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Net Zero Energy in a Residential Building Using Heuristic Optimization Solution

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Abstract
In recent times, improvement of building designs has been on a steady upward trend, precipitated by large greenhouse gas emissions of energy draining outmoded construction materials. Global energy crisis exacerbated by climate change has motivated the design and construction of energy efficient Net Zero Energy Buildings (NZEB). This paper proposes an energy management strategy for grid-connected Net Zero Energy Buildings that help to achieve a net zero balance of energy in Electrical Grid-Photovoltaic connected NZEB homes. The significance of NZEB was evaluated by providing insights into cost savings for the consumer's net energy consumption, and reduced carbon footprint. The proffered energy management strategy uses a single objective Differential Evolution (DE) optimization algorithm that prunes the demand for electrical energy through an efficacious appliance scheduling routine. A novel mathematical energy index is introduced that enables consumers to monitor the net energy imported from the electrical grid and maintain a zero-energy index. The proposed net zero energy concept is validated using DE and Genetic Algorithm (GA) based optimization techniques.
Keywords: Net Zero Energy Buildings, Differential Evolution, Energy Management, Single-Objective Optimization, Renewable Energy, Genetic Algorithm

1 Introduction

1.1 State of Art

The World Economic Forum Global Risk Report 2019, designates environmental concerns in the top ten major risk posed to humanity, in terms of impact and likelihood. This have adversely affected life on the planet, and set an alarm worldwide, to undertake remedial measures to control carbon footprints. The European Commission's Horizon 2020 is one such vision intended to tackle the climatic challenges around the world (Spataru et al. 2015). Developing countries like Brazil, China, and India are headed on a fast track towards self-sustained economy by augmenting their generation capacity for clean energy (Robert et al. 2018). Climatic challenges require a reappraisal of the modus operandi, by which humans harness nature. Increased usage of renewable energy is a positive step towards realization of economic security and switch over to clean energy. Enhanced use of renewable energy in 2018 had a notably greater impact on reduced CO2 emissions worldwide, to the extent of 215 Mt (IEA 2019). The 2016 Paris Climate Treaty set a capacity target of 175 GW renewable energy by 2022. Smartly managed, standards compliant renewable energy technologies can become a reliable source of clean energy (Madathil et al. 2019). Despite the impressive growth rate in India's economy, in recent times, the nation has a low per capita income rating compared to worlds developed economies. (Ranganadham 2018), reports that during the year 2016-17, India's electricity consumption increased by 7.8%. In 2015, India's per capita emission of CO2 equivalent was 1.6 t, about 38 % of the worldwide CO2 emissions (Srikanth 2018). India's electric power sector was the largest contributor of CO2 emissions in 2015, emitting 50 % of the total CO2 emissions from fuel combustion (Srikanth 2018). The electric sector contributes nearly 44 % of the total green-house gas (GHG) emissions in India (Sarangi et al. 2019). Globally, buildings account for nearly 40 % of the total primary energy consumption and one-third of GHG emissions (Ranganadham 2018). Of late, India's building sector has seen tremendous growth rate, expected to rise above 40 billion square meter by 2050 (Zhao et al. 2016). As per the Climate Works Foundation's Annual Report of 2010, India's total building energy consumption is about 33% with an annual increase of 8% (Yu et al. 2017). In its fight against climate change, the Government of India has identified buildings as one of the delinquent sectors; hence, Net Zero Energy Buildings (NZEB) that incorporate low carbon technologies are gaining traction for a reliable and sustainable future. In the recent past, NZEBs have drawn increased attention, in the wake of global impetus to conserve energy and minimize greenhouse gas emissions.

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1.2 Literature Review

The earliest attempts of zero energy was traced during 1960s and the net zero energy definitions were introduced in the year 2010. "A Zero energy building (ZEB) is a residential or commercial building with a greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies" (Pless et al. 2010). A ZEB can be ‘off ’grid or ‘on’ grid. Definition of a ZEB varies with respect to entity, organization and country. The term net zero energy was articulated in the year 2008 by the members of Task 40 as an annual energy balance between the generated and consumed energy for a building (Williams et al. 2016). In the technical report by the National Renewable Energy Laboratory (NREL) prepared under Task BEC7.1210, BEC7.1123 mentions about the grid-connected Net zero energy buildings (NZEB) that uses traditional energy sources when on-site renewable energy does not meet the loads and excess energy being exported to the utility when on-site generation exceeds the energy demand (Marszal et al. 2011). NZEB draws attention to the imperative of minimizing the overall usage of energy in building construction, along with efficient lighting and heating, ventilation and air-conditioning (HVAC) and systems. The design of smart NZEBs is possible with a combined approach to energy efficiency and passive designs (Garde et al. 2017). The optimized NZEB approach predicts and manages the impact on the grid (Harkouss et al. 2019). In (Yun et al. 2019), a heuristic glowworm swarm algorithm is designed to refine the optimization of the grid-interactive NZEB. In (Li et al. 2019), three methods to achieve advance NZEBs are described. (Li et al. 2019), suggests that by minimizing the energy demands of a building, enhancing on-site renewable energy supply, and matching the overall load based on the consumption pattern, energy demand and renewable energy supply, NZEBs can be realized. Development of appropriate models of building designs and control strategies are inevitable for the effective design and implementation of a NZEB, besides modeling the relevant thermal, electrical and architectural subsystems to meet the energy efficiency standards set by the national regulatory. The process of transforming an existing building to NZEB requires more effort because the existing buildings were not constructed on the basis of NZEB energy efficiency standards. To support the construction of NZEBs in India, the design methodologies and energy management strategies should be investigated. Optimization algorithms play a significant role in identifying the best solution parameters for the design and implementation of a NZEB. Various population based algorithms for optimization solution applications have been reported in several literatures. These algorithms find applications in the implementation of energy management strategies in NZEBs. In (Ghadimi et al. 2018), the authors suggest that; from the various proposed optimization techniques having several advantages; the choice of a technique should be made considering the application and need of the proposed system. The authors in (Gao et al. 2019), demonstrate that the choice of the algorithm is based on the accuracy and requirement of the desired candidate solutions. In stochastic optimization methods every uncertain parameter of the proposed problem can be modelled simultaneously (Abedinia et al. 2019). In (A. Khalid et al. 2018), the authors propose a hybrid optimization technique on the basis of genetic (GA) and bacterial foraging (BFA) algorithm to employ demand side management (DSM) in a residential building. In (A. Khalid et al. 2018), a load management technique is proposed to reduce electrical cost and user discomfort. Here, the authors in (A. Khalid et al. 2018) have looked into the concept of reducing wait time of the high priority electrical appliances thereby minimizing user discomfort. But the authors have not considered the user preference in the operation of the appliances to manage a net zero energy in the residential building by providing maximum electrical comfort. A hybrid algorithm was proposed in (A. Khalid et al. 2018) because GA has slower convergence rate and BFA diverges away from the optimal solution due to local search ability. In the paper (X. Jiang et. al 2019), the authors propose an optimization control strategy using GA based on the operating power and dynamic pricing. The GA tunes the operating parameters set according to user preference to minimize the daily electrical energy cost. Here, in (X. Jiang et. al 2019), the authors have not considered a mathematical model for annual net zero energy with maximum comfort. Other potential evolutionary algorithms (EA) such as differential evolution (DE) are also preferred in building optimization because DE can yield best optimization solution due to a better search ability (I. Essiet et. al 2019) .The authors in the paper (G. Hafeez, et. al 2020) suggest that various optimization algorithms like mixed integer linear programming (MILP) achieves the target of cost minimization and load scheduling with an increases in the system complexity. DE is a fast and accurate algorithm with better global search ability (I. Essiet et. al 2019). This faster and accurate search ability of DE helps in obtaining best optimum solutions for the proposed problem. The motivation for research behind the proposed paper is to promote a sustainable and eco-friendly future in the building industry. Hence this paper is focused on an energy efficient NZEB considering the case of India for simulation. Here, we are using the DE algorithm to establish the concept and obtain the desired results. The obtained results using DE has been compared with GA technique to validate the solution.

1.3 Novelty and Contributions

Although various studies have been carried out in the design and development of NZEBs, there is an obvious lack of consumer monitored net zero energy index model for a NZEB. To fill this research gap, in this paper, we propose a mathematical model to maintain a net zero energy index over the period of a year. This energy index is a consumer monitored model that encourages the consumer towards a sustainable and environmental friendly future. This paper discuss a single objective heuristic optimization model for NZEB using DE algorithm. The algorithm put forth a strategy, to maintain a net-zero mathematical energy index that helps end-users to monitor the energy balance in their residential buildings, obviating impact on consumer's electrical comfort. The significant work contributed by the paper can be summarized as:

- The work analyses the economic aspects of NZEB in the society in terms of the economic benefit a consumer attains when NZEB is employed, also the proposed methodology ensures maximum electrical comfort to the consumers.
- The work analyses the environmental contributions an NZEB can attain in terms of carbon footprint reductions.
- The work encourages the consumers towards a sustainable society by putting forth a novel consumer monitored energy index for residential buildings
- The work analyses four case scenarios to study the performance and limitations of NZEB system.
- The proposed simulation results using DE has been compared with the optimization solutions using GA to validate and verify the proposed concept

1.4 Paper Organization

The rest of this paper is organized as follows: section 2 details the functional overview of the proposed NZEB system; further a control methodology, problem formulation and energy index for NZEB is proposed. Section 3 discuss the implementation and performance analysis of the proposed NZEB model; it's economic and societal impact in India. Section 4 discusses the relevant conclusions derived from the paper and it is followed by the reference section.

2 Functional Overview of the Proposed Net Zero Energy Building Methodology

The significance of NZEB are manifested by few important considerations such as energy conservation by efficient building design and construction, power-conscious systems and appliances, onsite generation of renewable energy, and power-aware consumer usage. NZEBs stimulate end-users to be engaged in assiduous changes of energy usage pattern to diminish the energy drain on the grid. The net import-export of electrical energy, from a grid to NZEB and vice versa, sustains a net-zero electrical energy balance in the system.

The possibilities of converting a conventional residential building to a NZEB entail the abundant usage of renewable energy sources and smart energy management strategies. The latter incorporate smart operational and power-efficient features of the contemporary electrical appliances, in a residential building, so that a zero balance of electrical energy is maintained in the building. NZEB assumes a major role in the development of a sustainable future, evinced by its positive impact on the society. The proposed NZEB system discuss a single objective energy optimization control strategy that focus in the design of a controller to maintain net zero energy in a residential building. The suggested research methodology explores the possibility of efficient implementation of the controller by considering the net energy consumption data of end-users obtained from a survey of 1000 homes in India, solar PV availability data, and tariff details from State electricity board, India. A heuristic DE optimization technique is used in the proposed work as a strategy tool to obtain the desired global optimum solutions for the proposed concept of NZEB. The system model presented in the paper, examines the appropriate global optimum solutions for the proposed 408 variables in the system, hence a stochastic optimization based DE algorithm is preferred due to its simple approach in obtaining better optimum solutions.

2.1 Control Methodology of the Proposed NZEB Model

Authors of this paper promotes conformance to electrical efficiency standards through energy management strategies in an existing building. Fig.1 depicts the proposed NZEB model. The illustrated model summarizes the various process involved in the design of the proposed concept. The suggested procedures which entails the conceptual framework requires investigation data to support the identified objectives, which can be maintained through relevant methodology and decision making. NZEB is made possible when the electrical efficiency in the building is maintained by systematic scheduling of energy-efficient electrical appliances. However, not all energy-efficient scheduling leads to a NZEB. Optimum solution for a NZEB, requires the optimization of the best approach from several solutions. The population based search algorithms are the best approach to bring global optimum solutions. These optimization algorithms and combination of variables find solutions to objective function by satisfying the constraints (Zhu et al. 2019). The credibility of every algorithm depends on the type of objectives to be achieved. The proposed strategy prepares a day ahead schedule which is presented to the consumer for choice of preference whether to continue with the schedule or overlook it for the day. The consumer is advised to follow the prepared schedule to obtain a net zero energy import-

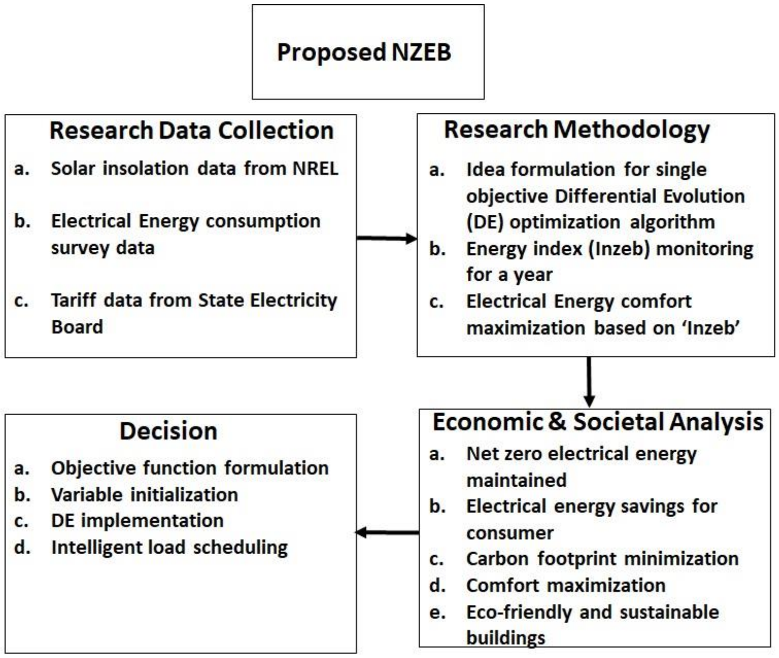

Fig 1. Proposed NZEB Model

export in the building. If the consumer fails in practicing the suggested schedule, the algorithm introduces comfort restrictions based on the energy index value.

2.1.1 Differential Evolution Optimization Method

Differential Evolution (DE) is a stochastic population based Optimization technique inspired by the biological evolutionary process of nature. It is an easy and simple algorithm to implement, DE provides fast, accurate, efficient optimum solutions. DE is a simple algorithm because it is easy to work with, and involves few control parameters such as scaling factor, crossover rate, mutation operation and population size. The DE algorithm can be explained in four steps namely; initialization, mutation, crossover and selection (Madathil et al. 2017). The flow chart of a DE algorithm is depicted in Fig. 2. The initialization process generates a random population containing vectors in the 'M' dimensional search space. These vectors have confined boundary limits and they undergo the process of Mutation and Crossover to obtain optimum solutions at each generation. The zth vector for the pth generation is expressed in equation 1. Where, *Randl,z(0,1)* is a random number between 0and 1, and *xUl*, *xLl* are upper and lower boundaries for the generated vectors. In the mutation process, the weighted difference between two vectors in the search space is added to a third vector to generate a new set of vectors called mutant vector.

$$xz, p = [x1z, p, x2z, p \ldots\ldots xMz, p] \qquad (1)$$

$$xl, z, 0 = [xLl + Randl, z(0,1)(xUl - xyLl)] \qquad (2)$$

The mutation process increases the diversity of the population. *xr1,M*, *xr2,M* and *xr3,M* are target vectors, selected at random corresponding to integers '*r1*', '*r2*' and '*r3*' respectively. The equation for mutation operation to obtain the mutant vector *er1,M* is expressed in equation 3 where 'm' is the weighted mutation factor.

$$er1, M = xr1, M + m(xr2, M - xr3, M) \qquad (3)$$

The mutant and target vectors undergo the process of crossover to obtain the trial vector. In the crossover operation, the trial vectors is obtained by comparing a random number with a crossover rate (CR). If the generated number is less than the CR, the mutant vector is accepted as a trial vector else target vector becomes the trial vector. The trial vector is evaluated based on their fitness values. The objective function is investigated for optimum value. This process of selecting the optimum is termed as the selection process and it is continued, until a stopping criteria is achieved. Table 1 illustrates the NZEB problem parameters using DE.

2.2 Problem Formulation

This section presents an overview of the single objective cost minimization problem. The cost optimization problem for NZEB minimizes the cost of electrical energy consumed over a year. The objective function for the cost minimization problem is given in equation 4. Slab pricing based electrical tariff is used for estimation of the cost of consumed energy. The tariff was obtained from the Kerala State Electricity Board's (KSEB) tariff for low tension(LT)

Table 1 NZEB Problem Parameters using DE

Parameters	Values
Population size	50
No. of. Generation	50
Mutation factor (m)	0.5
Crossover rate (CR)	0.9
Time interval (t)	1 hour
No. of variables	408

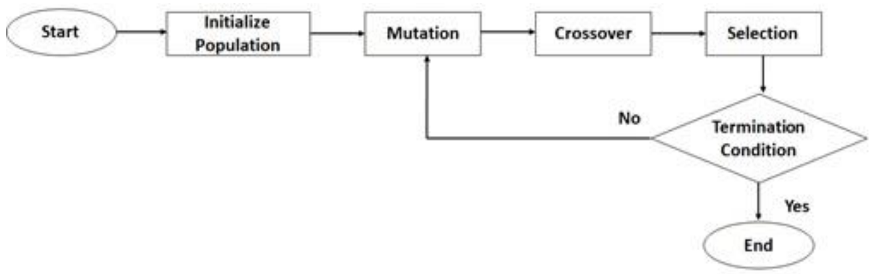

Fig 2. DE Algorithm

domestic consumers (Dinaraj et al. 2019). Equation 5 gives the cost of the consumed electrical energy cost for every hour of a day, accumulated over a year. The tariff of per unit electricity energy consumption, of the range between 0-500 units/month; is charged as 6.7 Indian rupees (Rs.)/unit and when the consumption goes above 500 units it accounts to Rs. 7.5/unit.

$$F = Minimize[C] \tag{4}$$

F = Objective function

$$C = \sum_{n=1}^{12} Ta * \sum_{t1=1}^{s} \sum_{t=1}^{24} Egrid(t) \tag{5}$$

s = No. of days of every month over a year

C = Cumulative cost of energy over a year

Ta = Tariff

Equation 6 represents the power balance in the system.

$$Pload(t) - Ppv(t) - Pgrid(t) = 0 \tag{6}$$

Where, *Pload(t)* = Load demand in the building at each time interval.

Ppv(t) = PV power supplied at each time interval

Pgrid(t)= Grid power imported at each time interval

Equation 7 and 8 calculate consumer energy demand per day and energy import per day from the grid respectively.

$$Edemand = \sum_{t=1}^{24} Pload(t) * t \tag{7}$$

Edemand= Energy demand cumulated per day

$$Egrid = \sum_{t=1}^{24} Pgrid(t) * t \tag{8}$$

Egrid = Energy imported from the grid per day

2.3. The proposed Energy Index for NZEB

A flow chart for the design strategy and implementation of the proposed mathematical energy index (Inzeb) for NZEB is portrayed in Fig.3. The formulation of 'Inzeb' varies with comfort time constraints such that a net zero balance of electrical energy is maintained inside the building with maximum electrical comfort. The formulated energy index is the ratio of the summation of energy imported from grid, for 24 hours of a day cumulated over a year to the net consumer energy demand, for 24 hours of a day cumulated over a year. The zero value of the energy index 'Inzeb' represents a net-zero energy in the building. If 'Inzeb' is less than zero it demonstrates export in the building, that means the net energy import from the grid is negative or in other words, the net electrical energy demand is less than the energy output from the solar PV module. If 'Inzeb' is greater than zero it illustrates import from the grid so that the net electrical energy demand is greater than the energy output from solar PV module. Energy index 'Inzeb' being zero is not only a measure of zero net energy maintained in the building but also shows that the net energy import-export over the period of a year is balanced. It indicates consumer-friendly usage of energy through operating hour restrictions of appliances when the solar energy is minimal. Hence the choice of the duration of hours of operation of the electrical appliances is calculated based on the numerical value of the energy index 'Inzeb'. Equation 9 displays the formulated mathematical energy index 'Inzeb'. The energy index may even be negative based on the net energy export in the system that depends on the net Solar PV energy output and the net energy demand. The maximum value of the energy index is one, when the net solar energy output is zero and the net energy demand in the building is imported from the grid. The consumers can have sensible usage of their energy appliances by monitoring the value of 'Inzeb'.

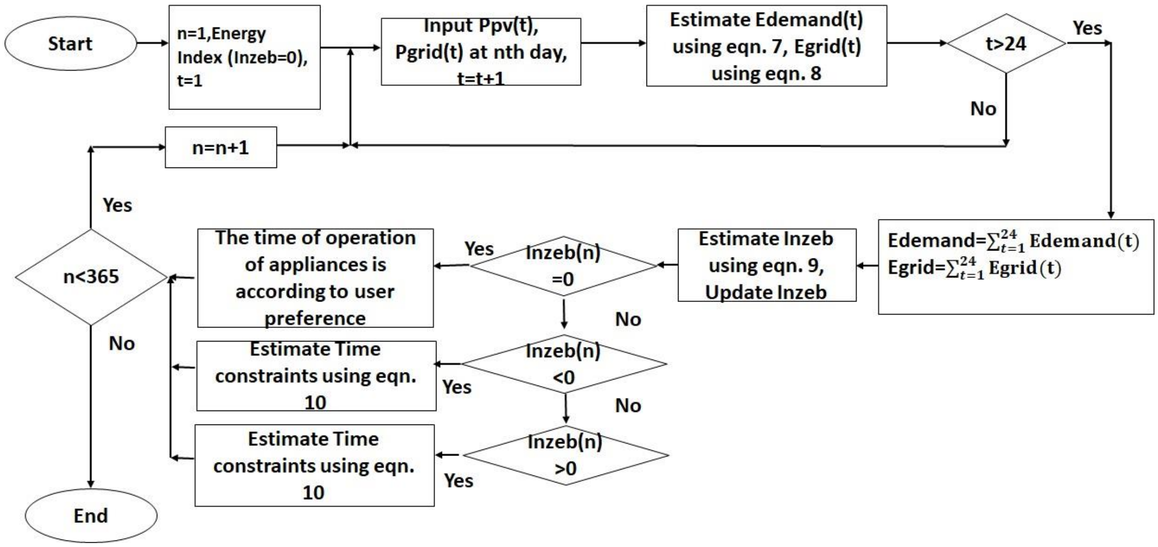

Fig 3. Proposed Mathematical Energy Index for NZEB

$$Inzeb = \sum_{n=1}^{365} Egrid \,/\, \sum_{n=1}^{365} Edemand \qquad (9)$$

2.3.1 Problem Constraints

The NZEB residential building model for Ernakulum, in the state of Kerala, India is chosen. Kerala has the abundant potential for solar energy, experiencing high solar irradiation during summer. On an average, the place receives solar insolation for 7 months a year except during rainy days. The solar insolation data of the considered city for NZEB implementation was obtained from the National Solar Radiation Database (NSRDB). The annual average solar irradiance of the place is 5.3kWh/m^2/day. The occupancy of the residential building is 4 and the building has seventeen electrical appliances with a total load of 6.505 kW power rating. A survey of 1000 households in Delhi, India was conducted by The Energy and Resources Institute, to understand the usage pattern of electrical appliances connected in the residential buildings (Jain et al. 2007). The data obtained from survey was used for the NZEB simulation study. The electrical appliances and their power rating are tabulated in Table 2. The maximum and minimum possible number of operational hours of the devices are tabulated in Table 3. The maximum-minimum operating hours of the appliances is selected by the consumer according to their preference. Here, in this simulation study the data was obtained from the survey conducted in Delhi. The range of operating hours does not mandate that the appliances must be operated over the duration of either the maximum or minimum operational hours. Washing machine which is a schedulable appliance, has been scheduled for operation between the hours 11-16, so that the device is programmed to operate during the availability of solar PV energy output. This was made possible with the help of intelligent load scheduling approach of the DE algorithm. The energy index (Inzeb), plays a significant role in the end-user's choice of operating hours of the appliances to maintain a net zero balance of energy in the home. The relation between energy index 'Inzeb' and operating number of hours 'T' of the devices is shown in the equation 10 where'd' represents the device number. The MATLAB simulations were performed using the annual solar irradiation data of Ernakulam, obtained from NSRDB Data Viewer.

$$T(d) = \left(\frac{1}{6}\right) * Tmax * \left((Inzeb^2) - 1\right) - \left(\frac{1}{4}\right) * (Inzeb + 2) * (Inzeb - 1) * (Tmax + Tmin) + \left(\frac{1}{3}\right) * (Inzeb^2 + 2Inzeb) * \ Tmin \qquad (10)$$

$$TMax(d) \geq T(d) \geq TMin(d) \qquad (11)$$

$$T(d) = TMax, \ \ when\ Inzeb = -2$$
$$(TMax + TMin)/2, when\ Inzeb = 0 \qquad (12)$$
$$TMin, when\ Inzeb = 1$$

The range of operation time of ‘T(d)’ is specified in equation 11. Equation 12, explains the conditions applied for formulating the relation between ‘T(d)’and ‘Inzeb’. The time constraints ‘TMax’ and ‘TMin’ are end-users deliberate comfort preferences to maintain NZEB and hence the consumers have the liberty to reset their options any day. The energy generated from Solar PV plays an important role in maintaining net-zero energy in the building. More the generated PV energy more is the electrical energy cost saving's realized by the consumer. Hence, the ratings of the PV module must be chosen wisely for NZEB. Here, a 5kW rated PV panel with 16% efficiency was considered for the simulation study.

Table 2 Power Ratings of Electrical Appliances

Appliance Number	Electrical Appliances	Number of Appliances	Power Rating (W)
1-5	CFL	5	11
6-9	Ceiling Fan	4	60
10	Television set	1	120
11	Washing Machine	1	700
12	Refrigerator	1	200
13	Water Pump	1	740
14	Geyser	1	1500
15	Air Conditioner	1	1750
16	Iron Box	1	1000
17	Computer	1	200

Table 3 Maximum-Minimum Range of Operating Hours of Devices

Device Number (d)	1	2-3	4-5	6-9	10	11	12	13	14	15	16	17
Maximum Operating Hours (TMax)	4	4	4	11	6	1	24	1	2	4	1	4
Minimum Operating Hours (TMin)	0	1	0	2	2	0	10	0	0	0	0	1

3. Implementation and Performance Analysis of NZEB Optimization Model

The DE algorithm was coded in MATLAB (2018b) and simulations were performed in pursuit of optimum results. The performance of the proposed NZEB system was carried out by assessing four case scenarios. In the first case, an attempt to maintain a net zero electrical energy in the building is targeted for a year. The second case scenario looked into the electrical energy savings obtained for a year when a NZEB and a non-NZEB residential home is considered. The third case studied the net carbon emissions in the building due to electrical energy import from the grid. The fourth case scenario attempts to vary the installed PV capacity to discuss and analyze the NZEB performance. The obtained ‘Inzeb’ and electrical energy cost was compared with the obtained GA solutions. Table 4 details the required GA parameters used for the problem simulation. The comparison of NZEB solutions with GA optimization algorithm is done to validate the proposed concept. GA is a global search algorithm with three operators; reproduction, crossover and mutation.

Table 4 NZEB Problem Parameters using GA

Parameters	Values
Population size	50
No. of. Generation	50
Mutation factor (m)	0.1
Crossover rate (CR)	0.65
Time interval (t)	1 hour
No. of variables	408

3.1 Results

Fig.4 depicts the aggregated annual electrical energy cost with and without NZEB constraints on the electrical load at the consumer's residence. The plot indicates considerable electrical energy savings when NZEB constraints were employed as compared to without constraints. For a non-NZEB residential building, an amount of Rs. 50498 is remitted to the state electrical authorities per year as energy cost, whereas a NZEB residential building remit an amount of Rs. 83 for a year. Hence, an NZEB home on an average saves Rs. 50415 per year compared to a non-NZEB which depends on the electrical grid for energy. Fig.5 illustrates the Index plot, net energy import from the grid, net consumer energy demand and availability of solar PV energy. These waveforms were plotted over the duration of a year. The Solar energy for 365 days is indicated by the Solar PV energy waveform. The energy index waveforms for a NZEB home settled down to zero value whereas a non-NZEB home imports energy from the grid indicating 'one' as the energy index value. The energy index waveform of the NZEB approaches a zero value when indexed over the period of a year signifying the net-zero import-export of energy. The algorithm schedules the appliances in such a way that despite of less PV energy availability during the rainy seasons, the algorithm manages to sustain a yearly net zero balance of energy in the residential building. Energy demand and energy import from grid is illustrated in Fig.5. From Fig.5, it can be noticed that a NZEB home has lesser energy import from the grid and lower electrical energy demand compared to a non-NZEB home. Fig. 6 portrays the net energy balance in NZEB were the net consumer energy demand being supplied by the solar PV energy and electrical grid. From Fig.6, it can be analyzed that during lesser solar energy output in the year, the net consumer energy demand is met mostly by the electrical grid. It is essential to select appropriate PV energy share to analyze the performance of NZEB. Fig.7 compares the energy index, cumulative energy cost, cumulative PV energy, and the cumulative energy import from the grid when

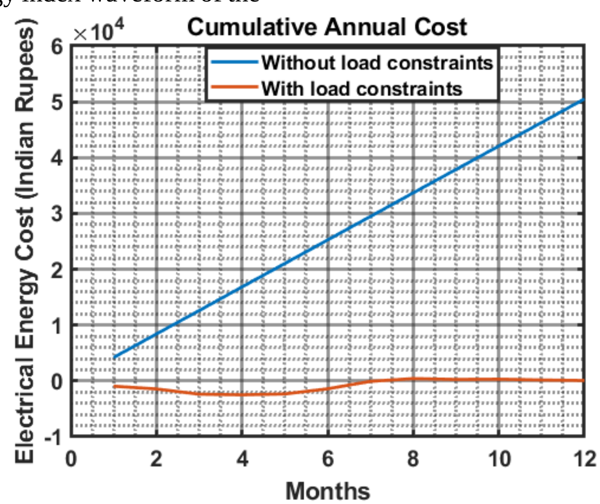

Fig 4. Cumulative Annual Electrical Energy Cost

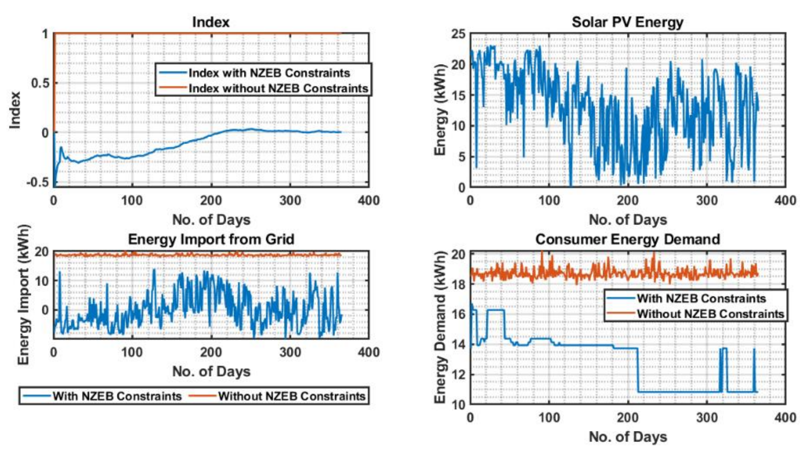

Fig 5. Energy index, PV energy output, Energy import from grid, Consumer energy demand

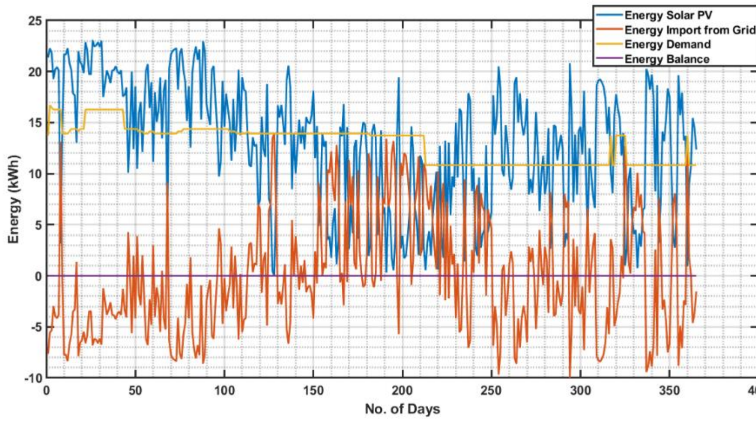

Fig 6. Energy solar PV, Energy import from grid, Consumer energy demand, Energy balance

the solar PV energy output varies at ±10% and ±30% of PV energy output. Results noted in Fig.7 validate that when the solar energy output was ±10% of the connected PV, a value closest to zero energy index was obtained as the algorithm was capable of maintaining a zero energy balance by employing the appropriate appliance constraints. The cumulative cost curve shows a net energy cost savings with +10% and +30% in the system. The net cumulative energy imported from the grid obtains a value of zero if the energy index is maintained at zero. A net-zero energy index sustains a net-zero energy import-export in the building.

Findings of this study draws attention to the selection

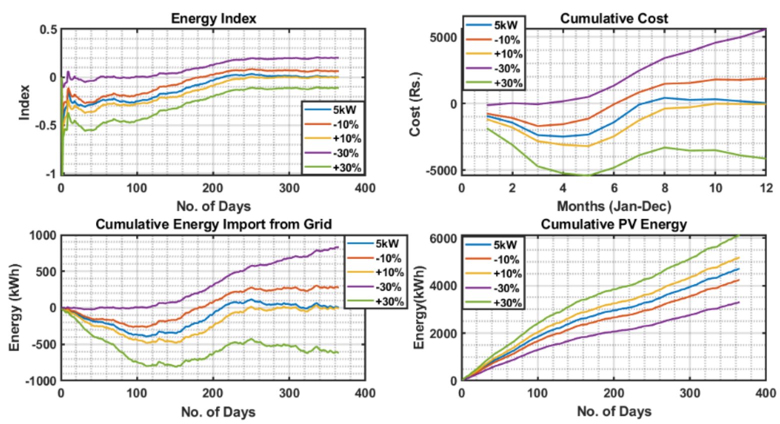

Fig 7. Solar PV varied to ±10% and ±30%

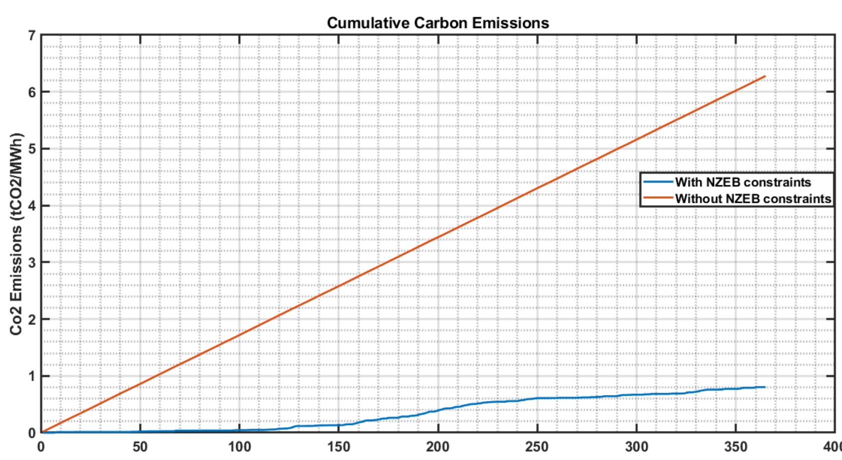

Fig. 8 Cumulative CO2 emissions

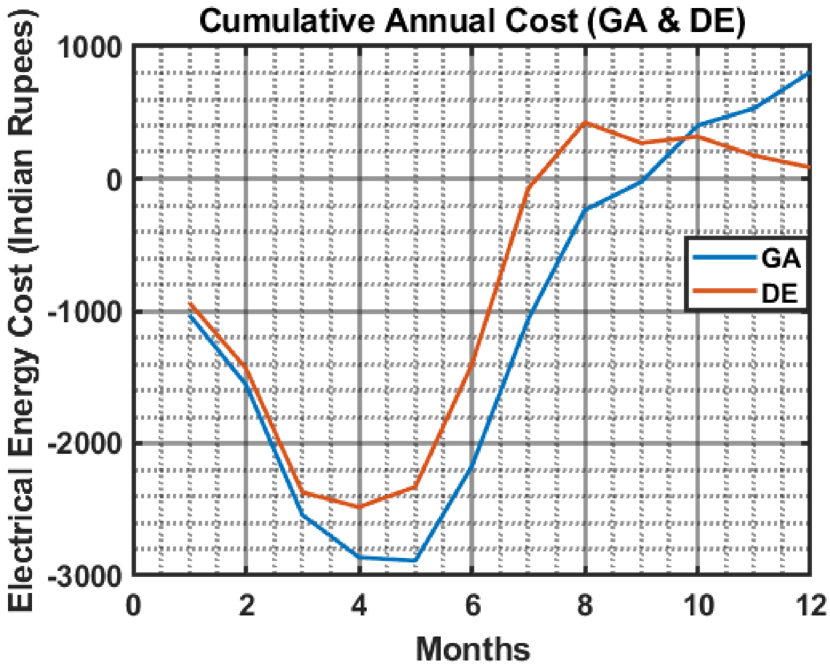

Fig. 9 Comparison of energy cost using DE and GA algorithms

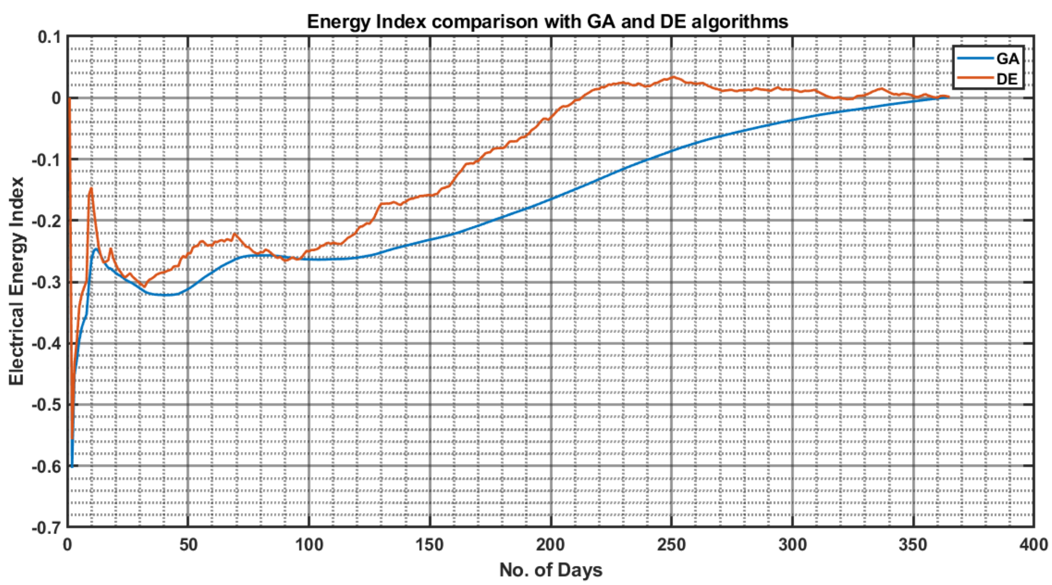

Fig. 10 Comparison of 'Inzeb' using DE and GA algorithms

of optimum PV capacity, in order to maintain a NZEB. The energy constraints imposed by the algorithm play a significant role in limiting the consumer's net demand for energy modulated by the availability of energy from the solar PV system. Fig.8 depicts the net CO2 emitted per year into the atmosphere by a NZEB and non-NZEB home. In India, 68.8 % of the installed energy generation capacity is sourced from thermal power stations, which have resulted in the combined grid emission factor of the Indian grid to be 0.92 tCO2/MWh (Singh et al. 2018); i.e., for every 1 MWh of electrical energy consumed from the Grid, 0.92 tonnes of CO2 is emitted into the atmosphere. From the simulation study it can be noticed that a NZEB home emits only 0.8tCO2/MWh per year compared to a non-NZEB home emitting 6.3tCO2/MWh per year.

Fig.9 demonstrates the cumulative annual electrical energy cost comparison of NZEB using both DE and GA optimization technique. The cumulative annual electrical energy cost for NZEB using GA in a year was calculated to Rs.805 whereas for DE it was estimated as Rs.83. The comparison of 'Inzeb' using GA and DE is presented in fig.10. It can be noticed that both GA and DE technique attains a net zero energy index over a year.

3.2. Discussion

The simulation results reveal that selection of a suitable PV module and energy-efficient constraints are inevitable for a NZEB. Variations in the energy output of the installed PV subsystem impose challenges in the maintenance of a net zero energy in residential buildings. Whereas, with sensible usage of energy, maximum performance of NZEB is possible. Renewable energy resources are a significant part of NZEBs. In India, solar PV plays an important role due to adequate availability of solar insolation. NZEBs can be made effective with the locally available, cheapest and efficient form of renewable resources. Though NZEB can be made possible with other renewable energy sources, a rooftop solar PV is the most viable option in India. With appropriate solar insolation, NZEB can be achieved efficiently helping the consumers to attain a pay back soon for their investment. The installation of a 5kW solar PV plant with on-grid inverter costs approximately Rs.200000 with the maximum subsidies by the state governments in India. The Punjab State Power Corporation Ltd. (PSPCL) India, introduced subsidies for residential consumers willing to install grid-connected rooftop solar systems ranging from 1kW to 10 kW with a price of Rs.125800 for the installation of a 5 kW solar PV (PSPCL 2020). The annual energy savings obtained with the deployment of NZEB was Rs 50415. The payback period for the installed 5 kW PV in a NZEB can be estimated as 4 years for an annual energy savings of Rs 50415.

To validate the proposed concept of NZEB, the electrical energy cost and electrical energy index were estimated using two different stochastic algorithms. A zero energy index with an annual energy cost of Rs. 805 was obtained in the case of GA. DE obtained better solutions compared to GA technique. This variation in results was due to the premature convergence of GA compared to DE which is more accurate and attains faster and better solutions.

The imposed NZEB constraints, restrict the operability of the appliances outside the minimum to maximum operating range. When solar energy is abundant, consumers can avail the appliances according to their indulgence and comfort. When solar insolation is less, operational constraints are offered for implementation. If the index shows maximum import into the building, operational constraints are strictly imposed. For NZEBs having higher export capability, consumers are provided with comfort relaxations. This control strategy helps in maintenance of a net zero balance of energy, over the period of a year.

Pursuit of a luxurious and comfortable life warrant larger energy supply which evoke stress scenarios in grid operations, depletion of conventional energy resources and increased emissions of carbonic pollutants into the atmosphere. Environmental threats emanated by the rise in global temperature and depletion of the ozone layer have a deleterious influence on society. Buildings are the major contributors to carbon emissions. With the increased usage of electrical energy in residential buildings, carbon pollutants have increased to levels that are unsafe for living species. The Smart Cities Communities Initiative of the Strategic Energy Technology Plan (SET-Plan) intend to achieve a 40 % reduction of carbon emissions by 2020. The increased carbon footprints have an inimical influence on the environment, leading to serious consequences on the human society. Hence, supporting the NZEB movement in India contributes to improvement in the quality of life of people with a future towards eco-friendly society. NZEB systems play a significant role in tackling the global climatic challenges affecting the living species. Weak enforcement of government regulations, low literacy rates and lack of awareness among consumers were identified as the significant challenges hindering the implementation of NZEBs in India.

The simulation results of the NZEB model highlight the significance of the proposed system, its contribution to the society based on the cumulative cost savings, and net carbon emissions. The proffered model has few limitations such as unpredictability of the end-users energy-usage patterns, affected by weather, and the unavailability of the user, in the building, due to emergencies and ambiguous real time solar insolation data.

These limitations lead to higher penalties in the daily predicted load schedule, which are compensated by the algorithm towards a net-zero energy balance, and compliant NZEB constraints, over the period of a year. The results of this study ascertain that promotion of NZEBs enhance the likelihood of a sustainable and environmental-friendly society. The proposed model fosters consumer support and is expected to motivate research and development in policy reforms, pricing schemes and NZEB construction design, in India. Findings of this research are anticipated to motivate the utility industry to manufacture cost-effective energy management gadgets for NZEB homes that sustain a net zero balance of energy in the residential building. The gadget may host any algorithm coded in it to obtain optimum solutions for the proposed concept. The proposed method is a generalized approach and requires no adaptation to other locations of sufficient availability of energy resources. But the algorithm requires significant parameters such as energy resources availability in the region and consumer energy consumption preference as input. The DE algorithm is preferred here as an aid in the process of implementation of the concept and hence the complexity of algorithm fails to affect the system. Here, in the paper the algorithm has been used as a tool to examine the best solutions for the proposed problem. The variable size considered for optimization was 408 with a time interval of one hour each. With the increase in the number of variables, the algorithm is expected to encounter challenges in time delay of the optimization process. Whereas, in contradictory; more accurate solutions are obtained when the time interval of variable changes every five minutes. Matlab was used as a platform for implementing the suggested method. Matlab when used for the development of the concept as a product prototype, may find challenges, and hence more advanced software platforms and applications can be preferred for implementation. As lessons learned from this investigation, the authors suggest the implementation of a NZEB model that account for the architectural and thermal constraints, considering the economic life cycle costing (LCC) analysis of grid-interconnected PVs in the system because an economically developed society assures a nations stability, development and security.

4. Conclusion

This paper analyzed the significance of sustainable development in society by employing Net Zero Energy Building (NZEB), and presented an energy index to benefit the consumers. Further, the paper implements a single objective electrical energy cost optimization model, using the Differential Evolution (DE) algorithm for NZEB. The methodology is implemented in the optimal scheduling of electrical appliances for a grid-tied PV NZEB system. The proposed system maintained a net-zero energy import-export in the building. The optimization model targeted maximum electrical user comfort in the NZEB home. The paper analyzed the NZEB with four simulation studies. The simulation studies were designed to educate or familiarize the consumers to the significant factors involved in maintaining NZEB, and judicious selection of the PV system, with energy efficient constraints, for optimal load schedule. The proposed NZEB model using DE algorithm was able to attain net zero electrical energy over a year in the residential building and it was validated using the energy index waveform. The case simulation study of Indian context was considered based on economic and societal aspects. With the deployment of NZEB in a residential home an annual energy saving of Rs.50415 was estimated. An amount of Rs.50498 was calculated as annual electrical energy cost for a non-NZEB residential building, whereas for a NZEB residential building it was calculated to Rs.83. The annual net CO_2 emissions of a NZEB was evaluated in the simulation study. An NZE residential building emitted 0.8tCO2/MWh as compared to 6.3tCO2/MWh for a non-NZEB. The obtained simulation values using DE technique was compared with GA solutions for desired results. The obtained simulation study results imply that NZEB designed buildings have a highly sustainable and positive impact on the society as compared to non-NZEB buildings in terms of reduced CO2 emissions, reduced energy import from the grid, and economical benefit to the end-users. The proposed algorithm is anticipated to hit the zero energy index target, over the course of a year's operations, even with high-energy demand and minimal solar irradiation, during certain parts of the year. Even though the algorithm hits the target mostly, but during certain period of the year, maintaining an NZEB can be quite challenging; with the luxury of comfort enabled for the consumer. Efficient storage is an appropriate solution to meet the challenge, and is also a future prospect for this research work.

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