# Zero Energy Buildings: Systematic Literature Review

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## 1. Introduction

Zero Energy Building or Nearly Zero Energy Building or Net Zero Energy Building- roughly means the same thing. ZEB for short is a building that has approximately zero energy consumption. The Zero Energy Consumption does not literally mean that the building does not consume any energy at all, on the contrary it is based on conservation of energy law in Physics. In a nutshell the building also generates energy from renewable resources, which is not just used to meet energy requirements of the building, but the surplus energy is also transferred to a transmission station or other building. Thus, ZEB is achieved. Use of ZEB is very crucial to save non-renewable resources like coal which are used to generate electricity. According to [1] the first ZEB built in California was by De Young Properties in 2013, which was capable of producing energy equivalent to the amount it consumed in a year. Although to achieve ZEB there are certain setups which cost money. Thus, every passing day, research is undergoing to optimize economic output in the best possible way.

Further, authors in [2] imply that ZEB plays a vital role in sustainable energy use, energy security, and respect for the environment.. The usage of ZEBs have utmost importance in today's world, and future world. In order to decrease degradation of the environment, it has become a priority to save the environment in every alternate possible way. ZEBs are very persuasive alternatives to reduce pollution.

There are several definitions and names for the Zero Energy Buildings. It is being called as Net Zero Energy Buildings because the overall energy consumed annually is approximately zero since it also generates energy, which is also a reason why it is being called Nearly Zero Energy Building. In a nutshell as aforementioned it is a building based on the law of Physics named 'Conservation of Energy'. The building produces energy from renewable resources, largely using sunlight. Although the definition from the US government is described in [3] which states that The Department of Energy has worked with the NIBS or National Institute of Building Science and a large number of market participants to develop a national definition of a zero-energy building with supporting nomenclature and usability guidelines. They are beginning to move towards the goal of building zero-energy buildings, but the definition of zero-energy buildings varies from region to region and builder. A widely accepted definition of the limits and goals of zero-energy buildings is essential to any government, public utility or individual's efforts to recognize or promote zero-energy buildings.

## 2. Articles categorization (we will use it for SLR)

| Categories | Articles |
|---|---|
| **Definitions, Building energy codes, ZEB achieving, Designs, Policies, Clusters**<br><br>**Thermal comfort**<br>**Costs, Economic optimization**<br>**Materials**<br>**Performance Analysis, Clusters optimizations, control** | **[4],[5],[6],[7],[9],[11],[12],[13],[14],[15], [16], [17],[18]** |
| **Countries, Different climates** | [4] → US, EU [5] → EU<br>[7] →Australia<br>[9] → US, EU, UK, Ireland, Japan, Canada<br>[10] → Germany, Singapore, etc.<br>[11] → Italy(Rome)<br>[12] → EU<br>[13],[14] → Multiple countries<br>[15] → EU, Italy<br>[16] → Climates<br>[17] → Luxembourg |
| **Renewable energy (production), Load matching analysis, Grid analysis** | **[9],[10],[11],[14],[13],[15]** |
| **Comparison and type of comparison** | [8] Type → Between different algorithms |
| **Technological devices like STPV** | **[16],[17]** |

## 3. Results and Discussions

**1**. ZEBs are persuasive, but require setups which are not cheap to install. In order to promote these, a design of a program is needed which is discussed in [4]. It falls under economic optimization and countries category. Authors present a framework based on a model for policymakers. The anecdotal evidence from the US and EU is presented. The model used for economic optimization is the mixed integer programming model. Moreover, contrary to the growth in recent years, authors argue that there remains uncertainty regarding energy investments, uncertainties and risks of PV which includes solar viability, performance and market unpredictability. All in all, a model is proposed which can help policy makers to regulate appropriate incentives that would promote ZEBs. Numerical products of the model implies that there are levels of thresholds that encourage ZEBs, which eventually depends on the cost of the renewable energy system annually and the case when energy is achieved through utility. Nevertheless, further the results showed that each building might have different potential to invest in the system depending on the financial circumstance of the owner. The authors moreover, presents a framework that can be used to categorize different classes of buildings for which renewable energy systems are viable. However, a better result can be produced by extension of the framework. According to the authors more data from a region is required to achieve this. The data should include annual load and potential areas for system installation for buildings in all the classes. One key aspect worth mentioning is that this model has been applied in Tampa, Florida, USA. In conclusion, an economic framework for policy making has been proposed.

**2**. Furthermore, [5] utilizes mixed-integer programming techniques as well. This article falls under the categories of countries, economic optimization, performance optimization,Thermal comfort. The anecdotal example of the EU draws attention to a new type of building known as Zero Emission Buildings. The only difference stated between Zero Emission buildings and Zero Energy Building is that the Emission building’s balance factor is calculated using carbon emission rather than energy units. Moreover the authors implies that PV is used as a key to reach ZEBs, and in summer the energy is exported to the grid while in winters electricity is a subject to import. In a nutshell the authors broadly discusses about the technologies that would be cost optimal, likewise of [4] the policies' influence and hourly operations are investigated, to analyse future changes, lifetime is divided into periods, and lastly the analysis of ZEB's interaction with grid through met electric load profile per hour. According to the authors in conclusion ZEBs have changed the perspective of a building from consumers to producers. This paper has goals and results similar to [4], However this paper discusses dynamics of the energy system of a building along with economic optimisation. It broadly provides a framework for the energy system to optimise economy simultaneously. Moreover [6] provides a similar energy and cost optimisation method through regulating size of battery storage system in roof top solar photovoltaic which is discussed further. Lastly, the ZEB concept has changed the status of buildings from consumers to key electrical players. From this development, the building's system of energy has gained new perceptions.

**Limitations of [5] according to the authors of [5]:**

Nevertheless, it has certain restrictions. Firstly, for every hour fulfilling the heat conditions of a building are necessary. Likewise, electric conditions per hour of a building should also be met. Secondly, to prevent same hour electric import and export 3 constraints should be applied in order to prevail either of both. Binary 0 and 1 are used to achieve this. These parameters and techniques are briefly discussed by the authors. Further, ZEB constraints are to fit according to the ZEB definition of a country. The authors particularly developed the framework with regard to EPBD. Lastly, a certain factor mentioned in the paper is to be multiplied in latter equations. However technological limitations are even more, which includes the integer formulation which is of utmost priority. The integer formulation should meet the minimum installed capacity else the model might choose small capacity.

**3**. Besides, [6] implies a method to choose the optimal size of battery energy storage system to optimize energy as well as cost for the Zero energy building with rooftop photovoltaic or PV. The authors start by reporting an argument by the International Energy Agency which states that energy demand and Carbon dioxide emissions are growing each passing day. Moreover, they provided anecdotal evidence from Australia which states that Australia has the highest number of homes with rooftop photovoltaic or Zero energy homes in the world. Thus, [6] lies in categories of

Countries and Energy and economic optimization. According to the authors Net Zero Energy Buildings (NZEB) are divided into five categories which are as follows:

1. Net zero site energy
2. Net zero source energy
3. Net zero emissions
4. Net zero energy costs
5. Nearly zero energy buildings

Further, the authors claim that there is no precise definition for these Zero energy buildings because of the inconsistencies in the energy generation by the source, which includes GHG emissions and encapsulated energy. The authors suggest that due to low economic incentives it is important to choose appropriate size of storage technologies and renewable energy generations. The additional pay for grid storage could be reduced however, in order to achieve that, extra investment BESS is required. All in all, this model has been used in a South Australian home which consumes approximately 5211 kWh of energy annually considering it has 3 similar energy producing rooftop solar PV systems. Through this model, optimal battery size is determined for non similar values of annual battery payment rate and thus, the installation cost for the battery. Moreover, it is being found that around 33.33% of the energy produced by the PV is consumed by the load directly and the other 66.66% due to inconsistencies between the generation and load patterns, is transported to the grid if BESS is not installed. However, with the installation of local BESS, energy swap with the grid and corresponding net payment annually reduces significantly. Further benefits of BESS include cuts in grid generation capacity and liberation of distribution network volume.

**Prediction by authors:**
The consistent declination of battery and converter costs along with increase in Electric RP usage, BESS installation would be more trending in the future.

**Key Advantage:**
If PV generation data and suitable load data are available, this method can be applicable globally.

**4**. As presented by [6], the energy storage system is of utmost importance. Further, [7] provides a method called Particle Swarm Technique which provides enhanced effectiveness in appliance scheduling and energy storage control. This paper falls under Performance Analysis, Clusters optimizations, and control, Thermal comfort, Economic Optimization. The authors start by claiming that improvement in efficiency and saving of energy are two obstacles of NZEBs due to increase in electricity demand day by day. Many control methodologies have been reported concerning the energy management:

1. Self-adapting intelligent technology
2. The multi-interface sensor network gateway architecture
3. The distributed algorithm of appliance scheduling
4. The multi-agent decision making control methodology
5. The consumption scheduling based on game-theory
6. The constrained Boolean satisfiability technique

The authors further mentions a tool named PSO which is used to improve comfort management and energy in a building. Their aim according to the authors is to address issues in residential areas nowadays where restrictions are applied by the grid operators about the feed in energy. Common AC microgrid is used.

**Method**: HiL Simulation

**Objective:** for testing control algorithms for Electric Energy Management System or EESS

**Aim**: To provide a PSO technique based EEMS to enhance effectiveness in scheduling of appliances and control of energy storage.

**Limitation/Demanding Characteristic according to the authors:** The need of operation in pre-installed facilities with tools available for consumers regarding the RES(Renewable Energy Source) and potential to be implemented in consumer available microcontrollers.

**Objectives:** Economic profitability and reduction of disturbances from the operation for end-users.

Further, the authors describe the HiL method through graphical results and setup for HiL.
All in all as the aforementioned PSO technique is proposed, a generic test environment generated in HiL for ZEBs. However, this PSO technique is further extended in [8] for multiple objectives, which is stated as MOPSO where MO → Multi-objective.

**Key advantages from the result:** 1. Satisfactory accuracy of HiL simulation.
2. Acceptable Computation in steady as well as dynamic state.
3. Can find optimal conditions for operation for RES.

4. Regulation of current and energy flow of the EESS.

Thus, protection of EESS lifespan, enhanced usage of energy storage capabilities, and cutting of usage peaks of energy demand in households can be achieved.

**5**. Moving ahead, according to [8], to achieve firm requirements in high performance building design, simulation build optimizations are move efficient nowadays. This paper is comparison based, which compares multi-objective optimisation algorithms. The authors implies that, due to opposing design criterias in the real world, it becomes important to consider multi-objective optimization on the contrary to single objective optimization. However, multi-objective optimisation algorithms' or MOOAs performance has been uncertain on problems of building optimisation, mainly because of the absence of research build evidence.

**Aims of the study according to the authors:**

1. Performance comparison of various evolutionary algorithms in building energy prototype optimisation.
2. Behavioural understanding of the aforementioned algorithms in solving multi-objective problems of optimization.

An outline of performance comparison of optimization algorithms in creating energy analysis of a building is provided.

**Methods:**

1) Choosing test algorithms
2) Setting of parameters for chosen algorithms
    2.1 Size of population is a priority parameter for it affects performance
3) Test prototypes
4) Objectives to minimize
5) Performance comparison criteria
   Seven algorithms are compared utilising the following criterias and corresponding signs:
    5.1 Execution time
    5.2 Convergence towards benchmarking ideal set, indication → *normalized generational*

*distance* (GDn)

5.3 Quantification of both the convergence and divergence → *Normalized inversed generational distance* denoted by IGDn

5.4 Divergence of solution in the Pareto-optimal set, indication → *normalized diversity Metric* (DMn).

5.5 On the Pareto-optimal set, number of solutions achieved, indication → *NoPsolution*

5.6 To the optimal Pareto front, the algorithms' solutions contribution.

This test as aforementioned compares seven algorithms with two population sizes i.e. 32 and 64 persons and two financial situations.

**Algorithms compared and their findings**:

1) pNSGA-II → Stable with acceptable performance indication return
2) MOPSO → Non competence in most of the performance criteria
3) PR_GA → Consistance competitive performance
4) evMOGA → Stable with acceptable performance indication return
5) ENSES → Non competence in most of the performance criteria
6) spMODE-II → Stable with acceptable performance indication return
7) MODA → Non competence in most of the performance criteria

Some might achieve good performance in one criteria, but low in the other, thus, there is no single optimal algorithm for all the optimization problems.

**Performance Rankings and Observations:**

1) Convergence of the solutions obtained: Superior → PR_GA, Worst → ENSES
2) Diversity of the solutions obtained: PR_GA, ENSES, and spMODE-II → Better than rest.
3) Execution time: Outstanding → None, Slowest → MOPSO, ENSES
4) Number of Pareto ideal solutions: More solutions than the rest → pNSGA-II, PR_GA, Worst → ENSES
5) Best solutions contribution to the Pareto fronts that are best: Better than rest → PR_GA, Non competitive → MOPSO, ENSES, MODA

Thus, it is observed that the PR_GA outclasses every other algorithm in most of the cases, while the ENSES was the worst performing of all with low scores.

**Two assumptions of importance for this test**:

1. Usage of algorithms' default settings
2. Each algorithm was executed for the same evaluation/population size.

**Limitations:**

1) No algorithm absolutely converged to the ideal Pareto front in 1800 evaluations.
2) The tests were performed on one building energy prototype due to computational expense of simulations, thus, the building model's influence on the results are uncertain.
3) To make the right choice, MOOAs knowledge is of utmost importance.

**Recommendation:**

The authors recommend the researchers to execute convergence tests to get the required figure of evaluation, to maximize the potential of a MOOA.

**6**. Basic understanding and definitions are of utmost importance to achieve the aforementioned optimizations, one needs to evaluate ZEBs or NZEBs first to achieve ideal setups. In [9] this evaluation of NZEBs is discussed, and how one should do it is reported in the form of a literature-research. The authors start by stating why these buildings are required in this modern world through the examples of the US, Europe and China. Most of the reasons are already mentioned in Introduction which implies the importance of ZEBs. The authors brief action plans of the national as well as local state governments of the US. However, the authors also report about similar action plans and proposals in the UK, Canada, and Japan. The worth mentioning claim by the authors is that the method of evaluation of the energy and the impacts of the environment, are not clear and comprehensive in majority of their NZEB projects as suggested by a literature search.

**Logic for evaluation used → object-methodology-trend.**

**The initial purpose for evaluation of NZEB** → Quantification of NZEB impacts on environment and energy.

However, according to the authors a clarified object is required prior to the evaluation for two issues which are → 1) Definition, 2) Energy-efficient measures.

**Methodologies:**

1. Research method:
   1.1 Four processes  of building life cycle:
      1.1.1 Preparation
      1.1.2 Construction
      1.1.3 Maintenance
      1.1.4 Demolition
2. Tools → Numerous simulation tools and algorithms exist nowadays, some of which are already mentioned above.
3. Performance indicator → Includes the following:
   3.1 Indoor comfort → Precondition sign for evaluation of NZEBs.
   3.2 Energy balance →, Energy balance analysis is a basic recommendation for evaluation
   3.3 Life Cycle Assessment → A research method, and not an indicator of performance. Also, it is usually used in the building world.

An overview about probable trajectories for carbon dioxide emission and energy consumption by domestic buildings proposed by SEAI or Sustainable Energy Authority of Ireland, was reported by the authors. The authors also refer to the role of energy systems which is already discussed in [6].

**Prediction:** The authors claim that due to development trends in NZEBs, it would become difficult in future to make an evaluation.

**Three factors of consideration for evaluation in future according to authors' experience and a literature research:**

1) Possibilities to integrate ERP with the conventional energy power to BES or Building energy system.

2) In a non long term basis, the utmost priority for the design of BES should be integration of BES which can realize a balance between generation of RES and consumption annually through a centralized control system.

3) Absolute self-sufficient NZEB that does not depend on the national grid, which however currently is farfetched.

The authors further briefly describe matching the load and integration of the grid, to which [10] is completely dedicated. [10] briefly analyze load matching and integration of the grid through the data that is monitored and simulated. All in all [9] reviews the global factors, definitions, policies, incentives, and development trends. Moreover, the authors conclude by implying that a globally accepted definition should include different tiers of boundary, criteria, credit, metric, etc. However, considering certain criterias like climate or economic factors, the definition may vary accordingly.

**7.** As mentioned above, [10] briefly talks about NZEBs, load matching, grid interaction, load management, self-generation and self consumption of a ZEB. The authors start by describing NZEBs. Their description is more or less similar as discussed till now in this report. Although, in this paper the author mentions the concept of energy conservation which is applied to attain Net Zero energy. Moreover, the authors mention a term called 'prosumers', which means that the buildings are producers as well as consumers of both heat and electricity, thus prosumers'. Further they claims that two dynamic phenomena which are closely-related must be addressed by implications and analysis of a NZEB, which includes:

1. Load matching (LM) → The interaction between the building loads and generation on-site.
2. Grid interaction(GI) → The import/export product interplay with the energy grids in the surroundings.

**Obstacles to manage and design possessed by interaction between demand and energy generation:**

1. Difference in retail prices and wholesale for the residential producer and consumers i.e. prosumers → Self consumption's promotion and discouragement of grid injection.
2. The distributing grids with an enormous number of NZEBs should be designed in a way such that it could manage generation and load → Reinforcement of grid or solution to the grid management is a requirement, at the expense of grid operator or/and consumers.

The authors describe an instance from Germany where the use and importance of these LMs had been promoted for the NZEBs, which was also the for few European countries which promoted the self consumption, However there is no explicit evidence which suggests the names of any of these European countries precisely.

**Objective:**

To contribute to the NZEBs role discussion in the future systems of energy by load matching and grid interaction.

Five case studies are analyzed with data of high resolutions, out of which three are built by monitoring real buildings.

**Aim:**
Choosing and suggesting a finite set of indicators (quantitative) that:

1. Can give practical data for buildings, operators and grid designers.
2. Globally understandable for people irrespective of their educational background, and do not need sophisticated simulation or extra resources.

Moreover, graphical representation is provided which describes daily or annually variation in indexes which are easily understandable.

Further, as aforementioned in discussion of previous articles, these authors too argue that the studies done so far lack comprehension and are not coherent. They claim that this is mainly due to complex and time unfriendly simulation tools. The authors further talk about methods by some of the different authors, but they are different from each other.

**Main goal as per the authors:** To analyze pros and cons of the indication components, and to identify users' groups for which they are suitable. In conclusion, all the present day existing LM and GI indicators used for evaluation of NZEBs are investigated. The graphical result is being discussed. Mostly, the graphical data is composed of annual and hourly variation in the indexes.

**Important point of consideration about case study:**
The selection of case studies was based on proximity of the energy balance approaching net-zero. Distant from zero cases, including net positive ones were discarded. Selected cases includes:
Monitored buildings → 3.

Simulated buildings → 2.

These five cases were to represent different climate zones, RE(renewable energy) technologies, and building topologies. On to that, a brief outline about these case studies has been provided.

**Results:**

1. Load matching components → Presentation of yearly values of load cover component, supply cover component, and the loss of load probability for both the categories of cases.

   1.1 Loss of load probability → Frequency of failure in coverage of on-site load by on site supply.

   1.2 **Heating-governed climate (Monitored 1 and 2)** → The graphical result on-

Denmark and Sweden have been discussed with the consequences. A variation in result was observed which the authors claimed was the result of huge variation in solar azimuth and altitude.

1.3 **Heating and cooling governed climate (Simulated 2)** → Situated in climates with both heating and cooling requirement like Spain as mentioned by the authors. The results are described briefly by the authors based on graphical data. However, a point of consideration mentioned is that the similar daily patterns could also be caused due to non-stochastic consumption used in generating simulated programs.

1.4 **Office building in a climate governed by cooling (Monitored 3)** → Similar to Monitored 2 in Singapore, in this case cover factors' seasonal variations is not important. This case i.e. Monitored 3 has a huge load cover component has a high synchronicity between the PV generations and the electricity load's profile shape. Further, graphical data sets and observations are discussed.

1.5 **In a heating governed climate with micro combined heat and power or micro CHP (Simulated 1)** → Finland based, and only case where CHP system operates with heat production priority. Further data and observations are discussed.

2. Grid interaction components → **Key issue:** connection capacity of a grid unknown during early phase. It is also discussed in a study by another author as mentioned by the authors. The data and result through graphs and grayscale plot are discussed in brief.

Lastly, various indicators for load matching and grid interaction used currently for the NZEB evaluation have been studied.

**8.** Another anecdotal instance like above has been examined in [11]. A stand-alone home's design process as a micro-grid from an energy view in Rome has been discussed. The house consists of all the required tools to check all the necessary comfort situations and achieve Net Zero energy. Usage of micro-grids the distribution network is reported to be a solution to tackle obstacles like:

1. Emission increase
2. Complexity and Market competitiveness
3. Low productivity

**Micro-grid** → A small sized electric grid equipped with distinct components for:

1. control
2. measuring infrastructure
3. communication

**Real life implementation:**
The representation of Micro-grid case study has been presented which is actually implemented in a real life building where a family of four people are residents in Rome, Italy.

**Composition of Micro-grid:**

1. PV system
2. BESS, which is discussed briefly in [6].
3. Appliances of high energy like lights, plugs, etc.

**Limitation according on the bases of author's reference:**
Such systems require high investments which cannot be met by saving some assets on bills during the plant's life cycle.
**Advantage However** → Reduces dependency of citizens on nation grids, and deviation of electric market price

**Method:**
Analysis of a stand-alone building as a Micro-grid by a comparative study with two different situations:

1. Standard
2. Optimized Case

**Results and conclusions:**
Concerning the energy view, absolute energy independence in a building is a possibility, but an oversized system is needed for the compensation of the uncertainty of the solar supplies.

**9.** Now from above [11], it is clear what microgrids are and why they should be used. Building on that [12] talks about grids that are smart, or smart grids for short. Moreover, a new variation of ZEB is introduced in [12] i.e. Zero grid Impact Buildings. All in all [12] briefly focuses on energy management in such kinds of buildings where smart mico-grids are used. A new concept is discussed for integration of buildings in micro-grids with ZGI or Zero grid impact as mentioned above. Therefore, **Aim of the paper → A concept for integration of buildings in micro-grids with ZGI.**

**Authors proposal by the study to achieve the aims:**
These aims are proved to be achievable with a system that is intelligent, based on a converter (AC/DC) connected by the coupling point of the building with the main-grid.

**Smart grids** → In transformation of traditional grids, a new system's implementation is inevitable. The transformed grids should be:

1. Flexible
2. Open access
3. Sustainable system

However, there is a different definition as mentioned below.

**Definition of smart grids by EU (European Union):**
An electrical network that can smartly integrate actions by each user connected to it, the users are as follows:

1. Generators
2. Consumers
3. Both 1 and 2 in one

This is to achieve supplies as follows:

1. Sustainable's efficient delivery
2. Economy
3. Secure electricity

Further, the authors briefly discuss MG or micro-grids, similar to [11], followed by description of a building's electrical system, system parts' control, results of simulation, the real life model at ENEA labs that was utilised in testing of the system in smart Microgrids ,and the conclusion.

**Method → Simulation**

**Tools used → MATLAB/SIMULINK**

**Key Result** → Confirmation of usefulness of the system and goodness of model in micro-grid applications.

Lastly, a custom power device (CPD) and the operation of CPD in a building with zero grid impact has been presented. A kind of configuration that allows the building to control active and reactive power making it act as a generator.

**10.** Similar to [11], stand-alone buildings with grids are discussed in [13], while contrary to [9], authors in [13] talk about design optimization and ideal control of the connected grid, and stand-alone net or nearly ZEB. The authors start by implying about ZEBs, their need, definition, and applications, but those are more or less similar to what has been reported in this report already. Further, an international task 40 under the supervision of IEA or International Energy Agency has been reported. Some instances from Europe, UK, US, France, etc. have been implied. Moreover, a map has been presented with 360 globally recognised ZEBs plotted.

**Three important steps to achieve ZEB target:**

1. Usage of strategic passive design
2. Energy optimal technologies
3. Energy producing technologies

However, the authors claim that there is no precise approach to realize and design a NZEB. Moreover, the authors report about a study by another author which proposes a twelve step procedure for the design.

**Design optimisation:**

Further, design optimization is being discussed which includes:

1. Methods used for optimization
2. Sensitivity or Uncertainty analysis included for majority of findings and robust design.

Equivalent to [10], this paper i.e. [13] also discusses the different climatic factors, but the discussion includes effects on design unlike of [10].

**Biggest obstacle in NZEB design, integrated with various kinds of ES (Energy systems) →** Numerous parameters of design should be simultaneously decided**.**

**Different methods used by different authors discussed:**

1. The graphical
2. Probabilistic

3. Iterative method
4. Annealing algorithm (Simulated)
5. Optimal sizing method
6. PSO, as aforementioned and discussed in [4].

Further, about the uncertainty or sensitivity analysis, the authors implies three main efforts for research on this particular subject which includes the categorisation as follows:

1. Consequences of uncertainty on the NZEB design.
2. Finding of certain parameters which triggers sensitivity of NZEB performance
3. Parameters' investigation which could determine the suggested configuration for the hybrid systems of energy.

The authors further talk about scheduling, similar to what was discussed in [4] about appliance scheduling, and energy system control which was also discussed in [12]. Moreover, use of smart technologies has also been discussed, which again has been reported from other articles. Thirty global NZEBs also have been presented. All in all, important issues of NZEB's control and design have been presented. Finally, **Recommendations and Challenges for future in developing such buildings** have been summarized.

**11.** Firstly, not different from others, [14] starts by mentioning the importance of environment safety, and promotes the usage of NZEB's importance. The authors refer to an instance of study applied to a building in Hong kong. Moreover, it is been reported that various studies on sensitivity analysis have been made which influences the following:

1. Peak loads
2. Annual Energy and cost
3. And thermal comfort in certain cases

Further the similar to [13] uncertainty analysis has been discussed.

**Methods:**

→ Schematic has been presented which shows macro-parameter influence of sensitivity analysis of a NZEB.

→ Performed study on dynamic simulation stage developed by TRNSYS.

**Case studies:**

Table with the list of studied parameters is provided. Mainly the parameters falls under the following categorization;

1. Building parameters
2. HVAC parameters
3. Energy systems (Renewable) parameters

**Results:**

→ Verification of the exhaustive approach of searching for optimization of storage and energy systems to get the lowest possible initial cost. Moreover, average values of the parameters are used in verification. Further, the results are briefly discussed with graphs, categorised as cases which are divided as per impacts on different parameters.

In conclusion, an investigation on the sensitivity effect of parameters categorised in three groups. Meanwhile, an approach has been proposed, namely the approach of Exhaustive Search to reduce and minimize the cost of storage and energy systems (renewable).

**12.** Now that various optimisation techniques and evaluations have been reported. Building on [12], [13] and others , understanding of [15] is easy. [15] talks about the demand side of micro-grids and its load control. Similar to others [15] presents instances from the EU regarding policies and approaches. Here, a new concept of TBS or technical building systems has been introduced. This paper mainly focuses on this TBS to present a prototype of architecture that is particularly appropriate for NZEB. The authors further report about the complexity in TBS that is present in the ZEB or NZEB, which are as follows:

1. Organisation of TBS in ‘Micro-grid approach.
2. Usage of the solutions that are innovative is a necessity.
3. Necessity of BEMS or Building energy management system, which is a SCADA system that should have the ability to :
   3.1 manage
   3.2 operate
   3.3 control the TS or technical system
4. The BEMS mentioned above requires a building manager that is a SMS or smart metering system.

A complete electric prototype of micro-grid has been presented for residential buildings, which are characterized by different unique connection points with the electric grid.

**Proposed Approach** → TBSs integration inside the building, which refers to the management and energy interplay. By this way, the entire building can be considered as a single subject that interplays with the distribution network advancing the cost and efficiency of energy.

Further, a new key term KZEB has been introduced. KZEB means Km Zero Energy Buildings. The authors discusses a paper that suggests approach towards transforming NZEB to KZEB with multiple aims:

1. Saving in cost without compromising user's comfort.
2. Load profile control to minimize effect on the distributor.

**Innovations presented by the proposed micr-grid prototype:**

1. Unique connection point and system of common distributor for the whole building → Architecture.
2. Domotic system integration with the system of global automation building, considering user privacy, but with the share of a few managements.
3. Thermal load management in accordance to the electric profile to utilise building's natural inertia as a system of storage.
4. In a building view point → Smart appliances management.

**Results:**
A building with 92 apartments in Campobasso, Italy, is used as a study case. Load profile of the building is simulated for different cases (4 cases) for a particular day in March.

In conclusion, small users or a building cluster aggregation in a supplied grid by a private and adequate network which is connected to the utility by a single connection point allows the control for usage of power, both technologically and economically. Moreover, it has been reported that load control helps in the improvement of the generated PV's power self consumption , which needs absolute collarbating users to prevent grid feeding.

**13.** Like most of the articles above, [16] also starts with how, why and what are ZEBs. The authors implies that various technologies are under research to reduce emissions and energy deamsn. Moreover, STPV or Semi-Transparent Photovoltaic which produces electricity, and has a potential to transmit light (visible), is reported to possess the highest potential to reach the technological goal aforementioned.

**Aim:**
To find if STPV at its basic level can achieve NZEB goals.

**Method:**
The selection of silicon build non-wavelength STPV, and created thermodynamic prototypes for the following:

1. Electrical
2. Optical
3. Thermal parameters

Built on the above model, a building's (office) annual estimation of net energy footprint for different climate situations has been made. Further, using EnergyPlus simulations of the building was performed in combination with calculation of power generation from an irradiance solar model.

**Results:**
The results proposes that for half of the visible transmittance, on clear glass STPV saves energy demand of around (in accordance to regions) :

1. Tropical region → 50%
2. Desert regions or hot regions → 30%
3. Scandinavian and chilled continental regions → 20-25%

However, if addition of low emissivity glass is considered then net savings increases to around the figures as below:

1. Tropical regions → 90%
2. Hot and desert regions → 60%
3. Rest of the regions → 45%-75%

In short, figures of merit of the system and device level have been proposed that considers the utilisation of natural light along with net saving of energy. Further, it has been shown that overall saving of the hot regions can be increased upto 100% if curtain efficiency techniques are to be adopted. Therefore, this proved STPV with glass of low emissivity, a globally promising technology.

**14.** Throughout the report, multiple optimization techniques have been discussed, in [16], a technological device STPV was discussed. [17] presents an approach which promises optimal sizing of such devices. The authors start by definition and discuss the importance of ZEBs and environmental impacts. These environmental impacts upto an extent have already been discussed in introduction and in [8].

**Aim:**
A new optimization prototype namely bi-objective which considers environmental effect and cost of trade-off for the sizing of ZEB devices, both thermal as well as electrical.

The authors further provide an enhancement in the model that has already been proposed in comparison to the existing prototypes → Priority of excess ZEB energy storage rather than its sale to the grid. Similar to [4] and [5] mixed integer linear programming has been used as an approach, but unlike them, here it is used with McCormick relaxation linearization to get a more controllable linear mixed-integer model.

**Method:**
The ε-constraint augmented method is used to solve the bi-objective model obtained.

**Results:**
As a case study, a building in Luxembourg has been used. The data sets and parameters used, and from where it has been received are discussed. Moreover, it has been reported that environmental effects of every device are dependent on manufacturing and technological processes. Different case study figures with graph plots and categorizations have been discussed in brief further.

Finally, assuming owner of the building's will of paying for environmental effects, a criterion for decision making has been proposed for the selection of ideal size of the devices amongst every solution (non-dominated) of the Pareto front. This Pareto front is known already as it has been discussed in [8].

**15.** Finally, a different simulation completely GUI based has been conducted in [18], which proposes a way for comfort and energy management. The authors start by implying that ZEBs have become a trend for future buildings nowadays. However, the obstacles in designing and controlling such systems that need employment of renewable sources of energy and energy efficiency, remain the same.

**Aim:**
To provide a simulation tool that is graphical user interface (GUI) based that can be utilised for improvement in comfort and management of energy.

**Method:**
A brief analysis and description of the simulation tool is provided. Users can manage buildings through the method of this GUI based platform . Building operation is applied with a control system (multi-agent) for the management of different comfort demands. PSO, which has already been discussed in [7],[8] and [13] is applied here as well for the optimisation of the control system to enhance comfort of the user, and save energy.

**Result:**
The figures without usage of PSO also have been provided and discussed. Moreover, a MATLAB based GUI simulation has been proposed through which, user's own preferences can also be set. Further, it has been reported that indoor surroundings cannot be maintained consistently due to power shortage for some period of time. To maximize the values of comfort in different conditions for operating, PSO is used.

All in all, the GUI model of simulation provided is an easy to use platform, and the results are easily observable. On to that, the results also contains the following, which is a massive **advantage :**

1. Net power consumption
2. Net user comfort

3. Real time circumstances of power supplies
4. Environmental parameters (Indoor)
5. Set points variation
6. Each comfort demand → Power consumption.

Moreover, different comfort demands set points are adjustable online to maximize net comfort level in accordance to the data (real-time).

## 4. Search questions

The research questions that may your report answer are:

1) What are ZEBs?
2) What are NZEBs?
3) What are Nearly ZEBs?
4) Why are ZEBs important?
5) Definition of ZEB?
6) What are the different categorizations of ZEBs?
7) Does a precise definition for ZEB exist?
8) How investments and policies affect usage of ZEBs?
9) What Zero Emission Buildings?
10) What are BESS and how are they useful in ZEBs?
11) How can BESS be useful in saving money?
12) What are the different control methodologies for energy management?
13) What are some examples of multi-objective performance optimization algorithms?
14) What is/are pNSGA-II, MOPSO, PR_GA, evMOGA, ENSES, spMODE-II and/or MODA?
15) What is load matching?
16) What is Grid interaction?
17) What is the importance of load matching?
18) What are load matching and grid interaction indicators?
19) What are Micro-grids?
20) What are Micro-grid's components?
21) What is the benefit of using Micro-grid?
22) Is it possible to achieve an absolute energy independent building? How?
23) What are smart micro-grids?
24) What is the European Union's definition for smart grids?
25) What is the biggest challenge in designing NZEB with various energy systems?
26) Why is the exhaustive search approach used?
27) What does a Building energy management system require?

28) What are the complications of a technical building system in a NZEB?
29) What makes Semi-transparent Photovoltaic a globally promising technology?
30) What are the different ways to optimise energy design?
31) What are the different economic optimization ways for ZEBs?
32) What are the environmental impacts which make ZEBs desirable?
33) What is the Particle Swarm Optimization technique and why is it used?

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