Abstract—In the last decades, the fossil fuel depletion has accelerated massively, leading to emit a huge volume of greenhouse gasses into the atmosphere daily and the earth temperature increase. New policies all around the world are devised to reduce the consumption of nonrenewable energy sources. Renewable sources of energy (RES), like wind and solar, are considered to provide future energy of the mankind activities. Future Smart Grid, which includes a lot of new technologies and standards, is the best matter to have RES vastly in utilization. Undeniably this extensive change of the electricity grid, requires sufficient research and investigation besides to excessive governmental investment. On the other side, the first steps for implementing a smart grid or employing RES should be practical and less expensive. As a result, household sector, and specifically buildings that are blamed for consuming about 40 percent of whole global energy seems to be a good point to start. In the next generation of buildings, the annual energy consumption is equal to generated on-site renewable energy and because of that, they are called Net-Zero Energy Building (NZEB). NZEB could be grid-connected or off-grid which suggests the best choice for electrifying remote isolate areas. In this paper, a review on new definitions and advances in the field of NZEB is presented.

Keywords—Net-Zero Energy Building (NZEB), Microgrid, Distributed Generation, Stand-alone Generating System.

I. INTRODUCTION

In the future smart electricity grid, integration of the power system is always regarded as a tremendous problem. Renewable Energy Sources (RES), such as wind and solar, paired with microgrid, smart grid, energy storage technologies are practical possibilities to tackle this question [1-3]. Obviously, coupling these elements demands a full perceptive of operational issues, expenses and certainly forecasting a return on asset [4]. Conceptually, NZEB is a building with significantly diminished operational energy demands which generates its own energy needs [5]. High efficiency building materials from one side and being supplied by renewable energies on the other side result in minimizing the energy demand of this kind of buildings [6]. In order to rate the energy use of homes and labeling them, there should be a unite standard. Home Energy Rating System Index (HERS) is a verified standard which calculates the energy efficiency of a home. Commonly, typical homes have a HERS rating of 125-135 while new standard homes have a HERS rating of 100 [7].

A home with HERS rating of zero denotes that the home is totally self-sustaining in case of energy consumptions. Though this home is still connected to the grid for increasing assurance and backup, the majority of the energy needs is provided through solar, wind and other RES. NZEBs should have no adversative energy or conservational impacts related to their operation. In other words, a NZEB should have high energy efficiency and generate at least the same amount of energy which it draws from the grid during a yearly period.

Since 2009, the federal agencies are forced to widely accomplish the utilization of net-zero energy in new constructional renovations and reformations by 2030 [8]. On the other side, by 2015, at least 15 percent of existing governmental constructions have to come across the guiding principles for federal leadership in viable and high performance buildings. Also, for all commercial buildings, a goal of net-zero energy use through 2030 is set by the Energy Independence and Security Act of 2007 besides to net-zero energy goal of 50 percent by 2040 and net-zero standard of 100 percent by 2050 [9-10]. The inevitable necessity of better accuracy in the definition of “Net-Zero Energy Performance” has been exposed by the investigation and studies in the field of energy issue. This paper aims to present a brief but useful review in the field of NZEB, relative advances and future predictions to help the recent advances and standards of this sector published faster and utilize and improve by the other researchers.

The rest of the paper is sketched as follows. The basic fundamentals of NZEB are discussed in section II. Various types of NZEBs are classified in section III and classification based on renewable energies is presented in section IV. Section V talks over off-grid NZEBs. In section VI and VII, cluster of NZEBs and managing multiple affecting design factors are reviewed respectively. Paper is concluded in section VIII.

II. NET-ZERO ENERGY BUILDING FUNDAMENTALS

A building, which its annual net energy consumption and carbon emission are zero is known as zero net energy building or commonly NZEB [11]. There are two other definitions for this kind of buildings; “Near-Zero Energy Building” or "Ultra-Low Energy Building", meaning that the building consumes slightly more energy than it produces annually, and, “Energy-Plus Building”, meaning that the building generates a surplus
of energy over a period of year. In European Union and the US, 40 percent of the total fossil fuel energy is consumed by conventional buildings, representing that they are most responsible sector for vast emission of greenhouse gases [12-13]. So, from both the aspects of environmental pollution and energy crisis of twenty first century, the NZEB is regarded as an influential means to evade these critical challenges. As the cost of nonrenewable fuels increases and due to the latest advances, the cost of renewable energy production technologies decreases, the NEZB will become more popular. New vast academic researches accelerate this procedure through designing complex computer models and predicting the efficiency of engineering designs by collecting and examining accurate energy performance data of traditional buildings [14-18]. Based on various possibilities of generation and storing energy coupled with the many options of energy measuring (relation to energy, cost or emissions), the NZEB concept allows a wide range of approaches. As said, in NZEBs, energy is generated through high-efficient equipment which modifies the output of RES (that are commonly wind and solar) and based on erratic nature of these sources of energy, there is an inevitable need for energy storage system (ESS). Consequently, although the NZEBs could be connected to the grid, the ESS is a fundamental part of its energy system. A procedural structure was set up due to scientific investigation of the joint research program; "Towards Net-Zero Energy Solar Buildings", revealing new diverse classifications according to the political objectives of the country, specific weather conditions and correspondingly basic requirements of indoor conditions [19].

As it is inferred from the definition of NZEB, the word "net" emphasizes that between the building and the grid, the energy is always substituting, and as is depicted in Fig. 1, in a NZEB the quantity of the absorbed energy from the grid, should be equal to the extra energy exported to the grid. Because of this building/grid energy interaction, the NZEB is considered as an active part of the smart grid whilst seasonal energy storage and oversized on-site renewable energy generation systems are desirable reduced through this interaction. As the number of NZEBs increases, the flexibility in shifting load demand and consequently reduction of relevant electrical losses increases [20-21]. In consequence, in a NZEB, a number of systems and technologies work together to achieve the final goal of NZEB. Fig. 2 depicts the basic energy system of a NZEB which is powered by PV arrays, wind turbines and utility gird. In this structure, the output energy of PV array and wind turbine will be saved into the battery bank, and when needed, will be converted to AC current with a suitable voltage and frequency level using appropriate converter and become used by NZEB habitants.

![Energy Balance Concept of NZEB](image1)

![Energy System Configuration of NZEB](image2)

When the battery capacity is full and the renewable sources are delivering energy, the surplus energy will be sold to the utility grid, and vice versa, the electricity will be purchased from utility grid when the level of the battery does not meet the NZEB energy demand. The utilization of an advanced energy manager unit that measures, monitors and stores all the energy follows, annual costs, components services and maintenances, etc. for having an accurate management and administration is inevitable.

Undoubtedly, like the other new innovations, NZEB has both positive and negative aspects, which in order to be operable and achievable, positive factors must prevail negative ones. The most important advantages and disadvantages of the NZEB are mentioned following.

### A. Advantages
- Free from upcoming legislative restrictions of energy and carbon emission penalties and taxes which may oblige the owners of inefficient buildings to pay new expensive retrofits.
- Extra energy reliability thanks to new photovoltaic systems which have about 30-year warranties and sophisticated energy storage and utility grid connection.
- Nearly zero monthly costs of energy.
- Environment friendly buildings without burning fossil fuels and not emitting greenhouse gasses into the atmosphere.
- Avoid widespread blackouts which are mostly caused by power plant and transmission line failure.
Presenting comprehensive administration on daily, monthly and yearly energy flow and relative prices in building by calculating on-site generated, imported and exported electricity courtesy of powerful computer of NZEB’s energy manager unit.

- Avoid high energy waste in outdated power plants and long transmission lines.
- Enabling the future microgrid and smart grid to emerge easier and quicker by preparing their fundamentals.

B. Disadvantages

- High initial constructive investment.
- High dependency on erratic nature of weather condition to harvest electricity.
- Annual net-energy is zero, so in some grid-connected cases, utility grid must still operate at high pressure, since NZEB may demand energy from grid at peak times. Therefor a NZEB may not reduce the power plant capacity.
- Higher capital costs and fundamental requirements and lower reliability for off-grid NZEBs.
- Call for high research and high experience for finding the most optimized construction site and energy components remain very few designers or constructors to build NZEBs [22].

III. CLASSIFYING VARIOUS NZEB TYPES

Based on the importance of energy usage classification and accordingly the choice of renewable energy to determine the strategies and design goals on implementing NZEBs, they should be classified in various types. Regarded to properties and characters of each one, some definitions for different types of them, which are assumed to be grid-connected, is formulated following. It is worthy to assume that a building may be considered a NZEB if 100 percent of the purchased energy comes from RES, even if the energy is generated off the site.

A. Net-Zero Site Energy Building

Net-zero site energy building satisfies energy needs by providing on-site renewable energy, meaning that it produces at least as much energy as it consumes. On the other hand, in this type of NZEB, the total energy consumed by this building is equivalent to the total energy delivered by on-site renewable sources.

B. Net-Zero Source Energy Building

The major energy needs for extraction, generation and delivering the energy to the site, are all categorized in source energy. Net-zero source energy building delivers at least as much renewable energy as it consumes during a yearly period. Related to the source energy system type, delivered and consumed energies are multiplied by the suitable site-to-source transformation multipliers to estimate the overall source energy of the building. The amount of energy which a net-zero source energy building produces equals to the amount of its used energy, plus the lost energy through transmitting the energy to the building. It means that the source NZNB must produce more energy than site NZEBs.

C. Net-Zero Energy Costs Building

Simply, in this category yearly net energy costs which a NZEB owner pays to the grid for imported energy is equal to that of grid which pays to NZEB owner for purchased renewable energy. So, in net-zero cost building, incomes from selling the on-site generated electricity to the grid, balances the cost of purchasing energy.

TABLE I. POSITIVE AND NEGATIVE ASPECTS OF NZEB TYPES [23]

<table>
<thead>
<tr>
<th>Definition</th>
<th>Positive Aspects</th>
<th>Negative Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net-Zero Site Energy Building</td>
<td>• Easy implementation</td>
<td>• Needs more PV and wind turbine export to balance fossil fuels</td>
</tr>
<tr>
<td></td>
<td>• Conventional method to construct</td>
<td>• Unable to equate fuel types</td>
</tr>
<tr>
<td></td>
<td>• No external circumstances influence performance</td>
<td>• Incomprehensive utility grid costs consideration</td>
</tr>
<tr>
<td></td>
<td>• Provable through on-site measurements</td>
<td>• Unable to account non-energy variations between fuel types</td>
</tr>
<tr>
<td></td>
<td>• Easy communication for the building community</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Energy-efficient building schemes and plans enhancement</td>
<td></td>
</tr>
<tr>
<td>Net-Zero Source Energy Building</td>
<td>• Easy achievement</td>
<td>• Unable to account non-energy variations between fuel types</td>
</tr>
<tr>
<td></td>
<td>• Equated on-site used fuel types energy value</td>
<td>• Source calculations too broad</td>
</tr>
<tr>
<td></td>
<td>• Better design for impact on nationwide power system</td>
<td>• Source energy use accounting and fuel switching can have a larger impact than efficiency technologies</td>
</tr>
<tr>
<td>Net-Zero Energy Costs Building</td>
<td>• Easy implementation and measurement</td>
<td>• Incomprehensive utility grid costs consideration</td>
</tr>
<tr>
<td></td>
<td>• Market forces result in a good balance between fuel types</td>
<td>• Requires large quantities of information for site-to-source alteration</td>
</tr>
<tr>
<td></td>
<td>• Demand-responsive control ability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Provable from utility grid bills</td>
<td></td>
</tr>
<tr>
<td>Net-Zero Energy Emissions Building</td>
<td>• Easy achievement</td>
<td>• Needs net-metering standards</td>
</tr>
<tr>
<td></td>
<td>• Better design for green power</td>
<td>• Tough pursuing due to highly volatile energy charges</td>
</tr>
<tr>
<td></td>
<td>• Non-energy variations between fuel types</td>
<td></td>
</tr>
<tr>
<td>Net-Zero Energy Emissions Building</td>
<td>• Easy achievement</td>
<td>• Requires suitable emissions factors</td>
</tr>
<tr>
<td></td>
<td>• Better design for green power</td>
<td>• Demands going further than NZEB to balance monthly infrastructure charges and services</td>
</tr>
<tr>
<td></td>
<td>• Non-energy variations between fuel types</td>
<td>• Needs mature net-metering standards</td>
</tr>
</tbody>
</table>
D. Net-Zero Emissions Building

NZEB offsets common harmful emissions like carbon, carbon dioxide, nitrogen oxides, and sulfur oxides. If a NZEB offsets all the emissions from all the consumed energy through renewable energy production during a year, it is called net-zero emissions building. Related to the emission of the grid, imported and exported energy is multiplied by the proper emissions multiplier to calculate the overall emissions of a building. Net-Zero Carbon Building or Net-Zero Emissions Building are the most common definitions of NZEBs. As said, all the environmentally harmful emissions produced by on- or off-site fossil fuel generators are offset by environmentally friendly renewable energies generated on-site. In more accurate calculation of emissions, the emission related to transportation losses should be accounted.

Table I represents all the discussed classes with their positive and negative aspects. The most positive aspect of Site NZEB is its easy implementation. In comparison with other classes, planning and operating of a Site NZEB is much easier. On the other side, it calls for more renewable energy harvesters like PV arrays in order to offset imported energy from the utility grid. Cost NZEB and Emission NZEB are the hardest classes to achieve due to their complex measurements and more expensive energy manager units.

IV. RENEWABLE-BASED SYSTEM ARRANGEMENT

Reducing the energy demand to the lowest feasible level and supplying the energy needs are respectively two principal rules of formulating NZEB definitions and classification. Before incorporating renewables, all feasible energy-efficient and cost-effective strategies should be considered. The first assumption in renewable-based classification is that all the NZEBs should initially diminish site energy demand over the building’s renewable technologies and energy efficiency, which stands for building’s insulation, high-efficiency HVAC equipment, ground source heat pumps, passive solar heating, day lighting, etc.

Based on the classification system, NZEBs are classified in two groups, one that uses off-site RES and another that uses on-site RES as is presented in Table II. In category I, all the building’s energy and its emissions are balanced by on-site renewable energies. In category II, some of the renewable energy needs is gained from project-site like ground-mounted PV arrays. Category III is supported by off-site renewable energies like biomass and category IV is supported by both on-site and off-site renewable energies. Although utilizing on-site RES minimizes the overall conservational effect of NZEB through evading transmission losses of the off-site RES, there is neither a best definition for NZEB, nor for their energy usage description and it is just the owner’s goal and environmental restriction that determines the suitable construction classification. In reality, each class has its advantages and disadvantages.

V. OFF-GRID NET-ZERO ENERGY BUILDING

Isolated NZEB that is not connected to any off-site energy utility is called off-grid NZEB. In this concept, the balance of production and consumption can be made on an hourly or even smaller basis. Obviously, this kind of NZEB needs a comprehensive provision of on-site renewable energy and respectively a vast capacity of ESS. An off-grid NZEB neither can send its surplus energy back to the grid nor can import energy from the grid. Thus, the production of RES must be bigger than the same grid-connected NZEB. On the other side, because of restriction in technologies of ESS, implementing an off-grid NZEB is more challenging. Most off-grid NZEBs use backup diesel generators and propane gas (for heating), but these elements wipe out the meaning of NZEB. But, since the relative technology has not advanced sufficiently and implementing extensive ESS still costs high, there is no other way to handle an off-grid NZEB. Undeniably, an off-grid building which uses no fossil fuels could be regarded as a pure NZEB, where no annual net-energy balances come to account.

VI. CLUSTER NET-ZERO ENERGY BUILDINGS

By developing NZEB technologies and decreasing relative costs, groups of NZEBs such as net-zero energy communities, towns, etc., will be more and more popular. This renewable-energy-based community could be connected to the electricity grid. In community-scale and hub-site systems, management, maintenance and efficiency are considerably higher. Since energy is the most important concern of any alone or cluster NZEB design, for crowded communities and districts, it would be more efficient from both technical and cost aspects to place all renewable energy generator and other equipment in one location, instead of distribute them in discrete buildings. Since energy is generated in one point, transmission and distribution losses could be regarded as the major disadvantage of community-based renewable energy system. Also, system failures and extra expenses such as distribution wiring, transmission losses and distribution transformers losses associated with district distribution systems come to case.

Single-building net-zero concepts could be developed to group buildings with native renewable energy system and to net-zero energy cluster buildings by a similar classification system [24]. Furthermore, renewable energy supply hierarchy concepts and energy harvest management approaches developed for individual NZEBs apply to net-zero energy communities too.

VII. MANAGING MULTIPLE DESIGN FACTORS

Coupling NZEB’s renewable energy system is a tough challenge. RES are erratic, electricity tariffs vary during a day and NZEB habitants have unpredictable energy demand. Following three most important elements are introduced.
A. Plug Load

In common buildings, almost 50 percent of the overall electricity use is accounted by plug loads like appliances, lighting, electronic devices, and the like, which using them depends on the building’shabitants. Therefore, in case of constructing a NZEB, the most innovative energy-efficient design and latest economic electrical energy modelling can only save the losses of the half of the consumed energy. Since the consumption behavior of the building’shabitants and the operating manner (which includes how many hours the building’s appliances are used, which times of day they occupied, were they used altogether, and the like), will undeniably have a significant effect on the plug load operation strategy and must be accounted in the NZEB energy analysis. On the other side, new appliances could be designed to couple with the energy system of NZEB and for example start to work automatically when the electricity demand of NZEB is lowest or when the energy storage has saved sufficient energy.

B. Energy Manager Unit

Precise monitoring, uncovers building’s operational performance, disorganizations and inefficiencies instantly or over a period of year. This leads to gain more powerful planning and energy performance management. Energy manager unit determines when to import energy and when to export energy, commands appliances like washing machine to start working or plug-in hybrid electric vehicle (PHEV) to start charging, and vice versa, utilize the stored energy in the batteries of PHEV at critical situations. By having several operational adjustments in response to energy monitoring, there will be an extended and powerful management and monitoring. NZEB owner is aware of how much energy is consumed, harvested, imported and exported, when the system was serviced and how much are the imported, exported maintenance costs. By this awareness, NZEB owner and habitants know how to manage their energy demands and what time they should shift their electricity demands.

<p>| TABLE II. NZEB CLASSIFICATION BASED ON SUPPLY SIDE OPTION [23] |
|---------------------------------|---------------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>NZEB Supply Side Options</th>
<th>Description</th>
</tr>
</thead>
</table>
| I        | Use RES directly connected to the NZEB electrical energy system.  
**Examples:** PV, solar hot water, building-integrated wind systems. | Feasible for: Site, Source and Emissions NZEB  
Less feasible for: Cost NZEB  
- Reaching an Emissions and Source NZEB position could be challenging, because during daily peak times, the emission and source multipliers are high.  
- Achieving a Cost NZEB will be tough regarding to the local net metering policies. |
| II       | Use RES as defined in category I  
**Examples:** PV, small scale wind turbine, solar hot water, low-impact hydroelectric.  
Use NZEB site available RES and the RES directly connected to the NZEB chilled/hot water distribution system. | Feasible for: Source, Site and Emissions NZEB  
Less feasible for: Cost NZEB  
- Reaching an Emissions or Source NZEB stage will be difficult, regarding to variations of exporting energy to grid during peak and off-peak periods.  
- Achieving a Cost NZEB will be tough regarding to the local net metering policies. |
| III      | Use RES as defined in categories I and II  
**Examples:** Wood pellets, biomass, biodiesel and ethanol.  
Use off-site RES for producing both electricity and heat. | Feasible for: Site NZEB  
Less feasible for: Source, Emissions and Cost NZEB  
- Reaching an Emissions or Source NZEB stage will be difficult, regarding to unpromising carbon and source multipliers. (If NZEB imports or exports electricity at high grid emission factors, this situation occurs.)  
- Since energy needs to be imported from off-site in low storage levels and recouping relative costs is defiant, achieving a cost NZEB is difficult. |
| IV       | Use renewable energy sources as defined in categories I, II and III  
**Examples:** Grid-connected PV/wind system.  
Import energy from off-site RES | Feasible for: Source and Emissions NZEB  
Less feasible for: Site and Cost NZEB  
- In general, achieving Site or Cost NZEB is very difficult.  
- Having assured source and emissions impacts, achieving Source or Emissions NZEB could be possible (if imports sufficient off-site energy). |
C. Photovoltaics

Based on grown demand for RES through last decades, the research and production of PV arrays has increased significantly. However PV arrays are often associated with existing typical buildings, commonly installed on the roof or on the walls, PV arrays are strongly regarded as the best RES of a NZEB which it can be easily mounted on the roof of the NZEB, mounted nearby on the ground or integrated to it and even can be located in a suitable (but not very far from) building site and be connected to the building through cables. Rooftop-mounted PV arrays were counting about 80 percent of Germany 9,000 MW solar PV arrays in 2010 [25]. As a main or auxiliary source of renewable produced electrical power, building-integrated photovoltaics (BIPV) are progressively incorporated into new domestic, commercial and industrial buildings as like NZEBs [26]. Roof- or wall-mounted PV arrays are the most common incorporation of the solar energy. A recent study using thermal imaging has shown that solar panels (specially wall-mounted ones), while keeping building’s heat at night, provide a passive cooling impact on buildings during day by letting air to circulate between panels and the building [27].

VIII. CONCLUSION AND FUTURE EXPECTATIONS

By the time, capital costs of renewable energies are high, but it worth because just after implementing, the energy expenses are almost free. Generally, implementing RES calls for extensive research, study, prediction and planning. Net-Zero Energy Building is one of the most promising means to smooth this way, since it has almost all the required technologies for a microgrid and a smart grid. It is not just electrical system which makes a NZEB; the build must be well-designed to meet the highest energy-efficiency and the least energy waste. The walls and the windows and the water pipes must be insulated as well. Undeniably, this procedure is not a small business, it needs huge amounts of investments and the governments should support this issue as an international concern.

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