Net-zero Energy Retrofit of an Existing Commercial Building in Temperate Climate Zone of India

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ABSTRACT

Buildings being responsible for a considerable amount of worldwide energy usage, and that too mainly in the form of electricity and space cooling. This study targets to integrate efficient building envelope materials and energy systems to reduce the building energy consumption significantly based on tropical climate context. The paper aims in retrofitting an office building in Bangalore, India into a nearly -zero energy building by roof-top PV installation. Design builder integrated with Energy plus simulation software is used to accomplish the energy simulations. A three-storey commercial building was analysed using simulations in Indian temperate climate zone, where space cooling is required. This study proposes net-zero energy retrofit guidelines for existing small sized, low-rise commercial buildings in temperate climate zone of India.

Keywords: Net/Nearly Zero energy building (NZEB), Building energy consumption, Retrofit strategies, Design Builder, Energy Simulations, Rooftop solar-PV

1 Introduction

With the population growth, the building energy utilization has scaled up rapidly in the world. Building energy accounts to about 40% of world's total energy consumption [1]. In buildings Heating, Ventilation and Air-conditioning systems contribute to more than sixty percentage of energy consumptions followed by lighting with thirty percentage [2]. Apart from energy-intensive systems, building envelope and the materials used also contribute to energy consumption.

For reduction of building energy consumption and resulting GHG emissions, retrofitting has become essential for existing buildings. However, it has challenges as there are no proper guidelines for retrofit interventions. Several studies have proposed retrofit frameworks and guidelines for residential and commercial buildings. Most of these studies are based on US and Europe as their policies align with the net-zero energy trend [3]. But overrecent years, retrofit projects in tropical climates have scaled up [4]. Since, commercial buildings contribute to significant carbon dioxide emissions, it is essential to upgrade existing commercial buildings through retrofitting strategies [5]. The building energy performance can be enhanced with the integration of renewable energy strategies, which got evolved into the concept of net-zero energy. Net/ Nearly zero energy building (NZEB) concept has proved to be the best solution, by generating renewable energy on-site. This helps reducing the building's dependency on the external grid electricity, thereby reducing operational carbon emissions.

The energy efficiency of buildings could be initially achieved by improving the building envelope or passive parameters, improving the Heating, ventilation and air-conditioning (HVAC) systems to reduce the cooling loads, by installing energy-efficient lighting systems and reducing the building energy need to an extent. The remaining energy demand can be offset by renewable energy generated on-site to achieve net-zero energy [6]. Few studies indicate NZEB studies are still in infancy stage in India, with the temperate climate zone untouched [7].

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1.1 Research Background

The significance of three design strategies of NZEB: active, passive and renewable strategies are well discussed in [8]. The study proposed energy efficient measures (EEMs) that lowers the overall energy demand. Similarily, some retrofit studies such as in [4] has considered commercial building in tropical climate of Singapore, in which the retrofits involved envelope, green roof, active HVAC systems and building management system (BMS). Likewise, in the study [9], 34 NZEB case-studies in hot and humid regions were analyzed, which covered the tropical regions and revealed that natural ventilation as an efficient measure in reducing the cooling demand. Overall, in most of the tropical climate zones, significant amount of energy is consumed for space-cooling.

The passive design strategies such as window-wall ratio, orientation, wall thickness are optimized for making the building envelope energy-efficient in a study based on office building located in subtropical monsoon climate of Bangladesh [10]. In addition to passive, the importance of active strategies were also discussed in the study [11] which indicated the possibility of energy reduction. Further, the building energy can be made efficient by making it net-zero, with the renewable energy integration, usually by Solar-PV systems [12].

Studies [13], [7] indicated that there are very few net-zero energy retrofit studies based on Indian climate and NZEBs are still in infancy stage. But, recently the net-zero energy design and retrofit studies have scaled up for CO2 mitigation and achieving the climate targets [8]. Some existing Indian NZE-retrofit studies such as [14] have covered the energy-efficient strategies, these studies have not analyzed the RE generation or solar-PV simulations. This paper proposes the retrofit strategies that can be applied in commercial buildings to reduce the building energy demand. The study here has designed the PV panels by doing the PV system design for the available roof-top area in PVSyst 7.2 software [15]. The novelty of this study is that the roof-top photovoltaic energy generation and the Solar PV performance are studied, unlike other studies, in the temperate climate zone of India. The intention of this study is to retrofit an existing building of Indian temperate climate zone into a NZEB. Also, with the roof-top PV system- design and modelling, the study aims to analyze the annual net-zero building energy balance by simulations.

2 Methodology

The retrofit approach presented in this paper has a systematic flow as shown in Fig.1, in which initially the building will be modelled and its base-case energy consumption will be simulated. Here, the modelling is done through Design builder software, which is integrated with Energy plus simulation software generated by U.S. Dept. of Energy (DOE). [16]. In the first scenario, the retrofit measures will be integrated to the passive side, followed by the retrofit interventions in the active side in the second scenario. After the application of each set of retrofit measures, the energy savings obtained with the intervention of these retrofit measures will be simulated. In the final stage, the remaining minimized energy demand will be covered by the roof top solar-PV installation [17]; thereby converting the existing building into NZEB.

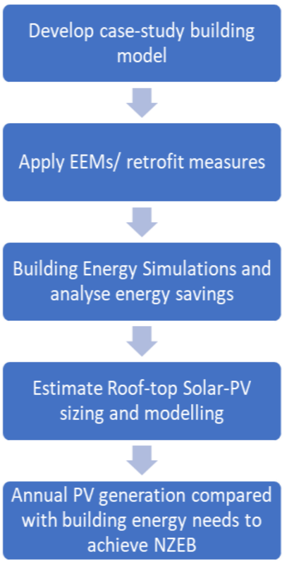

Figure 1: *Retrofit methodology for NZEB*

2.1 Case-study

In this paper, the commercial building taken for analysis is a commercial office building in Adugodi, Bangalore, India. Bangalore is the representative city for temperate climate zone in India. Bangalore's mean temperatures and relative humidity are 14-36 ^{o}C and 35-80%, respectively. [18]. Generally, cooling demand will peak during the summer months from april to june, based on which the cooling system is designed. But here, since the annual net-zero energy performance of building needs to be analyzed, the energy consumption will be simulated over a year.

Here the building and PV system were modelled using Designbuilder tool, as shown in Fig.2 in which initially, the cooling load required for the building was modelled and all the load factors, other activity inputs were accounted for simulation analysis. The software uses templates and weather files integrated with the Energy plus. The case-study building was modelled and simulated with Bangalore weather conditions.

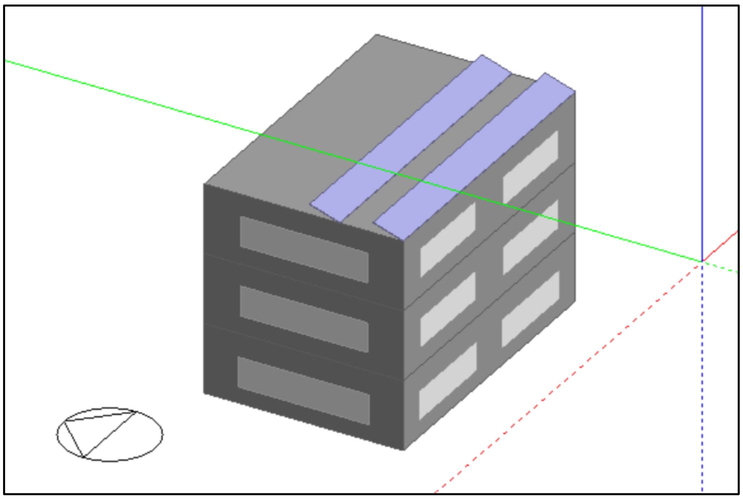

Figure 2 : *Office building model under case-study*

The building has 3 floors with single floor area of 150 m^2 and ceiling height of 3.5 m. The building data related to building envelope, existing cooling systems, lighting systems, occupancy, etc., were collected. Other than data collection, necessary considerations and factors required for analysis were taken from building codes such as ECBC and other relevant sources. The building information required for simulating base-case energy consumption is given in Table.1.

Table 1: *General building data of case-study building*

Sl. No.	Building component details	Input
1	Floor area	150 m^2
2	Employee no. occupied in each floor =	40
3	Window- wall ratio % =	30%
4	Occupancy density (people/m^2) =	0.26
5	Computers and other equipment power density (W/m^2) =	4.72

Here, in this study, the practically possible retrofit measures are applied to the case-study building and the energy savings obtained are analyzed. Roof-top solar PV system is installed to make the building into a NZEB and thereby achieving energy balance as net-zero over a year. The annual building energy consumption along with the solar-PV generation are simulated and compared, to realize whether the electrical loads are satisfied or not. The study helps in identifying the practical retrofit guidelines in making a building into a net/ nearly zero energy building in Indian scenario, with a case-study.

2.2 Retrofit Interventions

The space cooling demand for the building's existing-case was high, as the building envelope had poor insulation. The building had traditional walls with layers of inner brick wall, cement plaster and gypsum plastering as shown in Figure 3. There existed a scope of improving wall insulation along with the retrofit. The windows were single-glazing type with high U-value or solar heat transmittance. Also, the windows were leaking with heat energy transferring between outside and inside. The existing cooling system was highly energy intensive. The electricity consumption of the base-case or pre-retrofit case of the building was simulated with the existing building parameters.

Figure 3: *Thermal insulation calculation with wall layers*

The passive retrofit measures essentially involves replacement of singly- glazing type with more energy-efficient doubly-glazing type windows with low U-value and SHGC. Other strategies included improving the roof and wall insulation to reduce the thermal transmittance or heat transfers between internal and external environment. The thermal insulation in walls were added by fitting glass-fiber insulation boards at the inner surface of the walls, which are generally used in office buildings for thermal insulation. The U-value of wall got improved to 0.46 which is comparable to ECBC compliance.

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In the active side, more than any lighting system or equipment, the energy usage of HVAC system was very high. The existing inefficient high energy consuming packaged air-conditioning system can be replaced by highly energy-efficient split AC system with better coefficient of performance (COP) and low kW/TR. The existing HVAC system was packaged system with high electricity consumption. During monsoon and winter months within the building in some areas, natural ventilation is also allowed. Hence natural ventilation and mixed mode operation features was also considered in the template during simulation. With these retrofit measures integrated or applied to the building model, the building energy consumption was simulated to identify the influence of these measures on the energy consumption reduction.

For making the building energy net-zero, roof-top PV system was designed. The average solar irradiation in Karnataka is 1266.52 W/sq.m. Assuming 5.5 sunshine hours and 1 kWp solar rooftop plant will generate 5.0 kWh of electricity per day over the year. Here the rooftop area is 150 sq.m, of which 60-70% of the roof top can only be considered as the available area. As per the roof top solar- PV calculation provided in the website of Ministry of new and renewable energy (MNRE), the feasible solar-plant generation with the available 50% roof top area is 7.5 kW. The estimated annual electricity generation from solar-PV plant is 11250 kWh as per MNRE. The 7.5 kW solar PV system can be modelled in PVSyst 7.2 software. The PV module and inverter models were selected according to the regional availability. The PV array design data obtained was used to model the roof-top PV panels in design-builder for further building energy simulations and analysis.

3 Results and Discussions

From the energy simulation analysis of building model, it was identified that the retrofit measures in both active and passive side reduced the annual building energy consumption after retrofit as shown in Figure 4 and Figure 5 indicates monthly energy reduction achieved on retrofit with savings obtained. The reduced energy consumption of building after the implementation of retrofit measures or the remaining building electricity demand is 7016.858 kWh. Therefore, the energy generated by the PV panels installation on roof-top can offset the building electricity needs.

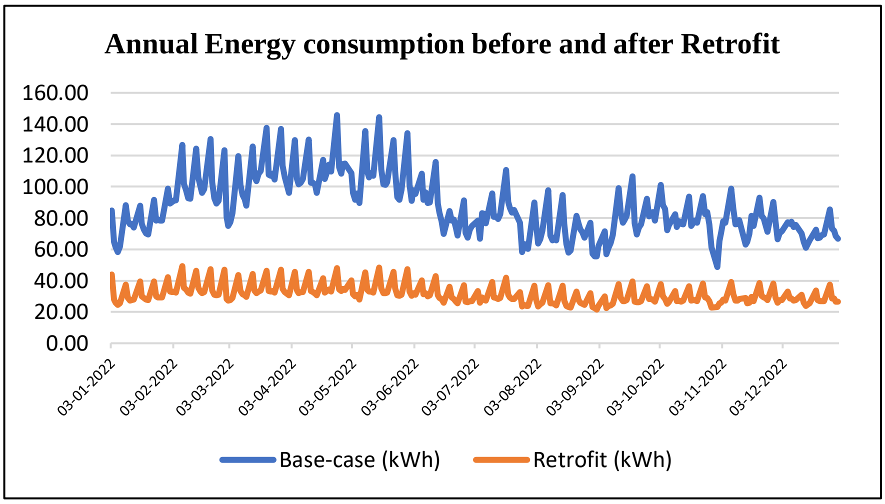

Figure 4: *Annual energy consumption before and after retrofit*

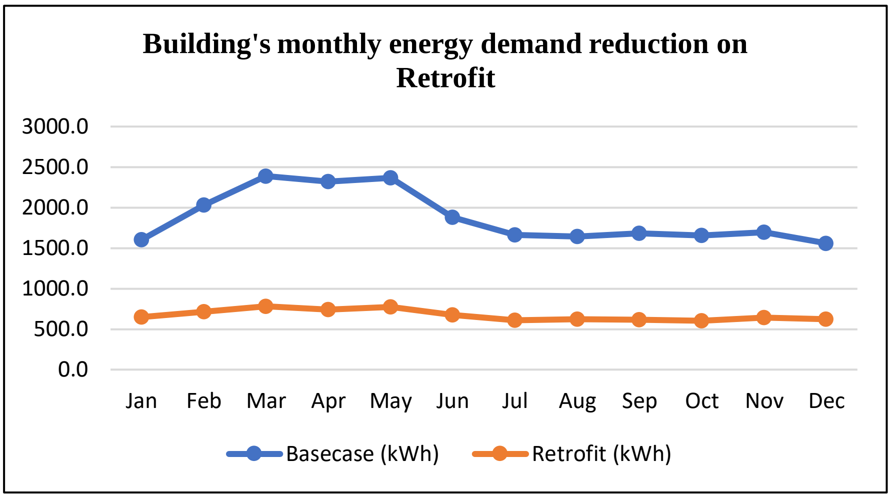

Figure 5: *Monthly energy demand reduction on retrofit*

The PVSyst 7.2 software designs the array and indicates, total number of modules with the number of modules in each string and the number of strings, as shown in Figure 7. By simulating in PVSyst software with the weather file corresponding to the location obtained from Metronome 8, the 7.5 kW rooftop solar PV system with 30 number of modules and total module area of 48 m² is expected to generate 16204 kWh/year, in its ideal optimum condition of performance ratio 0.83. However, practically it will be less. The photovoltaic energy performance of roof-top PV panels designed by PVSyst tool are as indicated in Figure 8. The PV array design data obtained here are used to model the roof-top PV panels in design-builder for further building energy simulations and analysis.

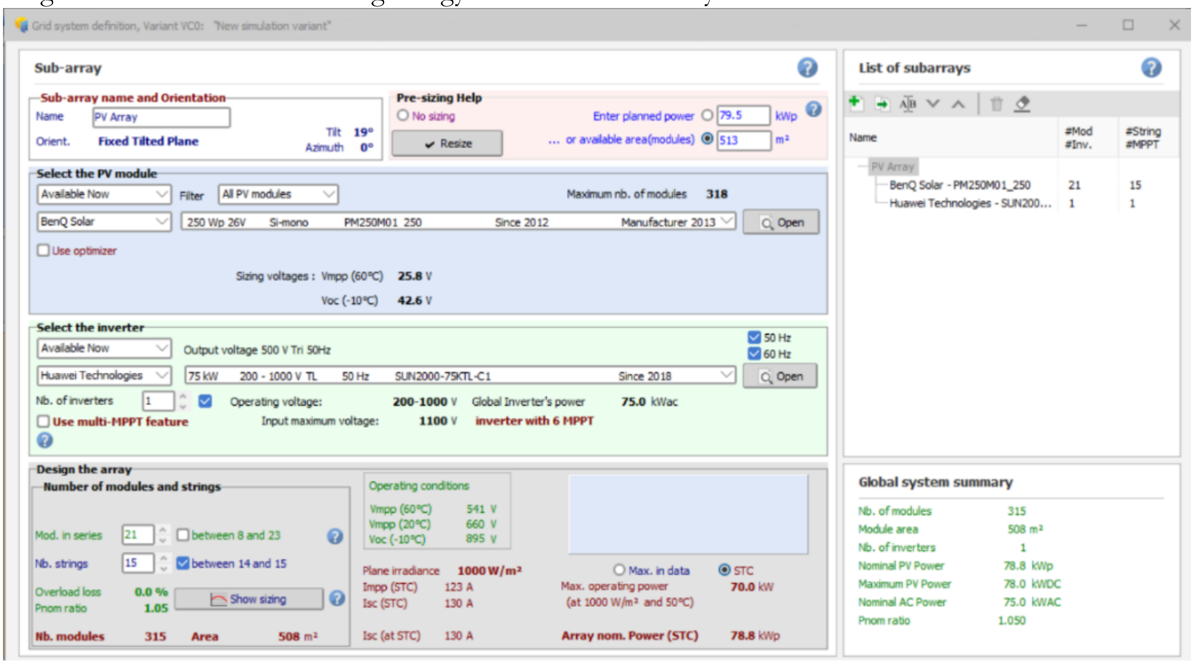

Figure 6: *Roof-top PV Grid system designed in PVSyst*

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	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	170.4	47.28	21.52	204.7	200.0	1691	1653	0.807
February	166.8	52.57	23.90	187.5	183.4	1523	1487	0.793
March	194.9	72.95	26.53	202.9	198.2	1632	1593	0.785
April	190.8	74.34	27.23	184.1	179.3	1484	1447	0.786
May	191.2	84.24	26.50	174.5	169.0	1430	1395	0.799
June	161.6	80.26	24.03	144.0	138.9	1210	1179	0.819
July	148.4	78.68	23.62	134.9	130.3	1138	1107	0.821
August	146.0	77.14	23.21	138.0	133.8	1164	1134	0.821
September	153.2	68.82	23.27	153.4	149.2	1274	1242	0.810
October	154.3	76.57	23.42	164.9	161.0	1375	1341	0.813
November	133.5	62.23	21.89	151.1	147.6	1269	1237	0.819
December	143.1	60.21	21.19	169.2	165.3	1424	1390	0.822
Year	1954.2	835.29	23.85	2009.3	1956.0	16614	16204	0.806

Figure 7: *PV Electricity generation results obtained from PVSyst 7.2*

Since, the building energy simulations of before and after retrofit cases were analyzed in design builder software, the photovoltaic energy generated on-site with the modelled roof-top PV system was analyzed in the same. The design builder results indicated annual photovoltaic power electricity of 12741.06 kWh and 12231.421 kWh with consideration of power conversion as shown in Figure 9. This could offset the remaining building energy demand of 7016.858 kWh, giving surplus electricity going to utility.

The building could achieve net-zero energy balance with solar PV panels covering 50% roof area. The energy performance of retrofit case with monthly PV generation, is as shown in Figure 10. The results indicated that PV-system generated significant solar power than the- building-energy demand. In this case, the-building could achieve net-zero energy, also has become a positive-energy building, by more renewable-energy generation than the building energy demand thereby giving surplus electricity back to grid.

Electric Loads Satisfied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	12741.064	181.58
Wind Power	0.000	0.00
Power Conversion	-509.64	-7.3
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	12231.421	174.31
Electricity Coming From Utility	2301.098	32.79
Surplus Electricity Going To Utility	7515.660	107.11
Net Electricity From Utility	-5214.56	-74.3
Total On-Site and Utility Electric Sources	7016.858	100.00
Total Electricity End Uses	7016.858	100.00

Figure 8: *Electric loads satisfied with PV generation simulations*

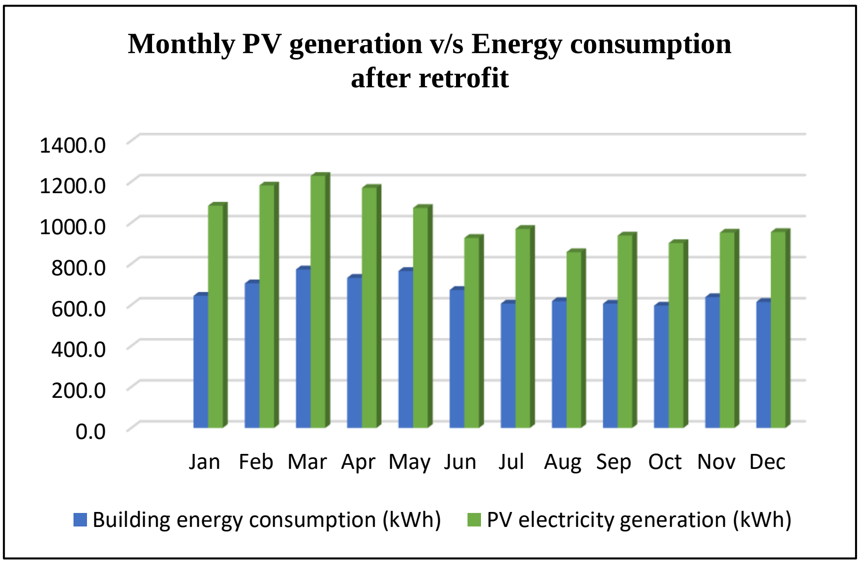

Figure 9: *Building energy demand vs. PV generation on-site*

4 Conclusions

This study offers the possibility of retrofitting existing small-sized commercial buildings into net/nearly zero energy buildings with efficient building envelope, cooling energy systems and roof-top solar-PV systems in temperate climate zone of India. The study proposed the net-zero energy retrofit guidelines or approach for reducing the building energy demand with effective systems and RE strategies. In addition, this study also offered a methodology by which the roof-top PV system can be designed and the electric loads satisfied by PV generation on-site. The photovoltaic energy generation along with the building energy demand can be analyzed over a year by design-builder simulations. With the suggested approach the office building here under case-study, could achieve net-zero energy.

However, the available roof-top area is a major constraint in achieving net-zero. In some special cases, the required orientation of PV panels incoming maximum solar radiation cannot match with the building form and orientation. Also, the building energy consumption generally increases with building area and size. In high-rise buildings, the building energy consumption will be too high to get offset with the limited roof-top PV installation. Therefore, this study has a future scope of exploring net/nearly zero energy buildings with building applied photovoltaics (BAPV). There is also a future scope of studying cost-benefit analysis with such PV retrofit technologies in commercial buildings of India.

5 Publisher's Note

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