Planning and integration of zero energy buildings with consumption analysis for metro cities in India

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Abstract: Due to the ever-increasing scale of metro cities in India and increasing consumer energy demands, proper planning and design are needed to overcome this ever-growing menace. However suitable procedure, architectural design, material selection and integration of renewables into the existing infrastructure can aid in reducing this extra burden. We will study the demographics, available area and the capital cost for top four metro cities in India in context of the development and feasibility of integrating a renewable architecture to the existing building setup. The municipal corporation data, as well as site data, will be used to aide the research. The research will assimilate the site plan taking into account various categories of high rise buildings present in these areas. A comparative analysis will also be done to compare the cost of conversion of a conventional structure in these cities to a zero energy one. Public survey and opinionated research will be used to declare the constraints to the extent. It will be studied whether a renewable energy setup for these buildings is viable for prospects and anticipation of the general public. The results will be compared together for the four cities and possible reasons for the difference in establishment of setup will be discussed. In the end, an energy analysis will be done which will calculate the net yearly saving of such type of building compared to the existing setup and a possibility of a microgrid installation on a building.

Keywords: Zero energy building, Renewable, Material, Architecture, Energy, Analysis, Economic, Microgrid

1 Introduction

The continuous increase in energy consumption associated with rising energy needs, has promoted research applications in renewable energy resources such as solar energy and wind energy [1].

An important issue is to reduce energy consumption and CO₂ emissions in buildings, especially in residential buildings, which make up a big portion of energy consumption. In 2008, the consumption of world energy production was 36% in residential and commercial buildings. By country and region, European allies average 41%, Japan 34%, USA 34%, China 32%, South Korea 24% respectively. The energy consumed in residential and commercial buildings in 2016 was twice more than in 1971. In 2016, residential and commercial buildings had used up 40% of the major energy and 71% of the total electricity in the United States [2,3].

Humans consume a large portion of energy in residential buildings such as in apartments and commercial and public buildings such as stores, hospitals, and schools. Energy is also consumed in buildings when people spend their daily lives i.e. for instance while driving in a car or running a factory. They are consuming much of their energy in heating needs to enjoy a warm life. Even in the case of a living house, the different electrical appliances in the house also consume energy. Since the energy consumption of a building is high, research on the zero
energy buildings without using external energy started in earnest in various countries and regions such as Europe and USA from the early 1990s [4,5]. A zero-energy building (ZEB) is a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site of the building. In other words, the building energy generation itself can compensate for the energy consumed by the structure, so it is a block that can operate on its own without receiving electricity from the national or local power grid. A ZEB does not burn any fossil fuel and therefore do not possess carbon dioxide emissions. Hence it is also known as a zero carbon building or zero emissions building [6,7]. Once a zero energy building is setup, the effects on the energy consumption and environment will be long lasting, and it will have a long life. Therefore, constructing a new building to use only renewable energy without expending external sources can save a great deal of energy in the long run, but more importantly, it can eliminate carbon dioxide emissions. In Europe, as of 2008, more than 60% of residential buildings were built before 1975, which is good for traditional and historical preservation but consumes massive heating energy, which is an issue to be urgently solved regarding environmental protection and energy saving.

A ZEB can be named a net-zero site energy building, net-zero source energy building, a net zero energy emissions building, net-zero energy cost building, net off-site energy building, off-the-grid building. The energy saving plan of ZEB is distinct from traditional structures and requires many core technologies. Designers who design ZEB’s successfully combine well-proven passive design technology along with building air conditioning systems and use renewable energy such as solar, wind, and geothermal energy to supply lighting and maintain room temperature stability [8–10].

2. Setup of Zero Energy Building in India

2.1 Climate Assessment

A significant factor which needs to be mentioned upfront is the climate assessment for establishing a zero energy project. It impacts the marginal thermal loads of the project. A ZEB can be installed in any climate, but it is not possible for every building type. Hence to classify the building’s feature according to a weather, any classification system is needed, most common being Koppen classification, based on five climate categories categorized from A to E subdivided into several subgroups denoted by lowercase letters as shown in Table 1.

| Zone No. | Climate Zone Type     | Köppen Classification |
|----------|-----------------------|------------------------|
| 1A       | Very Hot-Humid        | Aw                     |
| 1B       | Very Hot-Dry          | BWh                    |
| 2A       | Hot-Humid             | Cfa                    |
| 2B       | Hot-Dry               | BWh                    |
| 3A       | Warm-Humid            | Cfa                    |
| 3B       | Warm-Dry              | BSk/BWh/H              |
| 3C       | Warm-Marine           | Cs                     |
| 4A       | Mixed-Humid           | Cfa/Dfa                |
| 4B       | Mixed-Dry             | BSk/BWh/H              |
| 4C       | Mixed-Marine          | Cb                     |
According to this requirement, our selected four cities fall under various zones as shown in Table 2.

Table 2- Climate zones at selected sites

|   | Climate Zones          | Zone |
|---|------------------------|------|
| 5 | Cool-Humid Dfa         |      |
| 5B| Cool-Dry BSk/H         |      |
| 5C| Cool-Marine Cfb        |      |
| 6A| Cold-Humid Dfa/Dfb     |      |
| 6B| Cold-Dry BSk/H         |      |
| 7 | Very Cold Dfb          |      |
| 8 | Subarctic Dfc          |      |

2.2 Site Assessment

A site assessment for establishing a zero energy project is done from the data collected during the climate assessment using various meteorological tools like Meteonorm. The climatically analyzed parameters are analyzed in depth keeping in mind the site specification. The specificities of the site must be analyzed keeping in mind the various restraints as this will affect the energy usage in the site. The site gives a better idea how the building needs to be raised. Positioning and massing of the building should be seen for the particular site. The climate data that is extracted from software tools can be utilized when creating an energy saving unit. Renewable resource involvement needs to be incorporated into the building hence proper provisions of renewable setup is also studied [11–13].

2.2.1 Site Constraints

The site assessment curtails various constraints which can put an effect on the development of the zero energy project which may include economic parameters, property, and usage of land parameters [14]. The site energy analysis needs to be predetermined which may involve the development of a site plan, models, diagrams, plots and collection of data for site analysis. The study involves the study of the site boundary, landscape, and topography for easy solar access, surrounding area, availability of resources and study of data sets giving information on climate. The climate of the site allows for better energy generation and better control of the production using natural methods. The surrounding buildings can aid in the wind flow process across the site. The accessibility of natural resources is also a prime concern where energy needs are not available due to some reason. The daily solar irradiation and the annual solar insolation at the site needs to be monitored to see how much energy can be generated by solar availability or else other means of energy generation have to be utilized. The connection to the grid may or may not be present catering to emergency situations but this is unfeasible to a zero energy project. They can play a role in balancing of energy by connection to grid through net metering. The horizon of sun needs to be studied if it can affect solar access at the particular site. The overheating due to the sun is also taken into consideration. It is useful to determine whether the site is ready for wind energy generation. This will vary immensely depending upon the location of the site. Mumbai and coastal areas are much more feasible for wind energy generation due to the impact of wind speeds while plain areas like Delhi and Noida are not suitable for energy generation.
Natural ventilation is very important for imparting natural heating and cooling across the building cutting off the cost of space heating methods. One method to naturally control the space heating and cooling of the building is to generate a microclimate. It is used to designate the localized climate considerations based on the specificities of a particular location. This climate can be controlled by various methodologies like controlling the sun and the wind in the design of backdrop elements and designing policies that maintain the climate. Since the climatic conditions in India are much more demanding for cooling, hence cooling microclimates are more encouraged. The temperatures in summers can soar up to 48 degrees which raises the need for effective cooling measures. Shades from the sun, solar reflectance, water sprays, cooling breezes from ventilation setups and vegetation that naturally decrease climatic heat are used to create such microclimates [15].

2.3 Materials
The materials that are used for constructing a Zero energy building in India depends greatly on the availability of material for construction. The material which is used to construct the walls of the vicinity is constructed with ready-mix concrete with Polypropylene carbonate (PPC) possessing additional 30% fly ash content. For flooring, the locally available stones are used for construction. The flooring is Terrazo which is done by stones locally available in market namely Cuddappa, Kota, Sand, Shahabad, Granite, Marble etc. which depends upon the availability of raw materials at different sites. The bricks that are preferred for the zero energy buildings are fly ash bricks. The fly ash material for brick is easily available and the major advantage of using such types of bricks is that it saves the land which would be utilized from its storage and also its material is useful for the ecosystem as it avoids polluting the land. Autoclaved aerated concrete (AAC) is a derived form of fly ash amalgamated with cement, lime, water and an aerating agent and manufactured as blocks and panels. The door material should be as such to provide the maximum amount of insolation that lowers the need for heating and cooling. The door lining should be fitted with foam or rubber seal which can lock the outflow of heat and cold nature of a room to outside atmosphere. Doors should be preferably rapid closing in order to avoid loss of insolation. In Delhi, the doors utilized were constructed with locally available material composed of jute and bamboo. However, with the latest advent of technology, plastic polymers are very much able to trap the temperature effect and offering a cheaper alternative. Extruded polystyrene or UPVC material for a window is used with completely airtight double provision and proper glazing besides including a glass material having low heat transmittance. Tiles for roofing should be made with high reflectance materials so that there is low heat absorption. One alternative method is to use a solar tile which consists of a solar panel embedded on the roof of the building which can generate energy from the roof of the building itself. Aluminium is avoided as it’s embedded energy is too high [16,17].

2.4 Steps for Energy efficient design
The light fittings in a ZEB are done, which include energy saving devices with high efficiency and conforming with the ECBC (Energy Conservation Building Code), 2007, India so that the total energy need of the building is reduced considerably [18]. The water heat from the building architecture is supplied to a refrigerant or a water chiller. They consist of air handling units with variable drives. The refrigerant is then transferred to a location where this extra heat can be sent back to the atmosphere outside the building. For places nearer to sea like Mumbai in our case a seawater-cooled condenser is a viable option where extra heat can be rejected safely and easily in an eco-friendly method. However costly corrosion preventive techniques raise the cost of the project but can be countered. To naturally reject heat the method used is the geothermal heat rejection system as utilized in Delhi where heat is sent to the earth to be absorbed and water can be conserved in cooling towers. Other setups include cooling by air and water which may also be utilized in some cases. In some advanced ZEB’s like in case of Delhi, further measures are undertaken to further decrease energy consumption. Dry cast resin transformers are utilized
which are very efficient for electric substations. Distributed generation is also promoted within the vicinity. The lifts at the building are regenerative in nature so that the elevator drives may be employed to recycle heat energy rather than wasting it. The building is integrated with an Integrated Building Management System (IBMS) which can be utilized for enhancing energy consumption and efficiency monitoring etc. A chilled beam is installed at the ZEB which is a type of convection HVAC system designed to heat or cool large buildings and it saves air handling unit power or fan coil unit by approximately 50 kW. An inconsistent flow of chilled water depending upon the expected load is circulated through the chiller and the related piping system in order to maneuver the system with efficiency. Cooling towers and air handling units are attached with variable frequency drives. Toilets are attached to energy efficient exhaust systems which regularly pump air out through a latent heat recovery system [19–23]. The lightning arrangement inside a ZEB should be highly efficient in order to reduce the energy load on the building and leave enough energy to cater to emerging energy needs from other energy usage applications. There are various energy efficient light fixtures varying from fluorescent T-5 lamps to CFL (compact fluorescent lamps) and LED’s (Light emitting diode). Hence lighting fixtures are used encompassed with T-5 lamps owing to higher efficiency. In order to optimize the effect of simulated lighting, lux level sensor is utilized. GRIHA is a green building evaluation system formulated in India by the Energy and Resources Institute (TERI) and it rates different types of buildings and registers its environmental impact on similar lines to International organization LEED (Leadership in Energy and Environmental Design) developed by USA [24].

2.5 Renewable Setup to cater to energy needs

The hot water flow throughout the setup is flown through the system which is heated suitably by the solar water heater. Solar water heating is a low-cost zero-emission method with typically no post-investment and it heats water through the utilization of solar energy as shown in Fig 1.

![Figure 1- Solar water heating system](image)

The external lighting in the building exterior is achieved through using solar panels installed on poles that receive a considerable amount of sunlight throughout the day. The total energy consumption of the facility is met through the use of solar powered panels and other renewable energy producing agents [11,25–27].

2.6 Converting a conventional building to a zero energy building

In order to cope up with the growing demand of going green, municipal corporations are giving incentives to encourage building owners to go green. There are now building ratings for green buildings like in India, GRIHA rating system was formulated and worldwide in many countries, the Leadership in Energy and Environmental Design (LEED) rating system is followed. There are various steps in converting an ordinary building to a zero energy one. The first step is
benchmarking. It is the audit of the energy usage and requirements of a conventional building and a measure of how the conventional building performs with respect to the green standard established by the industry. It is a measure of the energy consumed by different appliances and it also assimilates other needs of the building and what can be done to improve this setup. The next step in the conversion of a building to a zero energy building is to make a checklist of all the requirements for a zero energy building and aiming for a ZEB rating. To attain this goal how much of the equipment is needed by the building. It also takes into account the harnessing of local sources of energy like sun and wind and in addition devising a method to make the best use of them. Solar penetration and ventilation into the building need to be analyzed. Water conservation methods like harvesting need to be studied for its feasibility. Addition of energy efficient appliances and replacing the intensive ones are also studied. The third and final step is implementation. In this step with the energy audit of our building we can upgrade our existing Equipment to the latest energy-efficient technology and now we have to study what can we get back from the green building and how much savings can be accommodated by this latest development. Without reducing the demand if the ZEB setup is established then the results may not be too promising. Hence proper study and balance of supply and demand should be done in order to avoid any loss and poor payback on the consumer side [30–32].

Assuming a building consuming 90 units of energy annually. Now Assume that 60 units of the total are consumed by the air conditioning setup, 10 units are used by the water heating unit, 10 units by lightning and 10 units are consumed by other equipment. Hence the requirement for such type of setup is 90 units from the supply unit. Now the demand for energy is reduced due to utilization of geothermal air conditioning [28,29]. Hence the demand is lowered from 90 to 40 units. Hence energy saving is now implemented for the ZEB setup.

3. Case study of diverse buildings in India

A case study of following four buildings depicted in Figure 2 have been selected as shown in Table 3 below.

| Building Considerations | Delhi | Mumbai | Gurugram | Bengaluru |
|-------------------------|-------|--------|----------|-----------|
| Type                    | City-side Open building | Sea Side | Residential | Hospital Building |
| Climate Zone            | Humid Sub-tropical | Wet and Dry | Composite | Tropical wet and dry |
| Temperature Range       | 5°C-45°C | 21°C-32°C | 7°C-43°C | 14°C-36°C |
| Building Gross Area     | 9,565 sqm | 2,530 sqm | 4,575 sqm | 3,200 sqm |
| Occupancy               | 190 | 250 | 250-300 | 500 |
| Floors                  | 8 | 6 | 8 | 3 |
Figure 2- Building types at separate locations a) Paryavaran Bhavan, Delhi b) Office building at Mumbai c) Apartment complex at Gurugram d) Hospital at Bengaluru
3. Energy Compensation

Due to the adoption of the Zero energy concept, the energy consumption of the respective buildings has gone down considerably [33, 34] as shown in Figure 3 shown above. The energy consumption for four cities has been discussed below in Table 4 along with the percentage drop in consumption by extensively adopting energy efficient methods into the conventional energy generation setup.

Table 4 - Percent Annual drop in energy consumption for chosen building cases

|          | Conventional Units/m² | ZEB Units/m² | Area of site (m²) | Annual Energy Consumption kWh | Annual Energy Consumption kWh after drop |
|----------|------------------------|--------------|-------------------|-------------------------------|----------------------------------------|
| Gurugram | 194                    | 55           | 4575              | 8,87,550                      | 155550                                 |
| Mumbai   | 350                    | 120          | 2530              | 8,85,500                      | 303600                                 |
| Bengaluru| 400                    | 100          | 3200              | 12,80,000                     | 320000                                 |
| Delhi    | 204                    | 146          | 9565              | 19,51,260                     | 1400000                                |

The residential building at Gurugram does not accommodate any renewable setup hence the only feasible solution is to accommodate energy efficient fixtures and design which may decrement the energy consumption of a building. Hence roof insulation, highly efficient chiller, biomass utilization, ventilation, wall insulation, gas insulated glass window, T5 lamps and a load management system has been installed at the facility to reduce the consumption of the building. Similarly, for the hospital at Bangalore, a heat pump can be installed to counter the huge heating and cooling requirements at the hospital. Renewables are only encouraged for basic electricity needs and not for other critical requirements due to their unreliable nature. At the school building, renewables will play a major part. A load management system is also needed as the load is variable and distributed. The lightning system needs careful integration into the office building. For compensating the remaining energy needs of the system, a solar
energy setup needs to be set up due to easy installation and availability. The estimated solar system size for the four cities have been discussed in Table 5. Paryawaran Bhawan has an installed solar setup of 930 kW at Delhi which compensates the total energy needs of the system making it a perfect zero energy building hence making it an ideal candidate for establishing a microgrid setup where the supply of extra unutilized energy is done to nearby residential areas.

Table 5-Approximate solar system size for selected four locations

| Location | Average Peak Sun hours | kWh compensation requirement | Approximate solar system size under STC |
|----------|------------------------|-----------------------------|----------------------------------------|
| Gurugram | 4.44                   | 155550                      | 96 kW                                  |
| Mumbai   | 5.35                   | 303600                      | 155 kW                                 |
| Bengaluru| 5.32                   | 320000                      | 165 kW                                 |
| Delhi    | 4.29                   | 1400000                     | 894 kW                                 |

4. Conclusion

This study was performed to devise an insight into the energy needs of commercial society and what are the various methods administered to counter the same. For the metro cities of India, a study of the establishment of a zero energy setup was performed. An investigation of whether such a system would be feasible enough for future installation is performed. A study of different types of buildings, including the commercial and non-commercial buildings with different shares of renewable and non-renewable energy was made according to need and usage. The impact of the change in location of ZEB’s also gave a better understanding of the establishment of such buildings for a country typical as India with limited resources and a cap on the upper-cost value. Based on the balance of energy within the building, the economics of the ZEB’s change. It means that there is variation in the number of renewables integrated, change in energy needs and varying efficiency. Future work will talk about a much detailed study on all aspect of a zero energy conceptual framework and also analyze the roofing, window and door materials with ventilation requirements for setting up a zero energy building.

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