7th Bangladesh Conference on Industrial Engineering and Operations Management
December 21-22, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/BA07.20240252
Published: December 21, 2024

The Prospects of Zero Energy Building as an Alternative to the Conventional Building System in Bangladesh (A Review)

Md Alamgir Hossain, Nazia Muhsin
Department of Industrial Engineering,
BGMEA University of Fashion and Technology,
Dhaka, Bangladesh[1]
ahossain@buft.edu.bd, nazia@buft.edu.bd

AMM Shamsul Alam, Mehedhi Hasan
Department of Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh
ammshamsul@yahoo.com; mehedihasan.scien@gmail.com,

Abstract

Energy consumption in commercial and residential buildings worldwide accounts for about one-third of the world's energy and one-quarter of greenhouse gas emissions. If current trends continue, by 2025, buildings worldwide will be the largest consumers of global energy, using as much power as the transportation and industrial sectors combined. Recent studies have found that improving energy efficiency in buildings is the least costly way to reduce a large quantity of carbon emissions. By changing energy management practices and instituting technologies that enhance energy efficiency, building owners and managers can reduce energy consumption by up to 35%. However, energy efficiency efforts in buildings alone cannot address future demand for more energy by this sector. In order to achieve breakthrough solutions to this problem, it is evident that a coordinated effort in whole-building systems approach that emphasizes the necessity of integrating renewable on-site or distributed generation and energy efficiency is required to design the buildings of the future. Several International Energy Agency (IEA) countries have adopted a vision of so-called 'net zero energy buildings' (NetZEBs) as long-term goal of their energy policies. This NetZEB is very new in Bangladesh and it starts building green buildings which will lead to NetZEB in recent future. However, Bangladesh have to comply with IEA and must accept zero energy building concept.

Keywords
NetZEBs, Carbon Emission, Energy Consumption, Global Energy

1. Introduction
According to the Energy Information Administration (EIA), the building sector consumed more than 20% of the delivered energy worldwide in 2015, and this proportion will remain the same in 2040 (Welcome 2024). Meanwhile, building-related emissions have increased by 45% since 1990 (Clearvue 2024). In the United States, the building sector consumes more energy than any other sector — about 39 % of the country's total primary energy use in 2017 (Department 2024). However, these significant proportions of energy consumption and emissions harbor great potential to contribute to energy conservation and carbon emission reduction. Therefore, improving building energy efficiency and lowering the associated carbon emissions is a key strategy for addressing global issues such as energy consumption reduction, mitigating climate change, and reducing the carbon footprint of human activities.

Recently, net-zero energy buildings (NZEBs) have gained increased popularity in the building industry in many countries as a promising solution to reduce building energy consumption. The concept of self-sufficient and energy-autonomous construction has been popular for a long time for applications under severe conditions, such as solar-powered satellites in space or stand-alone construction in remote areas where facilities cannot be connected to power grids. Ionescu *et al.* (2015) reviewed the genesis of the energy-efficient buildings in history. The first fully functioning passive house (a nearly zero energy building) was actually not a house, but a polar ship named the Fram of Fridtj of Nansen in 1893 (Anmerkungen 2024). In building science, the term "zero-energy building" also is not recent. As early as 1976, researchers in Denmark proposed the term "zero energy house" for the first time by conducting research on solar energy for heating buildings in cold winters (Architectonics, 2024). The concept of an NZEB has been developed ever since, and recently it has become mainstream. This paper will use the term "net-zero energy buildings (NZEBs)." To sustain against rapid change of climate and global worming, Bangladesh must work on carbon emission, which would be minimize by building most of the high-rise building as NZEBs by 2050. In Bangladesh National Building Code (BNBC) it is found that solar panel is mandatory for all high-rise buildings to generate electricity, which must be supplied to national grid.

2. Concept, Definitions and other related Terms

The convergence of the need for innovation and the requirement for drastic reductions in energy use and greenhouse gas (GHG) emissions in the building sector provides a unique opportunity to transform the way buildings and their energy systems are conceived. Given that about one-third of GHG emissions can be attributed to buildings and given that buildings are estimated to account for around 40% of energy usage globally (Budget 2021), ZEBs provide significant opportunities to reduce GHG emissions and to reduce energy usage. Demand abatement through passive design, energy efficiency and conservation measures need to be simultaneously considered with the integration of solar systems and on-site generation of useful heat and electricity using a whole-building approach. Building energy design is currently undergoing a period of major changes driven largely by three key factors and related technological developments:

1. The adoption in many developed countries, and by influential professional societies, such as ASHRAE, of net-zero energy (Building 2024) as a long-term goal for new buildings;
2. The need to reduce the peak electricity demand from buildings through optimal operation, thus reducing the need to build new central power plants that often use fossil fuels;
3. The decreasing cost of energy-generating technologies, such as photovoltaics, which enables building-integrated energy systems to be more affordable and competitive. This is coupled with increasing costs of energy from traditional energy sources (e.g., fossil fuels).

A key requirement of high-performance building design is the need for rigorous design and operation of a building as an integrated energy system that must have a good indoor environment suited to its functions. In addition to the extensive array of HVAC, lighting, and automation technologies developed over in the last 100 years, many new building envelope technologies have been established, such as vacuum insulation panels and advanced fenestration systems (e.g., electrochromic coatings for so-called smart windows), as well as solar thermal technologies for heating and cooling, and solar electric or hybrid systems and combined heat and power (CHP) technologies. A high-performance building may be designed with optimal combinations of traditional and advanced technologies depending on its function and on climate.
There are four definitions of Net Zero Energy as follows: Net Zero Site Energy, Net Source Energy, Net Zero Energy Costs and Net Zero Energy Emissions (Cabinet, 2021). These brief definitions are:

1. Net Zero Site Energy: A site ZEB produces at least as much energy as it uses in a year when accounted for at the site.
2. Net Zero Source Energy: A source ZEB produces at least as much energy as it uses in a year when accounted for at the source. Source energy refers to the primary power used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and the appropriate site-to-source conversion multiply exported energy.
3. Net Zero Energy Costs: In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner spends the efficiency for the energy services and energy used over the year.
4. Net Zero Energy Emissions: A net-zero emissions building produces at least as much emissions free renewable energy as it uses from emissions-producing energy sources.

Torcellini *et al.*(2006) indicate that the unit applied in the ZEB definition can be influenced by (1) the project goals, (2) the intentions of the investor, (3) the concerns about the climate and greenhouse gas emissions, and (4) the energy cost. Therefore, they propose four different ZEB definitions: site ZEB, source ZEB, emissions ZEB and cost ZEB, respectively. The authors point out the advantages and disadvantages of each of the definitions i.e. easy implementation of 'zero site energy' and 'zero energy costs' definition, more international and not regional feature of 'zero source energy' definition, and calculation complexity of 'zero-energy emission' definition. The proposed distinction between different metrics is brought up and further discussed in a number of publications (Canada, 2024). Kilkis (2007) states that the metric of the balance in the ZEB definition should address both the quantity as well as the quality of energy, if we want to assess the complete building's impact on the environment. Therefore, he proposes a new definition for the term ZEB, in particular, a net-zero exergy building and defines it as a building, which has a total annual the sum of zero exergy transfer across the building-district boundary in the district energy system, during all-electric and any other transfer that is taking place in a certain period of time'. Mertz *et al.* (2007) and Laustsen (2008) distinguish only two units of the balance: emissions and energy, however, without specifying delivered or primary energy. The definition of 'Near Zero Energy Building' from the EPBD (Article, 2024) is clear and uses the primary energy as the metric for the energy balance.Many of the papers talk about using a mix by taking energy from the grid to supplement what the buildings cannot produce onsite (Article, 2024). Despite the ability to still be an NZEB if energy is taken from the grid, there is still a hierarchy. The developed hierarchy can be seen in Table 1.

Table 1. NZEB supply options hierarchy (Cabinet, 2024)

Options	ZEB Supply-Side Options	Examples
1	Reduce site energy use through low-energy building technologies.	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On-Site Supply Options		
2	Use renewable energy sources available within the building's footprint.	PV, solar hot water, and wind located on the building.
3	Use renewable energy sources available at the site.	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building.
Off-Site Supply Options		
4	Use renewable energy sources available off-site to generate energy on site.	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off-site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
5	Purchase off-site renewable energy sources.	Utility-based wind, PV, emissi ons credits, or other "green" purchasing options. Hydroelectric is sometimes considered.

Moreover, the hierarchy was also used to find the best option for NZEB with different purposes such as NZEB. Marszal *et al.* (2016) in their article highlighted the lack of a single definition for the term 'Zero Energy Building' and the inconsistencies in the way this term is applied. As an extension of this, they compare the differences in the ways in which the calculations of a ZEB are carried out. The main differences were identified as the inconsistencies in the source of energy generation (on-site vs. off-site), the inclusion of embodied energy, and the inclusion of GHG emissions.

Table 2 summarizes some of the key considerations of each NZEB or related concept model. It is apparent that the NZEB concept lacks a holistic, quantifiable, and widely accepted definition. Some of the risks associated with a lack of a common definition are that NZEBs could be poorly executed and risk becoming a status symbol for building owners rather than a practical goal in alleviating environmental, social, or ethical issues.

Table 2. Summary of NZEB considerations per model.

Model	NZ Site Energy	NZ Source Energy	NZ Emissions Energy	NZ Costs Energy
Applies to new buildings	?	?	?	?
Applies to retrofitted buildings	?	?	?	?
Consideration of climate change	No	No	No	No
Encourages energy efficiency measures	No	No	No	No
Consideration of the energy generation method/ fuel source	No	No	Yes	No
Consideration of energy storage	No	No	No	No
Consideration of embodied energy	No	No	Yes	No
Recognition of cost-saving opportunities	No	No	No	Yes
Grid connection	Yes	Yes	Yes	Yes
Ease of measurement for end-user	Yes	No	No	Yes
Consideration of economic viability	No	No	No	Yes

3. Design Strategy

When the design strategy of the NZEB model is considered, Lund-Andersen *et al.* (1976), suggested two things to consider, the first involving the methodology of zero energy building and the second involving the limitation of energy generation options. And Li *et al.* (2013), addressed two key approaches to be considered when implementing ZEBs. The first approach is to reduce energy consumption by limiting the amount of heat gain and loss, considering internal energy-efficient design and building facilities such as heating, cooling and utilities. The second approach is to use renewable energy technology such as PVs, wind turbines, solar thermal, heat pumps, etc. Aelenei *et al.* (2012) proposed a common design strategy to the NZEBs in comparison to Li *et al.* (2013) and Singh and Verma (2014), using 3 specific criteria. These design concepts are passive design strategies to minimize existing energy use typically associated with heating, ventilation, lighting and equipment, then active design strategies to implement energy-efficient systems and, ultimately, the implementation of renewable energy systems. The basic 3-step process is known as 'Trias Energetica,' and Gvozdenovi'c *et al.* (2015) has recently suggested an extension to the 5-step process.

In fact, it is unanimously agreed to prioritize energy efficient strategies in a ZEB design and to address energy deficits through the application of renewable energy technologies. Torcellini *et al.* (2009) believe that the energy demand of NZEB should be met from low cost, locally available, non-polluting, renewable energy sources. Although grid disconnection is desirable in this regard. But, Torcellini *et al.* (2009) assume that a grid connection is a valuable method for balancing electricity, believing that surplus energy will still be used by the grid, which may be false in times of high market saturation. Like Torcellini *et al.* (2009), Carrilho da Grac¸ *et al.* (2012)described that although potentially desirable, a grid disconnection is not generally feasible as technologies are unable to cope with the 'seasonal mismatch' of energy demand versus supply. This idea could be increasingly out of date with advancements and additional availability of energy storage technologies. However, this problem of grid disconnection could potentially be mitigated by the implementation of renewable district energy generation systems using a wide range of renewable energy generation methods.

When considering renewable energy technologies to be implemented into NZEBs, Torcellini *et al.* (2009) proposed that a set of criteria be considered to rank technologies in terms of their potential to minimize environmental effects, reduce transport and conversion losses, and to consider the durability of technology in terms of building life and technology availability. Good *et al.* (2016) studied PV technology and their impact on emission balances in buildings net-zero emission buildings. This research was limited to residential building types only. The research analyzed how the orientation of PV systems along with materials used can affect the energy efficiency of a building. Four PV system configurations were considered, which are all positioned on a flat-roofed home. Four different PV technologies were also considered, which were made up of different materials. Each system configuration was modeled using each of the different PV technologies to establish the energy yield and subsequently, which one is more efficient. Embodied emissions, avoided emissions, green-house gas payback and return on investment and the net emissions balance were also modeled for each case. The results show that the system with the largest area of high-efficiency Si-mono modules achieves the best lifetime emission balance.

When considering the load reduction strategies, Gagliano *et al.* (2015) and Evola *et al.* (2014) discussed strategies that result in high-value in terms of financial investment. When considering a multi-story apartment building in Sicily, Italy,

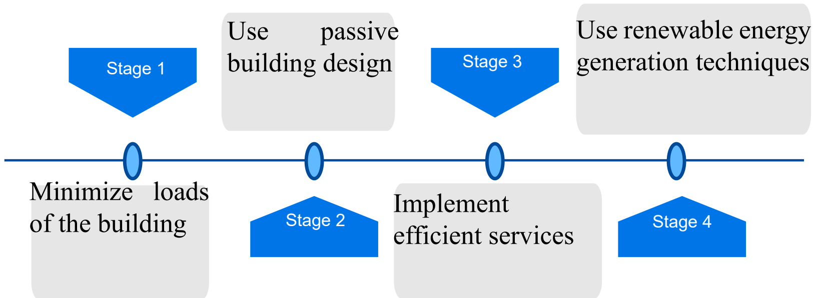

Figure 1. Hierarchical design strategy for NZEBs.

Gagliano *et al.* (2015) found that some of the most effective methods to achieve an 'enhanced saving building include optimizing the external wall insulation, reducing thermal bridging, using low-E and reflective windows and green roofs. Similarly, Evola *et al.* (2014) stated that some techniques to reduce loads with minimal financial efforts in a Southern Italian terraced house may include increasing the insulation, using a very-low emissive coating on the inner side of the windows, implementing movable shading devices, and tilt-and-turn opening devices for natural ventilation. Despite providing useful guidance, Evola *et al.* (2014) inferred that these strategies are not a one-size-fits-all solution, and particularly local climate must be considered to adjust individual design strategies accordingly. Further research into passive design and energy load reduction strategies is catalyzed in Europe by programs such as Horizon 2020, an initiative of the European Commission (The Paris, 2021).
Based on the literature, figure 1 offers a prioritized list of broad design steps that should be used to create an NZEB. Although NetZero energy consumption could be achieved by reordering these principles, it is argued that this hierarchy will create a sustainable NZEB.

4. Case Studies

Hoque (2010) presented a study that compares two net-zero energy homes (based on annual energy consumption) in New Jersey and Vermont, United States. The home in New Jersey is powered mainly by solar and the Vermont example is mainly powered by wind. In this region of the United States, a major emphasis in NZEB design is placed on reducing the heating load of the homes, given the colder climate. Furthermore, net-zero energy homes can be attractive to homeowners in this region as the United States government incentivizes NZEB design with tax breaks and incentives. Although there are notable advantages to choosing net-zero energy homes some of the potential barriers encountered by homeowners may include high design and construction costs (implying potentially long payback periods), lack of knowledge about sustainable design concepts, difficulty claiming tax benefits, and lack of designer and builder expertise in this field. The two homes considered in the study are both constructed of main timber, are open plan, use foam insulation to maintain a humidity of around 40–45%, and are oriented south to maximize solar heating and daylight. Hoque (2010) concluded that although both homes are well designed to significantly reduce energy usage, the success of both of these examples is reliant on the homeowners also being aware and conservative about their energy usage.

Table 3. Samples of established NZEBs

Building	**Building**
Nikini building,, Colombo, Sri Lanka	Adam Joseph Lewis Center for Environmental Studies, Oberlin College, Ohio, USA
Institute of Technology building, Cork , Ireland	Zion National Park Visitor Center, Utah, USA
CSIRO Energy Centre, Newcastle, NSW, Australia	Mosaic Centre, Edmonton, Alberta, Canada
H1 Home, Lebanon, New Jersey, USA	Efficiency House Plus, Berlin, Germany
P-1 Home, Charlotte, Vermont, USA	SOLAR XXI, Lisbon, Portugal

Ingeli andˇCekon (2016) evaluated the energy consumption and design features of a Slovakian example of a net-zero energy house. By analyzing the thermal insulation used in this house, Ingeli andˇCekon (2016) determined that airtightness plays an important role in low heat losses. The house researched in this paper is powered by a combination of solar and electric energy. Although the solar system is produced in the summer months and far exceeds the energy usage of the house, the most significant energy usage is during winter with around 10 times more energy used in winter than in summer. Ingeli andˇCekon (2016) suggested that although this house has a net-zero energy usage when unused energy is commoditized in the summer months, the designer of this property could implement further measures such as batteries and other renewable technologies to further reduce electric energy consumption and to better customize the renewable energy production for the winter conditions. This example demonstrates that although a building is considered an NZEB, it doesn't necessarily mean that the building is capable of sustaining the human activities off-grid. It also emphasizes that the consideration of the climate is vital to a sustainable NZEB. As well as considering the passive design and the implementation of current technologies, Wall *et al.* (2011) indicated that other factors that require consideration for ZEBs include building occupant behavior, future unpredictability in energy demand, and the integration of future renewable and energy storage technologies.

5. Notable national and international policy support for promoting NZEBs

Worldwide, there is relatively advanced policy support for NZEBs in regions such as North America and the European Union. Notable policies include the 2007 Energy Independence and Security Act in the USA and the 2010 European Performance of Buildings Directive, which both actively promote NZEB goals. The initiative, these regions with relatively good policy support coincide with more advanced research and progression towards creating NZEBs. Vasquez *et al.* (2016) indicated that although the existing regulations might lead to the 20% energy efficiency goal by 2020, but they are not sufficient for the 2050 energy and GHG-emission goals, showing that further research and development is still required.the United States, leading to the rapid and large-scale development of NZEB projects in these areas. Whereas Bangladesh includes in BNBC only for buildings of occupancy A shall use Solar or other renewable sources of energy to power 3% of the total electric load of the building.

Table 4. Summary of current policies for NZEBs in different countries and regions. (UP Building, 2024)

Country/ Region	Organization	Program	Content	Year
Europe	Directive on energy performance of building (EPDB)	ZEBRA 2020	New buildings are to be nearly zero energy from 2020	2010
Belgium	Brussels capital region ministry of environment	Brussels Passive House Law 2011	New construction or major renovation of a dwelling, office or school must comply with the passive standard 9nearly zeron energy) from 2015	2011
Germany	EPDB	Act on the promotion of renewable thermal energy	Aim of achieving an almost climate-neutral building stock by 2050	2010
France	Ministry of environment, energy and the sea	Act on energy transition for green growth	New buildings should be energy positive by 2020	2015
Denmark	The ministry for climate, energy and buildings	Building class 2020	Public buildings and private buildings are to be nearly zero energy buildings by 2018 and 2020, respectively	205
USA	Office of the Law Revision counsel	The energy independence and security act of 2007	50% of new commercial buildings by 2040 and all new commercial buildings by 2050 should be zero energy	2007
USA	US Department of energy (DOE)	The building Technologies Program	Realize NZEBs at low incremental costs by 2025.	2008
USA	The California Public Utilities Commission (CPUC)	Zero Net Energy Action Plan	New residential and commercial construction will be NZEBs by 2020 and by 2030, respectively. 50% of commercial buildings will retrofit to be NZEBs by 2030, and 50 of new major renovations of state buildings will be NZEBs by 2025.	20`5
USA	The new York state energy research and	Ultra-low energy buildings in a high-density urban	Beginning in 2025, all new buildings would required to build to very-low energy design targets.	2014

	development authority	environment		
Canada	British Columbia energy step code council	BC energy step code	New buildings must be 'net-zero energy ready' by 2032	2017
Canada	The city planning division of Toronto	Zero emissions Buildings Framework	The municipality committed to adopting Tier 2, 3, or 4 for all city-owned development with nearly zero emissions standards by 2026	2018
UK	Ministry of Housing, Communities and Local Government	National Planning Policy Framework	All new homes should be zero carbon from 2016, and all other buildings from 2019	2012
Japan	Ministry of Economy, Trade and Industry (METI)	Strategic Energy Plan 2014	Newly constructed public buildings and standard houses are to be zero-energy buildings voluntarily by 2020. Newly constructed buildings and houses are to be zero-energy buildings voluntarily by 2030.	2015
Korea	National energy roadmap and zero energy building certification	Building energy efficiency program	New building constructions should have net-zero energy consumption and non-residential buildings should have energy-saving rate of 60% by 2025	2012
South Africa	C40 and sustainable energy Africa (SEA)	C40 South Africa Buildings Program	Energy efficiency policies and programs towards a net-zero carbon performance for new buildings in south African cities are to be developed and implemented by 2020	2018
Sweden	Stockholm	Buildings in the context of a fossil fuel free city	All development on city-owned land must comply with a maximum energy use intensity, or specific purchased energy, of 55 kW-hours per square meter per year. Buildings this efficient can be considered to be zero or nearly zero energy buildings by 2040	2010
China	Ministry of housing and urban-rural development	The 13th five-year plan for building energy conservation and green building development	The construction of demonstration projects of ultra-low-energy and near-zero-energy buildings will reach more than 10 million square meters by 2020	2017
Australian	National strategy on energy efficiency	ZCA Buildings plan	Australia's emission goal is to reduce emissions to 26%-28% on 2005 levels by 2030	2009
Singapore	Building and construction authority	Building energy efficiency (BEE) R&D Roadmap and Solar PV Technology Roadmap	BEE to achieve improvements I the energy efficiency index (EEI) by 40%-60% over 2013 best-in-class buildings by the year 2030, super low energy (SLE) to achieve improvements in the EEI by 60% over 2005 industry levels by 2018 and 80% by 2030	2014
Malaysia	The sustainable energy development authority Malaysia	Zero energy building facilitation program	Intends to reduce its greenhouse gas (GHG) emissions intensity of GDP by 45% by 2030 relative to the emissions intensity of GDP in 2005.	2018
ASEAN	The ASEAN Member states	ASEAN Energy Awards	Zero energy building added to ASEAN energy Awards 2019	

Table 4 summarizes the current policies and regulations for NZEBs in various countries. Most are promulgated in Europe and 6. Worldwide current status of Zero-energy building

Countries worldwide are boldly combating the dual threats of global warming and greenhouse gas emissions by adopting innovative policies targeting Zero Energy Buildings (ZEBs). Between 2008 and 2013, a groundbreaking international collaboration spearheaded by researchers from 20 nations, including Australia, the U.S., and Germany, launched the "Towards Net Zero Energy Solar Buildings" program under the International Energy Agency (IEA). This initiative sought to harmonize ZEB definitions and establish practical frameworks to advance low-energy construction (LaRue 2013).

The 2015 Paris Agreement further amplified global climate commitments, uniting 197 countries in a shared mission to cap the 21st-century temperature rise at 2°C, with aspirations for 1.5°C. Through cooperative strategies and progressive policy updates, nations have embraced ZEBs as a pivotal solution to energy efficiency and carbon reduction (Laustsen 2008).

Spotlight on Global Progress:

Australia: Researchers pioneered visually transparent solar energy windows suitable for industrial production, with rooftop solar PV systems revolutionizing household energy efficiency (Li, 2013). By 2017, over 30% of Queensland homes integrated solar PV systems, achieving net-zero energy goals with innovative designs and a 6-star energy rating (Anderson, 1976).

Japan:
After the 2011 Fukushima disaster, Japan's energy crisis highlighted the need for conservation. In 2012, the government launched a Low-Carbon Society roadmap, aiming to standardize Zero Energy Houses (ZEH) and Buildings (ZEB) by 2020 (Marszal, 2011). Mitsubishi Electric began constructing Japan's first zero-energy office, and the SUSTIE ZEB facility in Kamakura achieved a 103% energy reduction (Mertz, 2007). Japan plans for all new homes to be net-zero energy by 2030 (Miller, 2018). Developers like Sekisui House introduced net-zero homes in 2013 and are now building Japan's first zero-energy condominium in Nagoya, featuring solar panels and fuel cells.

Canada:
Leaders like the Canadian Home Builders Association introduced the Net Zero Homes certification, while British Columbia's Energy Step Code set ambitious benchmarks for ZEBs by 2032 (Noguchi, 2008). Initiatives such as Build Smart and the Equilibrium Sustainable Housing Competition underscore Canada's commitment to driving ZEB innovation (Ross, 2020).

China:
As a leading greenhouse gas emitter, China is transforming its energy landscape. Policies since 2010 have elevated ZEB standards, supported by incentives for green buildings (Singh, 2014, Sinton, 1998). Landmark projects like the Pearl River Tower exemplify China's push for energy self-sufficiency through cutting-edge technology and sustainable design (Torcellini, 2006).

United States:
The Department of Energy's Building America Program, coupled with $40 million in funding and Solar Energy Tax Credits, has catalyzed advancements in energy-efficient technologies. Federal mandates target 100% ZEB compliance for new federal buildings by 2030, showcasing bold leadership in sustainable infrastructure (V'asquez, 2016, Wall, 2011).
Across continents, ZEBs symbolize a revolutionary approach to addressing the energy and environmental challenges of our era. From policy innovation to cutting-edge technologies, the global pursuit of net-zero energy is reshaping the built environment, driving progress toward a sustainable future.

7. Future Directions and Research Needs
Recent advancements in key technologies, particularly photovoltaics (PV), coupled with substantial cost reductions, have made achieving net-zero energy more feasible. However, seamless integration of PV and complementary technologies like heat pumps into buildings and systems still faces challenges in achieving cost efficiency at a broader system level. The evolution of these technologies will give rise to multifunctional building solutions such as prefabricated BIPV/T walls and roofs, semitransparent PV windows, smart shading and daylighting systems, advanced thermal storage, solar cooling, and intelligent building operation strategies.

Human behavior plays a critical role in the performance of Net Zero Energy Buildings (Net ZEBs). Strategies to mitigate occupant-induced uncertainties include:

1. Designing with passive techniques like optimal materials and geometry to reduce discomfort.
2. Employing smart, adaptive controls that learn and adjust to occupant preferences.
3. Utilizing performance dashboards to inform occupants of real-time and annual energy performance, encouraging behavior aligned with energy goals.

Scaling Net ZEB adoption requires a shift from individual buildings to clusters and neighborhoods, emphasizing integration with electricity grids and microgrids. While individual Net ZEBs offer significant potential, a systemic approach is essential to optimize community-level energy balance, addressing seasonal and diurnal energy variations. This vision includes innovations in urban design to maximize solar energy capture, advances in BIPV/T and heat pump synergies, and the use of district heating and seasonal thermal storage for cold climates.

The integration of plug-in hybrid and electric vehicles as energy assets adds a dynamic dimension, enabling storage, load management, and emergency power backup. The ideal mix of technologies, designs, and operations will depend on local climates, economic incentives, and community needs.

Case studies across diverse climates affirm that Net ZEBs are not merely aspirational but achievable. By leveraging advanced modeling, simulations, and meticulous planning, Net ZEBs can redefine sustainable development. The future lies in harmonizing innovative technologies, integrated designs, and community-scale solutions, driving us toward a resilient, energy-efficient world.

8. Conclusion

In conclusion, our Zero Energy Project has determined that solar energy stands as the most effective and sustainable solution for energy savings and cost efficiency. After thorough research and collaboration, we unanimously agreed that photovoltaic (PV) solar panels are the optimal choice for electricity generation. While the upfront installation costs may be significant, the long-term savings on energy bills make this investment not only economically viable but also environmentally responsible.

In an era of dwindling natural resources, this approach offers a self-sustaining, energy-efficient, and eco-friendly pathway to achieving a truly Zero Energy building. Strategically placing the solar panels on the south-facing backside of the building maximizes sunlight absorption, ensuring peak performance and efficiency.

As Bangladesh advances in integrating solar panels, promoting natural sunlight for lighting, and adopting solar heating systems to reduce dependency on air conditioning, the country is paving the way for sustainable development. We recommend that, in addition to BNBC guidelines, Bangladesh formulates a comprehensive master plan and enforces robust policies for Net Zero Energy Buildings (NetZEBs). These efforts would not only enhance energy security but also play a pivotal role in reducing carbon emissions, creating a brighter and more sustainable future for our planet.

References

Aelenei, L., Aelenei, D., Gon¸H. C., Lollini, R., Musall, E., Scognamiglio, A., Cubi, E., and Noguchi. M., Design issues for net zero-energy buildings. *In ZEMCH 2012-International Conference*, 2012.

Andersen, H. L., Christel S. K., Hertz, L., and Brondsted, H. E., Uptake of glucose analogues by rat brain cortex slices: Na+-independent membrane transport. *Journal of neurochemistry*, 27(2):369–373, 1976.

Anmerkungen zur geschichte https://passipedia.de/grundlagen/anmerkungenzurgeschichte. Accessedon02/23/2024.

Architectonics: The greenest building in sri lanka. http://architecturez.blogspot.com/2009/06/greenestbuilding-in-sri-lanka.html. Accessed on 02/18/2021.

Budget of the united states government, fy 2008. https://wayback.archiveit.org/all/20070820164033/ http://www.whitehouse.gov/omb/budget/fy2008/energy.html. Accessed on 03/05/2021.

Building america — department of energy. https://www.energy.gov/eere/buildings/buildingamerica. (Accessed on 03/05/2021).

Cabinet decision on the new strategic energy plan. https://www.meti.go.jp/english/press/2014/041102.html. (Accessed on 03/05/2021).

Chastas, P., Theodosiou, T., and Bikas. D., Embodied energy in residential buildings-towards the nearly zero energy building: A literature review. *Building and Environment*, 105:267–282, 2016.

Clearvue power generating glass 5 fans-youtube. https://www.youtube.com/watch?v=0tuqG21R08. Accessedon02/23/2024.

Department of energy. https://www.energy.gov/news/5648.htm. Accessed on 03/05/2021.

EPBD Recast. Directive 2010/31/eu of the european parliament and of the council of 19 may 2010 on the energy performance of buildings (recast). Official Journal of the European Union, 18(06):2010, 2010.

Evola, G., Margani, G., and Marletta, L., Cost-effective design solutions for low-rise residential net ZEBs in mediterranean climate. *Energy and Buildings*, 68:7–18, 2014.

Gagliano, A., Nocera, F., Detommaso, M., and Patania, F. Design solutions for reducing the energy needs of residential buildings. *In IREC2015 The Sixth International Renewable Energy Congress*, pages 1–6. IEEE, 2015.

Good, C., Kristjansdott´r T., Wiberg, A. H., Georges, L., and Hestnes, A. G., Influence of PV technology and system design on the emission balance of a net zero emission building concept. *Solar Energy*, 130:89–100, 2016.

Guilherme C. da G., Andr´e A., and Maria M. L., Solar powered net zero energy houses for southern Europe: Feasibility study. *Solar Energy*, 86(1):634–646, 2012.

Gvozdenovi´c, K., Maassen, W. H., Zeiler, W., and Besselink, H., Roadmap to nearly zero energy buildings in 2020. *REHVA Journal*, March, 2015.

LaRue, A. M., Cole, N. C., and Turnbull, P. W., Implementing california's zero net energy goals. Energy Efficiency: *Towards the End of Demand Growth*, pages 275–304, 2013.

Laustsen, J., Energy efficiency requirements in building codes, energy efficiency policies for new buildings. *idea information paper*. 2008.

Li D. HW., Yang, L., and Lam, J. C., Zero energy buildings and sustainable development implications–a review. *Energy*, 54:1–10, 2013.

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

Mertz, G. A., Raffio, G. S., and Kissock, K., Cost optimization of net-zero energy house. *In Energy Sustainability*, volume 47977, pages 477–487, 2007.

Noguchi, M., Athienitis, A., Delisle, V., Ayoub, J., and Berneche, B., Net zero energy homes of the future: A case study of the ecoterratm house in Canada. *In Renewable Energy Congress*, Glasgow, Scotland, pages 2008–112, 2008.

Pekka Huovila, P., Ala-Juusela, M., Melchert, L., Pouffary, S., Cheng, C., Urge-Vorsatz, D., Koeppel, S., Svenningsen, N., and Graham, P., Buildings and climate change: *Summary for decision-makers*. 2009.

Ross, A. M.,. A History of Environmental Education Centres Within the NSW Department of Education. *PhD Thesis*, The University of Newcastle, 2020.

Singh, P., and Verma, R., 'Zero-energy buildings—a review. SAMRIDDHI, *J. Phys. Sci., Eng. Technol,* 5(2):143–150, 2014.

Sinton, J. E., Levine, M. D., and Qingyi, W., Energy efficiency in China: accomplishments and challenges. *Energy Policy*, 26(11):813–829, 1998.

The paris agreement — UNFCCC. https://unfccc.int/process-and-meetings/the-parisagreement/the-paris-agreement. (Accessed on 02/23/2021).

Torcellini, P., Crawley, D., Pless, S., Getting to net zero. Technical report, *National Renewable Energy Lab.(NREL)*, Golden, CO (United States), 2009.

Torcellini, P., Pless, S., Deru, M., and Crawley, D., Zero energy buildings: a critical look at the definition. Technical report, *National Renewable Energy Lab.(NREL)*, Golden, CO (United States), 2006.

UP BUILD. The European portal for energy efficiency in buildings. OVERVIEW— Zero-Energy Buildings: Does the Definition Influence Their Design and Implementation. Accessed on 02/18/2024.

Wall, J., Reedman, L., Rowe, D., and Linsell, D., Eco-efficient technology solutions towards net zero: an Australian case study. *In Proceedings of 6th World Sustainable Building Conference*, pages 1–10, 2011.

Welcome to the mosaic centre: Canada's biggest net-zero building - green energy futures. https://www.greenenergyfutures.ca/episode/first-net-zero-office-building. Accessed on 02/18/2024.

Biographies

Dr. Md Alamgir Hossain, a distinguished academic leader and researcher, joined BUFT as a Professor of Industrial Engineering in January 2023 and quickly rose to become the Dean of the Faculty of Fashion Studies (FFS) in February 2023. Currently he is serving as Treasurer at the BUFT. Dr Hossain graduated from BUET, Dhaka, from Mechanical Engineering Department in 1999 and received PhD from Swinburne University of Technology, Australia in 2005. Dr. Hossain is an accomplished researcher with over 50 publications in renowned journals and conferences.

Dr. Nazia Muhsin graduated from the MIST on 2008 in Mechanical Engineering. Her academic journey continued in Japan, where she earned a Master degree in Bioresource Engineering in 2015 from the University of Tsukuba. She furthered her studies and obtained a Ph.D. in Bioresource Engineering in 2018, also from the same university. Currently, Nazia serves as an Assistant Professor in the Department of Industrial Engineering at BGMEA University of Fashion and Technology. Her research interests include Multi-criteria Decision Analysis (MCDA), Geographic Information Systems (GIS), and Remote-sensing, with a focus on their applications in environmental and resource management.

A M M Shamsul Alam graduated from Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh with BSc in Mechanical Engineering in 1993 and MSc in Mechanical Engineering in 2000. He received his MBA with a major in Operations Management from American International University Bangladesh in 2010. At present he is serving as an Associate Professor in the Mechanical Engineering department of Sonargaon University, Bangladesh. His research interests include heat transfer, fluid mechanics, IC engine, optimization, lean manufacturing, and scheduling.

Mehedhi Hasan is an enthusiastic researcher on composite materials and their applications. He graduated from Sonargaon University with a degree in mechanical engineering. In addition to doing research on sandwich structures, reinforcing effects, and thermal insulation boards. He has several conference papers published.

Additionally, biomedical engineering and biocompatibility interest his attention. His dedication to groundbreaking research is shown by his published conference papers and current studies on sandwich structures, the effects of reinforcement on composites, and thermal insulation boards.