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Net Zero Energy Buildings and Their Designing Characteristics- A Review

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Abstract: The paper aims to discuss Net Zero Energy Building (NZEB) as an effective solution to conserve energy and limit carbon emissions which are threat to our environment. It highlights the significance of various designing strategies of NZEB and analyzes the operational feasibility of these systems. Furthermore, numerous factors regarding the general characteristics of a NZEB's is surveyed including the selection of Renewable Energy Sources for on-site electrical generation, the Energy Storage Systems for generated surplus energy, and the building optimization techniques and recommendation of a feasible net zero energy network. Environment and climatic hindrances that may affect the design of a net zero energy building at the time of implementation is also examined. The idea to implement NZEB can provide tremendous opportunity for states to reduce their energy consumption and can simultaneously bring improvements in public health.

Keywords: Net Zero Energy Building, Renewable Energy Sources, Energy Storage System.

I. INTRODUCTION

The increasing demand of energy in recent decades has led power sectors and consumers to conserve energy to cope with issue of imbalance in supply and demand. The urban regions make about 70%, and the housing construction & developing structures put up about 40% addition to the Green House Gas (GHG) emissions. It has been known that the buildings come up with approximately 50% of the world's air pollution, 42% of GHG emissions, 50% of water contamination and 48% of waste to the surrounding [1]

The increase in electricity consumption around the world as reported in Global energy statistics [2] can be seen in Fig. 1.

Moreover, the traditional power systems are subjected to (i) energy losses because of ageing infrastructure, heat dissipation; especially in the transmission process where about half of the energy is lost due to distant generation stations [3], (ii) environmental hazards due to carbon emissions, and (iii) the increasing prices of fast depleting non-renewable resources, that mostly consist of fossil fuels [4].

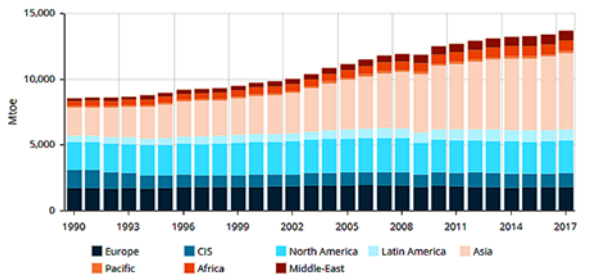

Fig.1 Global Energy Consumption [2]

Among aforementioned issues, pressure to curb carbon emissions over last few years has significantly increased as these emissions lead to greenhouse gases which are extremely hazardous to the environment.

During last two decades, carbon emissions occurred worldwide [5] is shown in Fig. 2. It is estimated that at least 25% of emissions occur from the energy generation sources catering to the demand of residential and commercial sector [6]. Nonetheless it is incurred that buildings accounts for around 40 % of global energy consumption [7]. Hence, along with energy and transportation sectors, the building sector also needs to play a key role in effective climate policy.

Therefore, building sectors at their end can employ efficiency measures in new and existing buildings to reduce their energy intensities. The energy efficiency measures can reduce two-thirds of CO_2 emissions needed to achieve climate protection. Besides energy conservation can effectively solve the other stated problems.

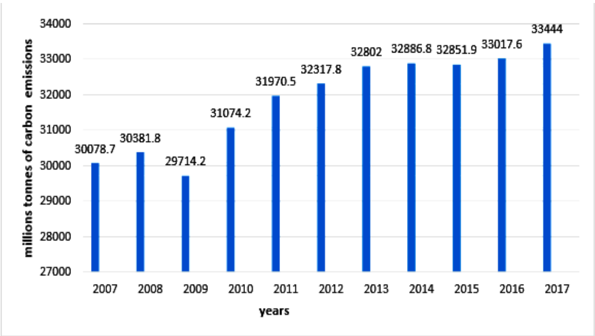

Fig. 2 World Carbon Emissions [5]

In recent years many attempts are made by construction sector to conserve energy. Passive strategies, such as insulating, weatherizing, up gradation of HVAC systems yet these can be costly and temporary solutions as the climate changes [8] [9]. One such example is the ost central system that is provided with a thermostat that can change the temperature of the entire house [8], yet this system does not significantly contribute either towards grid's energy conservation or electrical transmission system.

Thus, the goal of energy conservation may be achieved through implying both active and passive strategies. One such solution is the Net Zero Energy Buildings (NZEBs).

A NZEB is a building in which the consumption of energy throughout the year is equal to the energy produced on site using renewable resources [10]. The NZEB functions in a two-way manner. It can be observed from Fig. (3), that it can consume electricity from the grid as well as supply the same to the grid. The presented solution is already in process by the European parliament directive [11], and in accordance to it, by the end of 2020, all the newly constructed buildings are to be built according to the NZEB standards of energy and emissions.

In this paper some general design characteristics of NZEB have been discussed, followed by evaluation and discussion on RES that are supposed to yield efficient design and optimization of NZEBs. Selection criterion is based upon the classification and the key performance indicators as given in [12].

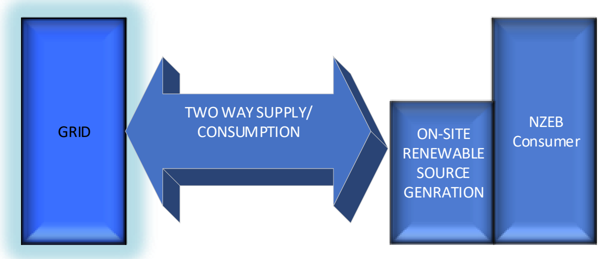

Fig.3 NZEB Network

II. GENERAL DESIGN CHARACTERISTICS OF NZEB

A feasible design of NZEB may be flexible enough to meet different building requirements pertaining to the conditions in which it exists.

There are several factors that generally affect the plan and strategy of a building. In order to achieve an affective NZEB, we may need to consider the following factors: (i) amount of energy a building consumes, (ii) the number of people it may accommodate,(iii) the climatic conditions [13], (iv) the location of the building [3], (v) renewable resources most suitable for on-site production [10] , (vi) an operative computer to manage the flow of energy to and from the building [3], (vii) and the battery energy storage system [14].

Some of the most crucial factors are discussed as follows:

A. Selection of Energy Sources

Selection of RES for on-site production may be considered as the most important part in designing of a NZEB. It is dependent upon the energy requirements and the weather conditions affecting them in the form of temperature, consumption, emissions [14]. Various RES presently incorporated are discussed in Section III.

B. Energy Storage Systems

Energy Storage Systems (ESS) may be deemed as basic requirement for NZEBs, however they are generally neglected. Since NZEBs are generally referred to as buildings that continuously supply and receive energy from the grid nevertheless at times the surplus energy generated in a NZEB is wasted due to non-requirement by the grid. For such instances, we need an operative Energy Storage System (ESS).

Battery Energy Storage System (BESS) is considered most common among ESSs. BESS is used for energy time-of-use arbitrage [15], that is to say it is used in order to store surplus energy that is not required at the time of its generation, and may be supplied when needed. In a NZEB a BESS can be used in power quality improvement [16] and voltage enhancement [17]. Moreover BESS may also be used to deliver energy to consumers and operations other than its respective NZEB. For example, the energy stored in BESS may be utilized to electrolyze water, and produce hydrogen gas to be used as fuel in hydrogen vehicle [15], and may supply energy to electric vehicles [18].

Regarding BESS design different techniques may be employed. The work in [15] presents a flexible design using the Particle Swarm Optimization (PSO) method with an objective to achieve optimal power and energy capacity. Results [14] using PSO is given in Table 1with equilibrium of energy at charging-discharging. The optimal charging-discharging capacity of the proposed BESS has been depicted in Fig. 4.

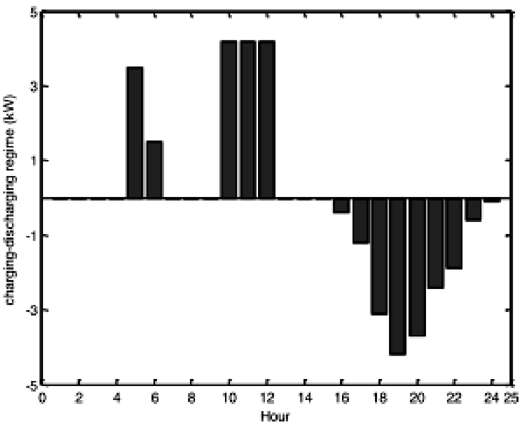

Fig.4: Charging-Discharging of BESS [15]

C. Building Energy Management System

A NZEB comprises of effective Building Energy Management Systems (BEMS) that are aimed at increased energy efficiency levels while integrating the RESs into the system. [19].

The characteristics of an efficient BEMS may be explained in terms of its flexibility, cooperation between different zones, agents and components, fault tolerance, maintenance, user friendliness etc. [20]

D. Building Optimization

Building optimization in a NZEB is an authentic system to assess scheme choices and to get the perfect solution for a specific purpose uttered as objective functions under several limitations [21].

In a NZEB optimization proposed in [22], the base case design environments, RES, and the simulation products are defined. Then, optimization problem of a wide range of design and operating measures is presented; including wall and roof insulation levels, windows glazing type, window to wall ratio (WWR) in eastern and western facades, cooling and heating set points, PV and SC systems sizing. The optimization is to be located and carried out using “MOBO”, a Multi-Objective Building Optimization device proposed by [19].

The method of building optimization has been introduced to minimize the cost relating to the high peak electricity tariff and the constraints related to the maximum heating power of the system. The projected energy management consists of over-heating the building during the hours before the peak knowing in advance the weather, occupation and internal additions for the day. [23]

III. RENEWABLE ENERGY SOURCES AND NZEB

Renewable Energy Sources (RES) can be regarded as the key factors in improving the environmental conditions worldwide. That is why many developed countries have taken the initiative to promote NZEBs. The ‘2020 Strategy’ of the European Union is one such initiative which aims at 20% increment of the use of renewable energy by 2020. [14]. Keeping in view its importance, some of the common RES in the light of different climatic conditions and operational feasibility have been discussed.

A. Solar Photovoltaic Systems

Solar systems are one of the widely used RES due to their low cost and operational feasibility. The increasing long-term energy demands of the consumers may be compelling many developed countries to use Solar photovoltaic (PVs) [24]. There are many recent on-going projects that are working on the solar PVs for reducing building energy demand in residential & commercial net zero buildings. [25].

Although out of entire solar energy incident on a typical PV, only 16% of it can be converted into electricity [26], the solar PVs may be an efficient source of energy in the hot climatic regions where the peak sun-hour energy consumption is high.

From Fig. 5, cooling and heating dominance in different residential and commercial buildings [27]can be seen, while Fig.6 shows the passive cooling and solar strategies that can be integrated with the solar PVs in a Zero Energy Solar House (ZESH) as explained in [28].

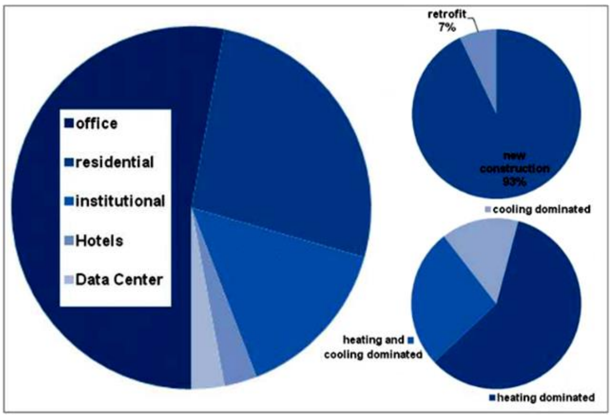

Fig.5 Heating and cooling dominance in residential and commercial buildings [24]

Another ZESHs proposed in [29] provides eco-friendly and clean electricity with only about 0.08-0.2 pounds of carbon dioxide per kilowatt-hour which is much less than the lifecycle emission rates of natural gas whose ranges lies in between 0.6-2 lbs. of CO2E/kWh and of coal that's range is about 1.4-3.6 lbs. of CO2E/kWh [25] may describe the significance of using PV as RES for NZEB.

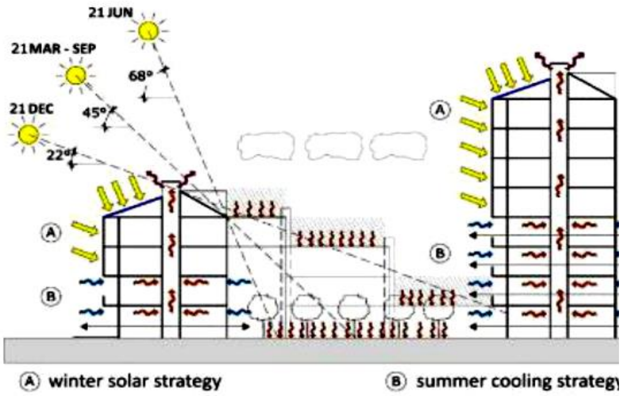

Fig. 6: Passive strategy w.r.t PV/T system [25]

B. Wind Turbine Systems

Net zero energy turbine homes (ZESHs) are considered as the homes that consumes wind energy generated power and consume this power in NZEB system criteria. [15]

Wind Turbine systems may also be a good RES choice for NZEBs but may be costlier and may require a large area due to the varying wind speed with the basic requirement of a location that must contains the area with the average annual wind speed of at least 9 miles per hour (4.0 meters per second) [30].This system may work well in sea side regions and peninsulas with regard to their wind speed requirements. The wind energy can also present good potential in minimization of greenhouse gases where wind potential is available [31] The system is not very cost efficient as its connection to the grid may be only made by expensive extensions which are quite costly depending on the terrain [30].

In [15], two systems have been fairly compared, and the comparison of the load demand of the two RES used in a NZEB has been shown at different hours with respect to the original load demand of the whole NZEB in Fig. 7.

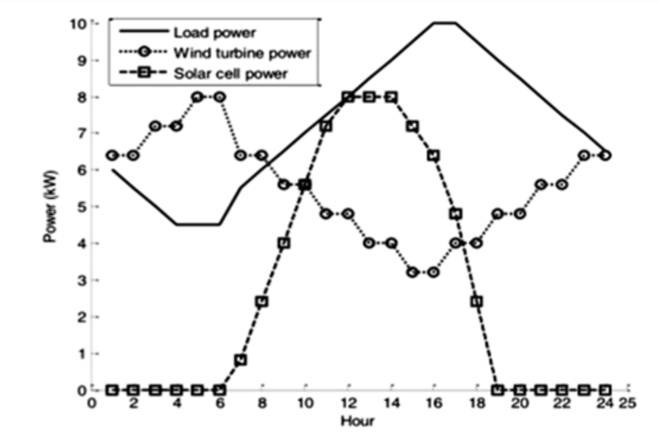

Fig. 7 load comparison of wind and solar RES in a NZEB [15]

Thus, appropriate choice of RES is based on climatic conditions. The solar systems are deployed in the hot regions and the wind turbine systems in the regions with strong sea breeze. The solar PVs may also be used in the mild climatic regions with some passive strategies and ESS' that can store the energy at time in which its surplus and supply it at the times when direct solar energy generation is not possible. Additionally, the load catering capability of wind turbine system is found to be better at the morning and evening hours, while that of solar system is found to be better at the peak hours of the sun. Hence may use both the systems for different time intervals during the day.

IV. CONCLUSION

Energy conservation is an effective way to resolve demand supply gap problem wherein building sector can contribute importantly. The paper has presented a brief literature regarding different designing characteristics of an efficient NZEB. Different methods of designing of feasible net zero energy networks have been discussed.

The main contribution of this work is that it provides a better understanding of the role of net zero energy networks in providing the power produced without any wastage, especially compensating the intermittent nature of renewable generation in the future energy demand. We also focused on the different generation structures and examined the relations between environment and net zero energy buildings, that may prove helpful in compensating the increasing demand of clean energy generation.

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