Creative Construction Conference 2019, CCC 2019, 29 June - 2 July 2019, Budapest, Hungary

Energy Retrofitting of a Commercial Building Towards a” Net Zero Energy Building” by Simulation Model

Aakash Patel^{a,*}, Dhruv Ghodasara^a, Nimish Bhatt^b, Anurag Kandya^c

^aDepartment of Civil Engineering (PDPU) – Pandit Deendayal Petroleum University, Raisan, Gandhinagar, Gujarat - 382007, India.

^bLecturer, Department of Civil Engineering (PDPU) – Pandit Deendayal Petroleum University, Raisan, Gandhinagar, Gujarat - 382007, India.

^cAssistant Professor, Department of Civil Engineering (PDPU) – Pandit Deendayal Petroleum University, Raisan, Gandhinagar, Gujarat - 382007, India.

Abstract

Energy is one of the major drivers of a growing urban infrastructure development. The consumption of energy by different sectors of urban infrastructure are very high and the amount of energy produce is not enough to meet the huge demand of energy. According to several types of research, it is found that building sector is consuming about 40% of energy which is very significant. For heating and cooling of building sector 32% energy is used and its major impact is greenhouse gas emission. This study presents a simulation model that combines building properties and energy consumption of an existing commercial Building in Ahmedabad city (India). This research targets to study how to integrate active design strategies and energy-efficient building materials to improve the building performance and reduce energy consumption towards Net Zero Energy Building (NZEB). This research will suggest few changes in materials of building will be considered as retrofitting and it can lead to the concept of Net Zero Energy building (NZEB). For the analysis and simulation of energy, Design- Builder software is used.

© 2019 The Authors. Published by Budapest University of Technology and Economics & Diamond Congress Ltd.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2019.

Keywords: *Energy Retrofit; Net Zero Energy Buildings (NZEB); Commercial Building; Building Envelope; Simulation.*

1. Introduction

Energy is a basic requirement for economic development in almost all major sectors of Indian economy-agriculture, industry, transport, commercial, and residential. In India, 33% of the total energy is used by the buildings, out of which 24% by residential and 9% commercial as shown in Figure 1. Buildings are one of the major consumers of energy and are the third largest consumers of energy, after industry and agriculture.

*Corresponding author: Author email: patelaakash1495@gmail.com

Figure 1. Consumption of Electricity by Sectors in India during 2016-2017

The absolute figure is rising fast, as construction booms, especially in developing countries such as India. Currently, approximately 659 million m² spaces are used as commercial space and in 2030, it is estimated that it would increase to 1,900 million m² and by then more than 60% of the commercial built space would be air-conditioned as shown in Figure 2. [1]

Figure 2. 66% building stock is yet to be constructed

Mentioning the harmful emissions in India, the CO₂ per capita emissions reached 1.73 Metric ton/year in the latest [2]. For this reason, the building sector represents a large potential for significantly reducing energy demand and harmful emissions.

In commercial buildings, the high demand for energy used for lighting, heating, ventilation, and air conditioning leads to a significant amount of carbon dioxide emissions. To control this escalating reliance upon fossil fuels and tackle future climate change, it is important to apply effective techniques to upgrade the existing commercial buildings, developing energy efficient commercial buildings based on the integration of advanced energy-saving concepts and adaptive reuse methods. On one hand, taking Net-Zero Energy Building (NZEB) concept into commercial retrofits will improve the energy efficiency levels in existing commercial buildings, exploring the possibilities of involving renewable energy sources in order to reduce their dependence on external energy infrastructure. On the other hand, since the life of commercial buildings is extended and possible demolition waste is avoided, net-zero energy commercial retrofits also contribute to the development of a sustainable urban regeneration form [3].

The idea of NZEB has been widely explored and implemented during the last few years as a way to achieve energy efficiency in the building sector and encourage renewable energy incorporation on-site. “Net or nearly zero site energy buildings (NZEB) are highly efficient buildings with extremely low energy demand, which is met by renewable energy sources. Such buildings produce as much energy as they consume, accounted for annually” as shown in Figure 3.

Figure 3 “Net Zero Site Energy Concept”

Through reusing and upgrading existing buildings, the performance of the existing commercial buildings can be improved, thus bringing more opportunities to reinvigorate the large stock of existing commercial buildings and benefit local economies in the long run. Typically, achieving net-zero energy goals can be realized through improving building enclosures, implementing passive design strategies, installing high-performance HVAC systems to reduce heating and cooling loads, reducing lighting and other electric loads, thus making it possible to offset the required energy balance with renewable means, such as solar photovoltaics or wind turbines. Achieving net-zero energy goals is a challenging objective, especially when it comes to retrofit projects, because more constraints are typically imposed on existing buildings than new construction. This paper presents the effective ways to address those physical and economic constraints in commercial retrofits and investigates applicable strategies to achieve NZEBs [3].

Energy-efficient measures, applied to existing buildings during minor/major retrofits, reducing their energy consumption, building envelopes can be grouped into three categories:

1. wall thermal insulation and thermal mass
2. windows/glazing (including day- lighting)
3. reflective roof /green roofs

This study examines the potential of retrofitting an office building in order to become NZEB using DESIGN BUILDER software.

2. Methodology

Firstly, make the present building in DESIGN BUILDER software and simulate its energy consumption was examined. The second step was the minimization of energy consumption applying energy-efficient measures. Finally, the minimized energy was covered applying renewable energy technologies on the building in order to achieve the conversion of the present building into NZEB Figure 4.

Figure 4 Step of the Project

The minimization of energy consumption requires the application of energy-efficient measures. Energy-efficient measures can be classified into three categories: measures which could be applied in building envelopes. Four scenarios

were examined aiming at minimizing the energy consumption of the building and three more in order to cover this minimized energy with renewable energy technologies. Those scenarios are presented in Table 1.

Table 1 Description of Scenario

Description of Scenarios			
Scenario – 1	Combination of following improvements on building envelopes	Insulation on Walls	Replacement of Windows
Scenario – 2	Combination of following improvements on building envelopes	Insulation of Ceiling	
Scenario – 3	Combination of Scenario 1 & 2		
Scenario – 4	Installation of Photovoltaic Panels		
Scenario – 5	Combination of Scenario 3 & 4		

3. Case Study

3.1 Description of the study area

The building IB Law House located in the Navrangpura, Ahmedabad, Gujarat, India. For Indian climate, the comfort range of still air corresponds to 23-41 °C dry bulb temperature with 30– 60% relative humidity. In India Winter, occurring from October to February then Summer season, from April to June and Monsoon or rainy season, from July to September.

Ahmedabad's comes under the mostly hot & dry or all year round. Ahmedabad's Mean Monthly temperature (°C)>30, its Relative Humidity>50.

Weather Data Sources: -

This report illustrates the typical weather station at Sardar Vallabhbhai Patel International Airport, based on hourly weather reports and model reconstructions from January 1, 1980, to December 31, 2016.

Temperature: -

The hot season occurs in 3 months, from April to June, with an average daily high temperature above 38°C. The hottest month of the year is May, with an average high of 42°C and low of 28°C. The cool season occurs in 3 months, from December to February, with an average daily high temperature below 30°C. The coldest month of the year is January, with an average low of 13°C and a high of 27°C as shown in figure 5.

Figure 5 Average High and Low Temperature

The "mean daily maximum" (solid red line) shows the maximum temperature of an average day for every month for Ahmedabad. Likewise, "mean daily minimum" (solid blue line) shows the average minimum temperature. Hot days and cold nights (dashed red and blue lines) show the average of the hottest day and coldest night of each month of the last 30 years as shown in figure 5.

3.2 Building data gathering

The building IB Law House is situated in the Navrangpura, Ahmedabad, Gujarat, India, its coordinates are 72.57° Longitude 23.03° latitude. The building was constructed in 2011 and it is a two-story building with a total height of 10.50m and total length of 20m.

The ground floor (258 m²) and the first floor (262 m²) consist of two main offices, entry lobby, waiting hall, two prayer room, conference room, record room, toilets, and pantry room. The second floor (34 m²) accommodates for the storage area, toilet, and stair cabin as no employees work there. The building has ground floor, first floor and second floor with terrace with a total 28 numbers of zones, 12 numbers of zones are fully air-conditioning and others are naturally ventilated.

Building operating schedule is from 10:00 am until 7:00 pm every day only Sunday close, office work is light work such as typing, consulting, meeting, it can include internal corridors providing access to the office space, tea/coffee making facilities or kitchenettes within the office space and also area for photocopiers, building general information is shown in Table 2.

Table 2 Building summary

	Description
Location	IB Law House, Navrangpura, Ahmedabad, Gujarat
Orientation	West East (WE)
Use	Office Facility
Office Occupancy	30 (with Owners and Employees)
Stories	Ground Floor, First Floor and Second Floor with Terrace
Total Area	1026 sq.m
Building Area	544.52 sq.m
Structure	Mixed Type Structure with RCC & Bricks
Building Height	10.5 m
HVAC System	Split AC + Mechanical ventilation system without heat recovery
Lighting System	All are LED Lights

Based on architectural drawings and specifications, the original design was simulated using the program Design Builder to investigate the energy efficiency Figure 6. The typical floor plan of the ground floor, first floor, second floor with terrace and 3d model for the prototype are as seen in Figures 6a and 6b respectively.

Figure 6a Typical floor plan for the case study building

Figure 6b 3d model for the case study building

3.3 Building data analysis

The most important data to be considered in this case is the energy consumption data because it has a direct impact on the amount of energy to be saved either through retrofit or to be generated by the renewable energy system. The electricity consumption data from Torrent Power, Ahmedabad, Gujarat, India is used, an average consumption monthly rates were detected as seen in Figure 7 from the actual electricity bills of the case study building.

Figure 7 Monthly electricity consumption of the case study office building – 2018

3.3 The initial condition of the Building

The case study has been analyzed via computer software tools (Design Builder) according to its original orientation and weather conditions.

By analyzing the data provided in the previous section and through visual investigation, it was found that the building's energy performance can be categorized as poor due to the following:

- The building is only insulated by the traditional thermal insulation on the roof of the top floor as provided by the owner.
- There is traditional shading over the windows to prevent direct sunlight from entering the interior space.
- The windows are single glazed.

- The windows are leaking, so the amount of heat energy transferred from the outside to the inside is significant.
- The HVAC system is a split system not central, and mostly in a moderate condition.

Cross-section view of wall, roof and window with overhang and internal blinds as shown in Figure 8a, Figure 8b and Figure 8c.

Figure 8a Cross-section view of the

Figure 8b Cross-section view of roof

Figure 8c Cross-section view of a window with overhangs and internal blinds

The electricity consumption data from simulation in design builder software. The energy consumption is approximately 24,113 kWh (45 kWh/m²) for cooling, 11,439 kWh (21 kWh/m²) for auxiliary, for lighting and computers & equipment is 4,413 kWh (8 kWh/m²) and 3,357 kWh (6 kWh/m²) and for miscellaneous is 167 kWh (0.31 kWh/m²) respectively as shown in Figure 9.

Figure 9 Energy simulation data of original office building

4. Building Components

4.1 Wall

Walls constitute a major part of the building envelope and receive a large amount of direct solar radiation. The resistance to heat flow through the exposed walls may be increased by increasing the thickness (thermal mass), through the cavity wall, by the use of insulating material or by applying light-colored whitewash or distemper on the exposed side of the wall. As per Energy Conservation Building Code (ECBC), recommended U Value wall assembly for 24-hour use building and for daytime use building are given in Table 3.[4]

Table 3 Opaque Wall Assembly U-Factor and Insulation R-value Requirements

Climate Zone	Hospitals, call centres (24-hours)		Other Buildings (Daytime)	
	Maximum U-factor of the overall assembly (W/m ² *K)	Minimum R-factor of the overall assembly (m ² *k/W)	Maximum U-factor of the overall assembly (W/m ² *K)	Minimum R-factor of the overall assembly (m ² *k/W)
Composite	U-0.440	R-2.10	U-0.440	R-2.10
Hot and Dry	U-0.440	R-2.10	U-0.440	R-2.10
Warm and Humid	U-0.440	R-2.10	U-0.440	R-2.10
Moderate	U-0.440	R-2.10	U-0.440	R-2.10
Cold	U-0.369	R-2.10	U-0.352	R-2.35

4.2 Roof

The roof of a building receives a significant amount of solar radiation. Thus, its design and construction play an important role. The heat gain through roofs may be reduced by the use of insulating materials may be applied externally or internally to the roofs. According to ECBC the recommended U-value of roof assembly should be 0.261 and the R-value 2.10 for 24-hour use building and 0.409 and the R-value 2.10 for daytime use building, recommended roof Assembly U-Factor and Insulation R-value Requirements for 24-hour use building and for daytime use building are given in Table 4.[4]

Table 4 Roof Assembly U-Factor and Insulation R-value Requirements

Climate Zone	Hospitals, call centres (24-hours)		Other Buildings (Daytime)	
	Maximum U-factor of the overall assembly (W/m ² *K)	Minimum R-factor of the overall assembly (m ² *k/W)	Maximum U-factor of the overall assembly (W/m ² *K)	Minimum R-factor of the overall assembly (m ² *k/W)
Composite	U-0.261	R-3.5	U-0.409	R-2.10
Hot and Dry	U-0.261	R-3.5	U-0.409	R-2.10
Warm and Humid	U-0.261	R-3.5	U-0.409	R-2.10
Moderate	U-0.409	R-3.5	U-0.409	R-2.10
Cold	U-0.261	R-3.5	U-0.409	R-2.10

4.3 Vertical Fenestration

Fenestration includes products with glass or other transparent or translucent materials. Fenestration, Vertical: Windows that are fixed or movable, opaque doors, glazed doors, glazed block, and combination opaque and glazed doors installed in a wall. In ECBC there are some criteria like:

- Maximum allowable Window Wall Ratio (WWR) is 40%.
- Minimum allowable Visual Light Transmittance (VLT) is 0.27.
- Assembly U-factor includes both frame and glass area weighted U-factors.
- Assembly SHGC includes both frame and glass area weighted SHGC (Solar Heat Gain Coefficient)

as per ECBC the recommended U-factor and SHGC requirements shown in Table 5.[4]

Table 5 Vertical Fenestration Assembly U-factor and SHGC Requirements for ECBC

	Composite	Hot and dry	Warm and humid	Temperate	Cold
Maximum U-factor($w/m^2 \cdot k$)	3.00	3.00	3.00	3.00	3.00
Maximum SHGC Non-North	0.27	0.27	0.27	0.27	0.62
Maximum SHGC North for latitude > 15°N	0.50	0.50	0.50	0.50	0.62
Maximum SHGC North for latitude < 15°N	0.27	0.27	0.27	0.27	0.62

4. Case Study Simulation: Findings and Analysis

As it has been stated before in the Methodology section, the case study has been analyzed via computer software tools (Design Builder) according to its original orientation and weather conditions. By entering the building envelope parameters and material specifications and glazing transparency, the program can analyze the inputs and provide accurate data on an annual basis which helps to evaluate different passive design elements that influence the energy efficiency of the building. The results show more U-factor and R-factor in wall, roof and windows shows a high above that required, as seen in Figure 10a, Figure 10b and Figure 10c.

Figure 10a U-value and R-value of wall

Figure 10b U-value and R-value of Roof

Figure 10c Effect of U-value, SHGC and VT in window

In terms of the interior environment, on an annual basis, Figure 11 shows hourly temperatures which are examined to define the temperature variable between seasons in the interior spaces. These are used to calculate the cooling/heating load demanded that provides thermal comfort for occupants, and determines the total heat gain according to the building construction materials (walls and windows). The results are as follow:

- 1) From November to March (winter season): the average external temperature is between 21.3 °C and 34.9 °C.
- 2) From April to October (summer season): the average of external temperature increases to between 31.1 °C and 41.1 °C.
- 3) From November to March (winter season): the average internal temperature is between 20.7 °C and 30.2 °C.
- 4) From April to October (summer season): the average of internal temperature increases to between 30.9 °C and 41 °C.

Figure 11a Outside Temperature of the building Including Top, Front, Left, Right and Back View

Figure 11b Ground floor Inside Temperature of the building

Figure 11c First floor Inside Temperature of the building

5. Scenarios of minimizing the energy consumption of the building

➤ Scenario-1

In this scenario, changes in the building envelope were examined. These changes include, firstly, the increase in wall insulation and windows aiming at the reduction of the thermal transmittance between the internal and the external environments, i.e. the U-value, SHGC, VT. The next measure, applied, was the replacement of present windows with more energy-efficient ones with lower U-value, SHGC and VT. These measures are presented in Table 6 and Figure 12.

Table 6 Wall Insulation Assembly

Building Component	Thermal Transmittance/U value (W/m ² *K)	Thermal Resistance/R value (m ² *k/W)
Wall		
Glassfibre wool(50mm)	0.534	1.871
1.5cm Cement plaster + 23cm Burned brick + 5cm Glassfibre wool insulation + 1.5cm Cement plaster

Figure 12 Window Replace into Low Electrochromic Reflected Coloured Double Glazing with Argon Gas (6mm/13mm Argon Gas)

➤ Scenario-2

In this scenario, changes in the building Roof. These changes include, firstly, the increase in roof insulation aiming at the reduction of the thermal transmittance between the internal and the external environments, i.e. U-value and R-value. These measures are presented in Table 7.

Table 7 Roof Insulation Assembly

Building Component	Thermal Transmittance/U value (W/m ² *K)	Thermal Resistance/R value (m ² *k/W)
Roof		
XPS Sheet HFC/CO ₂ Blowing(70mm)	0.361	2.767
4cm Concrete Flooring + 7cm XPS Extruded Polystyrene Sheet + 5cm Cement Motar Mix + 12cm RCC with 2% steel + 1.5cm Cement plaster		

➤ Scenario-3

In this scenario it was examined how much energy consumption can be achieved by applying measures on building envelopes and internal conditions. Figure 13 describes the combination of Scenario 1 & 2. Form the combination of the scenario 1 & 2 the building energy reduces and the model output is 32265.73 kWh/year shown in Figure 13.

Figure 13 Reduction of energy consumption applying different scenarios

➤ Scenario-4

Average solar irradiation in GUJARAT state is 1,266.52 W/sq.m 1kW solar rooftop plant will generate on an average over the year 5.0 kWh of electricity per day (considering 5.5 sunshine hours). In this case, the building has an accessible working roof area is round about 250sq.m. As per Ministry of New and Renewable Energy in the solar rooftop calculator, 25.0 kW feasible plant size as per site area. Total electricity generation from the solar plant in Annual is 37,500 kWh/year and life of the Photovoltaic panel is 25 years that means solar plant Life-time generation is 9,37,500 kWh (Ministry of New and Renewable Energy).

➤ Scenario-5

From Scenario 3, the reduced energy consumption is 32265.73 kWh/year. The PV panels installed on the rooftop building produce approximately 37500 kWh/year but there is always any system constraints and also the electricity generation is may vary from location condition during on site. So, renewable energy technologies in total produce almost the same quantity of energy consumed.

6. Conclusions

This research investigated how to achieve net-zero energy in existing buildings. And the objective was how commercial buildings in Ahmedabad can reach net-zero energy goals, by taking a commercial two-story building as a research target, the results show an almost 30% reduction in annual energy consumption after applying a combination of scenario to reduce the annual consumption and increase the building energy performance. Most of the energy savings were obtained just through optimizing the existing situation, without replacing or increasing efficiencies.

Focusing only on the energy reduction, by applying energy-efficient measures without considering the cost required, it is the combination of the four energy-efficient scenarios each causing a reduction in the required energy.

Scenario 1, according to which changes on Building Envelope were applied on wall and windows, proved the most energy-efficient among the first four scenarios. The main reason for this effectiveness is because it managed to reduce the cooling needs, which are the main source of consuming energy in the building, by 69%. The less effective scenario proved Scenario 2, as well as, it brought about only a slight reduction in required energy.

In conclusion, the energy-efficient measures with descending efficiency order are the following;

- Increasing the insulation on the walls in Internal and External, improve Thermal Transmittance and Thermal Resistance.
- Replacement of Windows with increasing the airtightness of the building.
- Increasing the insulation on the roof and reducing the heat gain effect on the building.

Concerning the renewable energy, the PV panels produce energy (37,500 kWh/year) it is contributing to achieving NZEB. The PV panels produce the most significant quantity of energy from March to September. Therefore, the energy production derived from renewable energy sources has the same quantity as the energy consumption of the building. Subsequently, by applying the best-case scenario (energy-efficient measures in combination with renewable energy sources), the retrofitting of the present building in order to become an NZEB is achieved.

Acknowledgments

The authors cordially acknowledge Pandit Deendayal Petroleum University (PDPU), Gandhinagar for the resources and financial assistance to carry out the study. The software used for analysis were from sot department of PDPU. These supports are gratefully acknowledged by us. I also express our gratitude to Mr. Naimish Bhatt and Dr. Anurag Kandya for their valuable suggestion and motivation. The authors would like to acknowledge the support of IB LAW House, Navrangpura, Ahmedabad, Gujarat, India for providing data and files for this research which is been conducted as a part of a dissertation for M. Tech in Infrastructure Engineering and Management, Pandit Deendayal Petroleum University, Gandhinagar, India.

References

- [1] Bano, F., & Kamal, M. A. (2016). Examining the role of building envelope for energy efficiency in office buildings in India. *Architecture Research*, 6(5), 107-115. <https://doi.org/10.5923/j.arch.20160605.01>
- [2] CO₂ emission in India: <https://www.worldbank.org/en/about>
- [3] Aksamija, A. (2015). Regenerative design of existing buildings for net-zero energy use. *Procedia engineering*, 118, 72-80. <https://doi.org/10.1016/j.proeng.2015.08.405>
- [4] Energy Conservation Building Code © 2017 Bureau of Energy Efficiency Energy Conservation Building Code for Residential Building 2017, Part I: Building Envelope.
- [5] ASHRAE 90.1. ANSI/ASHRAE/IES Standard 90.1, Energy Standard for Buildings except low rise residential Building. Atlanta : ANSI/ASHRAE/IES, 2013.
- [6] AbuGrain, M., & Alibaba, H. (2017). Optimizing existing multistory building designs towards net-zero energy. *Sustainability*, 9(3), 399. <https://doi.org/10.3390/su9030399>
- [7] Bigot, D., Miranville, F. A., Ingar, I., Guichard, S., & Boyer, H. (2010). Thermal performance of photovoltaic systems integrated in buildings. *Solar Collectors and Panels, Theory and Applications*, 405-28. <https://doi.org/10.5772/10347>
- [8] Brock, L. (2005). *Designing the exterior wall: An architectural guide to the vertical envelope*. Wiley.
- [9] *Building Energy Simulation : A Workbook Using Designbuilder*, Vishal Garg, Jyotirmay Mathur, Surekha Tetali, Aviruch Bhatia.
- [10] CBRE. CBRE: India Office Marketview - Q1 2015. CBRE India. [Online] April 2015. [Cited: september 5, 2016.] <http://www.cbre.co.in/aboutus/mediacentre/mediaarchives/Pages/Office-space-take-up-witnesses-46-rise-in-Q2-2016-over-Q1-2016.aspx>
- [11] Chalfoun, N., Cardona, V., & Franz-Ünder, R. (2011). Using computer simulation as a tool to develop a net-zero energy code for Tucson, Arizona. In *Building Simulation*.
- [12] Charnalia, A., Mathur, J., & Rawal, R. INTEGRATION OF SOLAR PHOTOVOLTAICS: TO SUFFICE INTERIOR LIGHTING ENERGY CONSUMPTION OF OFFICE BUILDINGS IN AHMEDABAD.
- [13] Climate Ahmedabad. Available online: https://www.meteoblue.com/en/weather/forecast/modelclimate/ahmedabad_india_1279233
- [14] Code of Practice for Energy Efficiency of Building Services Installation (2015).

- [15] Albadry, S., Tarabieh, K., & Sewilam, H. (2017). Achieving Net Zero-Energy Buildings through Retrofitting Existing Residential Buildings Using PV Panels. *Energy Procedia*, 115, 195-204. <https://doi.org/10.1016/j.egypro.2017.05.018>
- [16] ES ISO 2012 : Thermal performance of windows, doors and shading devices – Detailed calculations.
- [17] Ferrari, S., & Beccali, M. (2017). Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. *Sustainable cities and society*, 32, 226-234. <https://doi.org/10.1016/j.scs.2017.03.010>
- [18] IS : 3792 – 1978 Guide for Heat Insulation of Non-Industrial Buildings.
- [19] Kang, J., Ahn, K., Park, C., & Schuetze, T. (2015). Assessment of passive vs. active strategies for a school building design. *Sustainability*, 7(11), 15136-15151. <https://doi.org/10.3390/su71115136>
- [20] Kumar, S., & Ambassador, E. E. (2011). *Benchmarking Energy Use in Buildings and Cleanrooms*. Bangalore: ISA Vision Summit.
- [21] Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I., & Napolitano, A. (2011). Zero Energy Building—A review of definitions and calculation methodologies. *Energy and buildings*, 43(4), 971-979. <https://doi.org/10.1016/j.enbuild.2010.12.022>
- [22] National Building Code of India 2016 : Volume 1.
- [23] National Building Code of India 2016 : Volume 2.
- [24] Pyloudi, E., Papantoniou, S., & Kolokotsa, D. (2015). Retrofitting an office building towards a net zero energy building. *Advances in Building Energy Research*, 9(1), 20-33. <https://doi.org/10.1080/17512549.2014.917985>
- [25] S.Suresh, R.Prasanna, K.Rajeshkanna, S.Rajmareeswaran (2019). Experimental investigation of Thermocrete panel. *International Research Journal of Engineering and Technology (IRJET)*.
- [26] Sailor, D. J., Elley, T. B., & Gibson, M. (2012). Exploring the building energy impacts of green roof design decisions—a modeling study of buildings in four distinct climates. *Journal of Building Physics*, 35(4), 372-391. <https://doi.org/10.1177/1744259111420076>
- [27] Sharma, S. K. (2013). Zero energy building envelope components: A review. *International Journal of Engineering Research and Applications*, 3(2), 662-675.
- [28] SP : 41(S & T) – 1987 Handbook on Functional Requirements of Buildings(Other than Industrial Buildings).