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Comparison of Cost and Energy Efficiencies of Zero Energy Residential Building and Conventional Building

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Abstract: *Energy is a very important factor in our day to day life. In India, the energy requirement is increasing at a rapid rate. Studies reveal that the energy requirement of our country in 2030 will grow by 95% compared to the present. The building sector is the main primary energy consumer. This will increase until the energy consumed by a building is from a renewable source. As a result now a day the topic of Zero Energy Buildings (ZEB) has received increasing attention. In this technique, renewable resources are the main sources of energy and sustainable building techniques are used to reduce the initial investment of construction. This study is the comparison between a conventional building and ZEB using Life Cycle Cost Analysis. From the overall data, it found the cost of the material, maintenance, and energy consumed for a life span of 20 years is less using ZEB technique. The only factor is that the process used to implement this technique may vary depends upon topography and location.*
Keywords: *Building Orientation, Day Light, Energy efficiency measure, Life Cycle Cost Analysis, Zero Energy Building*

I. INTRODUCTION

Building construction is a combination of a designer's skill and owner's imagination. All building projects include some elements in common such as design, finance, estimation and legal consideration. In developing countries like India energy is one of the main constrain, more than 40% of energy is consumed by buildings [1]. Buildings, in general, are categories into residential, commercial and industrial buildings. In this residential buildings place a major role in consuming energy due to the ever growing population. So to save energy we should implement an efficient method. There are few building methods which can reduce energy consumption such as green buildings, passive buildings, ZEBs etc. Out of this ZEBs are more efficient. According to National Renewable Energy Laboratory in Golden Colorado, the term ZEB refers to a house that produces as much energy as it consumes within a given period of time, usually a year. A ZEB is working as an integration of energy production and energy reduction techniques [1]. Energy efficient houses and ZEB can claim as sustainable, but the zero energy goals mean a house is either zero energy or not [1].

In this research residential building is taken for the study. Residential building is a simple model to create awareness among the public about new technologies and its benefits. Effective use of building envelopes, appliances, technologies, energy production techniques and building design will result in an efficient ZEB.

Engineers are responsible for the direction and management of their construction projects. To introduce various methods the engineer must have an understanding of economic properties, the design of fundamentals, material properties, and management techniques. This research will provide guidelines to assist engineers for designing energy efficient residential buildings.

This study showcase that to build an efficient building based on ZEB concept we don't need to compromise safety, quality performance, health, and comfort. The important objectives of this study are;

- To find out measures to reduce unwanted energy used in building sector
- To study about various energy efficient & cost effective techniques
- To find out risk in the field of energy efficient structures and
- To find out whether the investments in ZEB are economic or not

II. METHODOLOGY

This study chooses a residential building for example to analyze the energy and economic performance. The following diagram shows the scheme of work adopted for the project.

Fig 1: Scheme of work adopted for the project.

a. Data Collection

The following details collected from existing conventional buildings:

- Plan and estimation of construction
- Electronic appliances used
- Hours of operation and total energy consumption

The plan and estimation help to find the space utilization, the orientation of buildings, provision of openings and materials used for construction.

Electronic appliances are shortlisted by finding their usage pattern. Usage pattern will give a clear picture about the existing usage and its relevance.

For calculating hours of operation and total energy consumption, all the equipment are enlisted and their corresponding operational hours are estimated. The power rating of equipment added gives the total energy consumption during the operational hours.

b. Design & Estimation

Conventional building's design and estimation process are monitored and a new enhanced level of designing is followed in ZEB. The designing process includes additional features such as energy efficient and cost effective techniques, energy star appliances etc.

c. Analysis & Comparison

Analyzing the buildings include estimation of existing energy efficiency features, the cost of construction and maintenance. The comparison of the efficiency and related cost of these buildings mainly by life cycle cost analysis gives the overall benefit and performance of ZEB. From the comparison, it will reveal the feasibility of ZEB technique in the building sector.

III. ESTIMATION AND LIFE CYCLE COST ANALYSIS

a. Data Collection - Buildings Details and Energy Usage

The study is carried out to an existing single storey residential building. It is constructed as per the conventional method (i.e. construction using brick and concrete). The location of the building is in the Parassala Village (in Kerala, India). It's not using any energy efficient methods to improve its performance. The performance of this conventional building can be improved by using ZEB technique. Hence in the given site a ZEB designed and its performance studied theoretically. The details of buildings are given in the following table.

Table I. Conventional building and Zero Energy building details

	Conventional Building	***Zero Energy Building***
Location	Parassala	Parassala
Length of site	23.3m	23.3m
Width of site	17.25m	17.25m
Site area	401.92m^2	401.92m^2
Plinth area	147.88 m^2	146.65 m^2
Carpet area	92.194 m^2	116.32 m^2
Length of building	15.62 m	15.05 m
Width of building	9.84 m	13.58 m

The energy needed in a building per day greatly depends on the behavior of its occupants and its performance. Studies have shown a dramatic difference in energy use, some homes using more than the twice of others [2]. The important problem found in the conventional building is small doors and windows openings cause poor natural ventilation and daylight inside the home. Hence lights and fans are required even in morning to improve the indoor quality. The number of occupants in the given building is 4 and the calculation of electric current needed per day is done with the help of the average electricity per hour per day for each appliance is taken from the building. For ZEB these values are assumed based on obtained data and the techniques used. From these details average daily electricity needed is calculated as

; (Wattage × Hours Used Per Day) ÷ 1000 = Daily Kilowatt-hour (kWh) consumption (1)

From the survey, the average electricity needed per month is 360kWh for conventional building and 219kWh for ZEB. With the help of energy efficient measures, ZEB reduces around 30% of its energy needs. From these details percentage, energy consumption of each appliance represented using pie diagram as shown in Fig. 2.

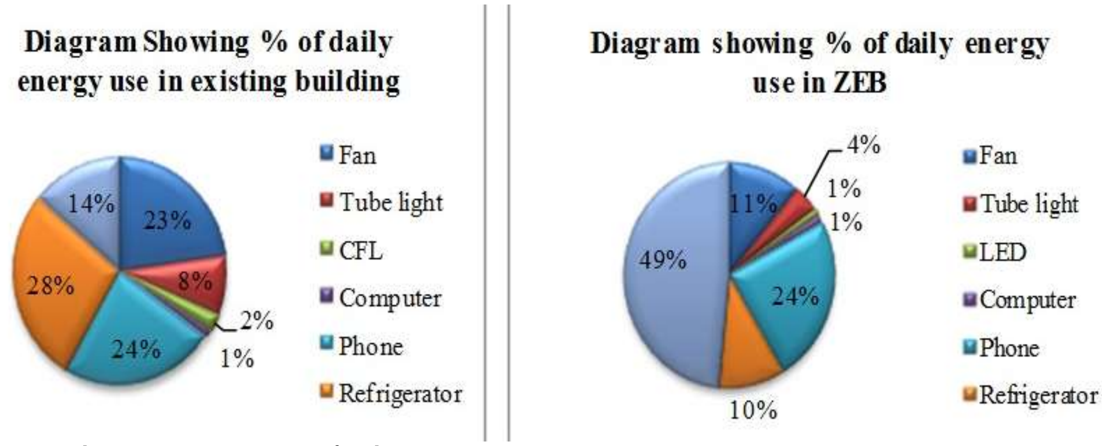


Fig 2. Average electric energy consumption of appliances

The other forms of energy required for the conventional building are natural gas in every year is 9 cylinders (each 12.5kg) and annual average amount of daily water required by one person is Per capita average consumption of water in liters/ person/ day, which is 135 l/h/d (Handbook on Water Supply at Chennai). But ZEB reduces 9 LPG cylinders to one cylinder with the help of biomass gas plant. Rainwater harvesting systems also provided to collect water, which can't completely offset the water requirements.

b. *Design and Estimation*

i. Design Features

Even though new technologies are developed residential energy use is increasing day by day. To overcome this situation various energy efficient building technologies are developed such as green buildings, passive buildings, and ZEBs etc. Significant Problems that signify the importance of ZEB are;

- High energy use of residential buildings and growing population
- Increasing standard of living and rising number of apartments
- Interrupted power supply due to power deficit and Increasing cost of energy

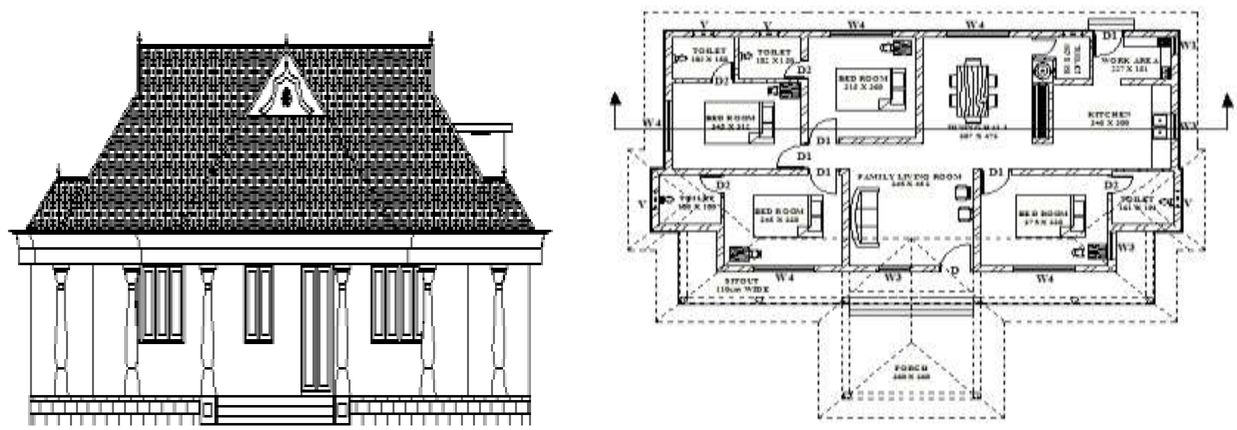


Fig. 3. Elevation and Plan of conventional building using AutoCAD

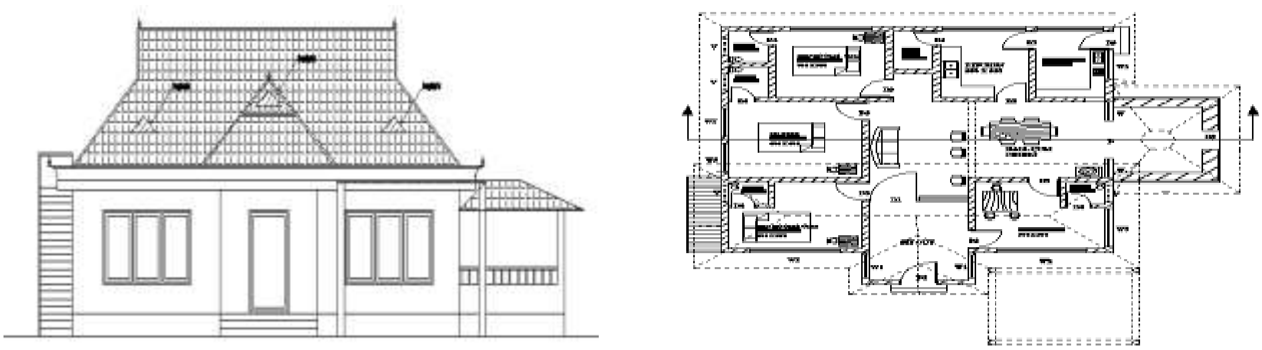


Fig. 4. Elevation and Plan of ZEB using AutoCAD

Here the design of ZEB typically combines energy efficiency strategies with renewable energy technologies. The application of improved technology can moderate these needs. Energy efficient building shells, appliances, building designs and energy production techniques can lower energy consumption in the residential sector. This will help to reduce the steady increase in the price of energy up to a great extend. The result in zero annual utility bills. Special features adopted for the designs are;

- Planning site orientation preferably with the longer axis of the building to be in East – West direction.
- Enhancement of use of natural and cross ventilation of air with in the building by maximum window wall ratio (0.5) than normal building (0.32)
- Placements of large windows on the north side to enhance daylight and energy efficient glasses are used to reduce heating effect of the sun.
- Hollow terracotta bricks (size: 9 x 4 x 3 inch) are used instead of normal bricks to improve the insulation property and to avoid wall plastering.
- Filler slab method is used with the help of hollow terracotta bricks for roofs to minimize the use of concrete.
- Ceramic tiles are used for flooring which will reduce cost and provide a cooling effect.
- Application of energy efficient features such as energy efficient appliance, rainwater harvesting system, and biomass gas plants etc.

3.2.1. Planning and Scheduling using Primavera

Project planning and scheduling is one of the most important pre-construction tasks determining the success or failure of the project and shows the estimated duration of the project. Primavera is the most commonly used software for scheduling. Plant, equipment, and machinery can be used effectively. Here both buildings are scheduled in Primavera for estimating the duration of construction and to estimate the cost and resources.

Scheduling of conventional building is as shown in Fig. 5. The critical path and the estimated time to complete each work are also given. The red bars indicate the critical path. Based on this the work will start on 1 July 2016 and finish on 25 March 2017 i.e. it will take 154 days to complete the conventional building construction.

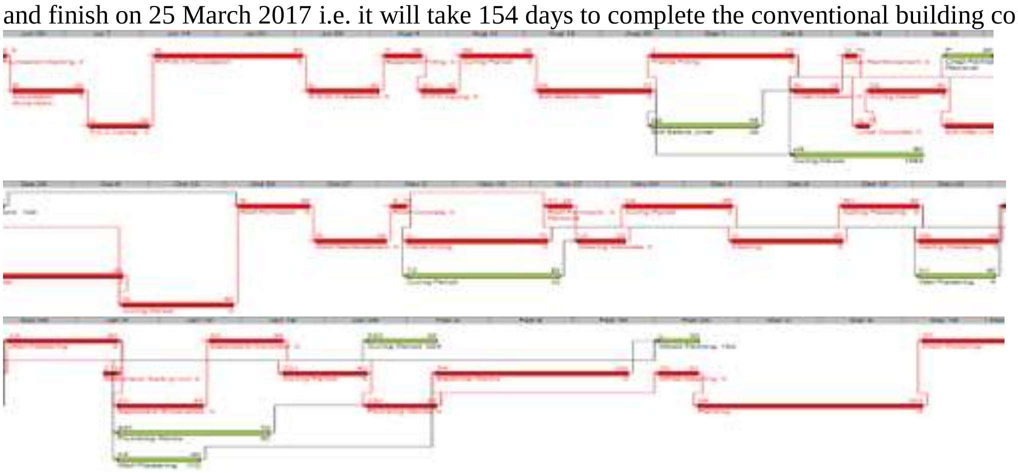
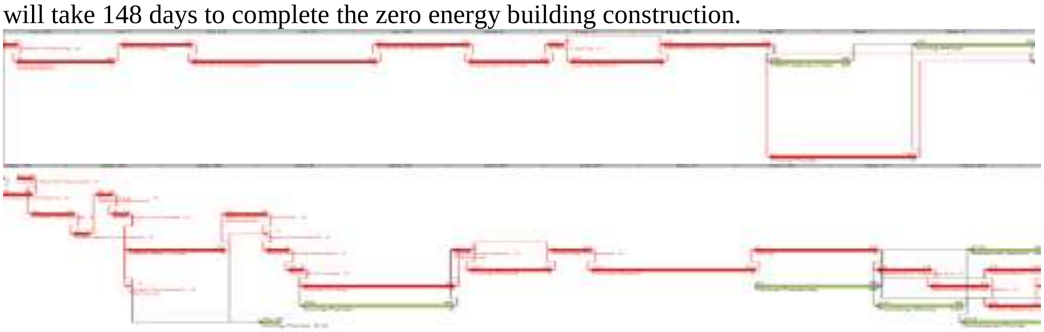


Fig.5. Conventional Building Schedule

Scheduling of zero energy building is as shown in Fig. 6. The critical path and the estimated time to complete each work are also given. Based on this the work will start on 1 July 2016 and finish on 23 January 2017 i.e. it will take 148 days to complete the zero energy building construction.



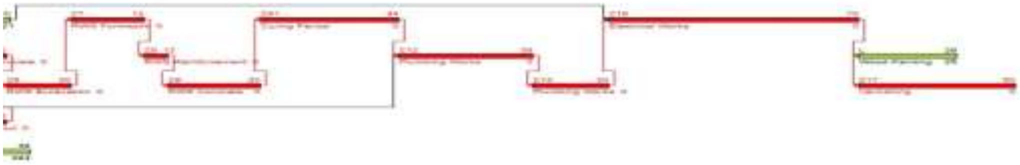


Fig.6. ZEB Schedule

3.2.2. Resource And Cost Estimation

An estimate of manpower and materials is generally required for pre-planning and budgeting of materials and its procurement. The calculation of different materials is done with the help of following data. The numbers of working days are 5 days. For human resources working hours is 8hrs i.e. from morning 8 am to evening 5 pm. There has a 2-hour break in between them. The salaries of workers are given as per the present conditions. Abstract of quantity and cost estimation for conventional building and ZEB is added below. Estimation is done by manually and by using Primavera and got almost same construction cost. Manual cost is used for calculation purpose. The cost obtained from Primavera for conventional building and ZEB are as shown in Fig. 7 and Fig. 8 respectively.

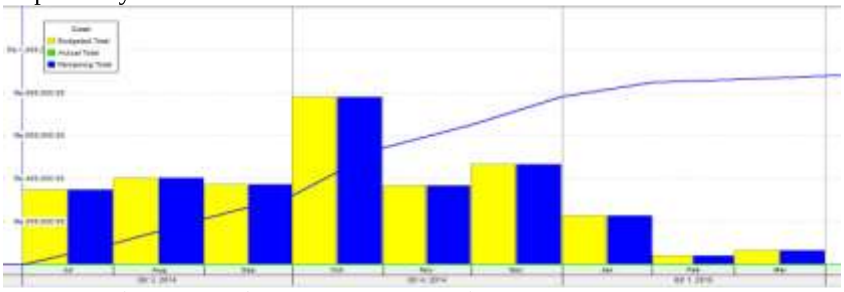


Fig. 7. Cost of construction for conventional building from Primavera

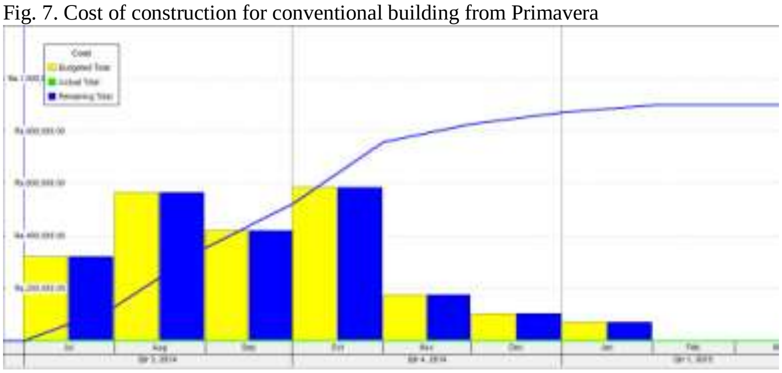


Fig. 8. Cost of construction for ZEB from Primavera

From Primavera the total cost of construction for conventional building and ZEB are Rs. 2400000/- and 2700000/- respectively. From manual calculation, it is around 2150000/- and 2805877/- respectively.

3.3. Analysis and Comparison

3.3.1. Life Cycle Cost Analysis

Life cycle cost analysis [LCCA] is a method for assessing the total cost of facility ownership. It includes all costs of acquiring, owning and disposing of a building or building system. LCCA is especially useful when project alternatives that fulfill the same performance requirements, but differ with respect to initial cost and operating cost, have to be compared in order to select the one that maximizes net savings.

The purpose of an LCCA is to estimate the overall cost of the project alternatives and to select the design that ensures the facility will provide the lowest overall cost of ownership consistent with its quality and function. The LCCA should be performed early in the design process while there is still a chance to refine the design to ensure a reduction in life cycle costs [LCC]. The costs associated with LCCA are the initial cost of construction, energy and water cost, operation cost, maintenance cost, repair cost, replacement costs and residual costs. After identifying all costs by year and discounting them to present value, they are added to arrive at total life cycle costs for each alternative. The equation used for calculating LCC is

; $LCC = I + Repl - Res + E + W + OM\&R + O$ (2)

Where

LCC – Total LCC in Present Value (PV) rupees of a given alternative

I – Present Value investment cost (if incurred at base date, they need not be discounted)

Repl – Present Value Capital Replacement costs
Res – Present Value residual value (resale value, salvage value) less disposal costs
E – Present Value of Energy Costs
W – Present Value of Water Costs
OM&R – Present Value of Maintenance, Nonfuel operating and Repair Costs
O – Present Value of Other Costs

Life Cycle Cost Analysis of Conventional Building

For Life Cycling Cost Analysis of Conventional Building, a study period of 20 years is taken into consideration. In this construction costs, energy costs and costs for home appliances are calculated separately for their future value. For LCCA they are converted to present value with the help of discount factor. In India, present discount factor by Reserve Bank of India (RBI) is 8%. For calculating Present Value following Equation is using,

; Present Value (PV) = FV / $(1+r)^n$ (3)

Where
FV – Future Value n years hence
r – Discount rate
n – Number of periods over which the cash flow occurs

Initial Cost

Construction cost for building	= Rs. 2150000/-
Cost for Home Appliances	= Rs. 203320/-
Cost for Natural Gas arrangements	= Rs. 3000/-
Total Initial Cost for Conventional Building	= Rs. 2356320/-

Operation, Maintenance and Replacement Costs

Present Value of Water Charge for 20 years	= Rs. 395/-
Present Value of Electric Charge for 20 years	= Rs. 486440/-
Present Value of Fuel Cost for 20 years	= Rs. 117150/-
Present Value of Home Appliances for 20 years	= Rs. 281710/-
Present Value maintenance of building	= Rs. 218840/-
Present Value of Total Operating Maintenance and Replacement Cost for Conventional Building	= Rs. 1104535/-
LCC for Conventional Building	= Rs. 3460855/-

Life Cycle Cost Analysis of Zero Energy Building

For Life Cycling Cost Analysis of Zero Energy Building, a study period of 20 years is taken into consideration. In this construction costs, energy costs and costs for home appliances are calculated separately for their future value. For LCCA they are converted to present value with the help of discount factor. In India, present discount factor by Reserve Bank of India (RBI) is 8%.

Initial Cost

Construction cost for building	= Rs. 2805877/-
Cost for Home Appliances	= Rs. 161912/-
Cost for Biogas Gas arrangements	= Rs. 3000/-
Total Initial Cost for Conventional Building	= Rs. 2970789/-

Operation, Maintenance and Replacement Costs

Present Value of Water Charge for 20 years	= Rs. 395/-
Present Value of Fuel Cost for 20 years	= Rs. 6850/-
Present Value of Home Appliances for 20 years	= Rs. 260520/-
Present Value maintenance of building	= Rs. 131300/-
Present Value of Total Operating Maintenance and Replacement Cost for Zero Energy Building	= Rs. 399065/-
LCC for Zero Energy Building	= Rs. 3369854/-

The difference between LCC of Conventional Building and ZEB is around Rs. 100000/-. From this study, it is clear that LCC for ZEB is less than that of Conventional Building. Hence ZEB is much efficient and economic than the conventional building. The main reason for these much cost reduction is in ZEB the electric current cost is completely eliminated with the help of solar panel system.

3.3.2. Future Value Estimation of Conventional Building and ZEB

The future value of Conventional Building and ZEB are calculated with the help of rate of return (r). This is to find out the payback period of initial investment of both the buildings. For the calculation of this here it takes 20 years of the study period. Costs taken into consideration are an initial cost, the cost of energy for the 20 year period, the cost of home appliances for the 20 year period. Equation used for future value calculation is,

; Future Value (FV) = PV x $(1+r)^n$ (4)

Where
PV – Present Value
r – Rate of return or interest rate
n – Number of periods over which the cash flows occur

Conventional Building

Initial Cost

Construction cost for building	= Rs. 2356320/-
Cost for Home Appliances	= Rs. 203320/-
Cost for Natural Gas arrangements	= Rs. 3000/-
Total Initial Cost for Conventional Building	= Rs. 2562640/-

Future Value of Energy Cost, Cost for operation, maintenance and replacement cost for home appliance and Maintenance cost for building for 20 years

Water Charge	= Rs. 1830/-
Current Charge	= Rs. 2267270/-
Fuel Cost	= Rs. 546020/-
Total Future Value of Energy Cost for 20 years	= Rs. 2815120/-

The future cost for home appliances including their operation, maintenance and replacement cost = Rs. 131022/-
The future cost of building maintenance for 20 years = Rs. 1020000/-
Total Future Value of Conventional Building = Rs. 6528782/-

Zero Energy Building

Initial Cost

Construction cost for building	= Rs. 2970789/-
Cost for Home Appliances	= Rs. 161912/-
Cost for Biogas Gas arrangements	= Rs. 3000/-
Total Initial Cost for Zero Energy Building	= Rs. 3135701/-

Future Value of Energy Cost, Cost for operation, maintenance and replacement cost for home appliance and Maintenance cost for building for 20 years

Water Charge	= Rs. 1830/-
Fuel Cost	= Rs. 31900/-
Total Future Value of Energy Cost for 20 years	= Rs. 33730/-

The future cost for home appliances including their operation, maintenance, and replacement = Rs. 1214282/-
The future cost of building maintenance for 20 years = Rs. 612000/-
Total Future Value of Zero Energy Building = Rs. 4995713/-

From this future value calculation, it is clear that the total cost required for a ZEB for 20 years including its construction cost, operation cost, maintenance cost and replacement cost is much less than a Conventional Building. Hence ZEB is much efficient than a conventional building.

3.3.3. Payback Period

The monthly income of the family is Rs. 60000/-. Hence the yearly income is Rs. 720000/-. From the future forecasting of salary with present salary as base data, it gets the family will get Rs. 33000000/- after 20 years. The diagram shows a comparison of the 20-year cost of a building.

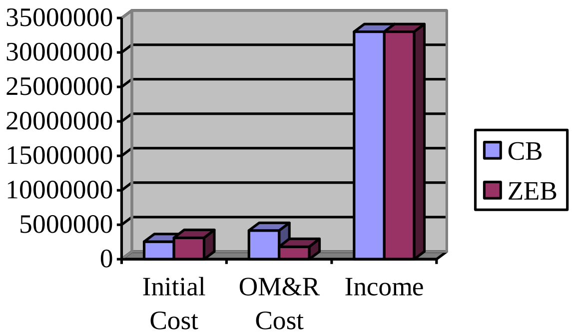


Fig. 9. Future Value comparison of Initial cost, Operation Maintenance & Replacement cost (OM&R) and Income of Conventional Building (CB) and Zero Energy Building (ZEB)

The payback period of initial investment for ZEB and the conventional building will obtain with in 4 years and 3 year period respectively. The total cost or benefit obtained for the owner after 20 years in ZEB is higher than conventional building. Hence ZEB is much efficient than Conventional Building.

IV. CONCLUSION

This study reveals, the performance of ZEB increased with the help of natural renewable resources, high-efficiency home appliances and improved insulation of building envelope. The suggested ZEB can reduce around 30% of electric energy needs compared to the conventional building.

From the LCCA of both the buildings, it is clear that the total cost needed for a ZEB for 20 years is much less than that of a conventional building. The payback period for ZEB is 4 years and for the conventional building is 3 years. But in the case of overall maintenance cost and environmental impact, ZEB is showing high performance compared to the conventional building. Hence this study proves that ZEB technology can effectively adapt to all building sector to maintain the sustainability of the environment. The main drawback of this technology is its high initial investment. To reduce the initial investment large scale constructions should start in the field of ZEB, it can reduce the cost of energy efficient technologies. For that from government level awareness should be given to constructors about the benefits of ZEB, which will help to attract more people to turn to sustainable technologies and can preserve our environment.

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