Net Zero Energy Apartment

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Abstract. In India, construction is the second largest industry next to agriculture, with respect to its contribution to the economy of our country. Construction sector consumes a lot of energy throughout the life cycle of the buildings and contributes immensely to the emission of greenhouse gases like carbon dioxide. Considerable amount of water is being consumed during the construction activities. It is found that India’s water table is decreasing, Hence, there is a need to bring down en-ergy consumption and conservation and harvesting of water by implementing green and zero energy concepts. Net zero energy building is defined as a building with zero dependence on external source of energy. The main aim of this study is “Planning, analyzing and designing a 5 floor apartment building by implementing zero energy concepts and techniques”. Planning has been carried out by taking into account, the orientation aspects. Planning and plotting of the structure has been car-ried out using AutoCAD. Further analysis is done in STAAD Pro V8i and Cype taking the design loads for both zero energy and conventional building. Energy saving components such as rainwater harvesting system, solar panels, biogas plant, and wind energy and sewage treat-ment plant have been implemented as per standards. The dependence on external energy source is reduced by making use of the alternative energy sources such as solar PV panels, biogas and wind turbine where by making it economical environmental friendly. Estimation of the materials based on the drawings and specifications is carried out. Lastly, a comparative study of conventional versus zero energy building is done by performing cost benefit analysis of solar panel system. By using rainwater harvesting system the water bills reduced by 27% annually and by installing a solar panel with a capacity of 233 Kw/h led to the energy savings by 20 % annually. Also from the cost estimation, the payback period for green building was approximately 2.9 years for solar power.

Keywords: Net zero energy, biomass, solar energy, rain water harvesting

1. Introduction
The world today is encountered with global warming and climate change. Besides other contributors, extraction of natural resources as building materials itself consume energy, cause environmental degradation and contribute to global warming. Buildings are the largest energy consumers and greenhouse gas emitters, both in the developed and developing countries. Urgent changes are therefore required relating to energy saving, emissions control, production and application of material. There is an urgent need to use renewable resources, and to recycle and reuse building materials. It is a well-established fact that increasing carbon dioxide emissions has led to rise in global warming. There is a depletion of nonrenewable energy sources. Saravan, et. al. (2018) focussed on energy usage and power generation. By using zero energy concepts they concluded that zero energy concepts reduce the global warming and help to restore the nature. Maheshwari, et al. (2017) studied the concepts of solar panel
system and concluded that solar panels are the solution for generation of electricity. Reshmi (2015), found out the methods to use in construction to find the most cost effective way to reduce the building energy consumption. She also stated that zero energy building requires more government incentives or building code regulations. Sunil (2015), reviewed the zero energy buildings and numerous traditional approaches and future components were investigated. Santosh (2015), focused on various design processes to achieve energy efficiency and concluded that building sector has opportunity to reduce environmental impact by incorporating energy efficient technologies. Gandhi (2014), focused on designing a building to attain maximum energy efficiency and came up with the design of a building where maximum illumination is obtained. Sandheep, et al. (2018), calculated the time required to recover the cost of installation of solar panels.

The present study focuses on effective planning of a residential apartment by using natural resources, and designs based on eco-friendly materials. Bangalore, known as the IT hub of India is growing fast in the past few decades. Due to this many people migrate from various parts of the country leading to the rise in the real estate sector. Currently Bangalore’s population is 11.882 million and it is expected to grow to 18 million by 2035. It is very important that the building construction should be sustainable with the adaptation of the emerging green technology as well as implementation of zero energy concepts.

2. Method and methodology
The structure chosen for the study is a G+5 apartment with a floor height of 3m and a parking lot. The site dimensions are 100m x 80m. Each storey comprises of 2 flats of 2BHK and 3 flats of 3 BHK. The process of fixing all the directions with respect to the rising sun direction to get maximum benefits from nature is called orientation. Three factors determine orientation: sun, wind and landscape. Longer walls of the proposed apartment are planned along north south direction and the shorter walls along east west to get minimum radiation during summer and maximum solar radiation during winter. Bedrooms are placed on the windward side. Due to breathing and sweating, humidity rises resulting in discomfort and unpleasant conditions. Hence proper ventilation and cross ventilation are provided for easy movement of wind. The sizes of various rooms and height of the building have been fixed as per National Building Code of India (2016) norms and Bruhat Bengaluru Mahanagara Palike (BBMP) guidelines. The analysis and design is carried out in “STAAD.Pro V8i” software. But the structural details are not discussed in this paper. The paper discusses only the net zero energy concepts adopted and studied. Figure 1 shows the plan of ground floor of the apartment. The cost estimation of the apartment has also been carried out.

The elements of net zero energy concepts and techniques to be adopted in buildings are presented in Table 1.

| Water conservation                        | Designs related to zero energy building                      |
|-------------------------------------------|-------------------------------------------------------------|
| 1 Use of efficient plumbing fixtures      | Solar Panels                                                |
| 2 Dual flush Toilets                     | Sewage treatment plant                                      |
| 3 Bathroom Sink Faucets                  | Biogas plant                                                |
| 4 Shower heads(rain sense shower)        | Wind Energy                                                 |
| 5 PRV (pressure-reducing valve)          | Rainwater harvesting                                        |
| 6 Re-circulating hot-water system         |                                                             |

Table 1. Net zero energy concepts and techniques to be adopted
Low flow plumbing fixtures are the fixtures that use significantly less water than conventional plumbing fixtures. They have been proposed in the study for 50 flats with an average of 4 persons per family containing a total of 150 toilets. So 150 toilets are flushed 6 times a day which equals to 900 times per day by saving 2430 litres of water per day exclusively for flushing alone. Table 2 gives details of low flow plumbing fixtures used and the savings achieved in water consumption.

### Table 2. Details of low flow plumbing fixtures and savings achieved in water consumption

| Type of fixture | Dual flush Toilets (per day) | Bathroom Sink Faucets | Shower heads | PRV (pressure reducing valve) |
|----------------|------------------------------|-----------------------|--------------|------------------------------|
| Consumption of water | 4.7 to 7.4 litres | 5.5 litres per minute (lpm) | 9.5 lpm, 35psi | |
| Savings in water consumption | 2.7 litres per flush | 3.6 lpm | 10 lpm | 35psi |
| Savings per day | 2430 litres | 3.6*50* 5mins=2700 lpd | 10*4*5= 2000 lpd | |
| Savings per year | 657000 litres | 985500 l per year | 730000 l per year | |

Total savings in water is **2372 m³ per year** due to low flow plumbing fixtures.
2.2 Rooftop Rainwater Harvesting Design (RWH)

The rainwater collected is stored in the storage tank which is used for non potable uses like flushing and gardening. Assuming a run off coefficient of 0.8, for a roof area of 2692 m$^2$ and considering 979.88 mm (or 0.979 m) (from the rain fall data of Bangalore). The catchment area for RWH is found to be 2692 x 0.979 x 0.80 i.e. 2108 m$^3$. Non-potable water requirement for family for dry season is 90 * 5*60*50 flats i.e. 1350 m$^3$. This is based on the dry period, the period between two consecutive rainy seasons designing for 90 days. Two tanks of size 7m x 7m x 3.5m can meet non-potable water requirement of a five member family for the dry period. The diameter of the down take pipe is 100mm. The total savings in water consumption resulting from low flow plumbing fixtures and rain water harvesting has resulted in savings in water consumption by 25%.

2.3 Design of Sewage Treatment Plant (STP)

Sewage treatment is the process of removing contaminants from municipal wastewater, containing mainly household sewage plus some industrial wastewater. A by-product of sewage treatment is a semi-solid waste or slurry, called sewage sludge. The details required for design of Sewage Treatment Plant are presented in Table 3. Table 4 gives details of sewage flow and the tank capacity required.

| Population for a portion of apartment (G+5) | Water supply for a day per capita | Maximum demand | Average daily consumption 1/day | Maximum Daily Consumption 1/day |
|--------------------------------------------|----------------------------------|----------------|---------------------------------|---------------------------------|
| P 30*5+20*3=210                             | 135                              | 1.5 times the average demand | 210x135= 40.5x10$^3$            | 1.5x40.5 x 10$^3$ = 60.75x10$^3$ |

80% of water supplied to the apartment becomes sewage.

| Quantity of sewage required to be treated per day (Q) l | Peak flow in Detention Period of 3 hours (l/day) | Capacity | Net area of screen openings required | Gross area required | Gross area of screen to be provided |
|--------------------------------------------------------|-----------------------------------------------|----------|-------------------------------------|---------------------|-----------------------------------|
| 0.8x60.75x10$^3$ = 48.6x10$^3$ l                         | Peak flow 48.6x10$^3$                         | 6.07  x10$^3$ =6.07 m$^3$ | (6.07)/(0.3) = 20.23 m$^2$ | 20.28x6/5 =24.276m$^2$ | (24.28) /sin 60 = 28.03 m$^2$ |

Gross area is calculated by assuming the velocity through the screens as a maximum velocity of 0.3 m/s and using rectangular steel bars 1 cm wide as screen, placed at 5 cm clear spacing inclined at 60$^0$ to horizontal.

2.3.1 Grit Chamber and Sedimentation Tank:

Considering settling velocity between 0.016m/s and 0.22m/s, flow velocity as 0.3m/s and a detention period of 5 hours, a grit chamber of dimensions 10mx1.3mx1.55m is to be provided. Quantity of sewage to be treated = 48.6x10$^3$ l/day. By adopting the various design requirements shown in Table 5, a rectangular tank of 4mx1.0mx2.5m has been designed. Table 6 gives the details of yearly water requirement, recycled water available from STP, water available from RWH and saved from low plumbing fixtures.
Table 5. Various design requirements for sedimentation tank

| Detention period | Velocity of flow | Capacity | Depth of tank | Free board | Total depth |
|------------------|------------------|----------|---------------|------------|-------------|
| 4 hours          | 0.2 m/min        | 8.1 m³   | 2 m           | 0.5 m      | 2.5 m       |

Table 6. Details of annual Water requirement, recycled water available from STP, water available from RWH and water saved from low plumbing fixtures

| Total water requirement (m³) | Water Recycled from STP (m³) | Water saved from low plumbing fixtures (m³) | Water obtained from RWH (m³) |
|-------------------------------|-------------------------------|---------------------------------------------|-------------------------------|
| 15521.61                      | 5794.74                       | 2372                                        | 1375                                        |

Figure 2 gives the details of water required, recycled water obtained from STP, water obtained from RWH, and water saved from low plumbing fixtures. The total savings in water requirement yearly is around 60%.

Figure 2. Water required, recycled water obtained from STP, water obtained from RWH, and water saved from low plumbing fixtures

2.4 Design of Solar Panel:

Solar energy offers numerous benefits for building owners as well as to the environment. While non-renewable energy sources like oil, gas and coal are becoming increasingly scarce, the sun’s energy is limitless. Lights, fans, and other electrical appliances consume power. Number of wattages consumed by each appliance is found and multiplied by the number of hours. Total units in one floor = 10: 3 BHK = 6 and 2 BHK. The total power consumption was found to be 197.34 KWh/day and the total Wattages required is 2752 watts. The sizing of PV Panels is shown in Table 7.

Table 7. PV Panel details

| PV Panel sizing | Appliance usage for one floor | Total PV panels energy needed | Total panel capacity needed Assuming 5.5 hours of daily sunshine | Number of PV panels needed rated peak watt output= 265watt |
|-----------------|--------------------------------|------------------------------|-----------------------------------------------------------------|----------------------------------------------------------|
| For 5 floors and basement | =\((5\times197344) +3.840\times9867 \) 23.84 watt hours | 986723.84x1.3 =1282740.992 Wh/day | =\( 1282740.992)/(5.5) =233225.6349 \) | =233225.6349/265 =880.09 panels =881 panels |
| Total area of the roof = 2692 m² | Total area occupied by panels = 1308.285 m² | | | |
Inverter rating should be more than the total watts used by the appliances and its DC. Table 8 gives details of batteries designed as a part of the solar power design.

**Table 8. Battery details for Solar power design**

| Total watts of all appliances | For safety, inverter should be considered 25-30% bigger in size | Taking 3000 watt capacity inverter | 45% of energy needs to be stored in the batteries | Applying temperature correction of 0.96 for Bangalore |
|-----------------------------|-------------------------------------------------|---------------------------------|---------------------------------|--------------------------------------------------|
| 2752 watts                  | 2752 + (0.2*2752) = 3302.4                      | Number of inverters = 2         | 197344*0.45 = 88804.8 Wh      | Capacity of battery 130543.056/0.96 = 135982.35Wh |

Assuming the appliance receives direct power daily for 5.5 hours from the panel by the inverter and around 55% of power out of 220.313 kWh/day is directly supplied from the panel through inverters during the day. Table 9 gives the size of solar charge controller.

**Table 9. Size of the solar charge controller**

| Power from charge controller to the inverter is 2752 Watts | I=P/V; I=2752/24: I=114.66 A |

The cost of arrays, batteries, Inverter and installation charge is found to be INR 71,00,000 with additional cost of wiring taken as 5% of total system cost. The total cost works out to be INR 74,65,500.

**COST RECOVERY**

From the tariffs set by BESCOM, Bangalore Electricity Supply Company (Karnataka, India) and assuming an average price of INR 7.00 per unit.

Gross electricity bill = 7*1282.740*30 = 269375.4 INR

Cost recovery of Solar panels is 28 months or 2 years 4 months.

2.5 Design of biogas plant

The anaerobic fermentation is a biological process aiming to transform organic matter into methane. It is an anaerobic process made in a neutral and oxygen free environment. Table 10 provides details of kitchen and green waste generated in the Apartment. Also the details of liquid and solid sewage generated are provided in Table 10. Table 11. Gives the details of methane yield and energy production from the biomass.

**Table 10. Details of liquid and solid sewage generated**

| Kitchen waste | Green waste | Liquid sewage (From STP) | Solid sewage wasted (kg) |
|----------------|-------------|--------------------------|--------------------------|
| 80 kg/day      | 1.5 kg/day  | 48.6 x 1031              | 30% of 48.6 x 1031 = 14.58 |
| S_d=[ 80 (kg/day)+1.5 (kg/day)+14.58(3g/day) ]×2=192.16 l/day |

The retention time considered was 62.5 days and the digester volume was found to be 13 m³. Hence a 15 m³ digester was proposed with the radius of the dome being 2.05 m. The dimension of the digester was found to be 1.15*3.50 sqm, and the outlet chamber was found to be 2.604 m³ in capacity.

**Table 11. Methane yield and energy production from the biomass**

| Biomass        | Methane produced in m³/total | Quantity kg/day | Quantity total/year | Methane produced m³/year |
|----------------|-----------------------------|-----------------|---------------------|--------------------------|
| Food waste     | 220                         | 80              | 29200               | 6424                     |
| Green waste    | 110                         | 1.5             | 547.5               | 60.225                   |
| Sewage waste   | 250                         | 14.58           | 5321.7              | 1330.2                   |

Total 7814.65
Considering calorific value of methane as 9.94 kWh/m$^3$ and 5% of energy loss, the energy supplied by the biogas in one hour is 8.88 kW of the energy supplied in one year is found to be 77788.8 kW

2.6 Wind Turbine

The wind turbine can generate power in urban environments by catching wind that blows in any direction. Typical wind turbines are only able to hardness wind that is blowing horizontally. In a complex urban environment where buildings interfere with air flow, winds are more likely to be travelling in every direction. Considering the parameters mentioned in Table 12, a wind turbine has been designed and the diameter of the rotor blade obtained is 1.97m and actual rated power of the turbine rating is found to be 26kW.

| Table 12. Parameters needed for Wind Turbine design |
|-----------------------------------------------|
| Average wind speed in Bangalore | Density of air kg/m$^3$ | Capacit\y factor | Number of hours in a year | Coefficient of performance | Transmission losses | Generator losses | Overall loss factor |
|-----------------------------------------------|
| 5.6 km/h = 5.6/3.6 =1.56 m/s                 | 1                             | 0.30                  | 8760                     | 0.40                      | 0.90             | 0.90               | =0.40× 0.90 × 0.90 = 0.324 |

3. Results and Discussions

The 3d view of the structure shown in Figure 3 was done using Revit software. Figure 4. gives the details of energy production from solar power, wind and biomass. Figure 5 shows the details of energy required and produced. The energy needs of the Apartment have been met by about 99% from solar, biomass and wind.
Figure 4. Details of Energy Production

Figure 5. Details of Energy required and produced

The total cost of the structure was estimated to be INR 3.5 crore.

4. Conclusion

1. The cost recovery of solar panels is 28 months or 2 years 4 months.
2. The solar system installed is capable of producing 82% of the power requirements.
3. The biogas plant setup can 17% of the electric requirement.
4. The wind turbine installed can generate 0.2% of the total power requirement.
5. Total savings in water requirement yearly is around 60% by installing Rain water harvesting, using low plumbing fixtures and using recycled water from STP.
6. As concluding remarks, though the initial investment is higher for net zero energy buildings in the long run, zero energy buildings prove to be more beneficial and economical not only in the environmental aspect but also social aspect by enhancing users comfort and health.

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