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Review

A Review on Harnessing Renewable Energy Synergies for Achieving Urban Net-Zero Energy Buildings: Technologies, Performance Evaluation, Policies, Challenges, and Future Direction

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Abstract: As urbanization continues to accelerate globally, energy demand in cities is reaching unprecedented levels, contributing to greenhouse gas emissions. In response, the concept of net-zero energy building (NZEB) is becoming a sustainable solution for urban energy needs. NZEB aims to achieve a net-zero energy footprint by balancing the energy it consumes with the energy it produces, primarily from renewable energy (RE) sources. This comprehensive literature review-based study explores the role of RE synergies in the context of urban NZEBs, including discussions on definition and development of NZEBs, RE-synergies for achieving NZEBs, sustainable trends and clusters of NZEBs, climate change impacts on NZEBs, their performance evaluation, policy and regulatory frameworks, and challenges and possible solutions related to NZEBs. It has been identified that while customizing NZEB definitions to align with regional energy supply and demand is important, the same is highly dependent on building architectural and micro-climate features. The assessment of climate change effects and NZEB practices should involve evaluating building energy equilibrium, occupant comfort, and interactions with the energy grid. There are still some technical, policy, and socio-economic challenges that need more attention to provide comprehensive solutions for further enhancing the sustainable development/performance of NZEBs and achieving their goal.

Keywords: climate change; net-zero energy building; renewable energy; sustainability; performance; cost

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1. Introduction

The buildings sector is responsible for about 30–40% and 15–25% of the primary energy use in developed and developing countries, respectively [1,2]. Also, this sector is responsible for 19% of global greenhouse gas (GHG) emissions [3,4]. Thus, being a major consumer of energy and a significant source of GHG emissions worldwide, the buildings sector is significantly contributing to climate change [5]. In order to reduce the energy usage and GHG emissions related to buildings for mitigating climate change [6], net-zero energy buildings (NZEBs) are considered as an effective solution [7]. Toward this end, numerous countries, regions, and organizations around the world have presented several politics/programs to promote the development of NZEBs [8–10]. Two examples of this effort are the United States Department of Energy's (US DOE) "Building Technologies Program" [11] and the European Union's (EU) "Energy Performance of Buildings Directive" [12].

To achieve annual energy balance in a building, a NZEB is integrated with, or relies significantly on, renewable energy (RE) technologies [13,14]. Generally, these technologies include solar, wind, hydro, geothermal, bio, and marine/ocean energy systems [15–17].

To achieve the intended performance objective, it is necessary to select the optimal configurations and capacities of the implemented RE systems in NZEBs through evaluation and optimization [7]. Marszal et al. [18] reviewed zero energy building (ZEB) definitions and calculation methodologies and highlighted the key aspects that need to be considered/elaborated before developing ZEB definitions [18]. Agbodjan et al. [6] carried out a bibliometric analysis of ZEB research and reported that the United State and United Kingdom had the most research studies on it [6]. Sartori et al. [19] introduced a framework for setting NZEB definitions [19]. Kapsalaki et al. [8] developed a methodology for the economic, efficient design of residential NZEBs [8], and Deng et al. [9] discussed the evaluation of NZEB performance [9]. Wells et al. [20] reviewed NZEBs with reflections on the Australian context and concluded that Australia should have separate sets of targeted policies for residential and non-residential buildings [20]. Ahmed et al. [21] assessed contributions of RE generation to the development of NZEBs [21].

As this explosion of interest in RE applied to NZEBs continues, there is a need for efforts to synthesize existing knowledge and examine the complex interplay of multifaceted dimensions (i.e., concepts, policies, technologies, and challenges) towards NZEBs in an urban context. In other words, current technological developments and case studies should be synthesized to assess the feasibility and potential of utilizing RE sources to transform urban buildings into energy-neutral or energy-positive entities. Furthermore, challenges and barriers impeding the widespread adoption of RE systems in urban environments should be examined, and policy frameworks and incentives that could promote integration should be discussed. Therefore, this study aims to explore the role of RE synergies in the context of urban NZEBs. A comprehensive literature review is conducted to discuss the definition and development of NZEBs, RE synergies for achieving NZEBs, sustainable trends and clusters of NZEBs, climate change impacts on NZEBs, performance evaluations of NZEBs, policy and regulatory frameworks, and challenges and possible solutions related to NZEBs. Finally, conclusions and future perspectives are summarized.

2. Research Methodology

This descriptive study falls under the category of comprehensive review studies. The research goals were defined with NZEBs as the target and we analyzed the previous research status and current trends of NZEBs. In order to identify the importance, research gaps, and challenges in NZEB, keywords of peer-reviewed journal papers on "net-zero energy buildings" were identified in the Scopus database. In the next step, the most relevant papers and articles were identified and collected from various databases, including Google Scholar, Scopus, ResearchGate, and Web of Science. In this case, information and sources that were consistent with or directly related to the research focus were used. Then, a thorough literature review and analysis were performed focusing on the current status of NZEB in terms of development and goals. RE synergies with NZEB and its performance evaluation tools, clustering and its regional regulatory frameworks, climate change impact, and challenges facing NZEB applications were selected as the main objectives of this study. At the end, the future direction of RE synergized NZEBs considering regional differences and climate change are discussed.

3. NZEBs: Definition and Development

Enhanced energy demand due to a growing population and urban concentration, as well as the complex contemporary problems of GHG emissions and climate change caused by fossil fuel-based energy use [22], have rapidly generated interest in energy-efficient buildings and/or buildings that can balance their energy demands with energy produced from RE sources. In general, NZEBs are residential or commercial buildings, including homes, schools, hospitals, and commercial facilities, that adopt a modern sustainable construction approach that aims to achieve a pivotal balance between energy consumption and RE generation [23,24]. This concept means advancing energy conversion and use from traditional methods of using fossil fuels to more economical and environmentally friendly methods. Accordingly, it has generally been developed with the primary goal of creating structures that produce as much energy as consumed over a specified period of time. The term “net-zero energy” is sometimes as widely used as the term “zero net energy” and “zero energy”, and the US DOE defines it as having the same meaning when considering the core goals and relationship of delivered and exported energy [24].

Due to the rapidly growing NZEB market and research, there have been many variations in essential definitions and terminology, and a clear definition is needed at this time. Given the Intergovernmental Panel on Climate Change’s (IPCC) definition, “net zero” can be achieved by mitigating global warming. This is accomplished by balancing anthropogenic removals with GHG (or its CO_2 equivalent) emissions from a built environment unit, such as a NZEB, over a specific period of time [4,25,26]. ZEB’s historical development can be traced back to the energy crisis of the 1970s, sparking early efforts to conserve energy in buildings [27]. However, NZEB’s explicit pursuit of a net-zero energy balance has gained significant momentum in subsequent decades, in line with the maturation of RE technologies and the increasing emphasis on sustainability within architectural growth [28]. In the context of building, various terms have been used, such as net-zero building, net-zero energy building, zero carbon building, and net-zero emissions building [26]. Sometimes, NZEBs and green buildings are used interchangeably or confused as eco-friendly buildings. Simply put, a green building refers to a building that has a positive impact or reduces negative impacts on the natural environment during specific design and operation processes [29]. However, a NZEB focuses on energy consumption within the building confines, considering on-site energy production and energy flow through the grid system. Obviously, considering these multifaceted interactions, it is necessary for each country or region to recognize the distinct characteristics of its own energy infrastructure and resources, architectural style, and climate, and to appropriately adapt the definition of a NZEB [19].

The goal of NZEBs can be achieved through a variety of approaches (Figure 1): (i) producing and utilizing RE or RE sources and integrating their technologies (“RE technology”), (ii) reducing energy demand through energy-efficient design and measures (“energy measure”), and (iii) using energy efficiently by connecting to energy infrastructure (“energy infrastructure”). RE technology is a representative way to reduce dependence on fossil fuels by leveraging RE technologies targeting net-zero to meet required energy demands [2]. Some buildings achieve energy neutrality by generating on-site RE independently of external utilities and operating active systems encompassing their solar power, wind turbines, geothermal heat pumps, and biomass systems [30–32]. Energy measures are a way to increase a building’s energy efficiency or reduce its energy needs through energy-efficient architectural planning and design. There are many cases of using mechanical equipment such as energy-efficient HVAC (heating, ventilation, and air-conditioning) or hot water equipment [33,34]. Examples of elements of NZEB design encapsulate a holistic approach that integrates passive design strategies, such as optimized building orientation for solar radiation, maximizing natural light, and good insulation, to effectively reduce overall energy demand [35]. Energy infrastructure is a way to manage surplus RE through the energy exchange between buildings and energy infrastructure to balance RE technologies and energy measures [2].

In reports from the National Renewable Energy Laboratory (NREL) of the US DOE [23,36], four definitions have been provided: (i) “Net-zero site energy”, the building generates RE at least equal to the amount of energy consumed by the building itself annually (accounted for at the site); (ii) “Net-zero source energy”, the building generates or purchases energy from RE sources at least equal to the amount of energy consumed by the building itself annually (accounted for at the source); (iii) “Net-zero energy cost”, in this building, the utility company pays the building owner at least as much money for the RE exported to the grid as the owner pays the utility company annually; and (iv) “Net-zero emissions”, the building generates or purchases RE equal at least to the amount of emissions-producing energy sources used by the building [23,36].

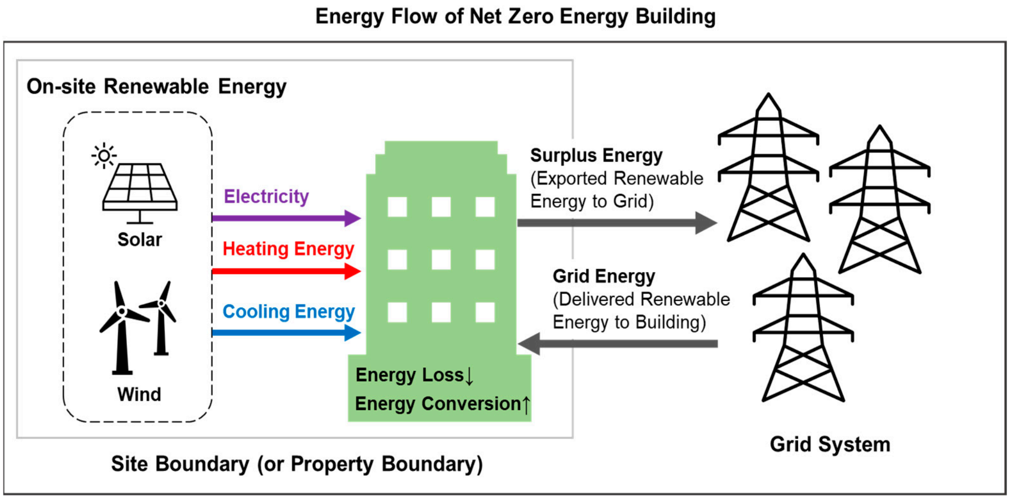

Figure 1. Energy flow and configuration diagram of a net-zero energy building to achieve net-zero.

Several countries (e.g., United States, United Kingdom, and China) are exploring ways to utilize NZEBs [37,38]. From 2014 to 2035, the global market of NZEBs and relevant applications is expected to grow at a compound annual growth rate of 44.5% [28]. Additionally, academic research on energy-efficient designs, cutting-edge RE-linked technologies, and the convergence of various energy sources for NZEBs are rapidly growing [2,26,28]. NZEBs are expanding in technology and scale. The evolution of NZEBs remains dynamic, continuously influenced by technological advancements, including the emergence of smart building technologies [33,39], advanced energy monitoring systems [34], energy storage solutions [40,41], and building-integrated RE systems [10,42,43], further improving performance and feasibility. Additionally, emphasis is being placed on a comprehensive assessment of the environmental impact of NZEBs throughout their life cycle, with a focus on life cycle assessment (LCA) and the embodied energy of materials [44,45]. As these buildings develop and proliferate, they are becoming not only a symbol of energy efficiency but also an important cornerstone in creating a sustainable and resilient built environment for future generations.

4. Renewable Energy Synergies for Achieving NZEBs

Building energy is consumed for a variety of purposes, but primarily through heating, cooling, ventilation, air conditioning, and electricity. To reach a net-zero energy balance in buildings, increasing the energy efficiency or reducing the load consumed within the building is a priority. However, the building's operation inevitably requires energy, and, in this case, energy produced from RE sources can be used [28,42]. In reality, the development of RE technologies, including solar (e.g., solar thermal, photovoltaic (PV)), wind, geothermal, hydro, bio (e.g., biomass, biogas, and biofuels), and marine/ocean, can serve as environmentally friendly alternatives to conventional energy systems [15–17,46]. In the context of residential energy consumption in the United States (2021), RE sources accounted for approximately 7% (calculated based on data from US Energy Information Administration [47]).

NZEBs utilize RE using on-site RE sources and/or by receiving it from off-site RE sources. The number of buildings in the United States reporting that they generate on-site RE has increased approximately 10-fold in the past decade, and on-site RE is supplying more than six times as much energy as in 2009 [48]. Solar energy is the main RE source used as an on-site RE solution (approximately 31%), while wind and hydro energy can also be used as on-site RE sources [2,49]. Solar technology can be delivered in a variety of forms across hot water, heating, cooling, and power supply. PV technology suffers from limitations in system power output due to factors such as shadow effects and ambient temperature. However, advancements in PV technology extend energy lifespan and reduce operating costs [50]. Tsalikis and Martinopoulos [51] reported that PV meets annual electricity demands with a payback of fewer than 7 years compared to conventional boilers and natural gas boilers, which only meet half of a building's heating requirements. In addition, building-integrated solar power generation technology is being suggested to enhance the energy density of solar energy [52]. This can approximately double the building's distributed PV output [53] and reduce cooling loads by up to 50% [54]. Wind energy can directly harness the wind's kinetic energy for mechanical energy or electricity via generators, and it is relatively cost-effective. Yet, because of its irregular supply tied to wind speed changes, limitations are posed. Its primary use in coastal regions may constrain supply in certain locations. But, according to Peacock et al. [55], a microturbine with a capacity of 1.5 KW per day achieved a maximum of 55% of the annual power demand for a 5600 kWh single dwelling and reduced carbon dioxide by thousands of kilograms. Although it is less economical than solar energy technology, it has a payback period of 26.8 years, demonstrating its feasibility for decarburizing the domestic sector [55]. Wind turbines have high initial costs and limited installation locations compared to solar energy technologies [2]. Hydro energy has been considered insufficient in its capabilities for NZEB due to limitations in location and scale [49]. Potential pumped hydroelectric storage (PHS) can also be utilized by introducing rainwater and pumped water on the roof. The potential performance of PHS could be influenced by building scale and its energy demands, and Jurasz et al. [56] reported a capacity factor of 25% for the turbine/pump (if charging 6 h and discharging 6 h per day). Although this system cannot fully meet residential electricity requirements, it is able to be used as a supplement to other primary energy sources and contributes to reducing residents' monthly energy consumption [49]. Independence from fossil fuels and the use of RE sources is the key to ZEBs.

According to the literature on the status of buildings and technology developments that utilize RE sources, implementing an ideal NZEB is not limited to a specific single renewable source and its technology [7,28]. Combinations of various RE systems are being proposed to offset the energy demands and loads of NZEBs (Table 1), and NZEB designs and models have been suggested [23,57–60]. Harkouss et al. [7] presented six solution sets including some RE systems (e.g., flat plate solar collectors, evacuated tube solar collectors, air source heat pumps, ground source heat pumps, solar assisted ground source heat pumps, biodiesel generators, absorption chillers, electric air cooled chillers, natural gas condensing boilers, cooling towers, PV systems, and residential wind turbines) to manage the energy needed for heating, cooling, domestic hot water (DHW), and electricity generation in designing NZEBs [7].

Although extensive research is being conducted on integrating RE sources into NZEB development, actual NZEB implementation is still in its infancy [21]. Moreover, because on-site RE generation and conversion are often limited, energy conservation and energy circulation beyond the property boundary are required to ensure the sustainability of RE utilization for NZEBs [61–63]. Accordingly, uncertainty can be resolved not only through energy acquisition using the grid, but also through hydrogen storage and fuel cell system integration within buildings [64]. RE utilization design and construction must be carried out giving consideration to the integration of various energies and various climate conditions, population, building density, and building type [2].

Table 1. Potential systems including RE to offset NZEB energy demands (according to information in Harkouss et al. [7]).

Categories of Building Energy Loads and Demands	Examples of Applied Devices and Systems
Cooling	Electric chiller Absorption chiller with hot water from evacuated tube solar collectors (ETSC) Air-sourced heat pump (ASHP) Ground-sourced heat pump (GSHP) Solar-assisted heat pump (SAHP) Biodiesel generator or biomass combined cool heat and power
Heating and domestic hot water	ETSC Flat plate solar collectors Concentrating solar collector Solar air collector Photovoltaic-thermal (PV-T) ASHP GSHP Solar-assisted GSHP Biomass-fired boiler Biomass combined heat and power (CHP)
Electricity	PV and PV/T Building-integrated PV (BIPV) Solar tracking for PV Wind turbines for residence Biomass CHP

5. Sustainable Trends and Clusters of NZEBs

As of 2023, 35 countries, such as the United States, Australia, Hong Kong, India, Brazil, Canada, Singapore, the Netherlands, New Zealand, etc., are participating in the "Advancing Net Zero" project, a global climate action program hosted by the World Green Building Council, making efforts for net-zero energy and NZEBs for the decarbonization of the built environment. There are approximately 500 net-zero commercial buildings and 2000 net-zero residential houses in operation worldwide. This is a small number, less than 1% of all buildings worldwide [65]. However, the NZEB market is estimated to exceed approximately USD 47.4 billion by 2026 [66], and NZEB case studies and academic interests are also growing rapidly [6,67].

In Europe and North America, there has been early interest in building energy consumption/efficiency/development and in research into ZEBs or NZEBs [68–70]. Europe in particular has come closer to reaching NZEB by implementing building energy efficiency policies and supporting the sponsorship of several retrofit programs. The number of net-zero buildings in Europe is the largest in the world, and many NZEB case performance evaluations and feasibility studies have been conducted across countries covering Northern, Southern, and Eastern Europe [71–75]. In North America, NZEBs have been implemented mainly for single-family homes, but the introduction of net-zero energy systems is expanding in commercial buildings and various institutional facilities within 5 years. Approximately 2.4% of K–12 schools in the United States generate on-site RE [48,76,77]. The number of properties with on-site energy systems is increasing, especially in California, Colorado, New York, and New Jersey [48]. On the other hand, ZEB development was adopted late in Asia [78,79]. In low-income countries especially, the NZEB development process is relatively slow due to cost and technology limitations [80,81]. According to Hu and Qiu [69], in China, there are few strict building code requirements and cultural thermal comfort levels are more flexible than in the United States and Western countries, so China has a higher potential to reach net-zero than the United States in the building sector [69].

Globally, NZEB technologies have usually been applied to new building constructions. Ultimately, it is believed that most of the new buildings will be constructed as near-ZEBs in the near future. When reflecting on global warming and decarbonization goals, the global building sector must reach net-zero carbon by 2050. However, to achieve this, there are limits to simply constructing new NZEBs, and the retrofit of existing buildings is required. The current building renovation rate is less than 1% of existing buildings each year, but to achieve net-zero carbon by 2050, the pace must increase by 3% per year [65]. The energy efficiency of existing building materials should also increase by more than 80% [69,82]. Retrofitting for NZEBs requires greater attention to the character of the existing building and environmental factors. However, several case studies have shown that NZEB retrofits with passive strategies, including optimizing envelope insulation, heating and lighting systems, shading and controls, can transform them into viable environmental options. These passive design interventions reduce CO_2 emissions and can also provide energy and environmental payback times shorter than the building's life cycle [83–85]. Ohene et al. [84] indicated that introducing solar PV technology to retrofitted buildings can even generate net positive energy, facilitating buildings converted to NZEBs within the payback period.

6. Climate Change Impacts on NZEBs

While NZEBs associated with RE technologies are significant for the built environment in tackling climate change at both the local as well as the global scale [86–88], there are broader dynamic changes, from microclimates to global climate change patterns, supported by both intensifying anthropogenic factors [89] and changing trends in the natural rhythms of climate parameters [90,91]. Due to the changes triggered by global climate change (GCC) and associated events, global perception as well as policies [92–94] for energy system usage and planning are also evolving [95], with various net-zero targets being set worldwide [96,97]. While there are numerous recent studies on GCC and the overall energy demand of built clusters, in discussions regarding NZEB and RE technologies, the propositions are still desirable. Recent and past literature attempts to gauge the interplay between climate change, building energy demand, and RE technologies are given in Table 2.

Table 2. Building energy demand affected by climate change and associated scenarios.

No.	Study Methodology and Scope	Study Findings (Energy Demand, Climate Change and Renewables Integration Perspective as Compared to the Present Scenario)	Reference
1	Building Energy Modeling (BEM) to forecast cooling and heating demands, factoring in climate change scenarios for the year 2050.	- 52% increase in cooling demand. - 39% reduction in heating demand.	[98]
2	Differential evolution-based optimization of NZEB-energy demand, with updated typical metrological year (TMY) data aligned with climate change scenarios.	- TMY data-based design fails to capture the short-term load fluctuations.	[99]
3	BEM to evaluate the NZEB potential of an academic campus with Integrated Photovoltaic (BIPV) system	- Integrated BIPV meets 62.5% of energy demand and supports peak energy requirements.	[100,101]
4	BEM to project nearly-ZEB energy demands with climate parameters and modifications matching a 2060 scenario.	- Heating loads decrease by 38–57%. - Cooling loads increase by 99–380%. - Best-fit mitigation strategy it to increase insulation and efficient renewables integration.	[102]
5	BEM with climate-input parameters updated along future climate data (projection to 2050) generated using the CCWorldWeatherGen tool (reference year: 2017, projection year: 2050).	- Net primary energy decreases by 23%. - In-situ renewable adoption increases by 85%.	[103]

Table 2. *Cont.*

No.	Study Methodology and Scope	Study Findings (Energy Demand, Climate Change and Renewables Integration Perspective as Compared to the Present Scenario)	Reference
6	Varied cooling techniques and set-point temperatures ranging between 24 and 28 °C were assumed to assess changes in cooling energy requirements over the current time period (2001–2020) and in the mid-future (2041–2060) in a simulation-based BEM with projected TMY and extreme climate data.	- Cooling energy increase from 1.7 to 5.8 times.	[104]
7	Analysis of the climate change impacts on the future energy performance of nearly-ZEBs across three zones of Italian climate.	- Rise in cooling load can vary from 8.2% by the year 2050 (Milan) to 94.1% by the year 2080 (Rome).	[105]
8	Future climate scenario creation from thirteen future climate scenarios downscaled from global climate models (GCMs) across a 90-year span (2010–2099). Solar and wind energy production projections considering the generated climate scenario.	- 23% fluctuation in solar PV energy. - 45% fluctuation in wind energy.	[106]
9	BEM with climate-input parameters from statically downscaled General Circulation Model (GCM) data. Energy demand projection over the next century in California.	- 25–50% increase in cooling demand.	[107]
10	Application of the downscaling method called "morphing", outlined by Belcher, Hacker, and Powell [108], to produce weather data files to evaluate the energy performance of a real NZEB.	- NZEB goals were not met for most years.	[5]
11	Estimating how various factors (climate change, building stock alterations, renovation strategies, and heating systems) collectively impact the future energy needs for residential air-conditioning, along with projections of greenhouse gas (GHG) emissions in Germany. (2060 projection from 1990 scenario.)	- 25–59% increase in cooling demand. - 44–78% drop in heating energy needs.	[109]
12	Review/analysis of studies conducted to explore the influence of outdoor temperature on maximum electricity usage	- Peak electricity load rises between 0.45% and 4.6%. - Energy consumption rise range is 0.5–8.5% per °C.	[110]

As highlighted in Table 2, the performance of NZEBs in association with RE technologies is still a very case-specific exploration, but so far explored notions suggest that we require a more in-depth and further generalized framework for assessment of NZEB performance as well as RE technology vulnerability with climate change, incorporating micro-climatic conditions with varied spatio-temporal granularity. In major existing NZEB practices poised to serve for more than 50 years, the system sizing is mainly done based on historical typical meteorological year (TMY) data, which are limited in capturing extreme events or climate change over the projected time period and reduce the reliability of the project's expected performance [71,111]. The effects of climate change and NZEB practices can be evaluated according to three primary elements: the equilibrium of building energy, the comfort of occupants in terms of temperature, and the interaction with the energy grid.

- Evaluating an energy balance involves comparing the total energy generated locally with the overall load of the building, considering variations during extreme scenarios [112,113].
- Occupant thermal comfort is an important factor for building energy usage and depends on changing outdoor thermal conditions. Further, following the COVID-19 situation, equal significance is placed on indoor environmental quality (IEQ), considering parameters related to both indoor air quality (IAQ) and thermal comfort [114].
- The interaction between an NZEB and the power grid, termed grid interaction, is affected by the variability of RE sources, leading to unpredictability. Climate change further complicates measuring this interaction, necessitating a dependable predictive framework to manage such uncertainties effectively [115].

Regarding energy equilibrium, climate change has the potential to influence both the demand for building energy and the supply of RE. The following section aims to evaluate the performance of these outlined factors. Considering the circumstances, there is a potential scenario where a NZEB might not achieve its energy-balance goal in the future. Therefore, a more in-depth investigation into how climate change affects the energy demand and supply of NZEBs could aid in improving overall energy demand and supply management. Though there are some exiting studies [116] that talk about mitigating the climate crisis impact, they are limited to certain small-time scenarios and specific cases, avoiding addressing mitigation measures under future average weather conditions or extreme scenarios.

7. Performance Evaluation of NZEBs

A building's actual performance can be assessed through three facets: energy usage, environmental impact, and economic viability [117,118]. The primary focus of the performance evaluation of NZEBs should be on aspects such as energy performance research methods, tools, and performance indicators [9]. Recent important studies analyzing the performance of NZEBs usually focus on their operational phase, evaluating the annual energy balance and RE technologies [88]. However, these studies often lack a detailed consideration of climate change impacts, especially regarding hourly building and RE system simulations. Before delving into how climate change affects performance modeling, typical NZEB performance evaluations encompass the building's entire life cycle [117,119]. This life cycle comprises four stages: preparation (manufacturing and transport), construction, maintenance, and demolition. Across these stages, energy consumption includes embodied energy, operational energy, and recycling energy. Here is an outline of the standard performance evaluation process for typical buildings [120–122]:

- Gathering data from experiments or simulations for a NZEB performance assessment, validating design decisions, and predicting operational performance interactions between the building and energy systems through simulations.
- Implementing construction based on the design scheme followed by obtaining the performance parameters of Building Energy Models (BEMs) through commissioning or experiments (for test buildings).
- Utilizing performance data, particularly from steady or semi-steady state tests, in a system simulation module to hourly record the dynamic operational performance for annual system evaluations.
- Conducting evaluations focusing on indoor comfort, system efficiency, net-zero energy balance, techno-economic aspects, and LCA [120–122].

A detailed exploration of the performance analysis can be obtained from past studies, as mentioned briefly in Table 3. Without exploring in-depth each performance aspect, this table provides a brief overview of key elements in performance studies crucial for assessing the good functioning of NZEBs in typical scenarios. This includes evaluation tools, a basic framework, and outcome highlights, offering insight into their utility in NZEB performance studies.

Table 3. Performance evaluation literature on buildings and/or NZEBs.

No.	Performance Evaluation Aspect	Tools/Models Overview	Evaluation Summary	Evaluation Aspect Impact	Relevant Reference
1	Indoor comfort	Fanger's PMV-PPD (thermal comfort) model.	Thermal comfort evaluation based on occupants' behaviors, including cooling, ventilation, illuminance, and acoustics preferences.	Prioritizing high-performance indoor comfort while minimizing active energy consumption.	[7,123]

Table 3. *Cont.*

No.	Performance Evaluation Aspect	Tools/Models Overview	Evaluation Summary	Evaluation Aspect Impact	Relevant Reference
2	Energy efficiency	Physical simulation-based Building Energy Modeling (BEM) tools/platforms (white box approach); data driven approach (black-box approach); hybrid approach (grey-box models).	Developed a baseline simulation model for energy demand, calibrated it, and explored augmentation with data-driven algorithms for a hybrid modeling approach.	Support operational energy balance analysis (EBA) for NZEBs, with or without renewable integration.	[124]
3	Techno-economic analysis (TEA)	Study can be assisted by BEM + energy management platform combinations like BEopt tool [125].	The framework works on a cyclic cost-benefit analysis in parallel to data-driven performance assessments (majorly energy related).	- Evaluate energy retrofit technologies. - Assess the NZEB approach for financial feasibility. - Analyze energy-efficient design decisions.	[125,126]
4	Typical Life Cycle Assessment (LCA) or Life cycle Impact Assessment(LCIA)	Independent building construction data-based assessment platforms (GaBi, SimaPro), or plugin support in other 3D modelling platforms (e.g., one-click LCA).	Operational energy, embodied energy, and carbon footprint evaluation for the construction phase.	LCA analysis helps in impact assessments of NZEB strategies in both embodied as well as operational aspects.	[119]
5	Dynamic LCA	An additional temporal impact factor (numerical relation) consideration to the typical LCA approach.	Conventional LCA lacks the capability to incorporate the impact of reduced emission factors associated with electricity generation.	Capture time-associated uncertainties in NZEB construction, operation, and cost.	[45]
6	Grid interaction of nearly-ZEB; renewables efficiency.	Simulation tools for single building level to city-scale aggregate RE sources projection calculation.	BEM model with scope for integrating RE sources (model data input granularity: day-wise peak generation capture).	- Validate and monitor nearly-ZEB operational status over defined time frame. - Evaluate onsite renewable energy system potential and grid intractability.	[127]

Regarding RE technologies, it has been highlighted that a crucial aspect of NZEBs is the advantage gained from power or thermal input derived from RE sources. However, recent research investigations have expressed concern over a susceptibility to climate change impacts [128,129]. Assessing the performance of RE utilization devices, like solar PV panels, is critical due to their inherently fluctuating output without auxiliary energy sources. Hence, evaluating these systems in both standard scenarios and extreme events holds significant importance [5,7,10,64,123,124] to ensure and implement parallel mitigation strategies, like energy storage through batteries, latent heat storage scopes using phase change materials, etc. [9].

Many nearly-ZEBs as well as NZEBs currently do not achieve full energy autonomy in an off-grid state. They still rely on establishing bidirectional connectivity via smart meters with a central grid [128,130,131]. To assess NZEB performance over various timeframes, two indicators—load matching and grid interaction—are frequently used. These indicators aim to analyze the interdependent performance of the grid, RE production, and the building itself. Evaluating load matching performance typically involves a ratio that measures how much of a building's demand is fulfilled by RE. This ratio can be improved through two methods: altering demand to align with generation (DSM—demand side management) and adjusting generation to meet demand. As discussions evolve towards optimizing the interoperability between the grid and RE sources, it is crucial to underscore the primary focus on robust performance evaluations. These assessments, particularly through multi-criterion optimizations, are vital for ensuring the effectiveness of RE technologies in conjunction with building operations systems [7,14,21,132].

The emphasis extends beyond mere discourse on grid–RE source interoperability, encompassing key facets such as system sizing, exploration of integrated solutions, iterations, and concurrent implementation with technologies like smart grids. It is imperative to acknowledge the temporal aspect, considering the time required for these processes. The overarching objective is to achieve optimal and harmonized performance, aligning RE sources seamlessly with building energy simulations. This integrated approach not only addresses current challenges but also anticipates the evolving technological landscape, with the ultimate goal of enhancing overall system efficiency and effectiveness.

8. Policy and Regulatory Frameworks

Governance structures, policies, and codes vary across regions and boundaries, especially for ZEBs. The definition of a NZEB and its dynamic functioning differs globally in terms of implementation [133]. A common initial observation is that building energy performance policies and codes are guiding each nation toward zero energy and emission goals applied through further federal and local regulations-based initiatives by giving incentives, certification of performance, etc. Here below is a very concise summary of the latest strategies and regulations directed towards NZEB practice in the United States, EU, and Asian counterparts (China and India) following the major discussion in [69]:

- United States cases: The United States primarily relies on two model codes for building energy efficiency: the International Energy Conservation Code and the ASHRAE 90.1 standard [134]. The US DOE defines a Zero Energy Ready Home as a high-performance and energy efficient home where most or all its annual energy use could be offset by RE systems [135]. In other words, a ZEB, over the course of a year, produces as much RE on-site as it consumes from external sources. The goal is to achieve a balance between the energy produced and the energy consumed, resulting in a net-zero energy impact on the grid [24]. Further, the International Living Future Institute of the United States certifies ZEB [136]. Regarding the California energy efficiency strategic plan, the state has objectives for the implementation of ZNE buildings in residential settings by 2020 and in commercial settings by 2030. The target for commercial constructions is to retrofit 50% of them by 2030, with an expectation that 50% of new significant renovations for state buildings will achieve ZNE building status by 2025 [137].
- European Union cases: The EU characterizes a nearly-ZEB as a structure with highly efficient energy performance requiring minimal energy largely sourced from renewables, including on-site or nearby sources, following major directives from the Energy Performance in Building Directive. Specifically, the mentioned directive has various timely amendments with the second version, Directive 2010, emphasizing the nearly-ZEB goal, setting targets for new buildings and public buildings by specific dates [138,139]. Further, the Renewable Energy Directive for EU [140] emphasizes the need for national regulations and codes to incorporate measures and policies regarding minimum levels of RE sources in new and existing buildings. Among many EU countries, Germany took NZEB goals more seriously, putting larger efforts for nearly-ZEBs

from the last two decades. Germany's stringent Passive House standard, created voluntarily, sets insulation and energy use intensity requirements, playing a foundational role in achieving net-zero energy targets aligned with EU goals by 2021. Later, these observations incorporated GHG emissions into the codes to achieve a carbon-neutral building stock by 2050, integrating multiple concurrent measures to meet the targets. It can be said that the consensus in Europe revolves around implementing nearly-ZEB definitions by reducing energy demand through energy-efficient measures and meeting the remaining demand with the utilization of RE sources [141,142].

- Asian cases: The Ministry of Housing and Urban-Rural Development of China describes nearly-ZEBs as buildings adapting to climate and site conditions, reducing heating, air conditioning, and lighting demands through passive design. They aim to maximize energy equipment efficiency, leveraging RE to the fullest. The objective is to achieve a comprehensive energy efficiency level of 82% in residential buildings and 79% in commercial buildings by 2030, compared to the performance baseline in the 1980s [14,69]. Presently, initiatives toward net-zero buildings in China operate on an individual and volunteer basis, without specific policy or building code mandates, although voluntary green building standards such as the Passive House standard and Green Star are in place [133].
- Japan's NZEB goals align with a broader framework aimed at reducing CO_2 emissions. The country set a zero-energy goal for new public buildings by 2020 and new residential buildings by 2030, emphasizing net-zero building as a key concept, where the limits were further revised to 2050 [143]. Regarding such initiatives, in 2016, the government allocated a substantial budget to promote energy efficiency technology for houses and buildings, showcasing examples such as the Sekisui House Head Office and the net-zero city of Sakai [69].
- The Bureau of Energy Efficiency, Ministry of Power, Government of India, has recommended guidelines for energy conservation in building space cooling through recommended optimum temperature settings [144]. In India, there has been a growing adoption of energy-efficient and green buildings since the post-2016 period. The Government of India has implemented various policies and regulations to enhance the energy efficiency of buildings, urging consumers to shift towards RE alternatives and establishing a long-term objective for ZEBs. Some impactful initiatives include the National Mission for Enhanced Energy Efficiency, the Jawaharlal Nehru National Solar Mission, the Integrated Energy Policy, the National Mission for Sustainable Habitat, and the National Mission for a Green India. Further, India introduced the Indian Cooling Action Plan in 2019, becoming a pioneer in the endeavor to operational energy reduction. Remarkably, in 2018, India's investment in solar energy exceeded the combined investments in all other non-RE sources. India's commitment to energy efficiency has effectively prevented the emission of 300 million tons of CO_2 from 2000 to 2018, leading to a 15% reduction in annual energy growth [145].

The regulations for nearly-ZEBs require the integration of RE technologies [146]. This integration often involves conventional solutions like PV systems in major global regulations. However, optimizing RE technologies across the entire NZEB concept requires further re-evaluation of global regulatory standards. The adoption of general regulatory standards has been slow in emerging markets, and the feasibility remains uncertain. Additionally, there is ambiguity regarding the transition from passive houses to high-performance houses in developed nations. To comprehend NZEB realization and its regulatory outlooks, it is vital to focus on drivers and existing barriers across various aspects [147]. Past studies [148,149] have indicated that the barriers and drivers of NZEB realization schemes vary across disciplines and jurisdictions. Objective-based discussions may not effectively resolve these challenges. However, some attempts [19,84,150] have addressed these limitations partially. As also noted from the various global region-specific regulations, major promotional strategies for NZEB among the public emphasize primarily energy efficiency, enhanced indoor comfort, and associated financial benefits [147–149].

A comprehensive promotional strategy, based on previous studies for transforming homes into nearly-ZEBs, has been outlined within existing policy and regulatory frameworks and also can be categorized into various themes and scales of (i) educational training and awareness; (ii) legislation; (iii) financial regulations; and (iv) industrial regulations. Under educational training and awareness, initiatives include public awareness initiatives, industry training and education programs, raising occupant and client awareness, and specialized training enhancements for zero-carbon building. However, the findings from previous studies underscore the critical need for a clear and robust policy framework in the forthcoming standard under educational training and awareness, responding to NZEB and global perceptions. Both government and industry sectors should prioritize enhancing public awareness regarding the necessity and advantages of zero-carbon homes to drive market demand. Under legislation, enhancements include building regulations, a strategic planning policy framework, accuracy in defining zero-carbon homes, wide-ranging political backing, implementation of incentive structures, and stringent guidelines for public land development. Acknowledging the significance of state government financial incentives is crucial in fostering the adoption of NZEB houses, especially to counterbalance potential extra capital costs and ensure the delivery of zero-carbon housing. Under financial themes, various strategies have been identified, including fiscal incentives, generating market demand, promoting cost-effective solutions, allocating investment funds, implementing recompense mechanisms, and capitalizing on economies of scale. Numerous contributors have suggested that providing financial rewards and facilitating investment access could significantly encourage the development of net-zero carbon buildings (NZCBs). Indeed, economic incentives play a crucial role in fostering market demand for homes with zero carbon emissions. These measures aim to create a conducive financial environment that supports the transition towards NZCBs. Within the industrial sector, key components of the strategy include supply chain integration, streamlined design approaches, design tailored to context, material accessibility, and implementing uniform specifications and rating systems. The construction industry currently faces a lack of awareness regarding the technologies and methods associated with NZEBs and NZCBs, posing a significant hurdle to implementation. Consequently, it is crucial for professionals in the construction industry to acquire technical expertise and knowledge necessary for the successful design, construction, and operation of NZEBs and NZCBs. This knowledge ensures that industry practitioners are equipped to navigate and implement the latest technologies and methodologies. Furthermore, it is imperative for building occupants to comprehend how to efficiently operate and manage the new technologies integrated into homes with zero energy and carbon emissions. This collaborative effort within the industrial sector aims to bridge the knowledge gap and facilitate the widespread adoption of sustainable building practices [148,151–154]. Upon analyzing the drivers, barriers, as well as promotional strategies, there is a need for systematic implementation and developmental pitching. This can be carried out through participatory-based barrier prioritization, where zonal, financial, and socio-cultural dimensions can be additional screening factors. Research by Ohene et al. [147] suggested that implementing appropriate measures can steer the building sector towards achieving net-zero goals. Though the primary aim of most of the studies was towards net-zero carbon, the energy angle should be included in the carbon scenario. Further, multi-stakeholder participation and a cumulative perception evolution are needed for NZEB realization, including (i) government/national-level strategies, (ii) industry-level strategies, and (iii) community-level strategies [147], as discussed below:

- Government/national-level strategies: At the national level, integrating building decarbonization tactics and energy performance initiatives within nationally determined contributions is crucial [148]. This approach comprehensively addresses gaps across national and sectoral levels. Government support for RE in buildings involves financial incentives such as grants, tax credits, and subsidies to reduce initial expenses for building owners and developers [155]. Mandates endorsing a specific portion of energy in buildings to be sourced from renewable origins further reinforce sustainability goals. Information and awareness-raising campaigns aim to educate the public and stakeholders about the advantages of energy efficiency and RE [156]. Additionally, governments can institute research and development programs, collaborating with industry and academic institutions to advance energy-efficient technologies and sustainable building practices [157].

- Industry-level strategies: Industry-level strategies include the implementation of NZEB certifications and rating systems [117,118,147,156]. These systems consider regional and geographical disparities, as well as seasonal or daily fluctuations due to climate change, to propose practical and cost-effective measures for achieving NZCBs. Capacity building for NZCBs, demonstration of feasible energy efficiency measures, and collaboration with research institutions are essential components of industry-level strategies [147].
- Community-level strategies: Though building codes and regulations in action typically focus on individual building-level strategies, adaptation in some studies, like [5,14,21,132,147,156,157], highlight the necessity of community-level adaptation of NZEBs or renewable integration as part of the standard. The majority of these initiatives are about altering user behavior through public education and awareness campaigns and educating occupants about the environmental impacts of their actions. Further, they also discuss several aspects, including the following:
    - The integration of smart building technologies, such as sensors and smart meters, enhances building management and energy efficiency.
    - Energy management systems empower building owners and managers to oversee real-time energy consumption, identify patterns, establish consumption goals, and monitor progress.
    - Energy audits provide a comprehensive examination of a building's energy usage, suggesting measures to enhance efficiency, often accompanied by a cost-benefit evaluation.
    - Include RE production and supply integration understanding at the community level through community building energy modelling as well as life-cycle cost analysis-based decision making frameworks [158].
    - A combination of passive and active measures, such as enhancing building envelopes, utilizing energy-efficient windows, green roofs, and intelligent HVAC systems, contributes to maintaining a comfortable indoor environment while reducing energy consumption.

9. Challenges and Possible Solutions

The evolution of NZEBs can continuously be influenced by technological advancements, including the emergence of smart building technologies [33,39], advanced energy monitoring systems [34], energy storage solutions [40,41], and building-integrated RE systems [10,42,43], further improving performance and feasibility, etc. To achieve global net-zero carbon, there are limits to simply constructing new NZEBs, and a retrofit of existing buildings is required. The current building renovation rate is low [65], but to achieve net-zero carbon, the pace must be increased.

There are still some technical, policy, and socio-economic challenges [21] that need more attention to provide comprehensive solutions to further enhance the sustainable development/performance of an NZEB and achieve its targets. The challenges may include, but are not limited to, vulnerability to climate change impacts of applied RE technologies for achieving NZEBs [88], achieving a best energy efficiency [6] or finding a best and efficient combination of RE technologies in NZEBs for each climate [7], and load match and grid interaction [9], etc.

It is obvious that, regarding energy equilibrium, climate change has the potential to influence both the demand for building energy and the supply of RE, and it is crucial to know if a NZEB can achieve its energy-balance goal in the future. Therefore, more in-depth investigations into how climate change affects the energy demand and supply of NZEBs can aid in improving the overall energy demand and supply management.

Shen and Lior [88] studied performance predictions of NZEBs equipped with RE technologies in future climates and reported that a PV system is a reliable onsite RE system under expected future climate conditions. To accommodate climate change impacts, there is a need to resize and reconfigure RE systems for future NZEBs [88]. Harkouss et al. [7] studied optimal design of RE solution sets for NZEBs in three different climates using a multi-criterion decision making methodology and suggested the following: (i) air source heat pumps for cooling and flat plate solar collectors for DHW production in hot climates; (ii) biodiesel generators for both electricity and hot steam for heating as well as DHW usage in cold climates; and iii) electric chillers for cooling and natural gas condensing boilers for heating and DHW use in mixed climates [7]. There is a need to develop new evaluation indicators for load match and grid interaction. A smart grid can benefit NZEBs [6].

There is a need for multi-stakeholder participation and a cumulative perception evolution for NZEB realization, including (i) government/national-level strategies, (ii) industry-level strategies, and (iii) community-level strategies [147].

Every country or regional area may need to adapt the NZEB definition to its own specific conditions [19]. In addition, there may be needs for legislative instruments, updating the building code, and financial incentives to building owners or developers for on-site RE system installations [159]. Furthermore, technical (e.g., customized solutions), financial (e.g., investment costs, payback periods, incentives), and social (e.g., residents/owners knowledge or interest) barriers in the decision-making should be considered [21] and the best strategies and technologies should be selected to convert existing buildings into NZEBs in different climates [7].

10. Conclusions and Future Perspectives

This study reviewed the definition and development of NZEBs, RE synergies for achieving NZEBs, sustainable trends and clusters of NZEBs, climate change impacts on NZEBs, performance evaluations of NZEBs, policy and regulatory frameworks, and challenges and possible solutions related to NZEBs. The key findings are:

- Being one of the major consumers of energy and a significant source of GHG emissions worldwide, the buildings sector is significantly contributing to climate change. In order to reduce energy usage and GHG emissions related to buildings, and to mitigate climate change, NZEBs are considered an effective solution.
- Academic research on NZEBs is increasing steadily. Also, the global market for NZEBs and relevant applications is expected to grow.
- In order to realize an annual energy balance, NZEBs depend on RE technologies. Optimal combinations of various RE systems should be utilized to offset the energy demands and loads of NZEBs.
- It is necessary for each country or region to recognize the distinct characteristics of its own energy infrastructure and resources, architectural style, and climate, and to appropriately adapt the definition of a NZEB.
- In low-income countries, the NZEB development process is relatively slow due to cost and technology limitations.
- The effects of climate change and NZEB practices can be evaluated according to three primary elements: the equilibrium of building energy, the comfort of occupants in terms of temperature, and the interaction with the energy grid.
- Multi-stakeholder participation and a cumulative perception evolution are needed for NZEB realization, including (i) government/national-level strategies, (ii) industry-level strategies, and (iii) community-level strategies.

Attention to some technical, policy, and socio-economic challenges and providing comprehensive solutions to those challenges can further enhance the sustainable development/performance of NZEBs and achieve their targets. More in-depth investigations are still needed on the vulnerability to climate change impacts for applied RE technologies for achieving NZEBs, how future climates might affect the energy demand and supply of NZEBs, achieving best design (e.g., building system) and energy efficiency, and finding a best and efficient combination of RE technologies in NZEBs for each climate, load match, and grid interaction.

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References

1. Li, X.; Wu, W.; Yu, C.W.F. Energy demand for hot water supply for indoor environments: Problems and perspectives. *Indoor Built Environ.* **2015**, *24*, 5–10. [CrossRef]
2. Wu, W.; Skye, H.M. Residential net-zero energy buildings: Review and perspective. *Renew. Sustain. Energy Rev.* **2021**, *142*, 110859. [CrossRef] [PubMed]
3. Edenhofer, O.; Pichs-Madruga, R.; Sokona, Y.; Farahani, E.; Kadner, S.; Seyboth, K.; Adler, A.; Baum, I.; Brunner, S.; Eickemeier, P.; et al. (Eds.) *IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014. Available online: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf (accessed on 10 February 2024).
4. Shirinbakhsh, M.; Danny Harvey, L.D. Net-zero energy buildings: The influence of definition on greenhouse gas emissions. *Energy Build.* **2021**, *247*, 111118. [CrossRef]
5. Robert, A.; Kummert, M. Designing net-zero energy buildings for the future climate, not for the past. *Build. Environ.* **2012**, *55*, 150–158. [CrossRef]
6. Agbodjan, Y.S.; Wang, J.; Cui, Y.; Liu, Z.; Luo, Z. Bibliometric analysis of zero energy building research, challenges and solutions. *Sol. Energy* **2022**, *244*, 414–433. [CrossRef]
7. Harkouss, F.; Fardoun, F.; Biwole, P.H. Optimal design of renewable energy solution sets for net zero energy buildings. *Energy* **2019**, *179*, 1155–1175. [CrossRef]
8. Kapsalaki, M.; Leal, V.; Santamouris, M. A methodology for economic efficient design of Net Zero Energy Buildings. *Energy Build.* **2012**, *55*, 765–778. [CrossRef]
9. Deng, S.; Wang, R.Z.; Dai, Y.J. How to evaluate performance of net zero energy building: A literature research. *Energy* **2014**, *71*, 1–16. [CrossRef]
10. Lu, Y.; Wang, S.; Yan, C.; Huang, Z. Robust optimal design of renewable energy system in nearly/net zero energy buildings under uncertainties. *Appl. Energy* **2017**, *187*, 62–71. [CrossRef]
11. United States Department of Energy. Building Technologies Program Planning Summary; pp. 1–5. Available online: https://www.energy.gov/eere/buildings/articles/building-technologies-program-planning-summary#:~:text=The%20U.S.%20Department%20of%20Energy's,marketable%20net-zero%20energy%20buildings. (accessed on 10 February 2024).
12. EU. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings. *Off. J. Eur. Communities* **2003**, 65–71. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:en:PDF#:~:text=The%20objective%20of%20this%20Directive,climate%20requirements%20and%20cost-effectiveness (accessed on 10 February 2024).
13. Scognamiglio, A.; Adinolfi, G.; Graditi, G.; Saretta, E. Photovoltaics in net zero energy buildings and clusters: Enabling the smart city operation. *Energy Procedia* **2014**, *61*, 1171–1174. [CrossRef]
14. Zhang, S.; Huang, P.; Sun, Y. A multi-criterion renewable energy system design optimization for net zero energy buildings under uncertainties. *Energy* **2016**, *94*, 654–665. [CrossRef]
15. Jafarinejad, S.; Beckingham, L.E.; Kathe, M.; Henderson, K. The renewable energy (RE) industry workforce needs: RE simulation and analysis tools teaching as an effective way to enhance undergraduate engineering students' learning. *Sustainability* **2021**, *13*, 11727. [CrossRef]
16. Jafarinejad, S.; Hernandez, R.R.; Bigham, S.; Beckingham, B.S. The intertwined renewable energy–water–environment (REWE) nexus challenges and opportunities: A case study of California. *Sustainability* **2023**, *15*, 10672. [CrossRef]
17. Jafarinejad, S.; Beckingham, B.S. *The Renewable Energy-Water-Environment Nexus: Fundamentals, Technology, and Policy*, 1st ed.; Elsevier: Amsterdam, The Netherlands, 2024.
18. Marszal, A.J.; Heiselberg, P.; Bourrelle, J.S.; Musall, E.; Voss, K.; Sartori, I.; Napolitano, A. Zero Energy Building—A review of definitions and calculation methodologies. *Energy Build.* **2011**, *43*, 971–979. [CrossRef]

19. Sartori, I.; Napolitano, A.; Voss, K. Net zero energy buildings: A consistent definition framework. *Energy Build.* **2012**, *48*, 220–232. [CrossRef]
20. Wells, L.; Rismanchi, B.; Aye, L. A review of Net Zero Energy Buildings with reflections on the Australian context. *Energy Build.* **2018**, *158*, 616–628. [CrossRef]
21. Ahmed, A.; Ge, T.; Peng, J.; Yan, W.C.; Tee, B.T.; You, S. Assessment of the renewable energy generation towards net-zero energy buildings: A review. *Energy Build.* **2022**, *256*, 111755. [CrossRef]
22. Cabeza, L.F.; Bai, Q.; Bertoldi, P.; Kihila, J.M.; Lucena, A.F.P.; Mata, É.; Mirasgedis, S.; Novikova, A.; Saheb, Y. Buildings. In *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Shukla, P.R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2022. [CrossRef]
23. Pless, S.; Torcellini, P. *Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options (No. NREL/TP-550-44586)*; National Renewable Energy Lab (NREL): Golden, CO, USA, 2010.
24. United States Department of Energy. A Common Definition for Zero Energy Buildings. 2015. Available online: https://www.energy.gov/sites/prod/files/2015/09/f26/A%20Common%20Definition%20for%20Zero%20Energy%20Buildings.pdf. (accessed on 10 December 2023).
25. Matthews, J.B.R. IPCC, 2018: Annex I: Glossary. In *Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*; Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2018; pp. 541–562. [CrossRef]
26. Loveday, J.; Morrison, G.M.; Martin, D.A. Identifying knowledge and process gaps from a systematic literature review of net-zero definitions. *Sustainability* **2022**, *14*, 3057. [CrossRef]
27. Cieslik, W.; Szwajca, F.; Zawartowski, J.; Pietrzak, K.; Rosolski, S.; Szkarlat, K.; Rutkowski, M. Capabilities of nearly zero energy building (nzeb) electricity generation to charge electric vehicle (ev) operating in real driving conditions (rdc). *Energies* **2021**, *14*, 7591. [CrossRef]
28. Jaysawal, R.K.; Chakraborty, S.; Elangovan, D.; Padmanaban, S. Concept of net zero energy buildings (NZEB)—A literature review. *Clean. Eng. Technol.* **2022**, *11*, 100582. [CrossRef]
29. United States Environmental Protection Agency. Sustainable Design and Green Building Toolkit, for Local Governments. EPA 904B10001. 2013. Available online: https://archive.epa.gov/greenbuilding/web/pdf/sustainable-design-permitting-toolkit-06_27_13_formatted.pdf. (accessed on 10 February 2024).
30. Marszal, A.J.; Heiselberg, P.; Jensen, R.L.; Nørgaard, J. On-site or off-site renewable energy supply options? Life cycle cost analysis of a Net Zero Energy Building in Denmark. *Renew. Energy* **2012**, *44*, 154–165. [CrossRef]
31. Cao, S.; Sirén, K. Matching indices taking the dynamic hybrid electrical and thermal grids information into account for the decision-making of nZEB on-site renewable energy systems. *Energy Convers. Manag.* **2015**, *101*, 423–441. [CrossRef]
32. Gondal, I.A. Prospects of Shallow geothermal systems in HVAC for NZEB. *Energy Built Environ.* **2021**, *2*, 425–435. [CrossRef]
33. Karlessi, T.; Kampelis, N.; Kolokotsa, D.; Santamouris, M.; Standardi, L.; Isidori, D.; Cristalli, C. The concept of smart and NZEB buildings and the integrated design approach. *Procedia Eng.* **2017**, *180*, 1316–1325. [CrossRef]
34. Santos-Herrero, J.M.; Lopez-Guede, J.M.; Flores-Abascal, I. Modeling, simulation and control tools for nZEB: A state-of-the-art review. *Renew. Sustain. Energy Rev.* **2021**, *142*, 110851. [CrossRef]
35. Barbolini, F.; Cappellacci, P.; Guardigli, L. A design strategy to reach nZEB standards integrating energy efficiency measures and passive energy use. *Energy Procedia* **2017**, *111*, 205–214. [CrossRef]
36. Torcellini, P.; Pless, S.; Deru, M.; Crawley, D. *Zero Energy Buildings: A Critical Look at the Definition (No. NREL/CP-550-39833)*; National Renewable Energy Lab (NREL): Golden, CO, USA, 2006.
37. United States Department of Energy. Zero Energy Buildings Resource Hub. Available online: https://www.energy.gov/eere/buildings/zero-energy-buildings-resource-hub (accessed on 10 December 2023).
38. Li, Y.; Mao, Y.; Wang, W.; Wu, N. Net-Zero Energy Consumption Building in China: An Overview of Building-Integrated Photovoltaic Case and Initiative toward Sustainable Future Development. *Buildings* **2023**, *13*, 2024. [CrossRef]
39. Hernández Uribe, O.; San Martin, J.P.; Garcia-Alegre, M.C.; Santos, M.; Guinea, D. Smart building: Decision making architecture for thermal energy management. *Sensors* **2015**, *15*, 27543–27568. [CrossRef]
40. Georgiou, G.S.; Christodoulides, P.; Kalogirou, S.A. Optimizing the energy storage schedule of a battery in a PV grid-connected nZEB using linear programming. *Energy* **2020**, *208*, 118177. [CrossRef]
41. Tsioumas, E.; Jabbour, N.; Koseoglou, M.; Papagiannis, D.; Mademlis, C. Enhanced sizing methodology for the renewable energy sources and the battery storage system in a nearly zero energy building. *IEEE Trans. Power Electron.* **2021**, *36*, 10142–10156. [CrossRef]
42. De Luca, G.; Ballarini, I.; Lorenzati, A.; Corrado, V. Renovation of a social house into a NZEB: Use of renewable energy sources and economic implications. *Renew. Energy* **2020**, *159*, 356–370. [CrossRef]
43. Mancò, G.; Guelpa, E.; Colangelo, A.; Virtuani, A.; Morbiato, T.; Verda, V. Innovative renewable technology integration for nearly zero-energy buildings within the Re-cognition project. *Sustainability* **2021**, *13*, 1938. [CrossRef]

44. Schiavoni, S.; Sambuco, S.; Rotili, A.; D'Alessandro, F.; Fantauzzi, F. A nZEB housing structure derived from end of life containers: Energy, lighting and life cycle assessment. *Build. Simul.* **2017**, *10*, 165–181. [CrossRef]
45. Asdrubali, F.; Baggio, P.; Prada, A.; Grazieschi, G.; Guattari, C. Dynamic life cycle assessment modelling of a NZEB building. *Energy* **2020**, *191*, 116489. [CrossRef]
46. Dincer, I. Renewable energy and sustainable development: A crucial review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 157–175. [CrossRef]
47. United States Energy Information Administration. Monthly Energy Review. April 2022. Available online: https://www.eia.gov/totalenergy/data/monthly/previous.php (accessed on 10 December 2023).
48. Energy Star. Commercial Buildings and Onsite Renewable Energy. Available online: https://www.energystar.gov/buildings/about_us/datatrends_research/renewable_report. (accessed on 10 December 2023).
49. Christopher, S.; Vikram, M.P.; Bakli, C.; Thakur, A.K.; Ma, Y.; Ma, Z.; Xu, H.; Cuce, P.M.; Cuce, E.; Singh, P. Renewable energy potential towards attainment of net-zero energy buildings status—A critical review. *J. Clean. Prod.* **2023**, *405*, 136942. [CrossRef]
50. Hernández-Callejo, L.; Gallardo-Saavedra, S.; Alonso-Gómez, V. A review of photovoltaic systems: Design, operation and maintenance. *Sol. Energy* **2019**, *188*, 426–440. [CrossRef]
51. Tsalikis, G.; Martinopoulos, G. Solar energy systems potential for nearly net zero energy residential buildings. *Sol. Energy* **2015**, *115*, 743–756. [CrossRef]
52. Luo, Y.; Cheng, N.; Zhang, S.; Tian, Z.; Xu, G.; Yang, X.; Fan, J. Comprehensive energy, economic, environmental assessment of a building integrated photovoltaic-thermoelectric system with battery storage for net zero energy building. *Build. Simul.* **2022**, *15*, 1923–1941. [CrossRef]
53. Redweik, P.; Catita, C.; Brito, M. Solar energy potential on roofs and facades in an urban landscape. *Sol. Energy* **2013**, *97*, 332–341. [CrossRef]
54. Yang, H.; Burnett, J.; Ji, J. Simple approach to cooling load component calculation through PV walls. *Energy Build.* **2000**, *31*, 285–290. [CrossRef]
55. Peacock, A.D.; Jenkins, D.; Ahadzi, M.; Berry, A.; Turan, S. Micro wind turbines in the UK domestic sector. *Energy Build.* **2008**, *40*, 1324–1333. [CrossRef]
56. Jurasz, J.; Piasecki, A.; Hunt, J.; Zheng, W.; Ma, T.; Kies, A. Building integrated pumped-storage potential on a city scale: An analysis based on geographic information systems. *Energy* **2022**, *242*, 122966. [CrossRef]
57. Hassoun, A.; Dincer, I. Development of power system designs for a net zero energy house. *Energy Build.* **2014**, *73*, 120–129. [CrossRef]
58. Shen, L.; Pu, X.; Sun, Y.; Chen, J. A study on thermoelectric technology application in net zero energy buildings. *Energy* **2016**, *113*, 9–24. [CrossRef]
59. Lu, Y.; Zhang, X.P.; Huang, Z.; Lu, J.; Wang, D. Impact of introducing penalty-cost on optimal design of renewable energy systems for net zero energy buildings. *Appl. Energy* **2019**, *235*, 106–116. [CrossRef]
60. Kim, D.; Cho, H.; Koh, J.; Im, P. Net-zero energy building design and life-cycle cost analysis with air-source variable refrigerant flow and distributed photovoltaic systems. *Renew. Sustain. Energy Rev.* **2020**, *118*, 109508. [CrossRef]
61. Mohamed, A.; Hasan, A.; Sirén, K. Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives. *Appl. Energy* **2014**, *114*, 385–399. [CrossRef]
62. Kotarela, F.; Kyritsis, A.; Papanikolaou, N.; Kalogirou, S.A. Enhanced nZEB concept incorporating a sustainable Grid Support Scheme. *Renew. Energy* **2021**, *169*, 714–725. [CrossRef]
63. Manzoor, B.; Othman, I.; Sadowska, B.; Sarosiek, W. Zero-Energy Buildings and Energy Efficiency towards Sustainability: A Bibliometric Review and a Case Study. *Appl. Sci.* **2022**, *12*, 2136. [CrossRef]
64. Mehrjerdi, H.; Iqbal, A.; Rakhshani, E.; Torres, J.R. Daily-seasonal operation in net-zero energy building powered by hybrid renewable energies and hydrogen storage systems. *Energy Convers. Manag.* **2019**, *201*, 112156. [CrossRef]
65. World Green Building Council. Every Building on the Planet Must Be 'Net Zero Carbon' by 2050 to Keep Global Warming below 2 °C—New Report. Available online: https://worldgbc.org/article/every-building-on-the-planet-must-be-net-zero-carbon-by-2050-to-keep-global-warming-below-2c-new-report/ (accessed on 10 December 2023).
66. PR Newswire. Global Net-Zero Energy Buildings (NZEBs) Market to Reach $47.4 Billion by 2026. News Provided by Global Industry Analysts, Inc., 03 Mar, 2022. Available online: https://www.prnewswire.com/news-releases/global-net-zero-energy-buildings-nzebs-market-to-reach-47-4-billion-by-2026--301493668.html (accessed on 10 January 2024).
67. Omrany, H.; Chang, R.; Soebarto, V.; Zhang, Y.; Ghaffarianhoseini, A.; Zuo, J. A bibliometric review of net zero energy building research 1995–2022. *Energy Build.* **2022**, *262*, 111996. [CrossRef]
68. D'Agostino, D.; Mazzarella, L. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. *J. Build. Eng.* **2019**, *21*, 200–212. [CrossRef]
69. Hu, M.; Qiu, Y. A comparison of building energy codes and policies in the USA, Germany, and China: Progress toward the net-zero building goal in three countries. *Clean Technol. Environ. Policy* **2019**, *21*, 291–305. [CrossRef]
70. Wei, J.; Li, J.; Zhao, J.; Wang, X. Hot Topics and Trends in Zero-Energy Building Research—A Bibliometrical Analysis Based on CiteSpace. *Buildings* **2023**, *13*, 479. [CrossRef]

71. Attia, S.; Eleftheriou, P.; Xeni, F.; Morlot, R.; Ménézo, C.; Kostopoulos, V.; Betsi, M.; Kalaitzoglou, I.; Pagliano, L.; Cellura, M.; et al. Overview and future challenges of nearly zero energy buildings (nZEB) design in Southern Europe. *Energy Build.* **2017**, *155*, 439–458. [CrossRef]
72. Garcia, J.F.; Kranzl, L. Ambition levels of nearly Zero Energy Buildings (nZEB) definitions: An approach for cross-country comparison. *Buildings* **2018**, *8*, 143. [CrossRef]
73. Attia, S.; Kurnitski, J.; Kosiński, P.; Borodiņecs, A.; Belafi, Z.D.; István, K.; Krstić, H.; Moldovan, M.; Visa, I.; Mihailov, N.; et al. Overview and future challenges of nearly zero-energy building (nZEB) design in Eastern Europe. *Energy Build.* **2022**, *267*, 112165. [CrossRef]
74. Good, C.; Andresen, I.; Hestnes, A.G. Solar energy for net zero energy buildings–A comparison between solar thermal, PV and photovoltaic–thermal (PV/T) systems. *Sol. Energy* **2015**, *122*, 986–996. [CrossRef]
75. Reda, F.; Fatima, Z. Northern European nearly zero energy building concepts for apartment buildings using integrated solar technologies and dynamic occupancy profile: Focus on Finland and other Northern European countries. *Appl. Energy* **2019**, *237*, 598–617. [CrossRef]
76. New Buildings Institute. 2016 List of Zero Net Energy Buildings. Available online: https://newbuildings.org/wp-content/uploads/2016/10/GTZ_2016_List.pdf (accessed on 10 December 2023).
77. New Buildings Institute. Getting to Zero. Available online: https://newbuildings.org/hubs/zero-energy/#:~:text=While%20still%20a%20nascent%20market,commercial%20and%20multifamily%20building%20space (accessed on 10 December 2023).
78. Zhang, S.; Wang, K.; Xu, W.; Iyer-Raniga, U.; Athienitis, A.; Ge, H.; woo Cho, D.; Feng, W.; Okumiya, M.; Yoon, G.; et al. Policy recommendations for the zero energy building promotion towards carbon neutral in Asia-Pacific Region. *Energy Policy* **2021**, *159*, 112661. [CrossRef]
79. Voss, K.; Musall, E. *Net Zero Energy Buildings: International Projects of Carbon Neutrality in Buildings*; DETAIL: Munich, Germany; Walter de Gruyter: Berlin, Germany, 2012.
80. Abdellah, R.H.; Masrom, M.A.N. Exploring the barriers of net zero energy buildings (NZEBS) implementation in Malaysia: Perception of Malaysian construction practitioners. *Int. J. Integr. Eng.* **2018**, *10*, 11–16. [CrossRef]
81. Islam, E.; Shah, A.; Karim, T.A. Role of Renewable Energy Policy in Ensuring Net-Zero Carbon Emissions and Energy Sustainability: A Bangladesh Perspective. In *Moving Toward Net-Zero Carbon Society: Challenges and Opportunities*, 1st ed.; Wu, H.H., Liu, W.Y., Huang, M.C., Eds.; Springer International Publishing: Cham, Switzerland, 2023; pp. 59–77.
82. Ruparathna, R.; Hewage, K.; Sadiq, R. Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1032–1045. [CrossRef]
83. Asdrubali, F.; Ballarini, I.; Corrado, V.; Evangelisti, L.; Grazieschi, G.; Guattari, C. Energy and environmental payback times for an NZEB retrofit. *Build. Environ.* **2019**, *147*, 461–472. [CrossRef]
84. Ohene, E.; Hsu, S.C.; Chan, A.P. Feasibility and retrofit guidelines towards net-zero energy buildings in tropical climates: A case of Ghana. *Energy Build.* **2022**, *269*, 112252. [CrossRef]
85. Razzaq, I.; Amjad, M.; Qamar, A.; Asim, M.; Ishfaq, K.; Razzaq, A.; Mawra, K. Reduction in energy consumption and CO_2 emissions by retrofitting an existing building to a net zero energy building for the implementation of SDGs 7 and 13. *Front. Environ. Sci.* **2023**, *10*, 1028793. [CrossRef]
86. Wills, A.D.; Beausoleil-Morrison, I.; Ugursal, V.I. A Modelling Approach and a Case Study to Answer the Question: What Does It Take to Retrofit a Community to Net-Zero Energy? *J. Build. Eng.* **2021**, *40*, 102296. [CrossRef]
87. Cabeza, L.F.; Chàfer., M. Technological Options and Strategies towards Zero Energy Buildings Contributing to Climate Change Mitigation: A Systematic Review. *Energy Build.* **2020**, *219*, 110009. [CrossRef]
88. Shen, P.; Lior, N. Vulnerability to climate change impacts of present renewable energy systems designed for achieving net-zero energy buildings. *Energy* **2016**, *114*, 1288–1305. [CrossRef]
89. Feng, J.; Gao, K.; Khan, H.; Ulpiani, G.; Vasilakopoulou, K.; Yun, G.Y.; Santamouris, M. Overheating of Cities: Magnitude, Characteristics, Impact, Mitigation and Adaptation, and Future Challenges. *Annu. Rev. Environ. Resour.* **2023**, *48*, 651–679. [CrossRef]
90. Hosseini, M.; Javanroodi, K.; Nik, V.M. High-Resolution Impact Assessment of Climate Change on Building Energy Performance Considering Extreme Weather Events and Microclimate—Investigating Variations in Indoor Thermal Comfort and Degree-Days. *Sustain. Cities Soc.* **2022**, *78*, 103634. [CrossRef]
91. Roy, P.S.; Ramachandran, R.M.; Paul, O.; Thakur, P.K.; Ravan, S.; Behera, M.D.; Sarangi, C.; Kanawad, V.P. Anthropogenic Land Use and Land Cover Changes—A Review on Its Environmental Consequences and Climate Change. *J. Indian Soc. Remote Sens.* **2022**, *50*, 1615–1640. [CrossRef]
92. Coppenolle, H.V.; Blondeel, M.; Van de Graaf, T. Reframing the Climate Debate: The Origins and Diffusion of Net Zero Pledges. *Glob. Policy* **2023**, *14*, 48–60. [CrossRef]
93. Klaaßen, L.; Steffen, B. Meta-Analysis on Necessary Investment Shifts to Reach Net Zero Pathways in Europe. *Nat. Clim. Chang.* **2023**, *13*, 58–66. [CrossRef]
94. Rosenow, J.; Eyre, N. Reinventing Energy Efficiency for Net Zero. *Energy Res. Soc. Sci.* **2022**, *90*, 102602. [CrossRef]
95. Suzuki, M.; Jewell, J.; Cherp, A. Have Climate Policies Accelerated Energy Transitions? Historical Evolution of Electricity Mix in the G7 and the EU Compared to Net-Zero Targets. *Energy Res. Soc. Sci.* **2023**, *106*, 103281. [CrossRef]

96. United Nations. United Nations Climate Action. Available online: https://www.un.org/en/climatechange/net-zero-coalition. (accessed on 10 December 2023).
97. Bouckaert, S.; Pales, A.F.; McGlade, C.; Remme, U.; Wanner, B.; Varro, L.; D'Ambrosio, D.; Spencer, T. Net Zero by 2050: A Roadmap for the Global Energy Sector. International Energy Agency (IEA). 2021. Available online: https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf (accessed on 10 December 2023).
98. Idrissi Kaitouni, S.; Chahboun, R.; Bouhssine, Z.; Cakan, M.; Brigui, J.; Ahachad, M. Simulation-Based Assessment of the Climate Change Impact on Future Thermal Energy Load and Indoor Comfort of a Light-Weight Ecological Building across the Six Climates of Morocco. *Therm. Sci. Eng. Prog.* **2023**, *45*, 102137. [CrossRef]
99. Chai, J.; Sun, Y. Differential Evolution-based System for Net-zero Energy Buildings Under Climate Change. In *Future Urban Energy System for Buildings*; Sustainable Development Goals Series; Zhang, X., Huang, P., Sun, Y., Eds.; Springer: Singapore, 2023; pp. 231–254.
100. Panicker, K.; Anand, P.; George, A. Typology-Wise Residential Energy Benchmarking and Net ZEB Potential: A Case Study of Residential Complexes inside IIT Kharagpur, India. In Proceedings of the BuildSys '22—Proceedings of the 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation, Boston, MA, USA, 9–10 November 2022; pp. 426–432. [CrossRef]
101. Panicker, K.; Anand, P.; George, A. Assessment of Building Energy Performance Integrated with Solar PV: Towards a Net Zero Energy Residential Campus in India. *Energy Build.* **2023**, *281*, 112736. [CrossRef]
102. D'Agostino, D.; Parker, D.; Epifani, I.; Crawley, D.; Lawrie, L. How Will Future Climate Impact the Design and Performance of Nearly Zero Energy Buildings (NZEBs)? *Energy* **2022**, *240*, 122479. [CrossRef]
103. Ascione, F.; De Masi, R.F.; Gigante, A.; Vanoli, G.P. Resilience to the Climate Change of Nearly Zero Energy-Building Designed According to the EPBD Recast: Monitoring, Calibrated Energy Models and Perspective Simulations of a Mediterranean NZEB Living Lab. *Energy Build.* **2022**, *262*, 112004. [CrossRef]
104. Sayadi, S.; Akander, J.; Hayati, A.; Cehlin, M. Analyzing the Climate-Driven Energy Demand and Carbon Emission for a Prototype Residential NZEB in Central Sweden. *Energy Build.* **2022**, *261*, 111960. [CrossRef]
105. Tootkaboni, M.P.; De Luca, G.; Ballarini, I.; Corrado, V. Climate change impact on the future performance of nearly zero energy buildings: A case study base analysis. Proceedings of Building Simulation 2021: 17th Conference of IBPSA, Bruges, Belgium, 1–3 September 2021; pp. 918–924. [CrossRef]
106. Yang, Y.; Javanroodi, K.; Nik, V.M. Climate Change and Renewable Energy Generation in Europe—Long-Term Impact Assessment on Solar and Wind Energy Using High-Resolution Future Climate Data and Considering Climate Uncertainties. *Energies* **2022**, *15*, 302. [CrossRef]
107. Xu, P.; Huang, Y.J.; Miller, N.; Schlegel, N.; Shen, P. Impacts of Climate Change on Building Heating and Cooling Energy Patterns in California. *Energy* **2012**, *44*, 792–804. [CrossRef]
108. Belcher, S.E.; Hacker, J.N.; Powell, D.S. Constructing Design Weather Data for Future Climates. *Build. Serv. Eng. Res. Technol.* **2005**, *26*, 49–61. [CrossRef]
109. Olonscheck, M.; Holsten, A.; Kropp, J.P. Heating and Cooling Energy Demand and Related Emissions of the German Residential Building Stock under Climate Change. *Energy Policy* **2011**, *39*, 4795–4806. [CrossRef]
110. Santamouris, M.; Cartalis, C.; Synnefa, A.; Kolokotsa, D. On the Impact of Urban Heat Island and Global Warming on the Power Demand and Electricity Consumption of Buildings—A Review. *Energy Build.* **2015**, *98*, 119–124. [CrossRef]
111. Aste, N.; Adhikari, R.S.; Buzzetti, M.; Del Pero, C.; Huerto-Cardenas, H.E.; Leonforte, F.; Miglioli, A. NZEB: Bridging the Gap between Design Forecast and Actual Performance Data. *Energy Built Environ.* **2022**, *3*, 16–29. [CrossRef]
112. Jones, A.; Nock, D.; Samaras, C.; Qiu, Y.; Xing, B. Climate Change Impacts on Future Residential Electricity Consumption and Energy Burden: A Case Study in Phoenix, Arizona. *Energy Policy* **2023**, *183*, 113811. [CrossRef]
113. Panda, S.; Mohanty, S.; Rout, P.K.; Sahu, B.K.; Bajaj, M.; Zawbaa, H.M.; Kamel, S. Residential Demand Side Management Model, Optimization and Future Perspective: A Review. *Energy Rep.* **2022**, *8*, 3727–3766. [CrossRef]
114. Kong, M.; Dong, B.; Zhang, R.; O'Neill, Z. HVAC Energy Savings, Thermal Comfort and Air Quality for Occupant-Centric Control through a Side-by-Side Experimental Study. *Appl. Energy* **2022**, *306*, 117987. [CrossRef]
115. Zhang, W.; Yan, C.; Xu, Y.; Fang, J.; Pan, Y. A Critical Review of the Performance Evaluation and Optimization of Grid Interactions between Zero-Energy Buildings and Power Grids. *Sustain. Cities Soc.* **2022**, *86*, 104123. [CrossRef]
116. Andrić, I.; Koc, M.; Al-Ghamdi, S.G. A Review of Climate Change Implications for Built Environment: Impacts, Mitigation Measures and Associated Challenges in Developed and Developing Countries. *J. Clean. Prod.* **2019**, *211*, 83–102. [CrossRef]
117. Hu, M. An Evaluation of the Retrofit Net Zero Building Performances: Life Cycle Energy, Emissions and Cost. *Build. Res. Inf.* **2023**, *51*, 179–191. [CrossRef]
118. Attia, S. *Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmap for Project Analysis and Implementation*; Butterworth-Heinemann: Oxford, UK; Elsevier: Amsterdam, The Netherlands, 2018.
119. Chau, C.K.; Leung, T.M.; Ng, W.Y. A Review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on Buildings. *Appl. Energy* **2015**, *143*, 395–413. [CrossRef]
120. Tabrizi, A.; Sanguinetti, P. Life-cycle cost assessment and energy performance evaluation of NZEB enhancement for LEED-rated educational facilities. *Adv. Build. Energy Res.* **2015**, *9*, 267–279. [CrossRef]

121. Li, H.; Li, Y.; Wang, Z.; Shao, S.; Deng, G.; Xue, H.; Xu, Z.; Yang, Y. Integrated building envelope performance evaluation method towards nearly zero energy buildings based on operation data. *Energy Build.* **2022**, *268*, 112219. [CrossRef]
122. D'Agostino, D.; Tzeiranaki, S.T.; Zangheri, P.; Bertoldi, P. Assessing nearly zero energy buildings (NZEBs) development in Europe. *Energy Strategy Rev.* **2021**, *36*, 100680. [CrossRef]
123. Dartevelle, O.; van Moeseke, G.; Mlecnik, E.; Altomonte, S. Long-Term Evaluation of Residential Summer Thermal Comfort: Measured vs. Perceived Thermal Conditions in NZEB Houses in Wallonia. *Build. Environ.* **2021**, *190*, 107531. [CrossRef]
124. Bajenaru, N.; Damian, A.; Frunzulica, R. Evaluation of the Energy Performance for a NZEB Office Building under Specific Climatic Conditions. *Energy Procedia* **2016**, *85*, 26–34. [CrossRef]
125. Rhodes, J.D.; Gorman, W.H.; Upshaw, C.R.; Webber, M.E. Using BEopt (EnergyPlus) with Energy Audits and Surveys to Predict Actual Residential Energy Usage. *Energy Build.* **2015**, *86*, 808–816. [CrossRef]
126. Ahmed, T.G.; Gudlaugsson, B.; Ogwumike, C.; Dawood, H.; Short, M.; Dawood, N. Evaluation Framework for Techno-Economic Analysis of Energy System Retrofit Technologies. *Energy Build.* **2023**, *286*, 112967. [CrossRef]
127. Magrini, A.; Marenco, L.; Bodrato, A. Energy Smart Management and Performance Monitoring of a NZEB: Analysis of an Application. *Energy Rep.* **2022**, *8*, 8896–8906. [CrossRef]
128. Basit, M.A.; Dilshad, S.; Badar, R.; Rehman, S.M.S. Limitations, Challenges, and Solution Approaches in Grid-Connected Renewable Energy Systems. *Int. J. Energy Res.* **2020**, *44*, 4132–4162. [CrossRef]
129. Lu, Y.; Wang, S.; Yan, C.; Shan, K. Impacts of Renewable Energy System Design Inputs on the Performance Robustness of Net Zero Energy Buildings. *Energy* **2015**, *93*, 1595–1606. [CrossRef]
130. Attia, S.; Hamdy, M.; O'Brien, W.; Carlucci, S. Assessing Gaps and Needs for Integrating Building Performance Optimization Tools in Net Zero Energy Buildings Design. *Energy Build.* **2013**, *60*, 110–124. [CrossRef]
131. Shin, M.; Baltazar, J.C.; Haberl, J.S.; Frazier, E.; Lynn, B. Evaluation of the Energy Performance of a Net Zero Energy Building in a Hot and Humid Climate. *Energy Build.* **2019**, *204*, 109531. [CrossRef]
132. Karunathilake, H.; Hewage, K.; Brinkerhoff, J.; Sadiq, R. Optimal Renewable Energy Supply Choices for Net-Zero Ready Buildings: A Life Cycle Thinking Approach under Uncertainty. *Energy Build.* **2019**, *201*, 70–89. [CrossRef]
133. Taherahmadi, J.; Noorollahi, Y.; Panahi, M. Toward Comprehensive Zero Energy Building Definitions: A Literature Review and Recommendations. *Int. J. Sustain. Energy* **2021**, *40*, 120–148. [CrossRef]
134. Cohan, D. Buildings: How are Building Energy Codes Developed? Office of Energy Efficiency & Renewable Energy, United States Department of Energy. 8 August 2016. Available online: https://www.energy.gov/eere/buildings/articles/how-are-building-energy-codes-developed (accessed on 10 January 2024).
135. United States Department of Energy, Buildings, Zero Energy Ready Home Program, Office of Energy Efficiency & Renewable Energy, United States Department of Energy. Available online: https://www.energy.gov/eere/buildings/zero-energy-ready-home-program (accessed on 10 January 2024).
136. International Living Future Institute. Zero Energy Certification Overview. 2022. Available online: https://living-future.org/zero-energy/certification/ (accessed on 10 January 2024).
137. California Public Utilities Commission. Zero Net Energy. Available online: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/zero-net-energy#:~:text=All%20new%20residential%20construction%20will,will%20be%20ZNE%20by%202025 (accessed on 10 January 2024).
138. European Union. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings. The European Parliament and the Council of the European Union, Official Journal of the European Union, 18.6.2010. Available online: https://eur-lex.europa.eu/eli/dir/2010/31/oj (accessed on 10 January 2024).
139. Economidou, M.; Todeschi, V.; Bertoldi, P.; D'Agostino, D.; Zangheri, P.; Castellazzi, L. Review of 50 years of EU Energy Efficiency Policies for Buildings. *Energy Build.* **2020**, *225*, 110322. [CrossRef]
140. Schöpe, M. Renewable energy directive. In Proceedings of the European Wind Energy Conference and Exhibition 2008, Brussels, Belgium, 31 March–3 April 2008; Volume 1, pp. 32–38.
141. Mata, A.K.K.; Cheng, S.H.; Jiménez Navarro, J.P.; Filippidou, F.; Reyna, J.; Wang, R. A Map of Roadmaps for Zero and Low Energy and Carbon Buildings Worldwide. *Environ. Res. Lett.* **2020**, *15*, 113003. [CrossRef]
142. D'Agostino, D. Assessment of the Progress towards the Establishment of Definitions of Nearly Zero Energy Buildings (NZEBs) in European Member States. *J. Build. Eng.* **2015**, *1*, 20–32. [CrossRef]
143. Kuwahara, R.; Kim, H.; Sato, H. Evaluation of Zero-Energy Building and Use of Renewable Energy in Renovated Buildings: A Case Study in Japan. *Buildings* **2022**, *12*, 561. [CrossRef]
144. Bureau of Energy Efficiency, Ministry of Power, Government of India. Recommended Guidelines. 2018. Available online: https://beeindia.gov.in/en/node/39288 (accessed on 10 December 2023).
145. Saini, L.; Meena, C.S.; Raj, B.P.; Agarwal, N.; Kumar, A. Net Zero Energy Consumption building in India: An overview and initiative toward sustainable future. *Int. J. Green Energy* **2022**, *19*, 544–561. [CrossRef]
146. Cerezo-Narváez, A.; Piñero-Vilela, J.M.; Rodríguez-Jara, E.A.; Otero-Mateo, M.; Pastor-Fernández, A.; Ballesteros-Pérez, P. Energy, Emissions and Economic Impact of the New NZEB Regulatory Framework on Residential Buildings Renovation: Case Study in Southern Spain. *J. Build. Eng.* **2021**, *42*, 103054. [CrossRef]
147. Ohene, E.; Chan, A.P.C.; Darko, A.; Nani, G. Navigating toward Net Zero by 2050: Drivers, Barriers, and Strategies for Net Zero Carbon Buildings in an Emerging Market. *Build. Environ.* **2023**, *242*, 110472. [CrossRef]

148. Ohene, E.; Chan, A.P.C.; Darko, A. Prioritizing Barriers and Developing Mitigation Strategies toward Net-Zero Carbon Building Sector. *Build. Environ.* **2022**, *223*, 109437. [CrossRef]
149. Pan, W.; Pan, M. Drivers, Barriers and Strategies for Zero Carbon Buildings in High-Rise High-Density Cities. *Energy Build.* **2021**, *242*, 110970. [CrossRef]
150. Cabeza, L.F.; Barreneche, C.; Miró, L.; Morera, J.M.; Bartolí, E.; Fernández, A.I. Low Carbon and Low Embodied Energy Materials in Buildings: A Review. *Renew. Sustain. Energy Rev.* **2013**, *23*, 536–542. [CrossRef]
151. Heffernan, E.; Pan, W.; Liang, X.; de Wilde, P. Zero Carbon Homes: Perceptions from the UK Construction Industry. *Energy Policy* **2015**, *79*, 23–36. [CrossRef]
152. Zhang, L.; Li, Q.; Zhou, J. Critical Factors of Low-Carbon Building Development in China's Urban Area. *J. Clean. Prod.* **2017**, *142*, 3075–3082. [CrossRef]
153. Zuo, J.; Read, B.; Pullen, S.; Shi, Q. Achieving Carbon Neutrality in Commercial Building Developments—Perceptions of the Construction Industry. *Habitat Int.* **2012**, *36*, 278–286. [CrossRef]
154. Pan, W.; Pan, M. Opportunities and Risks of Implementing Zero-Carbon Building Policy for Cities: Hong Kong Case. *Appl. Energy* **2019**, *256*, 113835. [CrossRef]
155. Gareiou, Z.; Drimili, E.; Zervas, E. Public Acceptance of Renewable Energy Sources. In *Low Carbon Energy Technologies in Sustainable Energy Systems*, 1st ed.; Kyriakopoulos, G.L., Ed.; Academic Press: Cambridge, MA, USA; Elsevier: Amsterdam, The Netherlands, 2021; pp. 309–327.
156. Georgiev, Z.; Paunova-Galeva, D.; Kenkmann, T.; Bürger, V.; Kranzl, L.; Toleikyte, A.; Atanasiu, B. Policy Scenarios and Recommendations on nZEB, Deep Renovation and RES-H/C Diffusion: The Case of Bulgaria. D4.3 and D5.6 from Entranze Project. September 2014. Available online: https://www.entranze.eu/files/downloads/D4_3_and_5_6/D4_35_6_ENTRANZE_Bulgaria_final.pdf (accessed on 10 January 2024).
157. Shen, L.; He, B.; Jiao, L.; Song, X.; Zhang, X. Research on the Development of Main Policy Instruments for Improving Building Energy-Efficiency. *J. Clean. Prod.* **2016**, *112*, 1789–1803. [CrossRef]
158. Rethnam, O.R.; Thomas, A. A Community Building Energy Modelling—Life Cycle Cost Analysis framework to design and operate net zero energy communities. *Sustain. Prod. Consum.* **2023**, *39*, 382–398. [CrossRef]
159. Cielo, D.; Subiantoro, A. Net zero energy buildings in New Zealand: Challenges and potentials reviewed against legislative, climatic, technological, and economic factors. *J. Build. Eng.* **2021**, *44*, 102970. [CrossRef]