Design of a Net Zero Energy Building in Bangladesh using Building Energy Optimization Simulation Tool

By

Waleed Aziz (131431)

Rafsan Ahmed Rashik (131466)

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Department of Mechanical and Chemical Engineering

Islamic University of Technology (IUT)

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Approved By:

Dr. Arafat Ahmed Bhuiyan
Supervisor, Lecturer,
Department of Mechanical and Chemical Engineer,
Islamic University of Technology (IUT),
Boardbazar, Gazipur-1704

Date: ____________

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List of Acronyms

NZEB	Net Zero Energy Building
RE	Renewable Energy
BEopt	Building Energy Optimization Tool
IEA	International Energy Agency
SHC	Solar Heating and Cooling Program
HVAC	Heating, Ventilation and Air-Conditioning
EER	Energy Efficiency Ratio
PV	Photovoltaics

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Abstract

A Net Zero Energy Building (NZEB) is a residential or commercial building with greatly reduced energy consumption by efficiency means, such that the remaining energy load can be supplied with Renewable Energy (RE) technologies. This paper tries to explore the concept behind NZEB and its different definitions. The life cycle costs associated with a NZEB and its feasibility. This paper also reviews all the different NZEBs around the world and provides a statistical analysis about their performance.

The main objective of this paper is to verify the feasibility of a Net Zero Energy Building in Bangladesh using simulation Building Energy Optimization Simulation Tool (BEopt). This is achieved by running software simulations over a hypothetical building in Dhaka, Bangladesh with parameters pertaining to Bangladesh and then analyzing the results to determine the feasibility of such a project.

Introduction

Residential and Commercial Buildings consume a great proportion of the total Electricity produced. Almost 40% of the primary energy in the United States or Europe, and nearly 30% in China. In Bangladesh, the residential sector consumes about 47% of the total electricity production[1]. New Buildings consume more energy than old ones, and are being built faster than the old ones can retire. This situation leads to the rising demand for electricity in the world and may lead to a catastrophic global energy crisis in the foreseeable future. The governments of the world are trying to increase their electricity production using RE technologies and are also promoting the construction of NZEBs.

From 2008, researchers from Austria, Canada, Finland, Italy, Korea, New Zealand, Norway, Portugal, Australia, Singapore, Belgium, Spain, Denmark, Sweden, France, Germany, Switzerland, United Kingdom and USA have been working together in the joint research program “Towards Net Zero Energy Solar Buildings” under the support of International Energy Agency (IEA) Solar Heating and Cooling Program (SHC) Task 40 / Energy in Buildings and Communities (EBC, formerly ECBCS) Annex 52[2]. In 2010, the European Commission and Parliament approved the re-form of the Directive on Energy Performance of Building[3]. The directive requires that buildings should be “Nearly Zero Energy Buildings” after 2019. With this decision, the expectation is that by 2020 energy consumption, as well as CO_2-emissions are lowered up to six percent in the whole EU. On the 30th of June 2011, the member states of the European Union have already developed national plans for conversion to this new directive[4]. The Federal Government of Germany has well-defined in its fifth energy research program: “The long-term objective is zero emission buildings”[5], England has expressed the intent: “all new homes to be zero carbon by 2016[6] and even the USA formulate in their political agenda such buildings as well as suitable balance ideas[7]. The Bangladesh Government has set a target to have 3,168 MW of RE capacity installed by 2021[8].

NZEB Concept

The five main forms of energy needs in a building are: Heating, Cooling, Domestic Hot Water, Lighting and Ventilation. The NZEB is designed in such a manner that it provides all of these required facilities but consumes very less energy compared to a standard building. This can be done by energy efficient design and using high efficiency appliances. The already reduced energy, which the building consumes is supplied using clean RE sources (e.g. PV Solar Modules, Wind Turbines, etc.). When the RE sources are not able to meet the required power load (for e.g. at night, rain, snow, etc.), the NZEB has to depend on traditional energy sources such as Gas and Electricity from the Grid, creating an Energy Debt. Conversely, when the NZEB produces excess energy than the required energy load, this excess energy is exported back to the grid, compensating the Energy Debt. By monitoring the amount of energy consumed by the building and the energy supplied back to the grid, we can achieve a “net zero energy balance” state. This may sound simple, but to actually design such buildings engineers need to consider a lot of factors. The design of NZEB is further explained in the later sections of the paper.

Definitions

The concept of a NZEB may seem simple at first, but despite all the research there is no globally accepted definition or understanding of the subject. This is because a NZEB is defined on the basis of boundary or metric. A definition depends on the goals of the project. Different individuals involved in the project will have different goals. Due to the presence of conflicting interests it becomes very difficult to define the NZEB. It is best defined by four broad definitions[9, 10].

Net Zero Site Energy

The total energy consumed by the building is at least equal to the energy produced on-site in the span of a year. To achieve a "net zero site energy" the energy measurements are made at the site. This makes the calculations and monitoring a lot simpler, hence implementation is the easiest. This definition is the least affected by external factors.

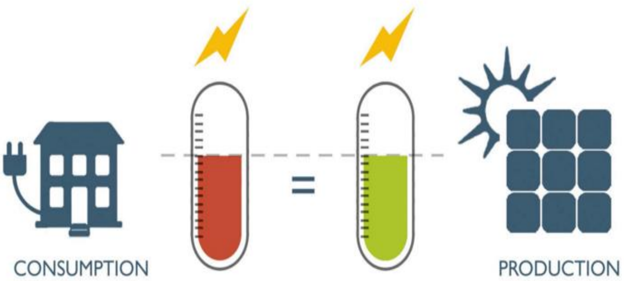


Figure 1: Net Zero Site Energy

A building consumes energy in the form of two different conventional energy sources, electricity and gas. To achieve the "net zero" goal the NZEB has to return the same magnitude of energy to the grid in the form of electricity, as that is the only type of energy that can be produced on-site. At the site one unit of electricity is equal in value to one unit of gas (conversion factor explained in the next section), but at the source electricity is over three times as valuable. Therefore, by this definition it means that for consuming three units of gas we need to export three units of electricity to the grid. To produce enough electricity to offset the gas a greater surface area of PV modules is required, which in turn increases the overall cost. But this also encourages the engineers to construct more energy efficient designs.

Net Zero Source Energy

In this definition, the energy losses associated with transmitting the energy to the building from the building is also factored in to the calculations. This means the energy consumed at the site is multiplied by a site-to-source conversion factor to calculate the total energy that needs to be exported back to the grid to reach the net zero goal. P. Torcellini in his inspiring paper about the life cycle assessment of a NZEB calculated the site-to-source conversion factor to be 3.37 for electricity and 1.12 for gas[11]. It comparatively easier to satisfy this definition as it can equate the values of different fuel types. This means that if the ZEB consumes 3.37 units of gas it only needs to export 1 unit of electricity to offset the energy. The building needs a lower surface area of PV modules, hence reduced costs. This also inspires the consumers to switch a greater portion of their fuel to gas.

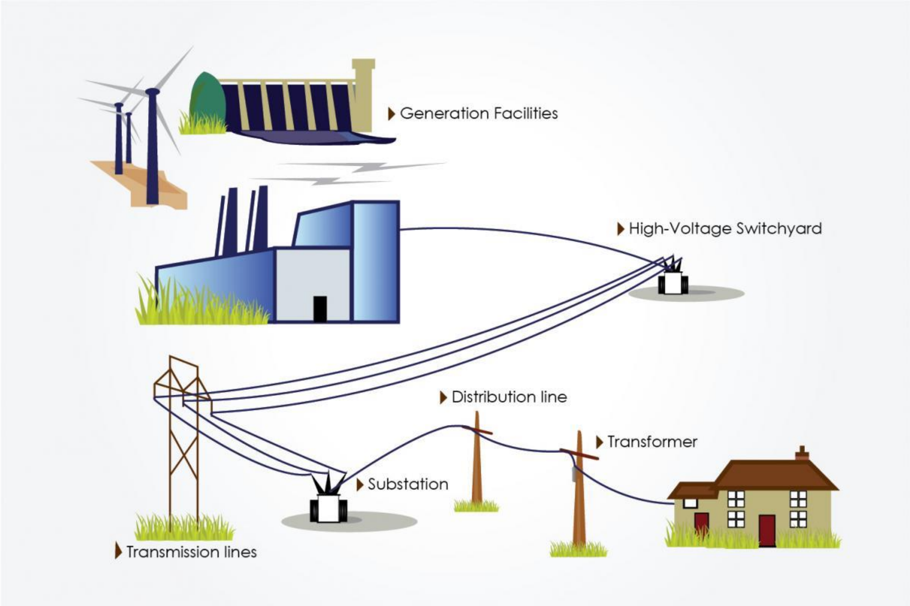


Figure 2: Net Zero Source Energy

But the site-to-source conversion factors mentioned above are only the average values. This means that the actual site-to-source conversion factor may differ drastically from region to region. This value may also vary with time. Therefore, energy measurements and monitoring of goals becomes much more difficult.

Net Zero Energy Costs

The cost of the total energy consumed by the building is equal to the credit received for exporting the excess electricity in a year. This system is very easy to implement as the total energy consumption can be measured easily from the utility bills. This is the only definition which considers all of the utility bill (the previous definitions do not consider all definitions leading to a lower load factor).

Figure 3: Net Zero Costs Energy

The prices of electricity, peak demand and taxes are highly volatile, which makes it difficult for calculations. A strict demand responsive control is required to achieve the goal. A skilled operator is required to properly manage the utility bills with the demand for electricity. In that sense, this definition is the most difficult to achieve.

Net Zero Emission

The amount of energy consumed by the NZEB from emission-producing sources is at least equal to the amount of excess energy produced by the building from non-emission-producing sources. If a building obtains all of its energy from a wind farm, this means that the building does not consume any energy from emission-producing source. Therefore, the building has already achieved Net Zero Emission. The implementation of this definition is pivoting on the geographic location of the NZEB. For instance, if the NZEB is located near a coal-fired power plant the NZEB would need to produce a much greater amount of electricity when compared to a NZEB near a hydroelectric power plant. There are basically no disadvantages in this definition and is the easiest to attain compared to all other definition.

Ideal Design of a NZEB

The threatening shortage of resources, climate protection and rising energy costs has worked as a forcing function for engineers and building owners to invest in building design which consumes the minimum amount of energy. The American Society for Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) has provided us with the most efficient design of a NZEB in their journals[12-16]. The design of a NZEB is divided into three separate stages.

1) Building Envelope Measures: The Building is oriented southwards to optimize natural day lighting this means less energy used for lighting during daytime. Skylights on the roof will facilitate daylighting. Passive solar heating in the winter and reduced heat gain through windows in summer. Increasing the thermal resistance (R-values) of walls and windows with enhanced insulation will result lower energy loss to the surrounding environment, hence less energy used for heating/cooling. Using overhangs and trees for shading the windows and to reduce amount of sunlight falling on them.
2) Energy Efficient Operations: High efficiency lighting with occupancy sensors and daylighting controls to lowers the lighting and cooling needs. Using high efficiency heating systems and minimizing stand-by losses[17]. Using maximum outside air for ventilation when outside air temperatures are mild. Using Ground Source Heat Pumps which increases the HVAC efficiency. The efficiency of the building may be further increased by training the building operators and occupants about the energy efficient operation of the building.
3) Renewable Energy Sources: Solar Collectors for heating the Domestic Hot Water (DHW) and space heating. Photovoltaic (PV) panels for generating the required electric load. Wind

Figure 4: Design of a NZEB

Turbines within the footprint (boundary) of the building. Biomass tank to generate Biogas on-site which can be used for heating and cooking. There may also be an option for Geothermal Energy used for Heating.

This design incorporates all of the technologies required to create the ultimate NZEB as shown in figure 1. But as great as the design seems it is virtually impossible to satisfy all the criteria. This is because all locations do not have the required infrastructure for a wind Turbine or a geothermal energy source. The insulating materials, occupancy sensors, high efficiency appliances and HVAC systems are very expensive and difficult to obtain. Therefore, a compromise design structure is incorporated. The cost analysis of the NZEB is discussed in later sections of the paper.

Design of a NZEB

To better understand the actual challenges involved in achieving a NZEB we need to perform a Life-cycle Energy Analysis. A life-cycle energy analysis considers the operation energy and the embodied energy of the building[18]. This means that in addition to the utility bills we also need to include the cost of constructing the house with efficiency measures added with the cost of installing Renewable energy sources along with the replacement and renovation costs in long-term calculations.

The first thing that we should understand is that there is no structured method for designing a NZEB and there is more than one way to reach the NZEB goal, as the design may vary depending on factors such as:

- The location of the building.
- The climate in which the building is situated in.
- The goals of the design engineer.

After accepting the above-mentioned points, we can get started with the design process. At first, we need to design a Base Case House (BCH). The BCH is a standard building designed in a similar fashion to the other building in the area. This BCH acts like a reference for our design. All changes from this point will be compared with the BCH. In our BCH we need to calculate the following:

- The thermal resistance and the unit cost of the material for the walls
- The thermal resistance and the unit cost of the windows
- The thermal resistance and the unit cost of the floor material
- The thermal resistance and the unit cost of the roof material
- The cost of the water heater
- The annual cost of gas used for heating water.
- The volume of domestic hot water required annually
- The amount of electricity consumed by lighting and other appliances and their costs.
- The cooling and heating loads of the HVAC system

The next step would be to convert all of the costs into an annualized format. By doing so we can get an idea on the annual costs involved in the design.

Efficiency design

Our next objective is to reduce the energy consumption of the building as much as possible. This is achieved by incorporating efficiency measures such as:

- Construction material with higher thermal resistance
- Changing the design to allow for daylighting

- Using solar collectors to reduce the water heater load
- Heat recovery from reject water
- Higher efficiency lights and appliances
- Higher efficiency HVAC system

By allowing for these changes, we need to perform the same calculations as above. We also need to keep in mind that by adding these efficiency measures we are reducing the operating costs of the building, but these improvements are more expensive and hence lead to a higher annualized cost.

Renewable Energy Source

By incorporating efficiency methods, we have reduced the energy consumption of the building. The next step is to add Renewable Energy sources to the design. The RE input to the system should compensate the remainder of the energy requirement of the building. After adding the RE sources now we also need to include the installation costs and the replacement costs of the RE sources in the long run. This leads to a further increase in the annualized costs of the building.

Cost Analysis

At this point, we have the design of the building, the estimate of the annualized costs of the building, the output of the RE sources is equal to the energy requirements of the building, hence zero utility bills. We need to keep in mind that just because there are no utility bills does not mean that our initial investments have been paid off, hence the NZEB target has still not been achieved. To achieve the NZEB target we need to calculate the payback period of the building and verify that whether the payback period is lower than the lifetime of the house (usually 30 years). If, however the payback period of the building exceeds the lifetime of the building, then the NZEB target is not achieved. We will need to change the design to reduce the investment costs and calculate the payback period again. This is called the Least-cost path which is explained in the later sections.

Analysis of Residential System Strategies Targeting Least-Cost Solutions Leading to Net Zero Energy Homes

The project aimed to develop integrated energy efficient and onsite/ renewable power solutions to be used in the production-basis to convert a normal house to a net zero energy house using research results in a cost-effective way[19]. This research is called Systems Research.

System research include analysis of system performance & cost savings, keeping in mind the interactions between mechanical and electrical systems, lighting systems, space conditioning systems, onsite energy, renewable energy systems etc.

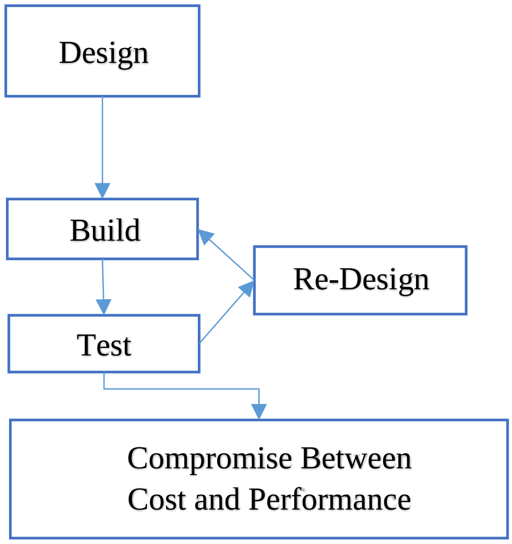


Figure 5: Overview of Building America Systems Engineering Process

Systems research innovates new engineering processes increasing housing efficiencies & flexibilities in production. Figure 6 represents the systems approach to develop advanced residential buildings.

All energy savings are based on source energy savings. It means that all the site energy was converted to source energy (primary energy) before calculating. The usual source-to-site energy conversion value is three for electricity.

<u>Least-cost Path</u>:

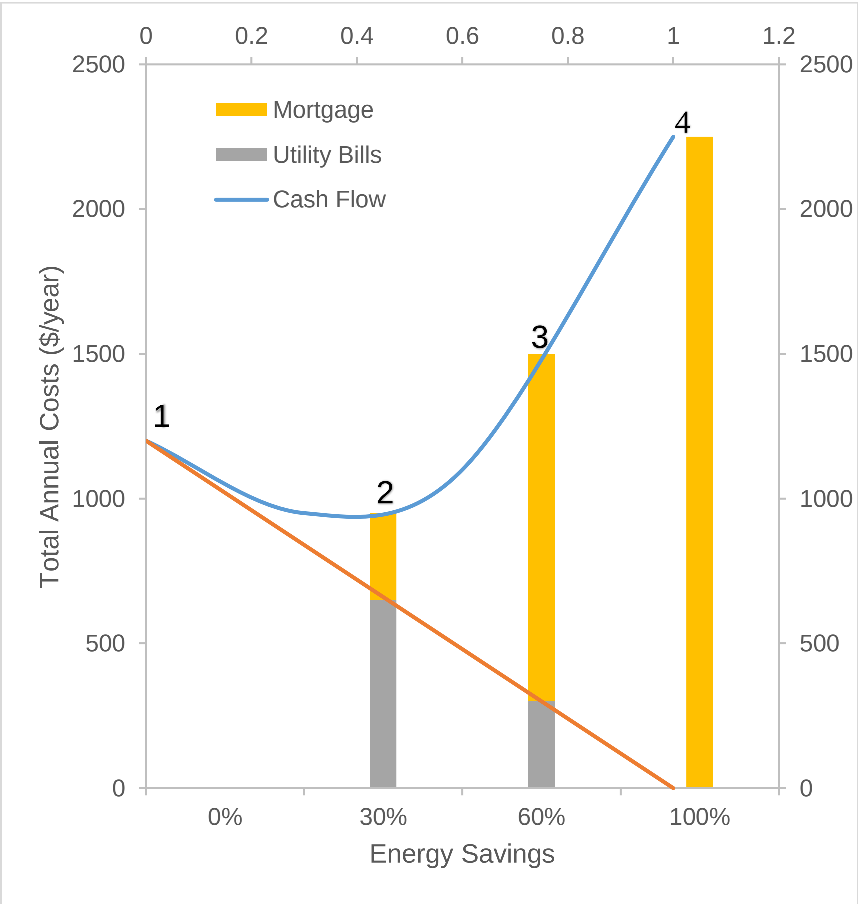


Figure 6: Overview of Building America Systems Engineering Process

Here, from point one energy is saved by engaging different energy saving measures like improving space conditioning, hot water, thermal distribution, lighting systems, windows redistribution etc. A minimum annual cost occurs at point 2. Additional efficiency systems employment results in increasing annual costs. At point 3, the cost of saving energy equals the cost of producing on-site energy. From point 3 onwards, onsite energy sources are added keeping the building design unchanged until Net Zero Energy consumption is achieved.

This path mainly depends upon the climate of the place. According to the climate, the minimal annual cost varies significantly[20]. Other factors are also in action such as the technologies used, availability of the technologies, location of the house etc.

Optimization:

The innovations for producing NZE houses should be such that it creates a balance between the investments in efficiency and the utility bill savings. Given a definite energy savings target, economic optimization can be used to find the lowest cost to achieve the goal. This is the initial step to find the optimal path to NZE house with the least cost.

However, optimal path cannot be followed fully accurately due to cost inflations, energy predictions & various other factors. So near-optimal solutions are needed so that the designers can follow the other paths to build a NZE house meeting target markets without compromising the overall energy efficiency of the building.

Sequential search analysis:

This method involves searching all the categories (wall type, ceiling type, window glass type, HVAC type etc.) sequentially & finding the least-cost path to NZE house[21]. In this method, simulations are done on the base case house to evaluate all the possible improvements of the building (at each step). The most cost-effective points are selected for the nominal path & put into building description. Then the process is repeated. The marginal cost is compared with the cost of setting up PV panels. It needs to be less than or equal to the PV costs. If it goes higher, the building description is held constant & PV capacity is increased to reach NZE house.

The sequential search method has several advantages. Firstly, it finds all the intermediate points along the least-cost curve. Secondly, it evaluates continuous path to reflect realistic construction method. Thirdly, near-optimal paths are also evaluated so that designers can construct building according to the builder & consumer needs.

However, since this is an analysis method, the results are subjected to the assumptions during the study. This method can be more perfected in collaboration with the on-field project research teams.

Net Zero Energy House

This research was performed by Miroslav Olegov Gerasimov, which is very innovative[22]. The main design of the NZE house will be based on photovoltaic array. The extra energy produced during the off-peak hours will be used to power an Electrolyzer. It will supply hydrogen to the fuel cells. There will also be a hydrogen storage tank to store the hydrogen. The fuel cells will provide power during nights & cloudy days and will work as an auxiliary power source during the peak hours.

Passive house design:

The main goal of this paper is to design a building, which will produce more energy than it consumes. It requires an efficient building following the German Passive House Standard.

According to the criteria, heating demand should be within 120 kWh/m^2. This can be done by using highly efficient HVAC system. This relies on high performance air exchanger having efficiency as much as 90%. The air exchanger exchanges the air of laundry room, bathroom & other utility rooms with fresh air with negligible temperature difference.

This type of houses requires the maximum utilization of solar radiation. For this, houses are designed with triple glazed windows on the south facing walls. These will provide enough daylight & reduce the necessity of heating by around 85%, since their gain is more than their losses.

The house should be air tight having no leakages. The U-values of the exterior walls should be less than 0.15 W/m^{2}K. To achieve this, the insulation layers are 25-30 cm thick depending upon the materials used.

The orientation should also be kept in mind so that solar radiation is properly utilized. South facing houses are the most common. Proper shading should also be designed to avoid the radiation of the summer sun.

Energy Balance:
Appropriate size of the energy system is very important to achieve NZEB. For this, precise calculations of the energy consumption of these systems are necessary.

Table 1: Energy Consumption Comparison

Category of energy consumption	Zero Energy Building Annual, kWh	Typical House Annual, kWh
Space Cool	921	1830
Space Heat	1767	12900
Hot Water	348	490
Vent. Fans	14	170
Pumps & Aux.	213	190
Misc. Equip.	1576	1590
Area Lights	598	530
Total	5437	17700

During the summer & spring, energy production is usually more than the consumption. This extra energy is used to power the Electrolyser that extracts hydrogen from the water & stores it in the storage tank.

This type of energy system eliminates the need of batteries, which supply power for a limited amount of time when there is sun or any other source of power available. However, the FC can produce electricity & heat as long as there is hydrogen in the storage tank.

Energy System:
Efficiency is the main target for achieving NZEB. For this, the usage of power is reduced drastically to increase the efficiency. Some of these are low-consumption energy efficient appliances, airtight building envelope, orientation, avoiding active solar heating, using passive solar systems & extra heat from FC for heating domestic water etc. These steps reduce the energy consumption. Therefore, PV array coupled with electrolyser & FC are enough to power the building’s needs.

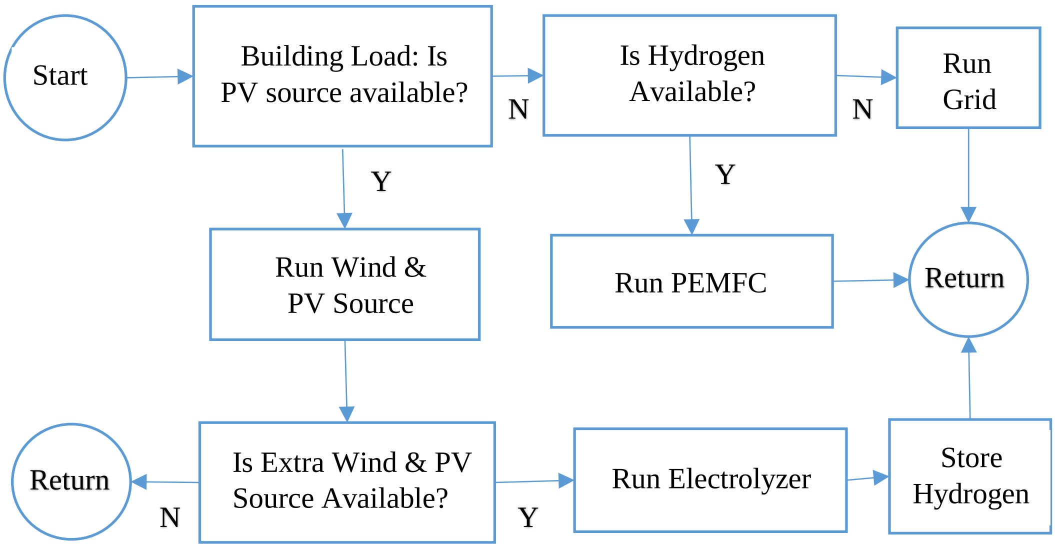


Figure 7: Combined Solar-Hydrogen System process flowchart

<u>Hydrogen System:</u>
Electrolyser is based upon PEMFC (Polymer-Electrolyte) technology & splits the hydrogen & oxygen from the water[23]. The produced hydrogen is then fed to the compressor line & the pressurized gas is then stored in cascade arranged pressure tanks. The tank having the least pressure is filled first & then the others accordingly.

The electrolysis is assumed to be 65% efficient where the waste is primarily in the form of heat. This heat can be used for space heating along with the heating by electricity. This decreases 15.1% of electricity needed for space heating.

Another advantage of this system is that the excess hydrogen can be used as supplement fuel for the hybrid vehicles, which will eventually decrease the utility bills.

<u>Environmental aspect:</u>
Only water is used as raw material for the combined Solar-Hydrogen energy system whereas other systems use natural gas/ oil. Therefore, there is no carbon-footprints left rather; oxygen is formed as a byproduct that does not pose any threat to the environment. Installation process is also environmentally friendly. Therefore, the system is green.

Further Research on NZEB Design

This section deals with the different angles of research taken by researchers around the world for designing a NZEB. Furthermore, this section provides a Literature Review on the methodology of research employed by researchers all around the world and the conclusion to which they arrived.

Case study of zero energy house design in UK

This case study was carried in Cardiff, UK[24]. Initially they collected the data for wind frequency profile and monthly solar radiation profile or the time period of a year. By analyzing the data, they were able to find out that the wind direction was generally towards the South-West. The amount of solar radiation was generally high throughout March to October. Implementing passive design into the building, they explored parameters such U-values of external walls, window to wall ratio and orientation. Four different values of U-values, four orientations (N, S, E, W) and various values of WWR.

Total of 64 cases were examined. They calculated the heating and cooling loads in all the cases using the simulation software OpenStudio. They modelled the domestic water heating system using TRNSYS 16.0. With this they determined the optimum mass flow rate of the DHW and the area of the solar collector. They devised a scheme for a grid connected renewable energy system. The system consists of a PV panel, Wind turbine and inverters, distribution board and Import export meters. By factoring in the annual electricity consumption, and the output of the wind Turbine and PV panels. They were able to determine if the building is able to reach the zero energy criteria. According to their calculations the so-called building actually produces more energy than it consumes.

Towards net zero energy design for low-rise residential buildings in subtropical Hong Kong

The aim of this paper is to check the design feasibility of a Net Zero low-rise residential building in the densely populated city of Hong Kong[25]. They selected the Village House Design, which is the most common design in the Hong Kong city. It is a 3-storey building with floor area of 65.3m^2 and floor to floor height of 3m. Standard architectural design of the building was adapted, all of the energy demands/loads of all the different systems were calculated. PV panels and BIPV were incorporated into the design. The software TRNSYS was used to run the simulations modelling the design for yearly periods. By analyzing the results, it was found that the performance of all systems was better than their expectations, however the design still had a net energy deficit of about 11,000kWh. They had also analyzed the effects of building orientation on the performance of the building. By improving efficiency of panels and by improved human operation of the house they will be able to reach much closer to the NZE target.

A Net Zero Energy Building in Italy: Design Studies to Reach the Net Zero Energy Target

The aim of this paper was to model the energy consumption and the on-site energy production of the Leaf House (LH)[26]. This building was designed to be a Net Zero emission building. The building does not quite reach the NZEB mark. The paper also tries to suggest ways in which the performance of the building can be improved to achieve the NZEB target. The Leaf house is located in Angeli di Rosora, Ancona, Italy; the building is south oriented (latitude 43°28'43.16 N, longitude 13°04'03.65 E), the altitude is 130 m. The site is characterized by a moderate climate, in detail:

- minimum annual temperature is -5°C;
- maximum annual temperature is 37°C;
- mean annual humidity is 67%;
- mean annual horizontal solar radiation is 302

The building is composed by three levels; every one contains a couple of twin flats. The ground and the first-floor flats measure 85.39 m2 each. The construction materials of the envelope are described along with their U-values. The thermal needs of the building are satisfied by a Ground-Source Heat Pump (GSHP). The electrical needs of the building are satisfied using PV solar panels installed on the roof. All systems are monitored by a control system. This system also records all data from the systems and analyses them using business intelligence tools. By analyzing the data, it was found that the systems reached close to the net zero target. To better understand the NZEB it was modelled using TRNSYS simulation software. The monitored data was compared to the simulated data, the discrepancies between them was slight and within acceptable limits. This analogy used to validate the model. A number of redesign hypotheses were proposed. By incorporating these changes in to the model and simulating, improved performance of most of the systems were observed. These improvements now allow the building to attain the NZEB target.

The Use of Genetic Algorithms for a Net-Zero Energy Solar Home Design Optimization Tool

This paper deals with the use of Genetic Algorithms as an optimization tool for the optimization of performance of NZEH[27]. The GA program works by initially generating several designs with different configurations. The GA program then calls the TRNSYS software to calculate the energy costs involved and comfort in population of each design. After the evaluation of all designs, an elimination process takes place after which on the most cost-effective and comfort design is selected. The GA optimization method is able to achieve near optimum results, but it has a certain drawback that it takes a lot of time to gather data, perform the simulations over a yearly period, and then analyzing the results.

In this paper 300 different simulations were carried out. They were carried out in 1-zone and 2-zone models. By analyzing the time, it took to complete the simulations, they were able to observe that 2-zone models took considerably more time. It was then concluded that the single zone model configuration for the whole house is the best option. The current processing power of the computers has limited the complexity of the models. Therefore, the entire building is considered as a single zone to reduce the computation time. This fairly reduces the accuracy of the simulation but, it saves us a lot of time and it gives designers the results with adequate levels of accuracy.

Getting to net zero energy building: Investigating the role of vehicle to home technology

The main objective of this paper is to verify whether by using the concept of Vehicle to Home technology, we are able to satisfy the daily electrical needs of a NZEB[28]. In their methodology the first step that they have taken is to design the NZEB. The have used the Design Builder software to design the building. After the design process comes the energy analysis and the optimization analysis. According to analysis they may need to improve their design. By analysis they are able to select the most energy efficient design which costs less, does not compromise the comfort of the occupants and also has no negative impact on the environment. The design also has to comply with the standard design codes. They had tested over 1900 setpoints out of which only 6 of them can be considered as viable options. Out of these 6 the one which as the lowest number of discomfort hours was selected according to the ASHRAE 55-2004 standard. The modeled a series of PV panels with a total area of 108 ft^2.

There is also an Electric Vehicle which stores excess generated electricity (just like the main battery of the PV system) and provides it during night time. The EV is modelled as a Battery which supplies electricity in some hours of the day. This made the calculations a little more difficult as the EV was attached to the power system only parts of the day and at some parts it was not connected. When both the main PV system battery and the EV battery are fully charged the excess electricity is sold to the grid. They collected the data on daily electric consumption of the building, electricity consumption in different zones, Temperature around the year, electricity consumption from the grid around the year, electricity sent back to the grid and they also made a cumulative comparison of energy consumption. By analyzing their results, they can conclude that the amount of electricity consumed from the grid is reduced by up to 68%, this allows for the payback period of PV installation to be significantly reduced. Hence this system vastly improves the performance of the building.

Design optimization and optimal control of grid-connected and standalone nearly/net zero energy buildings

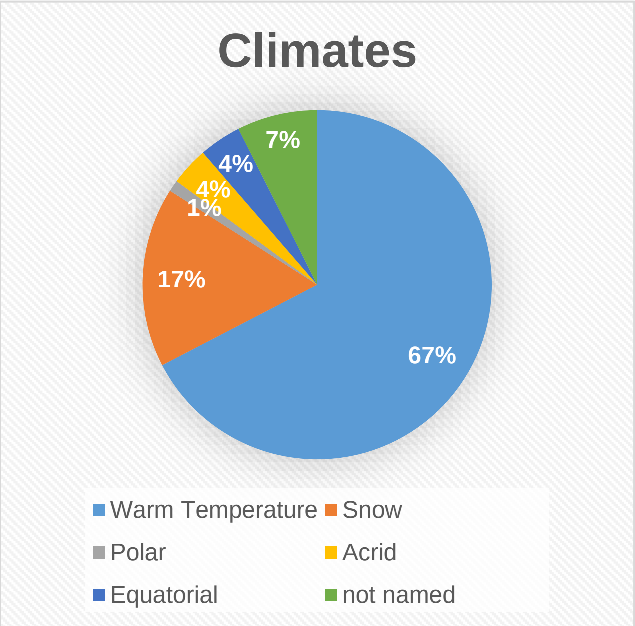
This is a review paper about the problems faced by engineers/architects during the design and control process of a NZEB[29]. The paper tries to provide an insight as to how the design process and the performance can be substantially optimized by addressing some of the more core issues. They first acknowledge that the NZEB does not have a single consistent definition, and without a proper understanding of the definition it's not possible to create an effective design. There is also no direct method/approach to designing the NZEB. They also mention that the effects of using different optimization methods and the climate condition have a huge effect on the design of a NZEB.

They even focus on the effects of uncertainty and sensitivity analysis for robust design and design system reliability. This takes into account the effects of uncertainty in the design process. Then the parameters which are most sensitive to the performance of a NZEB. The next key point that they touch on is the control system which manages all the systems in the NZEB. They also give an overview on the design features and performance of NZEBs around the world. Finally, by analyzing the overview they also make inferences about the future trends in NZEB designing.

Anna Marszal[30] writes in her paper that with the current price levels, it is more cost effective to invest on increasing efficiency rather than investing on renewable energy sources in the perspective of Denmark. S. Deng[31] writes in his paper that more effort should be given to the calculation of conversion factors using advanced simulation tools as these conversion factors play a vital role in the evaluation of NZEB performance. D. Kolokotsa[32] writes in his paper that more effort should be given towards the smart predictive controls and management schemes to improve the performance of NZEBs.

Statistical Analysis of NZEBs around the world

The number of NZEBs is on the rise globally, there are about 152 NZEBs in the US itself as of 2015[33]. Tobias Weiss[34] in his extraordinary paper classifies the different types of NZEBs and shows a statistical analysis on the performance of over 280 internationally verified NZEBs in different regions and climates.



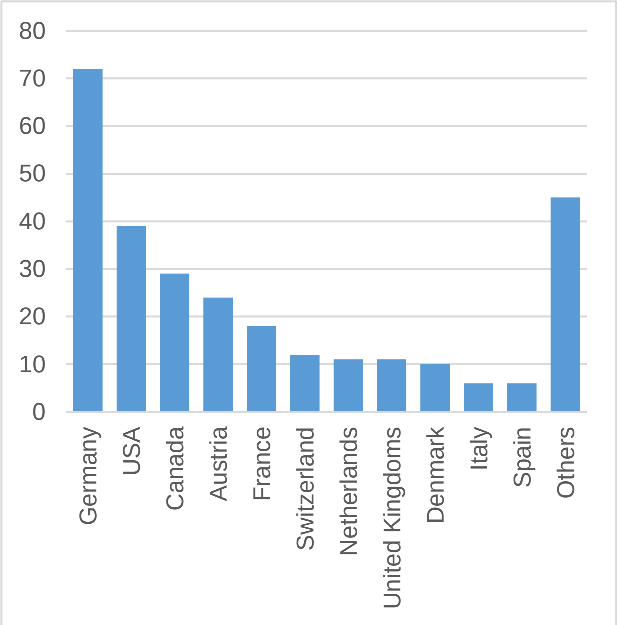


Figure 8: Number of NZEBs in different countries and Climates

The NZEBs can be classified in three categories:

- Small residential buildings
- Apartment buildings
- Non-residential buildings.

The small residential buildings and apartment buildings were built by focusing on resource shortage, climate protection, rising energy costs, etc. Different enterprises and the real estate industries built the non-residential NZEBs to improve the image of the company and to make their company more attractive than their competitors.

Most of the completed NZEB projects are situated in the North-Westerly countries and climates. This means that the design foe a NZEB is most suitable to thrive in warmer climates. The main driving functions for these projects is the ease of procurement of economic resources, headstrong technology and climate knowledge of the region. It also possible to construct NZEBs in the non-conforming climates, but greater expenditure must be spared for the cladding (envelope) for the same amount of comfort and needs.

The performance of the NZEBs is prominently dependent on the methods used for increasing the overall efficiency. The most common measures of increasing the efficiency are: advanced insulation, advanced day lighting, mechanical ventilation systems, mechanical solar shading devices, heat recovery from drain water, high efficiency appliances, etc. These systems not only promote the greater efficiency but greater comfort as well. The different energy saving measures used in the distinct categories of NZEBs are given in Figure 9.

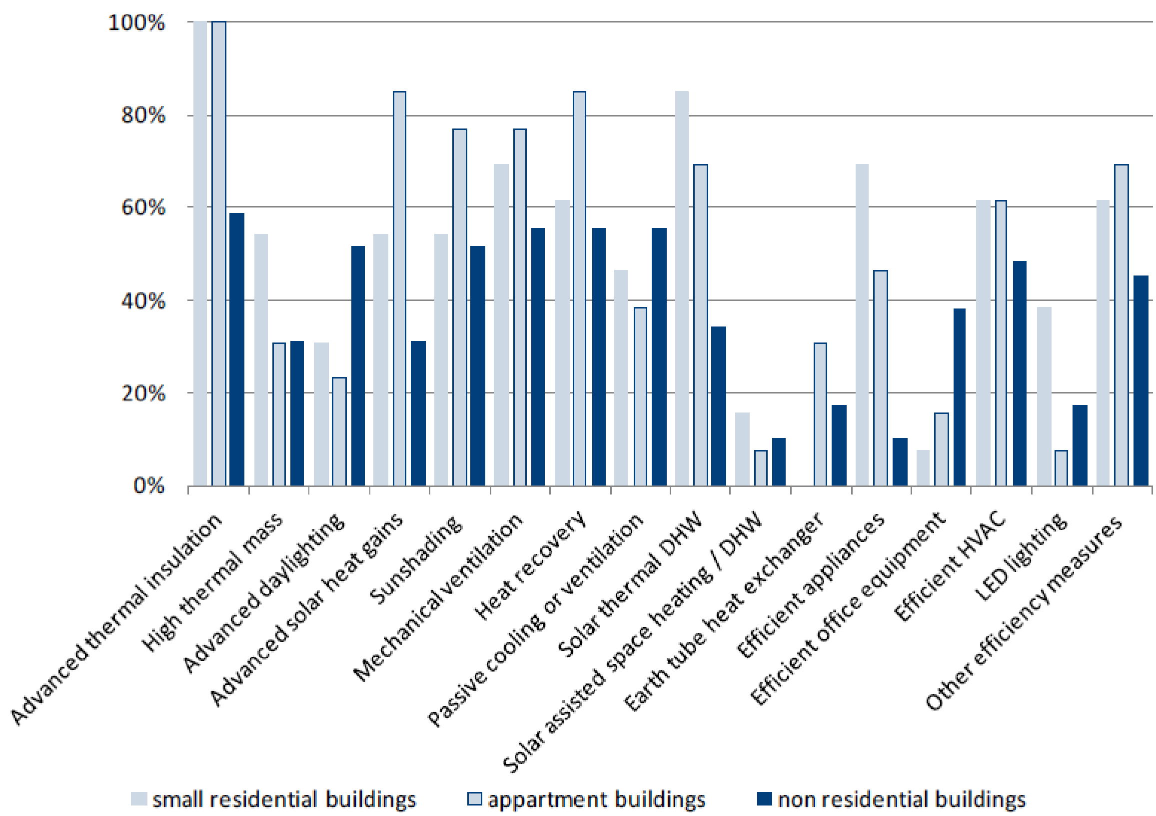


Figure 9: Energy saving measures in NZEBs

To reach the NZEB goal the other aspect which is just as important is the remaining load of energy which is generated by RE technologies. The dominant source of electricity production in this sector is PV panels as most of the projects do not have the infrastructure for a wind turbine or biogas plant. Due to the greater expense of PV modules most of the designs restrict the use of PV modules only for electrical appliances. All other sources of energy consumptions are being met with other on-site renewable energy sources such as heat pumps, solar collectors in smaller applications and Combined Heat and Power (CHP) plants due to their falling prices and rising efficiency[35]. In figure 10 the frequency of the different types of on-site RE sources are shown.

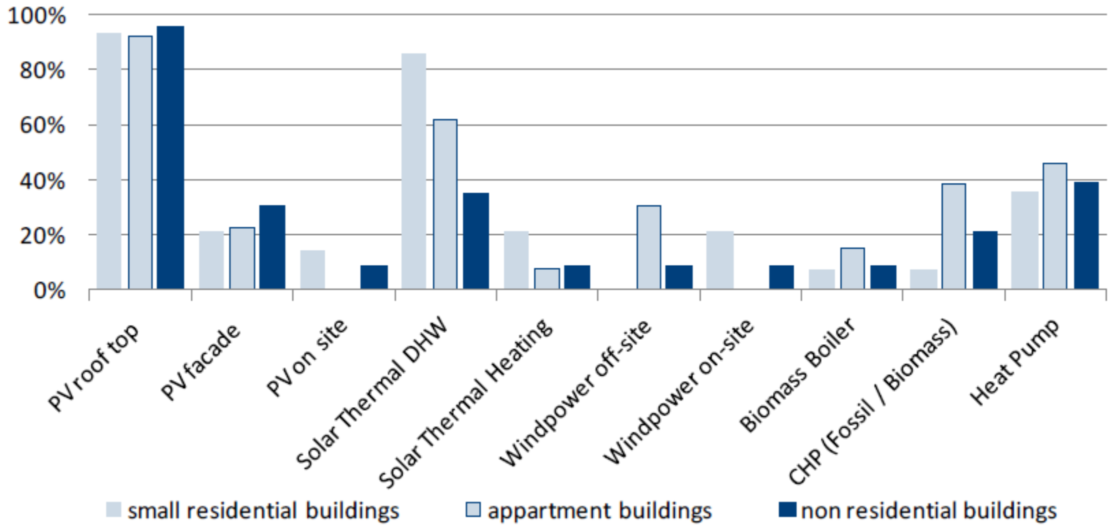


Figure 10: Different types of RE sources used by NZEBs

Building Characteristics Considered in this study

A simple two-story, 1600-ft^2 residential building having 4 bedrooms & 3+ bathrooms with an attached 300-ft^2 garage facing north was considered for this study. The building is modeled with crawlspace foundation, as it is good for dry climates (Bangladesh) and has a good storage capacity. The building has 2-ft eaves. Window area is assumed to be 15 percent of the floor area & is equally distributed between outside walls. The energy options considered in this study were space conditioning, envelops, lighting systems, major appliances, and residential PVs. No miscellaneous electric loads other than major appliances were added. The homeowner costs calculated in this study assume a 30-year mortgage at a 4% interest rate with a 2.4% general inflation rate, 3% discount rate. No maintenance costs were added. There are also various little descriptions which cannot be added because of space & time scarcity.

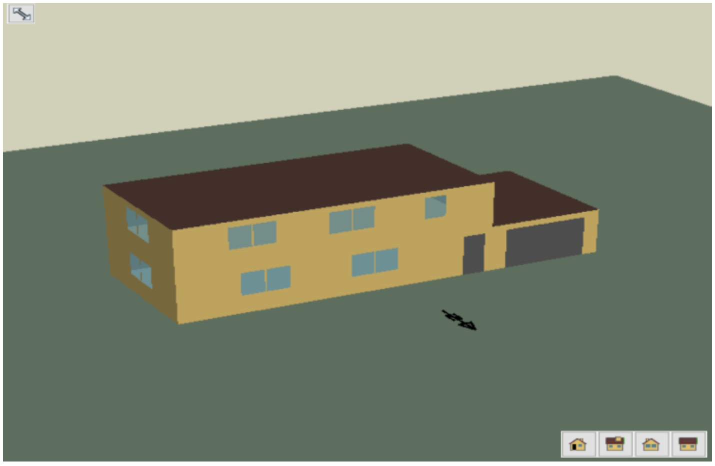


Figure 12: Front of the house

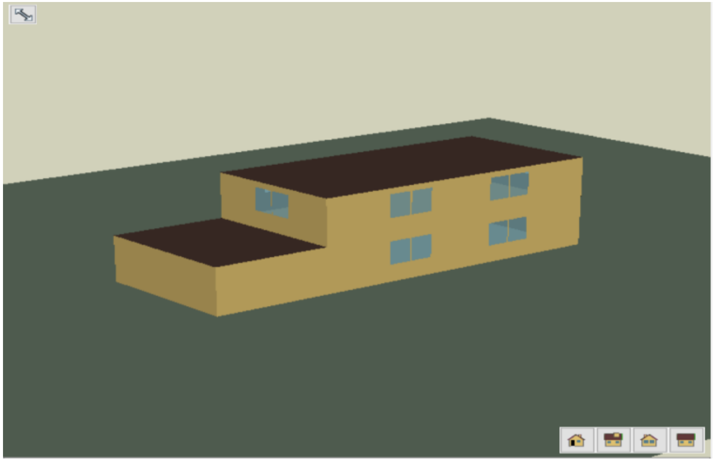


Figure 11: Backside of the house

Base Case Building:

Results are calculated relative to a base case building. The attributes of the building are assumed to be:

Exterior Walls: 6” concrete filled.

Wall sheathing: None.

Exterior finish: Brick, light.

Interzonal walls: Uninsulated.

Roof material: Asphalt shingles, light (Uninsulated).

Crawlspace: Uninsulated, unvented.

Windows: Clear, double, metal, air.

Interior shading: Summer, winter=0.7.

Doors: Wooden.

Room Air Conditioner: EER 8.5.

Lighting: 100% incandescent.

PV system: None.

In this study, other properties are held constant like the house is naturally ventilated (3 days/week), no type of heaters, cooling set point 76 degrees Fahrenheit, humidity set point 60% relative humidity, no water heater (water is assumed to heated by gas burner if required), Top freezer is selected for refrigeration purpose, plug load is 2274 units/year etc.

Costing:

Every option has an assumed first cost & lifetime. Some are input as unit costs & multiplied by a constant as required by the design (e.g., exterior wall costs are input per square feet & automatically multiplied by the wall area). Some are energy-specific (e.g., refrigeration). Inputs can also be based on total costs (e.g., cost of windows construction with different insulation values).

Building construction options (wall insulation, foundation insulation, widows etc.) are assumed to have lifetimes of 30 years. Appliances and equipment have lifetimes of around 10-15 years. Lighting lifetime is based on design model.

The material & replacement costs are US standard (as in BeOpt) & all costing are done in USD. Thus, the exact costing cannot be calculated from Bangladesh's perspective but a relative costing can be seen and an idea can be drawn from the study as to which materials are to be used.

However, the electric & gas bills are assumed to be Bangladesh standard.

Electric bill: Fixed-$0.56/month, Marginal-$0.064/kWh.

Gas bill: Fixed-$10.63/month.

Utility costs are assumed to have an inflation rate of 2.4%.

The cost estimates used in this study do not include the costs to re-engineer homes. It also does not include all the hidden costs (like importing from other countries), which can have a significant effect on designer decisions to implement new system designs.

Least cost path to ZNE:

The figure shows least-cost system curve for a new single family home in Dhaka. The y-axis shows percent energy savings and the x-axis shows energy related costs, including utility bills and mortgage payments for energy options. For the base case building (at x=0), the energy related costs are very high.

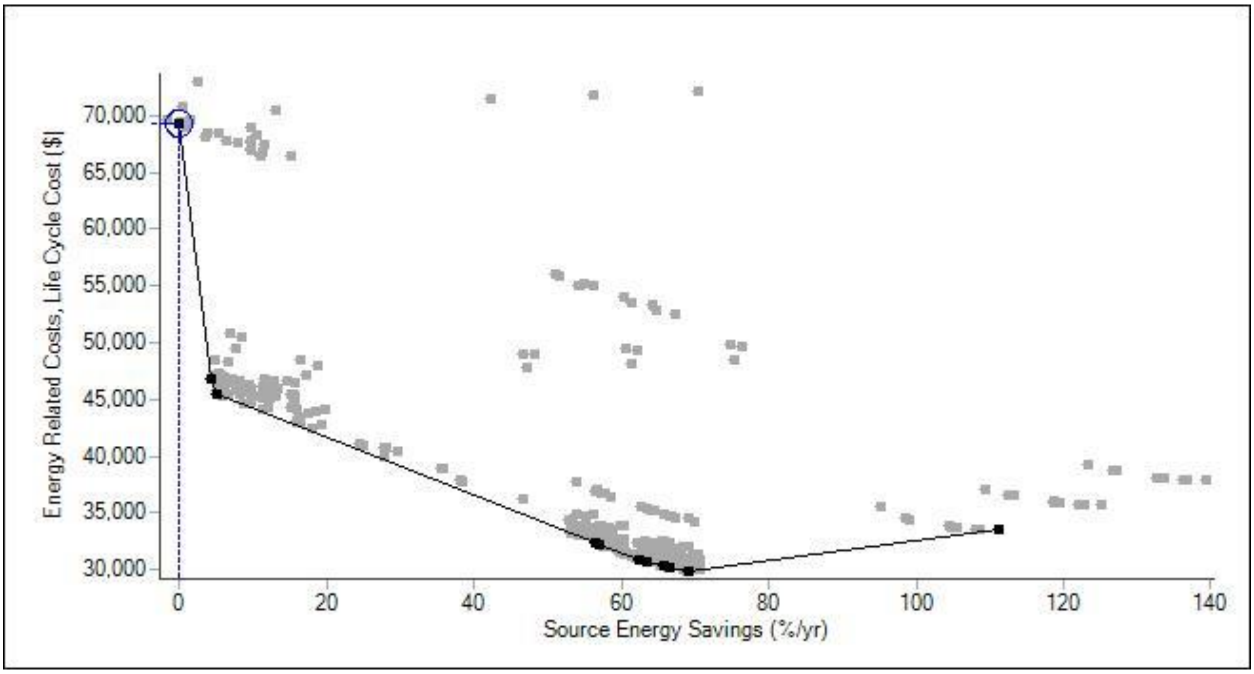


Figure 13: Least Cost Curve

The least cost path then goes downward because of using energy efficient means. The minimum cost point occurs at around 69% source energy savings, which is very efficient. And, it is achieved just by using energy efficient means for the building (e.g., insulating walls, crawlspace, using more efficient room conditioning & refrigeration system, using more insulating materials for doors & windows etc.).

Then, the least cost path turns into a straight line corresponding to the onsite power generation by PV panels for achieving 100% efficient building. The simulation was done until the PV had ended (according to the roof area) which led to the building being more than 100% efficient. It means that it is a positive energy building and it produces more energy than it consumes.

The options & materials used in this study were chosen keeping the availability of those in Bangladesh. For example, the exterior wall material was chosen to be concrete because it is the most common in Bangladesh. The options are also selected keeping the climate of Bangladesh (e.g., no heating equipment were selected because the winter here is not that severe) in mind.

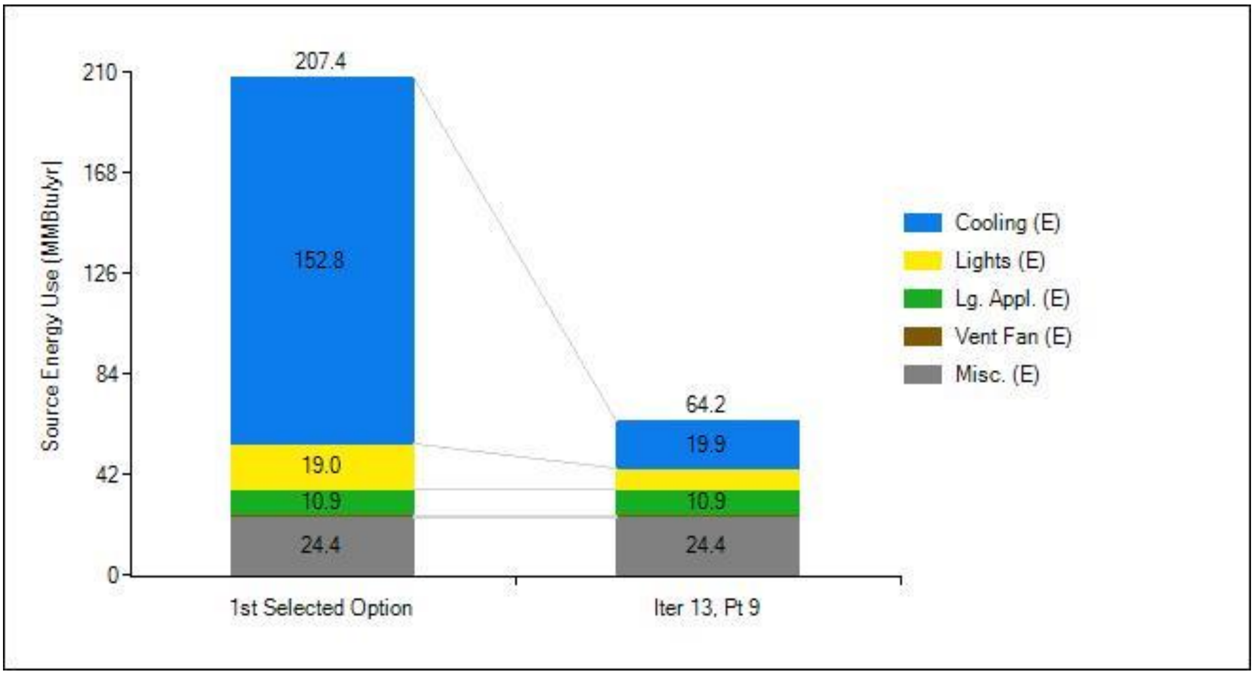


Figure 14: Comparison of energy usage between reference & minimum cost point

Minimum Cost/ PV Start Point Characteristics

The characteristics of the above stated minimum cost point that are different from the reference/ Base Case Building are:

Exterior Finish: Vinyl, light.

Interzonal Walls: R-13 Fiberglass Batt.

Roof: Asphalt shingles, White/ Cool colors with R-13 Fiberglass insulation.

Windows: Low-E, Double layer, Non-metal.

Room AC: EER 10.7, 30% conditioned.

Lighting: 100% LED.

The other characteristics are as same as the Base Case Building or kept constant throughout the simulation. Now if PV panels of 6 kW capacities are added on the roof with a tilt of 23 degrees, NZE house will be achieved along the least cost path. However, if these equipment or materials are not available, builder or designer can choose from the points that are the nearest to the least cost path. The costing maybe a bit higher than the least cost path but NZE house can be achieved and the costing will not be significantly higher than the least cost path.

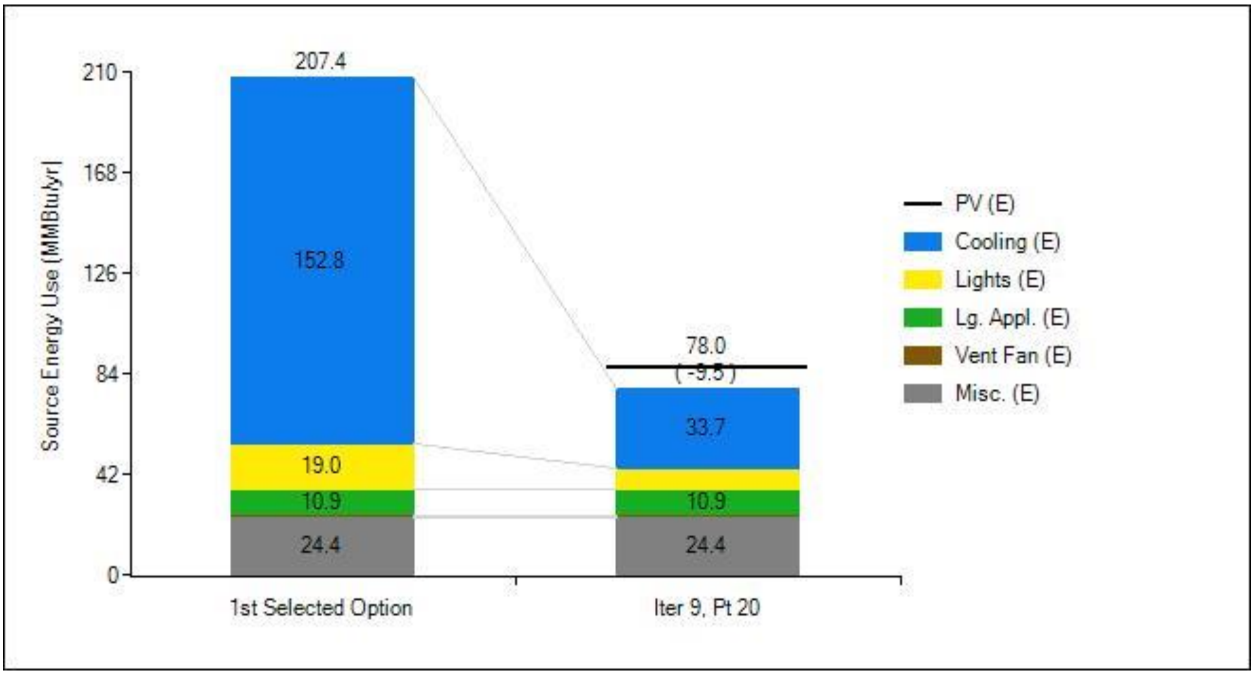


Figure 15: Comparison of energy usage between reference & around 100% efficient building

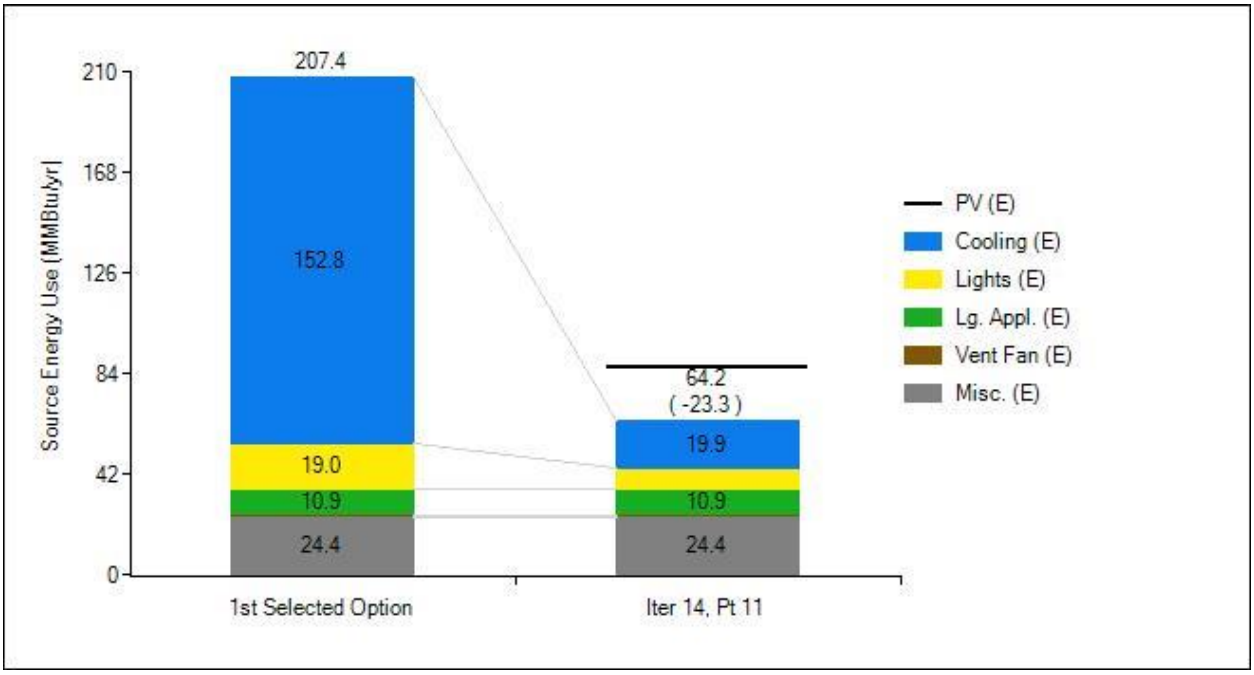


Figure 16: Comparison of energy usage between reference & maximum saving points

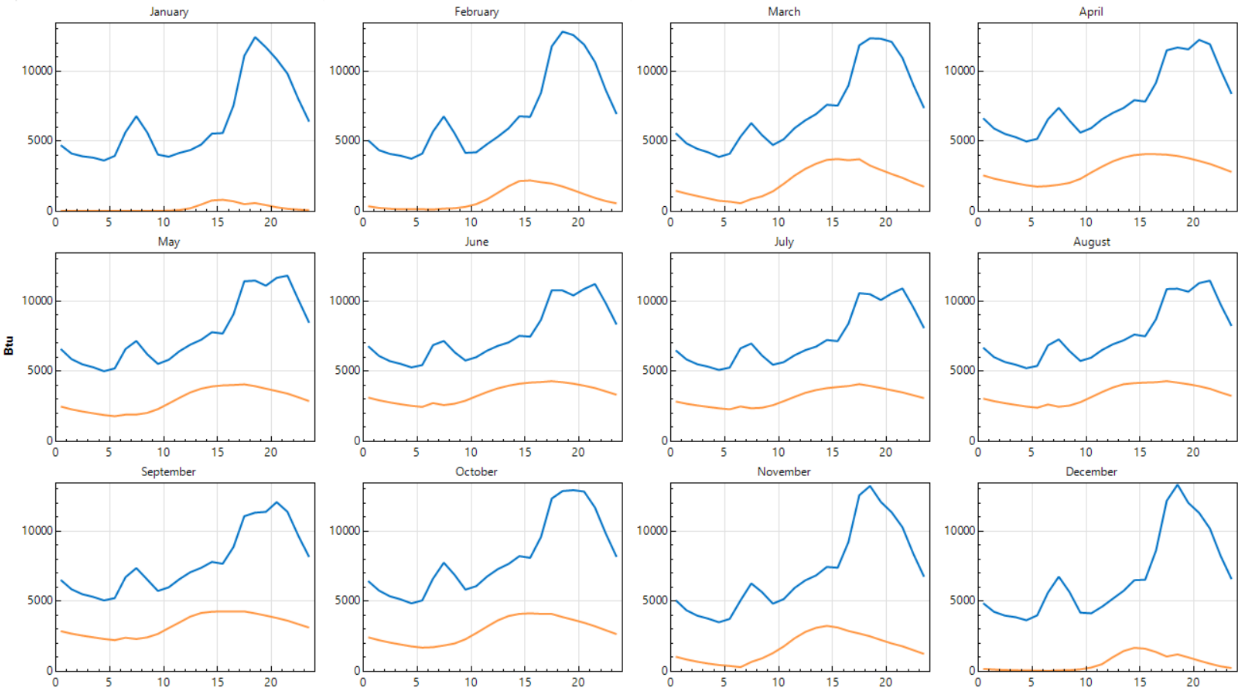


Figure 17: Annual profile of minimum cost/PV start point. Blue: Total energy required. Red: Energy required for only cooling

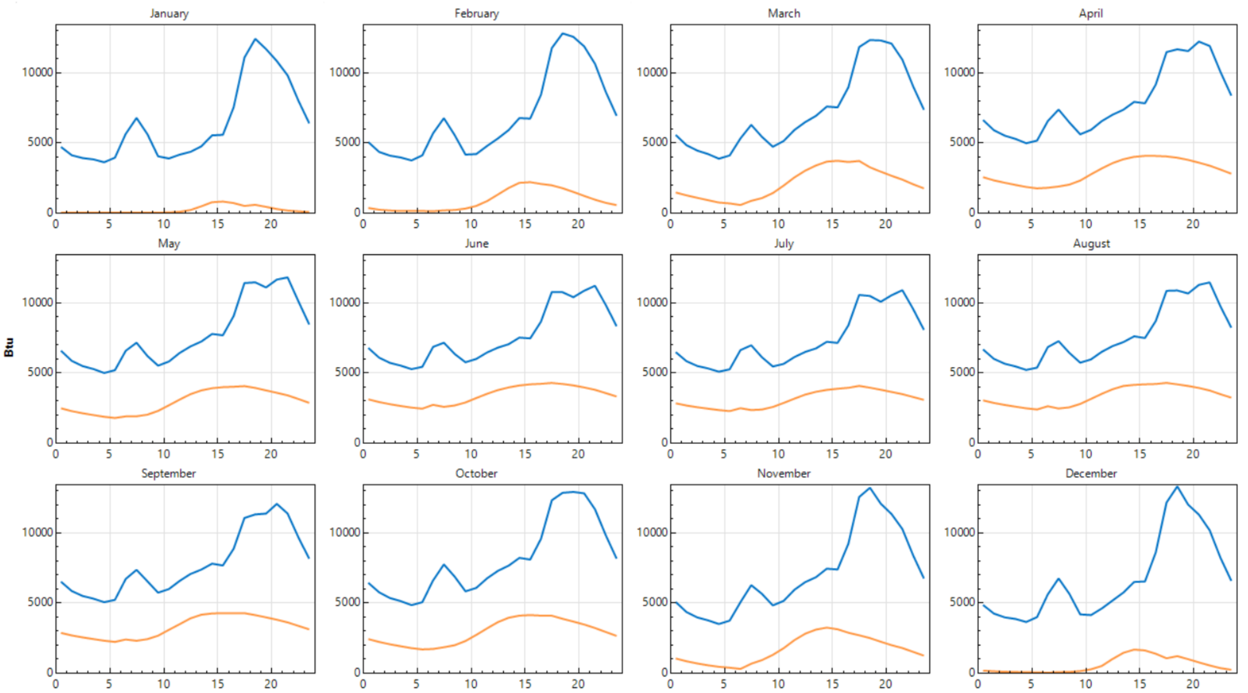


Figure 18: Annual profile of maximum saving point. Blue: Total energy required. Red: Energy required for only

Simulation Result Discussion:

It is quite visible from the Least Cost Curve that just by adding energy efficient means in our house; we can increase the energy efficiency and decrease costs significantly. The block charts show the comparisons quite clearly. Thus, we can conclude that even after compensating for the losses, NZEB in Bangladesh is very much feasible and there are further opportunities to work with this topic to make NZEBs in Bangladesh materialize.

Conclusion

The NZEB is a decisive solution to the global energy crisis for creating a better future. But it also suffers from limitations such as requiring extensive monitoring plans due to inflation rates, volatile electricity prices and the high costs of producing electricity with PV systems. This discourages most of the building owners from investing in NZEBs. According to the simulation results it is safe to conclude that the prospect of a Net Zero Energy Building in Bangladesh is feasible. Our research suggests that by further refining the renewable energy technology and ample support from the government, Net Zero Energy Buildings have a huge opportunity in Bangladesh.

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