceedings of the 46th Annual Conference of the Architectural Science Association (ASA/ANZAScA),* Griffith University, Gold Coast, Australia, 14–16.

Jadhav, S. D., 2015. Role of net zero energy building in energy security. *International journal of engineering sciences & research technology*, *4*(6).

Kalogirou, S. A., 2004. Solar thermal collectors and applications. *Progress in Energy and Combustion Science*, *30*(3), 231–295.

Kneifel, J., 2010. Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. *Energy and Buildings*, *42*(3), 333–340.

Koo, C. Hong, T. Park, H. S. and Yun, G., 2014. Framework for the analysis of the potential of the rooftop photovoltaic system to achieve the net-zero energy solar buildings. *Progress in Photovoltaics: Research and Applications*, *22*(4), 462–478.

Kraljevska, E., 2014. Estimated Benefits of Achieving Passivhaus and Net Zero Energy Standards in the Region of Waterloo Residential Sector and the Barriers and Drivers to Achieve Them. University of Waterloo.

Lan, H. Dai, J. Wen, S. Hong, Y.Y. Yu, D. C. and Bai, Y., 2015. Optimal tilt angle of photovoltaic arrays and economic allocation of energy storage system on large oil tanker ship. *Energies, 8(10),* 11515–11530.

Lindkvist, C. Karlsson, A. Sørnes, K. and Wyckmans, A., 2014. Barriers and challenges in nZEB Projects in Sweden and Norway. *Energy Procedia*, *58*, 199–206.

Liu, H. Zhao, Q. Huang, N. and Zhao, X., 2013. A simulation-based tool for energy efficient building design for a class of manufacturing plants. *IEEE Transactions on Automation Science and Engineering*, *10(1)*, 117–123.

Maistry, N. and Annegarn, H., 2016. Using energy profiles to identify university energy reduction opportunities. *International Journal of Sustainability in Higher Education*, *17(2)*, 188–207.

Margolis, R. and Zuboy, J., 2006. *Nontechnical barriers to solar energy use: review of recent literature*. National Renewable Energy Laboratory (NREL), Golden, CO.

Marszal, A. J. Heiselberg, P. Bourrelle, J. S. Musall, E. Voss, K. Sartori, I. and Napolitano, A., 2011. Zero Energy Building–A review of definitions and calculation methodologies. *Energy and Buildings*, *43(4)*, 971–979.

Marszal, A. J. Heiselberg, P. Jensen, R. L. and Nørgaard, J., 2012. On-site or off-site renewable energy supply options? Life cycle cost analysis of a Net Zero Energy Building in Denmark. *Renewable Energy*, *44*, 154–165.

Mekhilef, S. Saidur, R. and Safari, A., 2011. A review on solar energy use in industries. *Renewable and Sustainable Energy Reviews*, *15(4),* 1777–1790.

Meral, M. E. and Dinçer, F., 2011. A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems. *Renewable and Sustainable Energy Reviews*, *15(5),* 2176–2184.

Owen, A. D., 2006. Renewable energy: Externality costs as market barriers. *Energy Policy*, *34(5)*, 632–642.

Painuly, J. P., 2001. Barriers to renewable energy penetration; a framework for analysis. *Renewable Energy*, *24(1)*, 73–89.

Patil, S. T. Guptha, A. K. and Desai, D. B., 2015. A Conceptual Study of Zero Energy Buildings & Its Feasibility Analysis, 49–55.

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

Pless, S. D. and Torcellini, P. A., 2010. Net-zero energy buildings: A classification system based on renewable energy supply options. National Renewable Energy Laboratory.

Ramesh, T. Prakash, R. and Shukla, K. K., 2010. Life cycle energy analysis of buildings: An overview. *Energy and Buildings*, *42(10),* 1592–1600.

Roos, C. J., 2009. Solar electric system design, operation and installation: an overview for builders in the US Pacific Northwest.

Russell, R. Sunder, S. S. and Domich, P. D., 2008. Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings. *Report of the Subcommittee on Buildings Technology Research and Development. National Science and Technology Council*.

Sartori, I. Napolitano, A. and Voss, K., 2012. Net zero energy buildings: A consistent definition framework. *Energy and Buildings*, *48*, 220–232.

Sartori, I. Napolitano, A. Marszal, A. J. Pless, S. Torcellini, P. and Voss, K., 2010. Criteria for definition of net zero energy buildings. *International Conference on Solar Heating, Cooling and Buildings (EuroSun 2010)*.

Shi, L. and Chew, M. Y. L., 2012. A review on sustainable design of renewable energy systems. *Renewable and Sustainable Energy Reviews*, *16(1)*, 192–207.

Singh, G. K., 2013. Solar power generation by PV (photovoltaic) technology: *A review. Energy, 53*, 1–13

Sovacool, B. K. D'Agostino, A. L. and Bambawale, M. J., 2011. The socio-technical barriers to Solar Home Systems (SHS) in Papua New Guinea:"Choosing pigs, prostitutes, and poker chips over panels." *Energy Policy*, *39(3)*, 1532–1542.

Sun, L. Lu, L. and Yang, H., 2012. Optimum design of shading-type building-integrated photovoltaic claddings with different surface azimuth angles. *Applied Energy*, *90(1)*, 233–240.

Torcellini, P. Pless, S, Deru, M. and Crawley, D., 2006. Zero energy buildings: A critical look at the definition. *National Renewable Energy Laboratory and Department of Energy, US*.

Yuosoff, S. and Kardooni, R., 2012. Barriers and challenges for developing RE policy in Malaysia. *International Conference on Future Environment and Energy IPCBEE (28).*

Zomer, C. D. Costa, M. R. Nobre, A. and Rüther, R., 2013. Performance compromises of building-integrated and building-applied photovoltaics (BIPV and BAPV) in Brazilian airports. *Energy and Buildings*, *66*, 607–615.