Sustainable Approach for Conversion of Building to 'Zero Energy Building'

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Abstract. Energy efficient infrastructure is the need of the hour for sustainable development. Zero energy building (ZEB) is one of the concepts towards sustainability. One of the most effective ways to achieve sustainability is to convert existing buildings to zero energy buildings. In this study concept of zero energy building and various retrofitting techniques for conversion of existing building to zero energy is studied in detail. A case study of residential house in rural area has been done for retrofitting in which Building Envelope and Renewable Energy techniques are used for retrofitting. Cost analysis and recovery period of the retrofitting is carried out. The first 24 years are used to recoup the entire expense of the retrofit. Building is used for the remaining 16 years with the advantage of cost savings from retrofitting of Rs. 2, 87,445/-. From case study it is concluded that both the techniques are suitable and cost effective for conversion of residential house into zero energy building.

Keywords—*Zero Energy Building, Sustainable, Retrofitting, Energy Efficient, Building Envelope, Renewable Energy*

1. Introduction

Building operations in 2021 accounted for 30% of global final energy consumption and 27% of all energy sector emissions, according to data from the International Energy Agency (IEA). Of those emissions, 8% came directly from buildings and 19% indirectly from the production of the heat and electricity used in buildings [1]. Buildings currently account for between 30% to 40% of global energy production and 36% of CO2 emissions, according to the European Commission [2].

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India has always had a rural economy and since independence successive governments have tried to improve the rural infrastructure including energy infrastructure. To really bolster the rural economy, however, there is still more work to be done. In the current situation, there are many rural areas in India where the demand for power is not met or where load shedding is an issue. It's important to meet the needs of these rural communities. In order to meet this need, it is vital to find some better options. To address this issue there is urgent need of providing some practically feasible, economically viable and sustainable solution or solutions. Construction of Zero-Energy Building or conversion of existing buildings or houses in Zero Energy Building can be one of the practical and effective solutions.

Zero Energy Building (ZEB):

A ZEB is a structure that generates as much energy as it consumes over the course of a year. This is typically achieved through a combination of energy-efficient design and construction. The use of renewable energy can create a more sustainable and self-sufficient building environment.

The necessity of zero energy buildings stems from the growing global demand for sustainable and energy-efficient buildings. Zero energy buildings offer many benefits, including:

- Energy independence: Zero energy buildings generate their own energy, reducing their dependence on traditional energy sources and improving energy security.
- Cost savings: By reducing energy consumption and generating their own energy, zero energy buildings can result in lower energy bills and improved financial performance.
- Environmental sustainability: Zero energy buildings reduce greenhouse gas emissions and help to mitigate the impacts of climate change.
- Improved indoor environment: Zero energy buildings offer improved indoor air quality and thermal comfort, resulting in a healthier and more productive living and working environment.
- Technology innovation: Zero energy buildings drive innovation in energy-efficient and renewable energy technologies, creating new opportunities for research and development.

Given the numerous benefits of zero energy buildings, there is a growing need for buildings that are designed and constructed to minimize their energy consumption and maximize the use of renewable energy. This can help to create a more sustainable, secure, and economically viable built environment.

It is anticipated that building energy consumption will rise steadily as living standards rise and people's need for comfort grows. Energy consumption could surge by 50% in 2050 if no changes are made to the construction sector's energy efficiency [3]. By the end of 2020, all new buildings must be "virtually zero energy buildings," according to the revised EU Regulation on Energy Performance of Buildings (EPBD) [4]. Many countries have created specific energy conservation plans in a bid to reduce building energy consumption. A policy known as 20-20-20, for instance, was implemented by the European Union and aims for a 20% increase in energy efficiency and a 20% reduction in carbon dioxide emissions by 2020 [5]. From a life cycle environmental and economic standpoint, Moschetti et al. investigates a number of components in a pathway approach for the change from zero-energy to zero-emission building solutions [6]. According to Kristiansen et al.' findings on the possibility for factory-made, modular Zero Energy Buildings Off-grid buildings make it simpler to explain what ZEBs entail to the public [7]. It makes it apparent that achieving net zero energy must occur in actual operation and consider all energy requirements, particularly plug loads. Three factors—Social, Environmental, and Economic—have been employed by Lan et al. [8] to evaluate sustainability. With a primary focus on ZEBs, Belussia et al. consideration of high-efficient buildings exposes several related challenges. The volume and caliber of research studies demonstrate how solutions used to meet this criterion have evolved technologically [9].

In general, NZEBs employ two design strategies: reducing the amount of energy required in buildings by adopting EEMs (energy-efficient measures) and incorporating RETs (renewable energy (RE) and other technologies) to meet energy demands [10]. Building energy demand is primarily driven by the quickly expanding population, the trend towards urbanization, and the luxurious lifestyles of people who demand higher levels of comfort [11].

In order to reduce energy consumption and optimize the amount of renewable energy available on-site, Li et al. introduced heat insulation solar glass (HISG) modules. They also investigated the potential benefits of hybrid solar energy systems. The Design Approach towards Sustainable Development in Energy Efficient Building residential net-zero energy building has a prospect of commercialization. The concept and design of a residential net-zero energy building (a family of four) integrated with hybrid solar energy systems have been reported [12].

In the opinion of Liu et al., high-performance photovoltaic systems are necessary for low-rise structures to achieve zero energy [13].

The BSC's 10 guidelines for net-zero energy residential design are presented by Fanney et al. along with an explanation of the MEP and architectural designs for NZERTF that adhered to these guidelines. The importance of a high performer is highlighted by this design strategy [14].

There are many references available for zero energy buildings and the key parameters for achieving this goal. Few important references are presented here, along with the aspects of ZEBs they cover.

- International Energy Agency (IEA): The IEA has a wealth of information and resources on zero energy buildings, including definitions, case studies, and policy recommendations.
- U.S. Department of Energy (DOE): The DOE provides a comprehensive overview of zero energy buildings, including design and construction considerations, energy use patterns, and financial incentives.
- European Commission: The European Commission has published guidelines for achieving nearly zero energy buildings, including recommendations for building design, energy efficiency, and renewable energy use.
- Passive House Institute: The Passive House Institute provides information and certification for passive house buildings, which are a type of zero energy building that rely on energy-efficient design and construction rather than renewable energy sources.
- Green Building Council: The U.S. Green Building Council offers certification and information on sustainable building design and construction, including zero energy structures, through its LEED (Leadership in Energy and Environmental Design) program.

The key parameters of zero energy buildings include:

- Energy Efficiency: Zero-energy buildings are designed to use less energy by using energy-efficient lighting, HVAC (heating, ventilation, and air conditioning) systems, and insulation.
- Renewable Energy Sources: The building should generate its own energy using renewable energy sources such as solar, wind, or geothermal power.
- Energy Management System: A sophisticated energy management system is required to monitor energy use, regulate energy-efficient systems, and ensure that the building operates in an efficient and sustainable manner.
- Building Envelope: The building envelope, including windows, doors, walls, and roof, should be well-insulated to reduce energy loss and improve the building's thermal performance.
- Energy Storage: Batteries and other energy storage devices can be employed to store surplus energy produced by the building and utilize it in times of increased energy consumption.

- Green Space: Zero energy buildings often incorporate green spaces such as gardens and green roofs to provide additional insulation and cooling, as well as to improve air quality.
- Smart Technology: To maximize energy efficiency and minimize waste, the building should integrate smart technologies, such as building automation systems.
- Sustainable Materials: The building should use sustainable and environmentally friendly materials in construction and finishing.

2. Methodology

The key parameters of ZEB are studied in detail and the parameters which can be implemented in case of houses of rural area are identified. To establish the proper strategy for retrofitting the existing houses for the conversion to ZEB, a case study has been carried out. An existing house in rural area has been selected for the case study, all the details of which are presented in next section. Following study and analysis is carried out for the selected house:

A. Study of electricity utilization
B. Retrofitting for ZEB
C. Cost analysis and recovery period for retrofitting.

3. Case Study

A case study is a single-story home with a north-south orientation situated in a typical residential neighborhood in the Nashik area. The building has a total surface area of 165.585 square meters. The primary vertical circulation in the building is provided by one elevator and one staircase. The building has a 40-year lifespan.

A. Study of electricity utilization

The energy consumption of the house has been determined from the actual electricity bills of the house. Forecasting of

energy costs for the remaining life of the building is done using data from the previous five years.

Annual electricity charges for last five years are tabulated in Table no. 1

TABLE 1. ANNUAL ELECTRICITY CHARGES FOR LAST FIVE YEARS

Year	Electricity Charges (Rs.)
2018	7956
2019	8116
2020	8403
2021	8873
2022	8955

The forecasted energy charges for life of building is shown in Figure 1

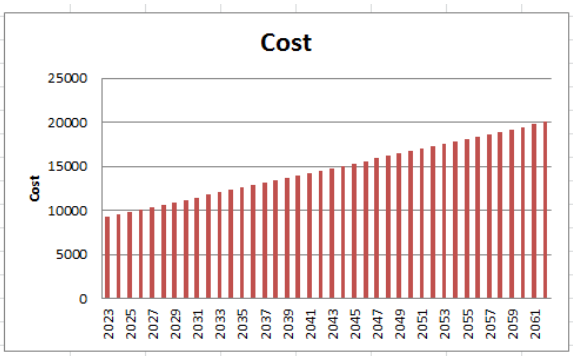

Fig. 1. THE forecasted energy charges for life of building

The total cost of electricity from 2023 to the end of life of building is Rs. 586374/-

B. Retrofitting for ZEB

Considering the existing conditions of the house and the cost effectiveness of retrofitting techniques, following key parameters are selected for the considered house

- Building Envelope: Windows, walls and roof are the members selected for applying retrofitting techniques for reduction in energy consumption.

- Renewable Energy Sources: Solar Energy

As the house is in the region, where solar energy is available and can be utilized for generating building's own energy hence solar energy has been selected among the renewable energies. The details of data collected, and calculations carried out in context with solar panel design, such as monthly average values of daily global solar radiation, orientation of panels, types of panels, inclination of panels etc. has been presented in subsequent section.

Hence the strategy adopted involves two approaches; one retrofitting techniques to reduce the existing energy consumption and second generation of energy to make the house self-sustained for energy needs. First approach will reduce the consumption, without adding much cost and it will reduce the load on solar system, further achieving the economy.

i. Retrofitting for reduction of energy consumption: 'Building envelope'

An effective border separating the conditioned interior of a structure from the surrounding environment is referred to as an energy-efficient building envelope. The cost of fuels and electricity used to regulate interior temperatures will go down with an efficient building envelope, which will also increase tenant comfort and safety. The following building envelope retrofitting approaches are applied in the case study

Window Coating:

The existing window part would be replaced with a double-glazed section that is 5 mm thick with a 12 mm air gap in between because it is single glazed and has inadequate insulation.

Glazing area for whole building=12.34 m2 (for 7 windows)

Price per m2 = 4962 Rs.

The amount of energy saved for every 100 square meters of glass retrofitted with energy-saving films, a building's energy needs is reduced by up to 10,600 kWh per year which is comparable to reducing its CO_2 emissions by about 9,500kg. Windows are coated with Blue, Black Unique Reflective Sun Control Films.

Total windows area = 12.34 m^2

Total frame area = 4.4 m^2

Net glazing area = 12.34 – 4.4 = 7.94 m^2

Price = 377 Rs. /m^2

Wall insulation:

To improve insulation levels and contribute to achieving thermal comfort within the building, thermal insulation boards made of compressed polystyrene are utilized. The boards are to be finished using standard finishing materials and fitted into the structure. The material is supplied in sheets of 1250 x 600 mm or 2500 x 600 mm. The thickness of the sheets varies from 25 to 50 mm, with 30 cm being the selected thickness.

Benefits of Wall insulation

- Keeping the house cool in the summer and warm in the winter will improve its thermal comfort.
- Lower heat loss through the external walls to save energy costs
- Cut down on the noise that comes inside the house from the outside
- Increase the fire resistance of the building.
- Preserve properties outside walls in order to extend its lifespan.

Total building circumference=165.585 m^2
Total windows area=12.34 m^2

Net cladding area=165.585–12.34=153.245m^2

Price = 300 Rs/m^2 (Quality Thermo-pack and Insulations)

a. Roof Insulation:

The most effective and popular way to stop heat from entering a building from the outside is to insulate the roof. Roofing sheets that are insulated can block up to 90% of the sun's rays. In addition to maintaining a steady temperature, roof insulation blocks out undesirable noise. Additionally, moisture condensation from insulated roofing sheets keeps your structure free from rot, mold, and dripping. Polyurethane foam (PUF) sheets are a common material used to provide insulation for roofs. As a result, a lot of architecture uses unique roof insulation materials, including PUF, to improve the thermal stability of the structures and pay particular attention to design.

Features of insulation on roofs:

1. It offers superior thermal efficiency
2. Provides strong mechanical support
3. It has solar radiation resistance
4. Serve as a wind, moisture, and air barrier
5. Use both interior and external insulation to stop the passage of vapor.
6. Different materials for roof insulation depending on the needs of the region.

Insulated roof panels' advantages

1. Heat Retention and Prevention: Warm and comforting spaces can be found in homes, offices, and other buildings with heat-insulating roofing. Consequently, assisting in reducing energy usage

2. Energy Savings: You can keep your space at the ideal temperature by using insulated roofing panels. As a result, you don't need to run your heater or air conditioner as frequently, which saves you money and reduces electricity consumption.

3. Serve as a Protection Layer: It shields the roof from the direct effects of the severe weather.

The floor of the building is covered in 3 cm-thick foam tiles. Due to its great heat resistance, this material has the potential to save a significant amount of energy. Furthermore, there is very little water absorption through submersion, which makes it

appropriate for rooftop use. It is readily installable with cement mortar and comes in basic grey or patterned options.

Net roof area = 65.86 m^2, Price = 200 Rs/m^2

ii. Renewable Energy Sources: Solar Energy

The location of the house maximizes sun exposure. The home is situated on a sizable slope that faces west and rises 4.65 meters above the road. The area just east and west of the terrace would be ideal for solar energy collection. The location and the building are easily visible from both the east and the west due to the absence of trees obstructing the view from either direction.

Data for design of solar panel is as follow:

- Location: Nasik, Maharashtra, India
- Global Horizontal irradiance GHI: annual average = 5.68 $kWh/m^2/day$
- Building average consumption: 128 kW
- Maximum power needed: 153 kWh during August

Panels basic data:

- The panels' orientation: Panels to be installed will facing east direction based on the solar data analysis provided previously.
- The panels' inclination angle: will be 12 degrees.
- Type of panels will be poly crystalline type because it generates the largest amount of energy in the Indian circumstances.

TABLE 2.CALCULATION FOR SOLAR PANEL

Global Horizontal irradiance	5.68 kWh/m2/day
Building average consumption	128 kW
Maximum power needed	153 kWh during August
The panels' orientation	installed facing east direction
The panels' inclination angle	12 degrees.
Type of panels	poly crystalline type
Panel voltage	36 volts
Current	8 A
Power Generation/ panel	288 watts/ hour
Generation time	6 am to 6 pm
Peak generation time	9 am to 4 pm
Total energy generated in peak generation time by one panel	6x288 =1728 watt= 1.728kw
Daily average energy demand of building	4unit
Maximum energy demand of building	5 unit
No. of solar panels required to satisfy maximum energy demand	3solar panel

C. Cost analysis and recovery period for retrofitting

As a first step toward achieving ZEB, the suggested retrofit measures can lower the amount of power used while improving the building's energy performance. The overall cost for the building to be converted to ZEB can be calculated as follows:

TABLE 3. COST OF RETROFITTING BY BUILDING ENVELOPE

Component of building	Area (m2)	Unit price (Rs./m^2)	Installation price (Rs./m^2)	Overall price (Rs.)
Wall insulation	153.245	300	90	59766
Roof insulation	65.86	200	100	19758
Window replaced with double glazed	12.34	4962	0	61231
Window coating	7.94	377	0	2993
Total price			Rs. 1,43,748	

TABLE 4. COST OF RENEWABLE ENERGY (SOLAR PANEL)

Item	Quantity	Unit price	Description	Overall price
PV on-grid system (after retrofit)	3 Panels	35000 Cost of panel per kW	Polycrystalline PV panels	Rs.1,75,000/-

The Total cost for the house to be converted to ZEB can be calculated as follows:

- Total Cost = Envelope Retrofit + Solar Panel
  Total Cost = 1, 43,748 + 1, 75,000
- Total Cost =Rs. 3,18,748 /-

Considering 5 % maintenance cost, the total cost is Rs. 3, 34,685/-

From the total retrofitting cost and forecasted electric charges in Fig. I it is found that in the first 24 years that is in 2046 the total cost of retrofitting is recovered. For remaining 16 years, building is utilized with the benefit of retrofitting and saving in the cost is of about Rs. 2, 87,445/-.

4. Conclusion

In the present study detailed study of Zero energy building has been carried out. Various techniques for conversion of existing building to zero energy have been studied. A case study in the rural area of Maharashtra has been carried out to convert residential house to ZEB. Building Envelope and Renewable Energy (Solar energy) techniques are used to convert the given house to net zero energy building. The cost analysis and analysis of recovery period for the conversion techniques is carried out. Following points are concluded from the case study

- Total cost of retrofitting is Rs.3,34,685/-
- Forecasted cost of electricity is Rs. 5, 86,374/- for life of building
- The total cost of retrofitting is recovered in first 24 years.
- For remaining 16 years, building is utilized with the benefit of retrofitting saving in cost is of amount Rs. 2, 87,445/-.

From the case study it is concluded that both the methods can be suitable and cost effective to convert existing structure to zero energy building.

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