energies

Article

Towards Sustainable Cities: A Review of Zero Energy Buildings Techniques and Global Activities in Residential Buildings

Gamal Ali Mohammed [1,2,*], Mahmoud Mabrouk [3,*], Guoqing He [1] and Karim I. Abdrabo [3]

[1] College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, China
[2] Faculty of Civil Engineering and Architecture, Thamar University, Thamar City 87246, Yemen
[3] Department of Urban Planning, Faculty of Urban &Regional Planning, Cairo University, Cairo 11562, Egypt; m.karim.ibrahim@cu.edu.eg
* Correspondence: zourina44@yahoo.com (G.A.M.); engmahmoudmabrouk@cu.edu.eg (M.M.)

Abstract: Under rapid urbanization-induced global warming and resource depletion, growing interest in zero-energy building (ZEB) and zero-emission building (ZEB) technologies have emerged globally to improve energy performance in homes and shape sustainable cities. Although several countries have released ZEB-enhanced strategies and set national standards and policies to promote ZEBs, construction projects are still limited to demonstration projects. This paper reviews global ZEB activities and state-of-the-art technologies for energy-efficient residential building technologies [based on an evaluation of 40 residential buildings]. Over 40 residential buildings on different continents were reviewed, and their technical details and performance were evaluated. Our results show that 62.5% of the buildings achieved the +ZEB standard, 25% of the buildings were net-zero energy buildings, and only 12.5% of the buildings were near-zero energy buildings. Solar PV is the most widely used renewable energy source in the studied cases, while in warmer climates, advanced cooling technologies and heat pumps are the preferred technologies. A building envelope and thermal ventilation with heat recovery are essential in cold climates. Our systematic analysis reveals that the thermal performance of the building envelope and solar energy are the most effective mechanisms for achieving energy efficiency and shaping sustainable cities.

Keywords: intelligent city systems; zero emission; sustainable cities; zero energy house; climate change

Citation: Mohammed, G.A.; Mabrouk, M.; He, G.; Abdrabo, K.I. Towards Sustainable Cities: A Review of Zero Energy Buildings Techniques and Global Activities in Residential Buildings. *Energies* **2023**, *16*, 3775. https://doi.org/10.3390/en16093775

Academic Editor: Jarek Kurnitski

Received: 29 March 2023
Revised: 21 April 2023
Accepted: 25 April 2023
Published: 28 April 2023

1. Introduction

Climate-change-induced high temperatures and CO_2 emissions have sparked widespread concern globally in increasingly risk-exposed cities [1,2]. Climate change is one of society's most significant and pressing challenges today and harms human life, communities, nature, and the environment [3]. Greenhouse gas emissions (GHG) from fuel consumption to cool buildings have significantly accelerated global warming [4,5]. When the temperature rises to abnormal levels, this is usually accompanied by an increase in energy consumption for cooling, affecting the high energy expenditure share. As a result, designing zero-energy sustainable buildings as a significant part of the city becomes a requirement rather than a risk-mitigation option [6,7]. The transition to renewable energy and meeting the climate goals of the Paris Agreement depend significantly on cities. Buildings are essential to sustainable development because they consume approximately 40% of the primary energy worldwide and contribute about 24% of greenhouse gas emissions [8]. In the Middle East, buildings consume 45% of the primary energy; during the summer, 70% of this is expended on air conditioning [9]. The ambient temperature can exceed 40 °C for more than 300 h in summer, and this value is expected to double by 2025. Since 2006, many slogans have been used, such as "net-zero-energy buildings", "zero-energy-cost buildings", "nearly-zero-energy buildings", "zero-emission buildings", and "net-zero-energy buildings" [10]. All refer to a ZEB with high energy performance, which means that the total amount of energy used by the building comes from renewable energy sources using technology such as heat pumps, high-efficiency windows and insulation, and solar panels. These techniques release less greenhouse gas into the atmosphere during their operation [11].

Energy consumption and resource depletion will continue until residential buildings are designed to satisfy people's living demands using technology that utilizes sustainable sources on-site or nearby to meet the growing energy demand [12]. Many countries have proposed initiatives to promote zero-energy buildings, such as the 2020 Energy Strategy and the United States program for sustainable cities [10]. These aim to develop building codes, construct ZEBs that are commercially sustainable, and achieve "marketing ZEBs and zero-energy commercial buildings by 2025" [13]. Other countries, such as China, Japan, Korea, and the GCC countries, have followed suit to chart their policies toward ZEBs by 2025 [14]. In a global effort, 50 demonstration solar heating and cooling projects of the International Energy Agency (IEA) have been built according to the passive house standard [15]. Twenty low-energy houses have been constructed in Sweden to help people worldwide agree on defining passive homes and low-energy dwellings [16].

One of the most effective zero-energy techniques is passive solar design, which involves orienting a building to take advantage of the sun's natural heating and cooling effects [17]. This can be achieved through large windows and skylights, shading devices, and thermal mass materials [18,19]. Another technique involves using energy-efficient materials and technologies, such as insulation, high-efficiency HVAC systems, and LED lighting [20]. These can help reduce the energy needed to heat, cool, and power a building, thus reducing its environmental impact [21]. This research reviewed the global progress of ZEBs and effective technologies adopted in practice by 40 selected zero-energy houses from different climates around the world in detail. The chosen cases cover all ZEBs and are thoroughly discussed for theoretical comparisons with general practices worldwide. This study aims to help architects design energy-neutral houses with existing materials and non-complex technologies.

2. Literature Review

2.1. Zero-Energy Buildings

Zero-energy buildings (ZEBs) are structures designed to consume only as much energy as they can produce through renewable energy sources over the course of a year. ZEBs are also referred to as net-zero-energy buildings (NZEBs) [22]. The goal of ZEBs is to minimize energy consumption by using energy-efficient technologies and renewable energy sources, such as solar panels, wind turbines, and geothermal systems. This can include features such as high levels of insulation, energy-efficient lighting and appliances, and passive solar design [23]. ZEBs are becoming increasingly popular to reduce greenhouse gas emissions and combat climate change. In addition to being environmentally friendly, ZEBs can also offer cost savings over time, as owners and occupants can save money on energy bills [24]. ZEBs can be designed for a variety of uses, including residential, commercial, and industrial buildings [10]. However, designing and constructing a ZEB can be more complex and expensive than designing and constructing a traditional building and requires a multidisciplinary approach involving architects, engineers, builders, and energy experts. Despite the challenges, ZEBs are seen as an important part of the transition to a more sustainable and low-carbon future and have the potential to greatly reduce energy consumption and greenhouse gas emissions in the built environment [25].

Various advancements in energy efficiency and numerous initiatives to reduce the environmental impact of building emissions, which rose by around 2% for the second year between 2017 and 2018, have been released [26]. These gains were mostly caused by expanding the world's population and a steadily expanding building floor area. In 2018, the building and construction sector was responsible for 36% of final energy use and 39% of carbon dioxide (CO_2) emissions from energy processes [27]. Buildings play a crucial role in the transition to clean energy [28,29]. In response to the Paris Agreement in 2015, the European Union (EU) set the lofty target of reducing greenhouse gas (GHG) emissions by at least 40% below 1990 levels by 2030 [30]. The EU has embraced a variety of steps to become the first climate-neutral continent by 2050, including moving to a clean, circular, and sustainable economy [31]. With the Renovation Wave (European Commission, 2020b), a component of the Green Deal, the European Union aims to double the yearly energy renovation rate of residential and non-residential buildings and repair 35 million building units by 2030 [3,6]. In 2018, an updated Renewable Energy Directive was implemented to promote using renewable energy sources, especially within the built environment [32]. The Energy Performance of Buildings of 2010 and its recast in 2018 will significantly contribute to making Europe's buildings highly energy efficient and decarbonized by 2050 [12]. Additionally, it facilitates the cost-effective transformation of existing buildings into nearly zero-energy buildings.

Furthermore, all new buildings have had to use negligible amounts of energy since 2020 [9]. Following Horizon 2020, a EUR 80 billion EU research and innovation program that funded many research projects on these topics from 2014 to 2020, Horizon Europe (European Commission, 2019a) will invest EUR 100 billion to pursue its targets between 2021 and 2028 [8]. Two factors are crucial in environmentally friendly urban planning; by 2030, Europe will be climate-proof and equitable. Europe will be prepared to recover quickly from natural disasters and adapt to the changing climate, and 100 climate-neutral cities will be run by and for their residents by 2030 [33,34]. These missions highlight the EU's aspirations to combat the environmental impact of the building sector. Additionally, positive energy communities, districts, and blocks can efficiently use their capacity to generate and store renewable energy [11,19]. With roughly 67% of the global population and accounting for approximately 70% of global energy consumption and CO_2 emissions, urban areas are undeniably crucial to the ongoing transition to renewable energies and low-emission technologies [3,9].

For this reason, in 2018, the European Union launched the "Positive Energy Districts and Neighborhoods for Sustainable Urban Development" program as part of the Strategic Energy Technology (SET) Plan "Smart Cities and Communities [35]." By 2025, this program will have helped to plan, deploy, and replicate 100 Positive Energy Districts (PED) to make buildings and cities more sustainable [21]. Regarding the above, many studies have investigated the impact of the windcatcher, which is an environmentally friendly technique and a viable and attractive strategy for sustainable building concepts to provide thermal comfort, indoor air quality, and low energy consumption [36].

2.2. Zero-Energy Building Strategies

Net-zero buildings are designed to use as little energy as possible by using passive building design [7,11,21]. Passive building design is a strategy that makes the most of natural sources of light, heat, and ventilation. For example, the Sustainable Energy Fund Office Building in Pennsylvania, as mentioned in gbdmagazine.com, is the first energy-positive building in the Lehigh Valley [12]. This building uses a combination of geothermal heating, triple-glazed curtain walls, and energy-efficient lighting to achieve net-zero energy consumption [22]. Similarly, the Joyce Centre for Partnership & Innovation in Canada, as mentioned in gbdmagazine.com, uses geothermal heating and cooling, radiant heating and cooling, and a building envelope that maximizes natural light to achieve net-zero energy consumption [37]. Another example of zero-energy buildings describes nearly zero-energy mixed-use buildings in China. These buildings are powered by rooftop photovoltaic panels and house 3000 students, faculty, and staff [12].

The development also encourages low-carbon transportation. These case studies demonstrate how materials that increase the energy efficiency of building projects, such as ROCKWOOL insulation, can be used to reduce the environmental footprint of buildings [38]. For example, the nearly zero-energy family house built in Glostrup, Denmark, uses a combination of insulation, heat recovery, and solar panels to achieve net-zero energy consumption [19]. Table 1 lists the most used ZEB terms, such as ZEBs producing more energy than the building needs, ZEBs and Net ZEBs producing as much energy as needed, and buildings near ZEBs having less energy than their needs [11]. In this paper, ZEB refers to a building that is connected to one or more utility grids, such as heating and cooling systems, gas pipe networks, biomass networks, or an electricity grid, so that the building can export and import energy from the grids to avoid energy storage on the site [18]. Over the past 2 decades, at least 300 projects have been completed with a zero-energy balance worldwide.

Table 1. Summary of zero-energy building categories.

Category	Case Study	Definition	
Energy Plus Building (+ZEB)	Sunlight House—Austria [39]	- Buildings that generate their energy from renewable and sustainable sources - They produce more energy than their consumption and deliver more energy to the supply systems over more than a year	
Zero Energy Building (ZEB)	Efficiency House Plus—Germany [39]	- Independent buildings that do not require connection to the grid even as a backup - They produce as much energy as they need and can store excess energy for use at nighttime	
Net-Zero Energy Building (Net ZEB)	Energy Flex House—Denmark [7]	- Buildings that rely on neutral energy for over a year and do not need any fossil fuels - They produce as much energy as they need and take a lot of energy from the grid and deliver it to the supply grid.	
Near Zero Energy Building (Near ZEB)	Carbon Light Home—UK [40]	- Buildings that have high-energy performance - They deliver more energy to the supply - They produce less energy than they need - The amount of energy required is covered to an extent by energy from other sources	

3. Methodological Framework

The effectiveness of zero-energy techniques in shaping climate-resilient sustainable buildings can be evaluated in several ways. One approach is to measure the energy performance of the building over time and compare it to industry standards or benchmarks. This can help identify areas where improvements can be made and demonstrate the techniques' effectiveness. Another approach is to assess the building's overall environmental impact, considering factors such as carbon emissions, water consumption, and waste generation. This can provide a more comprehensive picture of the building's sustainability and help identify areas for further improvements.

This research aims to look at high-efficiency, zero-energy homes to improve thermal performance and lower the energy needed to cool homes. Thus, looking into the expected benefits, energy savings from renewable and sustainable sources, and thermal comfort of the people living in the house is important. Our results should encourage ZEB techniques to be used in the building process of a zero-energy-efficient model in the residential sector of a hot and humid climate. This study used a descriptive-analytical method and conducted a mix of statistical, quantitative, and qualitative data analyses regarding energy performance. We analyzed the related performance indicators and extrapolated the various techniques and climate data. Literature reviews and online searches were used to collect data on global ZEB activities and cutting-edge technologies. A total of 40 zero-energy houses constructed in several countries worldwide were selected to examine zero-energy technologies and to identify their similarities, differences, and local adaptations. The criteria for choosing cases were as follows: (1) buildings are detached or semi-detached single-family houses; (2) the buildings cover different climates and various challenges. The results are presented in Section 3: passive energy techniques in buildings, service systems techniques (annual energy supply and annual energy consumption), and renewable energy generation.

4. Case Studies

Table 2 lists the location, climates, building area, techniques, legislative context, climate challenges, and energy performance of 40 ZEB projects around the world [16–50]. Data were available in terms of technical documentation, physical characteristics, size, and type of dwelling, as well as the energy needs of each building. Figure 1 gives an overview and global indication of the activities of the ZEBs (For more details, see Appendix A, Tables A1–A5). The architectural features of the 40 pilot energy-efficient building projects selected from the Annex 52/(IEA) Task 40 project database were used for analysis [21]. We consider the indicators of the ZEBs' activities based on Thomsen and Wittchen's approach.

Table 2. ZEBs projects chosen worldwide.

N.	Building Name	Location	Completion Date	Building Area m^2	Climate Variation	Refs.
1	Home for Life	Aarhus, Norway	2009	190	HHD	[40]
2	Maison Air Lumière	Paris, France	2011	130	HHD	[42]
3	The Solar House	Freiburg, Germany	1992	145	HHD	[43]
4	The Lighthouse	Watford, UK	2007	93	HHD	[37]
5	Leaf House	Marche, Italy	2008	477	HHD + LCD	[44,45]
6	Eco Terra house	Quebec, Canada	2007	141	HHD	[46]
7	The NZERTF	Gaithersburg, USA	2012	387	HHD + LCD	[44,45]
8	Para Eco House	Shanghai, China	2012	55.8	HHD + HCD + DD	[47]
9	Sabic and J&P	Riyadh, Saudi Arabia	2015	550	HHD + HCD + DD	[47]
10	Hybrid Z	Kanagawa, Japan	1998	228.5	HHD + HCD	[48]
11	Carbon Light homed	Rothwell, UK	2011	200	HHD	[46]
12	LichtAktiv Haus	Hamburg, Germany	2010	189	HHD	[46]
13	Efficiency House Plus	Berlin, Germany	2010	203	HHD	[44,45]
14	Riverdale House	Alberta, Canada	2007	234	HHD	[37]
15	Energy Flex House	Taastrup, Denmark	2008	216	HHD	[44,45]
16	Riehen House	Switzerland	2007	315	HHD	[47]
17	Lima House	Barcelona, Spain	2011	45	HHD + LCD	[47]
18	Green Lighthouse	Denmark	2009	845	HHD	[49]
19	Sun Lighthouse	Pressbaum, Austria	2010	945	HHD	[44,45]
20	Solar Settlement	Germany	2006	7890	HHD	[50]
21	Plus Energy Settlement	Weiz Styria, Austria	2006	105	HHD	[51]
22	Bed ZED	London	2002	75	HHD	[44]
23	The Eco Houses	Muscat, Oman	2014	150	HHD + HCD + DD	[47]
24	The solar village	Algeria	2012	87.75	HHD + HCD	[24,36]
25	The Habitat Home	Denver, USA	2007	119	HHD + HCD	[52]
26	The Wind House	USA	2008	260	HHD	[47]
27	The Solar Decathlon	China	2009	94	HHD + HCD	[3]
28	Jiao Tong House	Shanghai, China	2013	90	HHD + HCD + DD	[37]
29	Maison HANAU	Selestat, France	2013	178	HHD	[35]

Table 2. *Cont.*

N.	Building Name	Location	Completion Date	Building Area m^2	Climate Variation	Refs.
30	Villa ISOVER	Hyvinkää, Finland	2013	155	HHD + HCD	[53]
31	Single Family House	Nicosia, Cyprus	1982	396.9	HHD + HCD + DD	[10,54]
32	Zero-energy homes	Sharpness, Norway	2015	154	HHD	[27]
33	The Okamoto Solar House	Chiryu, Japan	2003	189	HHD + HCD	[14]
34	Demonstration houses	Czech	2003	86	HHD	[12,16]
35	Demonstration housing	Freiburg, Germany	2003	1370	HHD	[55]
36	The Baytna villa	Doha, Qatar	2013	220	HHD + HCD + DD	[56]
37	Single family detached	Catania, Italy	2003	144	HHD + HCD	[45]
38	Maison DOISY	Niort, French	2004	158	HHD	[7]
39	Semi-detached house	Dublin, Ireland	1950	160	HHD	[57]
40	De Duurzame house	Flanders, Belgium	2004	194	HHD	[11]

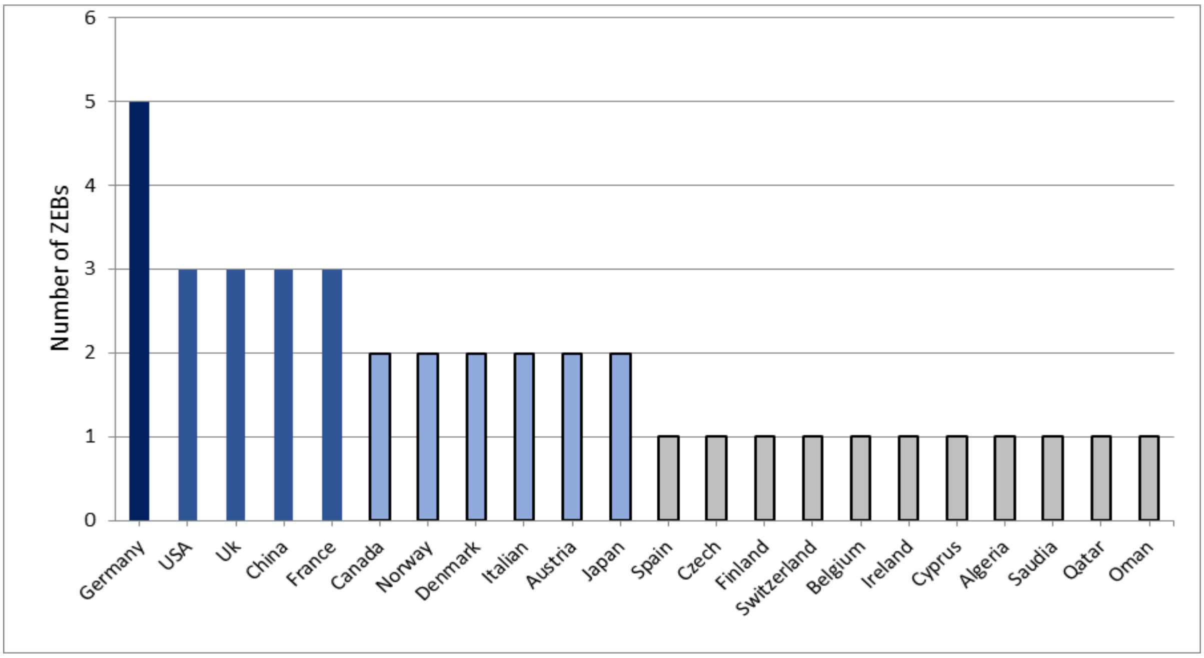

Figure 1. Number of ZEBs in different countries.

4.1. Residential Building Type and Scale

The chosen ZEBs varied in size and had building floor areas ranging from 55.8 to 550 m^2. In comparison, the average floor area of a global dwelling is 85 m^2. The Para Eco House, despite being the smallest in size, is an integrated house, and the technologies used in the building could easily be scaled up to create single-story buildings that are designed to be very efficient to minimize energy consumption and reduce the passive impact on the environment. Solar and wind power technologies in these buildings require a large installation area either within the site footprint or somewhere near the building. For small residential buildings with limited roof areas, it can be technically difficult to achieve the goal of a zero-energy building.

4.2. Climatic Zones

To classify the collected ZEBs by climatic zone, a common methodology was developed. Within each region, homogeneous or different climatic zones were considered to understand the difference in building energy use and renewable energy generation caused by climate variations (see Figure 2). The climatic zones were divided into five regions, and a roadmap was developed, warm temperate (19), polar (4), arid (4), Mediterranean (5), and snow (8). Since energy demand in regions of moderate to high temperature and humidity increases drastically, an emphasis is placed on moisture control.

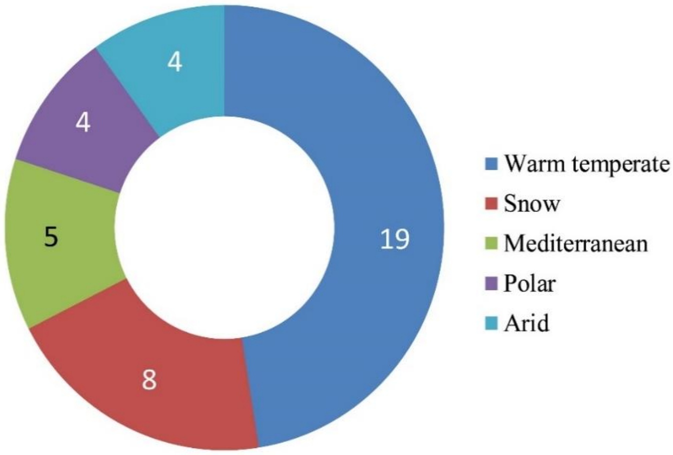

Figure 2. Number of ZEBs in different climate types.

5. The State-of-the-Art Technologies

General strategies of ZEBs include (1) reducing the need for energy through energy-efficient technologies and (2) adopting renewable energy [22]. Not all technologies are suitable for each building, and some technologies' implementation can be limited by a small building area. This study groups all technologies into four categories: passive technologies, active technologies, energy management, and renewable energy.

5.1. Passive Energy Technologies

Passive technologies are energy-saving techniques that consume no or negligible energy during operation. They have a long history in residential buildings compared with active strategies. Passive technology can be grouped in general into four categories: energy efficiency, building envelope (thermal insulation), passive cooling or heating, and thermal energy storage.

5.1.1. Buildings Envelope

An efficient building envelope can effectively reduce heat loss or gain through heat transfer. In hot climates, building envelopes are designed to reduce the penetration of solar radiation. The technical indicators are U-values and solar heat gain coefficients. Other than their unusually high levels of floor insulation, most ZEBs use relatively traditional foundations. Internal insulation systems are common; however, external insulation is often added to control thermal heat from the soil. As for the U-values of floors, the maximum value range is between 0.07 W/m^2·K and 0.90 W/m^2·K. In cold weather zones, a strict minimum standard (UF < 0.07 W/m^2·K to a maximum value of 0.15 W/m^2·K) is set for efficient insulation. Figure 3 summarizes the mean U-values of the ZEBs' envelopes.

Regarding exterior wall systems in all the buildings, various types of wall systems ranging from relatively standard frame constructions with an insulated exterior shell to the SIPS system were used to double up the walls. Insulation levels usually range from about 20 cm to 30 cm. U-values vary between 0.08 W/m^2·K as a minimum value and 0.90 W/m^2·K as a maximum value. Perhaps the biggest problem with wall systems is the cost. There are many ways to reduce airflow through walls, and the cost is more than double the cost of a conventional building wall, which costs anywhere from USD 20 to USD 70 per m^2.

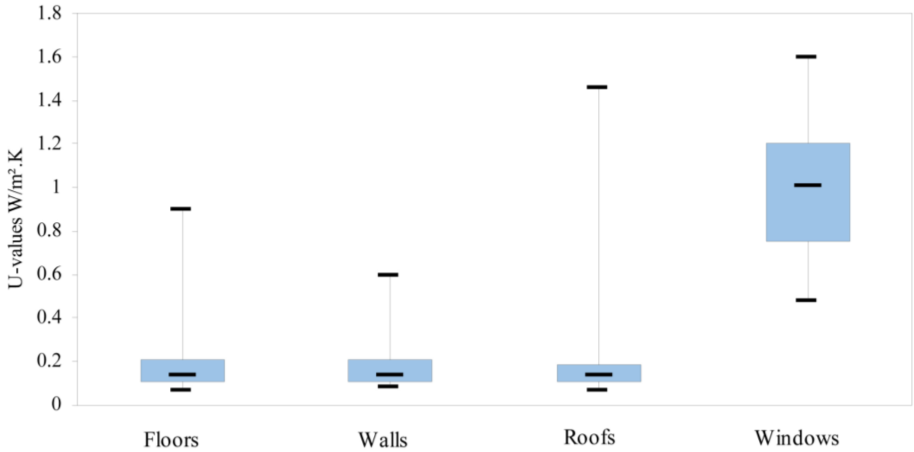

Figure 3. Mean U-values of the different ZEBs' envelopes.

In all buildings (except buildings with flat surfaces), the sharp angles restrict the installation of insulating materials in the sloping ceilings at the ends of the truss. These angles are not well suited to glass fiber insulation due to the interstitial condensation in the fiberglass layer. This reduces the total sufficient RSI value of the roof, and the problem is worse for low-sloping roofs. The Sabic and J&P house [31] and The Para Eco House [30] (arid climate) are characterized by a flat roof of reinforced concrete developed with a combination of thermal insulation and radiation reflectors that demonstrated a significant reduction in the heat passing through the concrete roof. According to Figure 3, all buildings' U-values are between 0.07 W/m^2·K and 1.46 W/m^2·K. Heat gain/loss through roof systems in case study buildings is more critical in low-rise buildings. Energy-efficient roof technologies include insulated and reflective roofs that reflect solar radiation, which are efficient in cooling-dominant climates.

As for windows, U-values vary between 0.50 W/m^2·K and 1.65 W/m^2·K, which suggests low values that are very close to the Passive House standard. A clear and interesting feature regarding windows' U-values is that the buildings with the best net-zero-energy performance (The NZERTF [29], Home for Life [23], Solar House [25], Lighthouse [26], and Para Eco House [30]) undergo heating and cooling challenges that are characterized by the U-values being greater than the values indicated in the windows for other buildings with cooling challenges (the Baytna villa [49] and Eco House [39]). This is a clear and interesting feature. However, insulation may not be very effective in cooling-dominant buildings with large internal heat loads in warm climates. Thus, the selection of the window may be more important for ZEB case studies than previously thought. The aim of most of the ZEB buildings' designs (all case studies) is to use the most technologically advanced window (the most energy efficient). The best reflective glass is selected to reduce solar heat and gain more energy efficiently. However, smaller or better-insulated window systems (arid climate) also reduce light absorption.

5.1.2. Passive Heating

Passive heating technologies are strategies for using natural energy sources, such as solar energy or the ambient environment, to harvest energy with no or limited energy costs. Common techniques include the Trombe wall, ventilated double-skin façades, and solar houses. One of the most effective zero-energy techniques is passive solar design, which involves orienting a building to take advantage of the sun's natural heating and cooling effects. This can be achieved through large windows and skylights, shading devices, and thermal mass materials. Other techniques use energy-efficient materials and technologies, such as insulation, high-efficiency HVAC systems, and LED lighting. These can help reduce the energy needed to heat, cool, and power a building, thus reducing its environmental impact. A "solar house" [25] is another example of a passive strategy that uses direct solar irradiation for space heating.

5.1.3. Passive Cooling

Thermal mass is the most commonly used passive cooling technique to reduce daytime peak load and internal daytime temperatures. In the case study buildings, thermal mass benefits are systematically assessed using a sensitivity analysis. It is generally believed that thermal mass should be combined with night ventilation (natural/mechanical) to take full advantage of its energy-saving potential. This design strategy in buildings in dry and Mediterranean climates has proven effective at avoiding the summer heat and reducing cooling requirements. A ventilation system is used in all ZEB case studies. Outdoor air is supplied via heat recovery ventilators (HRV), and this unit brings outdoor air into the house and continuously exhausts indoor air. This design strategy has proven effective at avoiding the summer heat and reducing cooling requirements in the "Sabic & J&P House" [31], "Eco House" [39], "solar village" [40], and "baytna villa" [49]. Passive cooling technology's contribution to reducing total energy consumption is 486 KWh/m^2/year, which is 17% of the total annual energy consumption in the 40 ZEB case studies, as shown in Tables A4 and A5 and Figure 4.

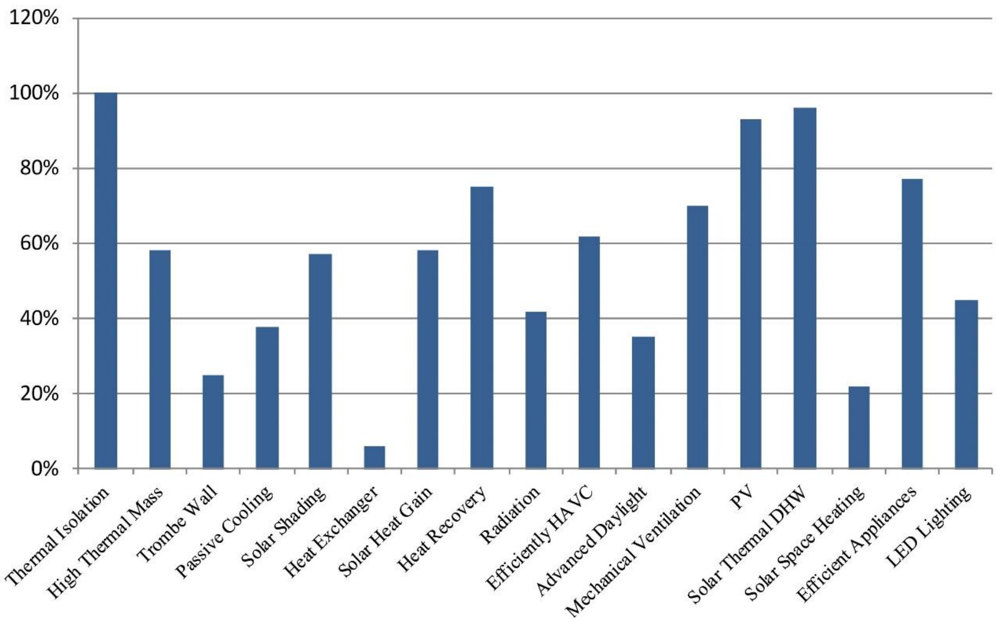

Figure 4. Energy-saving measures in selected ZEBs.

5.1.4. Thermal Energy Storage

Passive thermal storage energy is another practical approach to building thermal control that relies primarily on the storage of latent heat that is released through the thermal mass in the building or LED lighting, which has attracted increasing interest in research for decades. Although 17 ZEB case studies (43% of the 40 ZEBs) use LED lighting in practice, it is suggested that the combination of LED and night ventilation can achieve greater energy efficiency (see Figure 4). Thus, the LED would be effective in all 40 ZEB cases. The "Lighthouse" [26], Riverdale House [34], Green Lighthouse, Sun Lighthouse [37], Bed ZED House, Solar Settlement [38], Habitat Home [41], Jiao Tong House [44], Maison DOISY, urban semi-house [45], zero-energy home [47], and single-family house [46] are examples where thermal energy storage is used for space heating and cooling.

5.2. Operational Energy Demand

The annual energy demand of the chosen ZEBs varies between 17.1 KWh/m^2/year for the Solar House [25] and 120 KWh/m^2/year for the Solar Decathlon [43]. However, these are not comparable in terms of magnitude because they are not located at similar latitudes. The energy demand includes heating, cooling, DHW, ventilation, lighting, and appliances. In terms of energy-efficiency systems for heating and cooling, most of the projects use low-exergy systems in the form of radiant heating (in North America and Europe), cooling (hot humid climate zones), and mechanical ventilation by air heat recovery (all 40 ZEB cases). On the other hand, the use of low-energy lighting and energy-efficient electrical equipment, such as washing machines with hot water, is a strategy to meet the balance of energy consumption. However, the data on the use of operational energy added to the total primary energy are not clear. Despite this, all 40 projects have achieved low levels of energy demand. Used in a total of 38 out of the 40 study cases, energy demand for heating accounts for about 27.2% of the final annual energy consumption. Domestic hot water (DHW) is used in 40 cases and accounts for about 19.4% of the final annual energy consumption. Energy demand for cooling is present in 17 cases (42.5% of cases), representing about 11.6% of the final annual energy consumption. Ventilation is present in 40 cases, representing about 4.4% of the final annual energy consumption. Energy demand for lighting is present in 40 cases, accounting for about 8.4% of the final annual energy consumption, and appliances are present in 40 cases, representing about 29.1% of the final annual energy consumption. These data are shown in Figure 5.

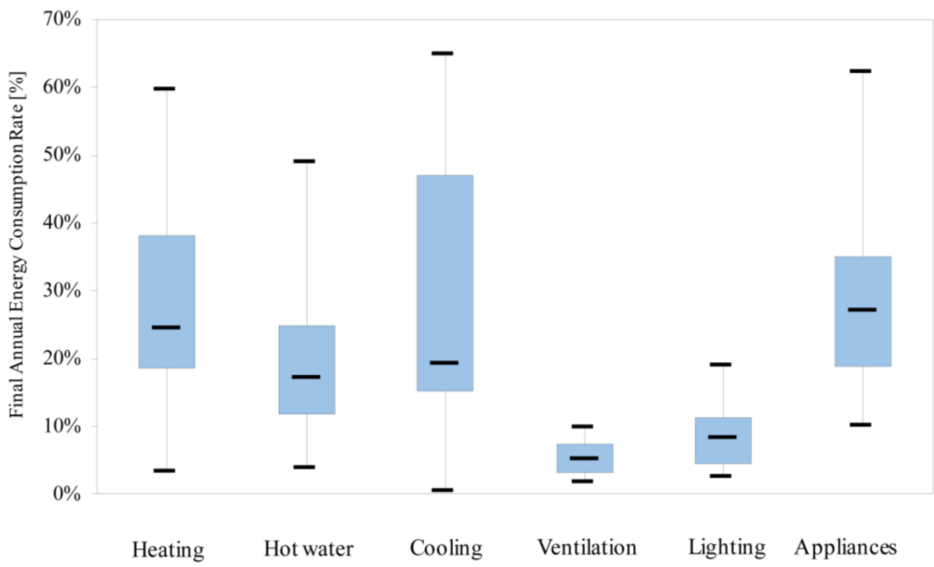

Figure 5. The total energy demand for the ZEB case.

The average heating consumption of newly constructed residential buildings is 21 kWh/m^2/year, while renovated houses achieve a similar level of 25 kWh/m^2/year, slightly lower due to restrictions involving thermal bridges, lack of good insulation in the slab, etc. The lowest overall consumption of energy is 25 kWh/ m^2/year, and the lowest domestic cooling hot water consumption is 12 kWh/ m^2/year.

Regarding HVAC systems, all the case houses use a solar thermal system for DHW preheating coupled with an electric, instantaneous standby heater. Some projects used preheated water from the solar energy system. Heat recovery systems are also common in these case studies. In the case of the DHW system, heat recovery can reduce the DHW load by about 17% to 26%. It has proven to be an effective and reliable technology. The ZEBs are usually quite airtight, and most ventilation air required is delivered by the mechanical system. Almost all buildings used heat recovery ventilators (HRV) for fresh air. They use a motion detection sensor that shuts down the HRV when the house is unoccupied.

5.3. On-Site Renewable Energy Systems

Thirty-eight of the case studies use various renewable energy supply options, ideally involving the application of low-energy technologies, which use sources that are available on-site from initial sources. Solar heat collectors, photovoltaic systems, biomass systems, and geothermal heat pumps are renewable energy technologies that are used as energy demand reduction technology. Figure 6a,b illustrates the mean technologies applied in different ZEB typologies.

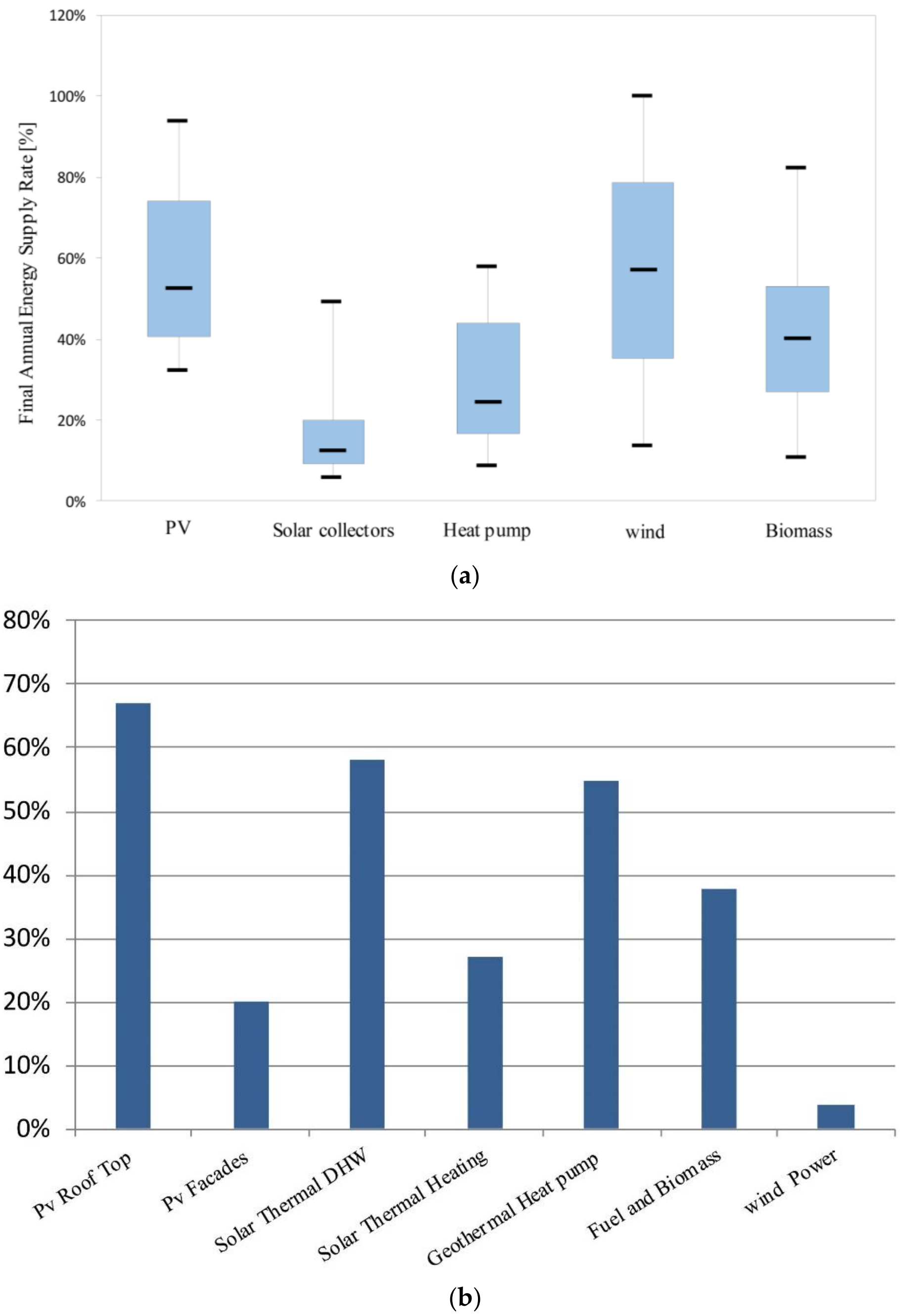

Figure 6. The total renewable energy supply. (**a**) Mean of the total energy demand for the ZEB cases. (**b**) The technologies applied in different ZEB typologies.

5.3.1. PV (Photovoltaic)

Photovoltaic energy is one of the most sustainable renewable energy technologies. In our ZEB case studies, photovoltaic (PV) systems including solar panels installed on the buildings' roofs and facades accounted for 35 cases, representing 87.5% of our ZEB cases. The estimated total annual photovoltaic with solar collector production is 1550 KWh/m^2/year. The electricity generation from PV systems on average covered 51.5% of the final annual energy supply in these buildings. The Solar Decathlon has the highest photovoltaic energy production with 137.5 kWh/m^2/year, [43], while the EcoTerra house has the lowest electricity production with 11.1 kWh/m^2/year [28].

5.3.2. Solar Water Heaters

In residential buildings, energy use for domestic hot water represents a large proportion of the overall household energy consumption. ZEBs utilize solutions and innovative developments to improve energy efficiency. For example, a low-profile complex hot water storage system has been developed to address the issue of architectural aesthetics. Solar thermal collectors for DHW and heating are present in 33 cases, representing 82.5% of the total, and they provide 13.8% of the final annual energy supply.

5.3.3. Heat Pumps

Heat pumps for selected ZEBs provide viable alternatives by restoring heat from different energy sources for use in different building applications. Recent advances in heat pump technologies focus on advanced cycle designs for heat and work systems, improved cycles, and wider use of applications. Geothermal heat pump systems are used in 22 cases, representing 55% of the total, and they provide 16.3% of the final annual energy supply.

5.3.4. Bioenergy

Bioenergy is a major source of high-demand performance for multiple uses in the building sector and is derived from forestry and agricultural waste. Biomass boilers in selected ZEBs applied a large number of residual resources to electricity production, DHW, and cooking. Fuel and biomass systems are present in 16 cases, representing about 40% of the total, and they provide 15.6% of the final annual energy supply.

5.3.5. Wind Turbines

Wind power generation differs from traditional thermal generation due to the irregular nature of the wind. The Lighthouse [26] and the Wind House [42] include wind power generation to deal with supply demand compatibility challenges in the electrical system. Wind power is used in 2 cases, representing 5% of the total, and it provides 2.8% of the final annual energy supply. Renewable energy systems should either generate energy for heating and cooling or provide the fuel necessary to run heating and cooling systems. With this in mind, most strategies make use of solar thermal collectors for the production of DHW and heating (the EcoTerra house [28] is not equipped with solar thermal collectors) and photovoltaic systems for electricity generation (the Lighthouse [26] does not have an on-site electricity generation system). For space heating and cooling using solar thermal heating (radiant heating) and on-site geothermal heat pump sources (heating/cooling), the use of biomass for heating purposes depends on the cost (Lighthouse) [26]; however, the availability of biomass from renewable sources is limited. Air source heat pumps are used to transfer heat (in the Home for Life [23], Maison Air et Lumière [24], Lighthouse [26], NZERTF [29], and Hybrid Z [32] ZEBs). Some buildings use a hydrogen fuel station (Solar House [25]), an auxiliary boiler and power plant fired by wood chips and natural gas (Leaf House [27]), and wind (the Wind House [42]) to generate energy. There is an opportunity to export excess electricity (Hybrid Z [32] and Solar House [25]), as is shown in Figure 6. For some years, solar thermal systems have increasingly been used due to their increased efficiency and small size. Solar energy is the most popular form of renewable energy used in buildings. Over the past decade, the number of zero-energy buildings that use geothermal heat pumps has increased due to improved heat pump technology, decreased investment costs, and the fact that there is no need to build chimneys or store fuel in buildings.

5.4. Energy Efficiency in ZEB Case Studies

There were five types of load distribution according to the climate characteristics as follows: (1) the cooling load is dominant in tropical regions; (2) space heating is dominant in North America and Europe; (3) both heating and cooling are important in the southern European region as it has a moderate climate; (4) South and East Asia feature a hot, humid climate where dehumidification is an important factor; and (5) cooling is dominant in West Asia (Qatar–Saudi–Oman) as it features a hot, arid climate. It can be seen from Figure 7 that not all chosen cases are strictly ZEBs. Some exhibit high primary energy consumption and high energy production; some have low energy consumption and low energy production. The Solar Decathlon [43] has the highest annual consumption of primary energy (120 KWh/m^2/year), with a value close to that of a typical high-performance building. The Solar House [25], on the other hand, has the lowest annual consumption of primary energy (17.1 KWh/m^2/year). For buildings with high energy consumption, there is a greater need for renewable and sustainable energy sources to compensate for the high demand for energy. In this study, 25 cases, representing 62.5% of the total, are categorized as plus-energy buildings; 8 cases, representing 20% of the total, are categorized as net-zero-energy buildings; and 7 cases, representing 17.5% of the total, are categorized as near zero-energy buildings.

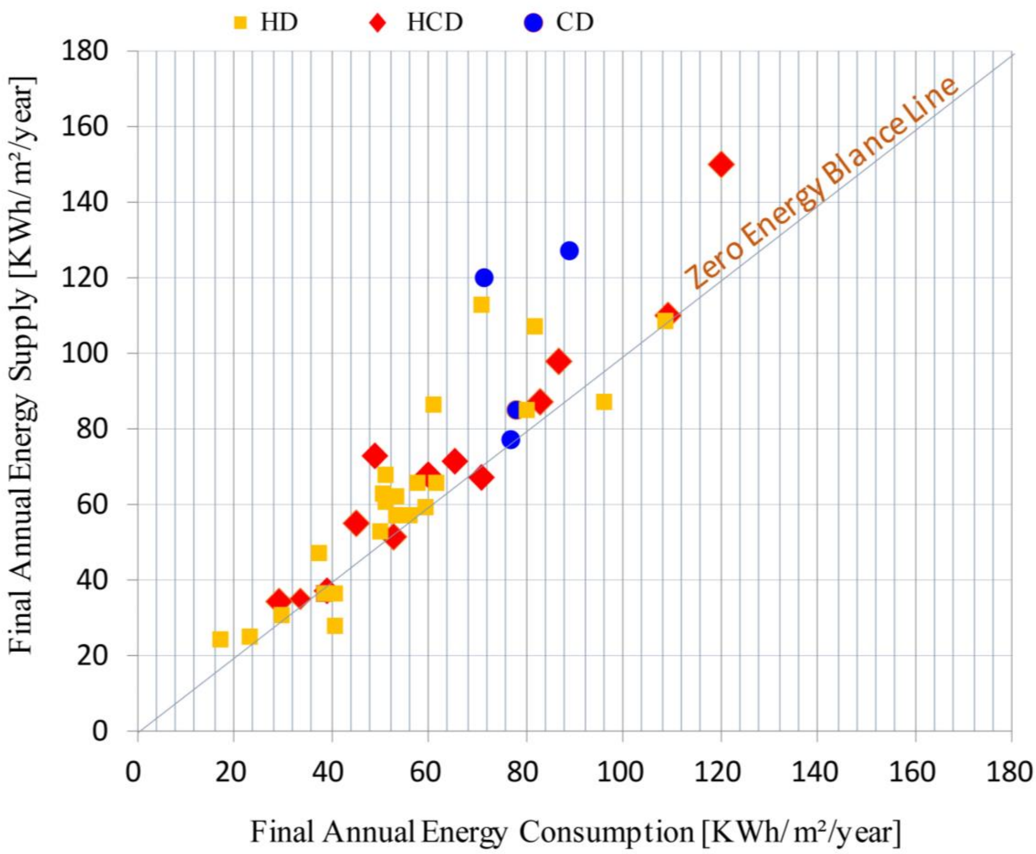

Figure 7. The energy efficiency of the ZEB cases according to the buildings' use and climate.

There must be a focus on buildings that are directly linked to energy infrastructure and not on independent buildings. In northern regions (North America and Europe), improving district heating energy efficiency is a priority; however, advanced cooling technologies are a priority in Asia. In moderate climatic regions, bi-modal heat pumps are a priority.

There are differences in the annual energy consumption of case study buildings in America, the EU, and Asia. In the US and Canada (5 cases), 25% of building energy consumption is accounted for by space heating, more than 19% is accounted for by water heating, 20% is accounted for by space cooling and ventilation, and 27% is accounted for by appliances and service equipment. In the EU (26 cases), 28% of energy consumption is accounted for by space heating, more than 25% is accounted for by water heating, and 43% is accounted for by appliances and service equipment. In Asia (9 cases), space heating and water heating account for 10% and 21% of total final energy demand, respectively; cooling accounts for 28% of energy consumption, which is much higher than in the US; and appliances and equipment account for 35% of energy use. The difference in the ZEB penetration in each country is due to many factors analyzed under the zero-energy building projects of 2020. One critical reason is the lack of a scientific methodology regarding how to define a zero-energy building, which leads to a wide range of limits for primary energy in different countries.

6. Zero-Energy Buildings' Role in Shaping Sustainable Cities

Zero-energy buildings (ZEBs) can play a significant role in shaping sustainable cities by reducing greenhouse gas emissions and improving the overall energy efficiency of buildings [58,59]. ZEBs can contribute to sustainable cities in various ways. (1) Reduced Energy Consumption: ZEBs consume less energy than conventional buildings, which reduces the demand for fossil fuels and the associated greenhouse gas emissions. This can help mitigate climate change and improve the air quality of urban areas. (2) Improved Air Quality: ZEBs typically use renewable energy sources, which do not produce harmful emissions. This can improve air quality and reduce the health risks associated with air pollution [4]. By improving the energy required to power buildings, enhancing resilience, and using renewable energy sources, ZEBs can help urban areas achieve their carbon neutrality aims and create healthier, more equitable spaces. (3) Economic Benefits: ZEBs can provide economic benefits to building owners and tenants by reducing energy costs and improving the value of the property. In addition, the development and maintenance of ZEBs help create jobs in the renewable energy sector. (4) Community Engagement: ZEBs can serve as a focal point for community engagement and education on sustainable building practices. They can also demonstrate the feasibility and benefits of sustainable buildings to the wider community [60]. (5) Urban Resilience: ZEBs can improve urban resilience by reducing the reliance on centralized energy systems and increasing energy independence. In case of a power outage or natural disaster, ZEBs can continue to operate using on-site renewable energy sources. In conclusion, zero-energy buildings are an innovative solution to reducing energy consumption, minimizing the carbon footprint of buildings, and promoting sustainability. Passive building design, renewable energy sources, and energy-efficient materials are some of the key features of zero-energy buildings. Multiple examples of zero-energy buildings from around the world demonstrate the feasibility and effectiveness of this approach.

7. Conclusions

Considering the variety of techniques and combinations of passive measures used to achieve the performance objectives of zero-energy buildings, ZEBs have the potential to reduce energy use, address increasing building energy demands, and generate energy from sustainable, renewable sources. Although several countries have released enhanced ZEB strategies, the implemented projects are still limited and face many challenges. This paper reviews two aspects of ZEBs: a strategic approach to ZEBs (or global ZEB activities) and state-of-the-art, energy-efficient building technologies, focusing on residential buildings. Over 40 residential buildings on different continents were reviewed, and their technical details and performance were evaluated. A total of 62.5% of the buildings included in this study achieved the +ZEB standard; 25% were net-zero-energy buildings; and only 12.5% were near-zero-energy buildings. Solar PV is the most widely used renewable energy source in the studied cases, but in warmer climates, advanced cooling technologies and heat pumps are preferred. Building envelopes and thermal ventilation with heat recovery is essential in cold climates.

We suggest that buildings be more environmentally friendly by connecting to a municipal and regional energy network that uses energy from renewable sources to make the supply side as reliable and flexible as possible. Using energy-saving solid measures to ensure that annual local energy consumption stays below the amount of renewable energy generated locally allows for more renewable energy to be used in existing regional power grids, making them more flexible, allowing consumers to change their use based on demand, and allowing for the better management of energy storage. Sustainable energy sources must be combined with the built environment to create value and social incentives. This includes renewable energy sources, recycled materials, and more (i.e., local storage, smart energy grids, demand–response, cutting-edge energy management systems, user interaction, and ICT). Finally, low-cost housing that enhances indoor energy quality should be provided to boost residents' health and happiness.

Some improvements to building envelope technologies are cost-effective, but others are still in the research and development stage. These challenges are particularly significant if a project aims to be a zero-energy building. Achieving a zero-energy building goal for small residential buildings with limited roof areas and constructing a passive house combined with photovoltaic and solar thermal collectors can be technically challenging. Exploring different topics and points of view shows how many additional problems cities could face. As a result, thorough plans for low-carbon resilience need to consider many different factors. More in-depth and ongoing research on low-carbon resilience is essential if these problems are to be solved, and effective and efficient urban governance is necessary to help reach Sustainable Development Goals. In summary, zero-energy techniques can be highly effective in shaping climate-resilient sustainable buildings, and their effectiveness can be evaluated via a range of methods, including energy performance monitoring, environmental impact assessments, and resilience testing. These techniques are critical for promoting sustainability and resilience in the built environment and for reducing the environmental impact of buildings.

Despite research discussions on the effectiveness of zero-energy techniques in shaping climate-resilient sustainable buildings, there are also several potential gaps in this research topic that need to be addressed. (1) Lack of long-term data: Many studies on the effectiveness of zero-energy techniques focus on short-term performance data, often only for a few years after a building is constructed. However, it is important to evaluate the long-term performance of these techniques over the lifetime of the building. Long-term data can help identify any issues or weaknesses in the design or implementation of zero-energy techniques and provide insights for future improvements. (2) While zero-energy techniques can significantly reduce energy consumption in buildings, occupants' behavior can also significantly impact energy use. A lot of research is needed to examine the role of occupant behavior in shaping the effectiveness of zero-energy techniques and that identifies strategies for promoting sustainable behaviors. (3) Lack of standardization: There is currently a lack of standardization in the evaluation and certification of zero-energy buildings, making it difficult to compare and evaluate the effectiveness of different techniques. A more standardized approach to evaluating zero-energy buildings could help identify best practices and promote the more widespread adoption of these techniques.

Author Contributions: Conceptualization, G.H.; Methodology, G.A.M. and G.H.; Software, G.A.M.; Validation, G.A.M.; Formal analysis, G.A.M.; Resources, G.H.; Data curation, G.A.M. and K.I.A.; Writing—review & editing, M.M. and K.I.A.; Supervision, M.M., G.H. and K.I.A.; Project administration, G.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data will be made available on request.

Conflicts of Interest: The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Abbreviations

ZEBs, Zero-Energy Buildings or Zero-Emission Buildings; solar PV, Solar Photovoltaic; IEA, The International Energy Agency; GHG, Greenhouse Gas; EPS, Energy Plus Software; IAQ, Indoor Air Quality; RES, Renewable Energy Sources; HVAC, Heating, Ventilation, Air Conditioning, and Cooling; HHD, High Heating Demand; HHD + LCD, High Heating Demand "HHD" + Low Cooling Demand "LCD"; HHD, High Heating Demand; HCD+DD, High Cooling Demand + with Dehumidification Demand; HCD, High Cooling Demand; CDD, Cooling Degree Days; HDD, Heating Degree Days; HCDD, Heating and Cooling Degree Days.

Appendix A

Table A1. Number of ZEBs in climate and different countries.

No	Building Name	Polar	Snow	Warm Temperate	Mediterranean	Arid	Total
1	Germany		2	3			5
2	China			3			3
3	UK			3			3
4	USA		2			1	3
5	Italy				2		2
6	Canada	2					2
7	Norway	2					2
8	Denmark			2			2
9	France			2	1		3
10	Japan			2			2
11	Austria		2				2
12	Finland			1			1
13	the Czech			1			1
14	Oman					1	1
15	Qatar					1	1
16	Algeria					1	1
17	Saudi A					1	1
18	Spain				1		1
19	Switzerland		1				1
20	Cyprus				1		1
21	Ireland		1				1
22	Belgium			1			1
	Total	4	8	18	5	5	40

Table A2. ZEBs projects chosen worldwide.

No	Building Name	Location	Completion Date	ZEB Type	Building Area m^2	Climate	Climate Type
1	Home for Life	Aarhus, Norway	2009	+ZEB (detached)	190	HHD	polar
2	Maison Air Lumière	Paris, France	2011	+ZEB (detached)	130	HHD	warm temperate
3	The Solar House	Freiburg, Germany	1992	ZEB(detached)	145	HHD	snow
4	The Lighthouse	Watford, UK	2007	Net ZEB (detached)	93	HHD	snow
5	Leaf House	Marche, Italy	2008	Net ZEB (detached)	477	HHD + LCD	Mediterranean
6	EcoTerra house	Quebec, Canada	2007	Net ZEB (detached)	141	HHD	polar
7	The NZERTF	Gaithersburg, USA	2012	ZEB (detached)	387	HHD + LCD	warm temperate
8	Para Eco House	Shanghai, China	2012	Net ZEB (detached)	55.8	HHD + HCD + DD	warm temperate
9	Sabic and J&P	Riyadh, Saudi Arabia	2015	Net ZEB (detached)	550	HHD + HCD + DD	arid
10	Hybrid Z	Kanagawa, Japan	1998	ZEB (detached)	228.5	HHD + HCD	warm temperate
11	Carbon Light homed	Rothwell, UK	2011	Semi-detached	200	HHD	warm temperate
12	LichtAktiv Haus	Hamburg, Germany	2010	Semi-detached	189	HHD	snow
13	Efficiency House Plus	Berlin, Germany	2010	+ZEB (detached)	203	HHD	snow
14	Riverdale House	Alberta, Canada	2007	Net ZEB (detached)	234	HHD	polar
15	EnergyFlexHouse	Taastrup, Denmark	2008	Net ZEB (detached)	216	HHD	snow
16	Riehen House	Basel-Stadt- Switzerland	2007	ZEB (detached)	315	HHD	snow
17	Lima House	Barcelona, Spain	2011	ZEB (detached)	45	HHD + LCD	Mediterranean
18	Green Lighthouse	Copenhagen N, Denmark	2009	ZEB (detached)	845	HHD	warm temperate
19	Sun Lighthouse	Pressbaum, Austria	2010	Near ZEB	945	HHD	snow
20	Solar Settlement	Schlierberg, Germany	2006	Semi-detached	7890	HHD	warm temperate
21	Plus Energy Settlement	Weiz Styria Austria	2006	Semi-detached	105	HHD	warm temperate
22	BedZED	Hack Bridge, London	2002	ZEB (detached)	75	HHD	snow
23	The Eco Houseas	Halban/Muscat, Oman	2014	+ZEB (detached)	150	HHD + HCD + DD	arid
24	The solar village	Boussaâda city, Algeria	2012	ZEB (detached)	87.75	HHD + HCD	arid
25	The Habitat Home	Denver, USA	2007	ZEB (detached)	119	HHD + HCD	warm temperate

Table A2. *Cont.*

No	Building Name	Location	Completion Date	ZEB Type	Building Area m^2	Climate	Climate Type
26	The Wind House	Charlotte, USA	2008	ZEB (detached)	260	HHD	snow
27	The Solar Decathlon	China	2009	+ZEB (detached)	94	HHD + HCD	warm temperate
28	Jiao Tong House	Shanghai, China	2013	+ZEB (detached)	90	HHD + HCD + DD	warm temperate
29	Maison HANAU	Selestat, France	2013	ZEB (detached)	178	HHD	warm temperate
30	Villa ISOVER	Hyvinkää, Finland	2013	Semi-detached	155	HHD + HCD	warm temperate
31	Single Family House	Nicosia, Cyprus	1982	Net ZEB (detached)	396.9	HHD + HCD + DD	Mediterranean
32	Zero-energy homes	Skarpnes, Norway	2015	ZEB (detached)	154	HHD	polar
33	The Okamoto Solar House	Chiryu, Japan	2003	Near ZEB	189	HHD + HCD	warm temperate
34	Demonstration houses	Černošice, the Czech	2003	Semi-detached	86	HHD	warm temperate
35	Demonstration housing	Freiburg, Germany	2003	Near ZEB	1370	HHD	warm temperate
36	The Baytna villa	Doha, Qatar	2013	+ZEB (detached)	220	HHD + HCD + DD	arid
37	Single family detached house	Catania, Italy	2003	Net ZEB (detached)	144	HHD + HCD	Mediterranean
38	Maison DOISY	Niort, French	2004	Net ZEB (detached)	158	HHD	warm temperate
39	Urban semi-detached house	Dublin, Ireland	1950	Near ZEB	160	HHD	warm temperate
40	De Duurzame house	Flanders, Belgium	2004	Net ZEB (detached)	194	HHD	Mediterranean

Table A3. Mean U-values of the climates and different buildings envelope.

No	Building Name	U Values W/m^2·K			
		Floor	Wall	Roof	Window
1	Home for Life	0.07	0.10	0.07	0.50 (Triple glazed)
2	Maison Air Lumière	0.129	0.124	0.098	1.30 (Triple glazed)
3	The Solar House	0.11	0.19	0.19	0.60 (Triple glazed)
4	The Lighthouse	0.12	0.11	0.11	0.70 (Triple glazed)
5	Leaf House	0.24	0.14	0.24	0.86 (Double glazed)
6	Eco Terra house	0.16	0.16	0.16	1.18 (Triple glazed)
7	The NZERTF	0.24	0.22	0.14	0.70 (Triple glazed)
8	Para Eco House	0.18	0.11	0.12	0.80 (Triple glazed)
9	Sabic and J&P	0.23	0.15	0.12	1.20 (Double glazed)
10	Hybrid Z	0.17	0.24	0.24	1.18 (Double glazed)
11	Carbon Light homed	0.11	0.11	0.11	1.6 (Double glazed)
12	LichtAktiv Haus	0.11	0.16	0.16	1.1 (Triple glazed)
13	Efficiency House Plus	0.11	0.11	0.11	0.70 (Triple glazed)
14	Riverdale House	0.10	0.10	0.08	0.568 (Triple glazed)
15	EnergyFlexHouse	0.105	0.08	0.09	0.75 (Triple glazed)
16	Riehen House	0.13	0.13	0.11	0.84 (Triple glazed)
17	Lima House	0.36	0.26	0.25	1.1 (Triple glazed)
18	Green Lighthouse	0.085	0.095	0.084	1.1 (Triple glazed)
19	Sunlighthouse	0.12	0.13	0.12	1.1 (Triple glazed)
20	Solar Settlement	0.16	0.12	0.12	0.48 (Triple glazed)
21	Plus Energy Settlement	0.10	0.09	0.11	0.80 (Triple glazed)
22	BedZED	0.1	0.11	0.10	1.2 (Triple glazed)
23	The Eco Houseas	0.13	0.13	0.13	0.70 (Triple glazed)
24	The solar village	0.9	0.6	1.46	2.5 (Double glazed)
25	The Habitat Home	0.13	0.25	0.17	0.80 (Triple glazed)
26	The Wind House	0.10	0.25	0.18	0.70 (Triple glazed)
27	The Solar Decathlon	0.20	0.34	0.23	1.2 (Triple glazed)
28	Jiao Tong House	0.30	0.31	0.21	2.5 (Double glazed)
29	Maison HANAU	0.112	0.16	0.108	1.28 (Double glazed)
30	Villa ISOVER	0.09	0.09	0.06	0.75 (Triple glazed)
31	Single Family House	0.40	0.40	0.40	2.25 (Double glazed)
32	Zero-energy homes	0.09	0.12	0.08	0.80 (Triple glazed)
33	The Okamoto House	0.29	0.27	0.13	1.5 (Triple glazed)
34	Demonstration houses	0,272	0,122	0,108	1.1 (Triple glazed)
35	Demonstration housing	0.18	0.13	0.11	0.90 (Triple glazed)
36	The Baytna villa	0.11	0.084	0.084	1.11 (Triple glazed)
37	Single family house	0.23	0.13	0.13	1.3 (Double glazed)
38	Maison DOISY	0.138	0.205	0.138	1.45 (Double glazed)
39	Urban semi-house	0.11	0.145	0.13	0.90 (Triple glazed)
40	De Duurzame house	0.10	0.12	0.13	0.78 (Triple glazed)
	Average	0.1666	0.16695	0.1682	1.07195
	High	0.90	0.08	0.07	0.50
	low	0.07	0.60	1.46	2.50

Table A4. Final Annual Energy Supply and Consumption in ZEBs.

No	Building Name	Final Annual Energy Supply [KWh/ m^2/Year]							Final Annual Energy Consumption [KWh/ m^2/Year]							
		Photovoltaic	Solar Collectors	Geothermal Heat Pump	Wind	Fuel/Biomass		Total	Heating	Hot Water	Cooling	Ventilation	Lighting	Appliances		Total
1	Home for Life	%46.8	%17.8	%35.4			%100	62.2	%29.2	%34.3		%4.3	%8.3	%23.9	%100	53.2
2	Maison Air Lumière	%43.8	%19.5	%36.7			%100	57	%42.8	%23.2		%7.2	%8.9	%17.9	%100	56
3	The Solar House	%64.7				%35.3	%100	24.1	%18.2	%8.8		%5.1	%6.5	%61.4	%100	17.1
4	The Lighthouse	%48.2	%25.4		%13.8	%12.6	%100	87	%23	%35	%10.8	%2.4	%4.7	%24.1	%100	83
5	Leaf House	%52	%17.2	%30.8			%100	51.7	%21	%26.5	%15.8	%8.7	%4.9	%22.9	%100	52.7
6	EcoTerra House	%39.8	%49.5	%10.7			%100	27.9	%24.5	%26.9		%6.8	%14.4	%27.4	%100	40.8
7	The NZERTF	%80.2	%10.6	%9.2			%100	34.9	%27.5	%10.9	%25	%6.2	%3.3	%27.1	%100	33.7
8	Para Eco House	%70.2	%29.8				%100	71.7	%18	%4.2	%16.5	%1.8	%13	%46.5	%100	65.3
9	Sabic and J&P	%84.8	%15.2				%100	85	%3.5	%16.5	%47	%5.1	%12.2	%15.7	%100	78.1
10	Hybrid Z	%75.5		%24.5			%100	37.1	%17	%24	%13.4		%17.2	%28.4	%100	38.9
11	Carbon Light homed		%42.2	%57.8			%100	87.2	%59.8	%17.6		%1.8	%4.6	%16.2	%100	96.30
12	LichtAktiv Haus	%34.3	%21.6	%44.1			%100	108.6	%58.2	%24.5			%2.9	%14.4	%100	108.5
13	Efficiency House Plus	%81.3	%18.7				%100	65.6	%33.8	%13.1		%7.9	%4.2	%41	%100	61.4
14	Riverdale House	%67	%22			%11	%100	36.4	%35.4	%19.2			%4.9	%40.5	%100	40.73
15	EnergyFlexHouse	%47.7	%9	%43.3			%100	66.1	%47.4	%10.4		%4.2	%4.1	%33	%100	57.6
16	Riehen House	%72	%11.7	%16.3			%100	68	%24.3	%26.4		%6.8	%9	%33.5	%100	51.4
17	Lima House	%35.7	%7.2	%57.1			%100	68.3	%6.2	%10.5	%65	%4.2	%3.8	%10.3	%100	59.9
18	Green Lighthouse	%65.1	%12.1	%22.8		gas	%100	30.7	%46	%13		%10	%15	%16	%100	30
19	Sun Lighthouse	%37.9	%11.7	%50.4		wood	%100	63	%47	%19		%4.9	%9.8	%19.3	%100	50.8
20	Solar Settlement	%48.7		%23		%28.3	%100	113	%24.3	%13		%5.8	%7.2	%49.7	%100	70.65
21	Plus Energy Settlement	%72.9	%13.9	%13.2			%100	61	%20	%11		%2.4	%4.2	%62.4	%100	51

Table A4. *Cont.*

No	Building Name	Final Annual Energy Supply [KWh/ m^2/Year]							Final Annual Energy Consumption [KWh/ m^2/Year]							
		Photovoltaic	Solar Collectors	Geothermal Heat Pump	Wind	Fuel/Biomass		Total	Heating	Hot Water	Cooling	Ventilation	Lighting	Appliances		Total
22	BedZED	%41.5	%8			%49.5	%100	107	%41.4	%17		%8.2	%6.4	%27	%100	82
23	The Eco Houseas	%87.5	%12.5				%100	120		%15.3	%47.5	%10	%4.8	%22.4	%100	71.7
24	The solar village	%94	%6				%100	77.5	%5.3	%4.1	%60	%3.1	%4.3	%23.2	%100	76.9
25	The Habitat Home	%40	%9	%23.6		%27.4	%100	110	%24	%12	%5.5	%3.8	%8.7	%46	%100	109
26	The Wind House				%100		%100	25.5	%30	%17			%10	%43	%100	23.18
27	The Solar Decathlon	%91.6	%8.4				%100	150	%36	%4.2	%26.3	%3.6	%3.5	%26.4	%100	120
28	Jiao Tong House	%37	%10			%53	%100	98	%38.1	%6.2	%19.2	%3	%19.1	%14.4	%100	86.9
29	Maison HANAU	%47.3	%8.2			%44.5	%100	86.45	%46.3	%16.3		%2.5	%2.8	%32.1	%100	61.26
30	Villa ISOVER	%41.9	%10.3	%47.8			%100	55	%38.2	%9	%0.5	%9.2	%9.3	%33.8	%100	45.3
31	Single Family House	%84.6	%15.4				%100	34.24	%5	%28	%26		%13.6	%27.4	%100	29.4
32	Zero-energy homes	%36.2	%6.2	%9.4		%48.2	%100	85	%20	%45		%6.5	%14	%14.5	%100	80
33	The Okamoto House	%67.2	%16.8			%16	%100	67.6	%17	%13	%15.2	%3.1	%5.7	%46	%100	70.9
34	Demonstration houses		%45.3			%54.7	%100	53	%24	%49			%9	%18	%100	50.2
35	Demonstration housing	%32.6	%21.9	%20.2		%25.3	%100	59.4	%23	%21		%9	%8.2	%38.8	%100	59.4
36	The Baytna villa	%89	%11				%100	127		%14.5	%51		%14	%20.5	%100	89.1
37	Single family house	%62	%9.2			%28.8	%100	73	%14.3	%16.9	%18.5	%9.2	%10.2	%30.9	%100	48.8
38	Maison DOISY			%17.6		%82.4	%100	36.80	%53	%24		%2	%4	%17	%100	38.80
39	Urban semi-house			%46.5		%53.5	%100	47.1	%29	%33		%7	%11	%20	%100	37.4
40	De Duurzame house	%38.3		%8.7		%53	%100	57.5	%15	%41			%13	%31	%100	53.5
		%51.5	%13.8	%16.3	%2.8	%15.6	%100		27.2%	19.4%	11.6%	4.4%	8.4%	29.1%	%100	

Table A5. Final Annual Energy Supply and Consumption in ZEBs.

No	Building Name	Final Annual Energy Supply [KWh/ m^2/Year]						Final Annual Energy Consumption [KWh/ m^2/Year]						
		Photovoltaic	**Solar Collectors**	**Geothermal Heat Pump**	**Wind**	**Fuel/Biomass**		**Heating**	**Hot Water**	**Cooling**	**Ventilation**	**Lighting**	**Appliances**	
1	Home for Life	29.1	11.1	22			62.2	15	18.3		2.3	4.4	13.2	53.2
2	Maison Air Lumière	25	11.1	20.9			57	24	13		4	5	10	56
3	The Solar House	15.6				8.5	24.1	2.1	1.5		0.7	0.6	12.2	17.1
4	The Lighthouse	42	22		12	11	87	19	29	9	2	4	20	83
5	Leaf House	26.9	8.9	15.9			51.7	11.1	14	5.7	4.6	5.2	12.1	52.7
6	EcoTerra house	11.1	13.8	3			27.9	10	11		2.8	5.9	11.1	40.8
7	The NZERTF	28	3.7	3.2			34.9	9.3	3.7	8.4	2.1	1.1	9.1	33.7
8	Para Eco House	50.3	21.4				71.7	11.8	2.8	10.8	0.7	8.5	30.7	65.3
9	Sabic and J&P	72.1	12.9				85	2.7	12.9	36.7	4	9.5	12.3	78.1
10	Hybrid Z	28		**9.1**			37.1	7	9.2	5.2		6.7	10.8	38.9
11	Carbon Light homed		36.8	50.4			87.2	57.6	17		1.8	4.4	15.5	96.30
12	LichtAktiv Haus	37.3	23.5	47.8			108.6	63.2	26.5			2.9	15.9	108.5
13	Efficiency House Plus	65.6					65.6	20.8	8.1		4.9	2.6	25	61.4
14	Riverdale House	24.4	8			4	36.4	14.43	7.74			2.02	16.54	40.73
15	EnergyFlexHouse	31.5	6	28.6			66.1	27.3	6		2.2	2.1	19	57.6
16	Riehen House	49	8	11			68	12.5	13.6		4.5	3.8	17	51.4
17	Lima House	24.4	4.9	39			68.3	2.8	4.9	39.5	2.5	2.2	8	59.9
18	Green Lighthouse	20	3.7	7		gas	30.7	14	4		3	5	5	30
19	Sunlighthouse	23.9	7.4	31.7		wood	63	24	10		2.5	5.1	9.2	50.8
20	Solar Settlement	55		26		32	113	17.2	9.2		4.1	5.1	35.05	70.65
21	Plus Energy Settlement	53		8			61	15	9		2.4	4.2	20.4	51

Table A5. *Cont.*

No	Building Name	Final Annual Energy Supply [KWh/ m^2/Year]						Final Annual Energy Consumption [KWh/ m^2/Year]						
		Photovoltaic	Solar Collectors	Geothermal Heat Pump	Wind	Fuel/Biomass		Heating	Hot Water	Cooling	Ventilation	Lighting	Appliances	
22	BedZED	54				53	107	34	14		6.8	5.2	22	82
23	The Eco Houseas	105	15				120		11	34	7.2	3.5	16	71.7
24	The solar village	72	5.5				77.5	4.1	3.2	46.9	2.4	3.3	17	76.9
25	The Habitat Home	44	9.8	26		30.2	110	25	13	7.5	3.8	8.7	51	109
26	The Wind House				25.5		25.5	7.17	3.31			2.5	10.2	23.18
27	The Solar Decathlon	137.5	12.5				150	43.5	5.2	32.2	4.6	4.5	30	120
28	Jiao Tong House	36.2	9.8			52	98	33.7	5.2	16.8	2	16.5	12.7	86.9
29	Maison HANAU	40.85	7.20			38.40	86.45	28.40	10.00		1.55	1.45	19.86	61.26
30	Villa ISOVER	23	5.7	26.3			55	17.3	4.6	0.2	4.8	4.2	14.2	45.3
31	Single Family House	29	5.24				34.24	1.47	8.24	7.69		4	8	29.4
32	Zero-energy homes	30.8	5.2	8		41	85	16	36		5	11	12	80
33	The Okamoto House	45.4	22.2				67.6	12.1	8.9	10.8	2.2	4.5	32.4	70.9
34	Demonstration houses		24			21.8	53	12	29			4.2	5	50.2
35	Demonstration housing	19.4	13	12		15	59.4	13.2	12.5		5	4.8	23.9	59.4
36	The Baytna villa	127					127		12.9	45		12.5	18.7	89.1
37	Single family house	52				21	73	7.3	8.9	9.5	4.2	5.2	13.7	48.8
38	Maison DOISY			6.50		30.30	36.80	20.80	9.50		0.65	1.70	6.15	38.80
39	Urban semi-house			21.9		25.2	47.1	10.7	12.2		2.5	4.5	7.5	37.4
40	De Duurzame house	22		5		30.5	57.5	8.5	22			7	18	53.5

References

1. Kolokotsa, D.; Rovas, D.; Kosmatopoulos, E.; Kalaitzakis, K. A roadmap towards intelligent net zero- and positive-energy buildings. *Sol. Energy* **2011**, *85*, 3067–3084. [CrossRef]
2. Kamal-chaoui, L.; Robert, A. *Competitive Cities and Climate Change*; OECD publishing: Paris, France, 2009; 172p. Available online: http://www.forum15.org.il/art_images/files/103/COMPETITIVE-CITIES-CLIMATE-CHANGE.pdf (accessed on 28 March 2023).
3. Mabrouk, M.; Haoying, H. Urban resilience assessment: A multicriteria approach for identifying urban flood-exposed risky districts using multiple-criteria decision-making tools (MCDM). *Int. J. Disaster Risk Reduct.* **2023**, *91*, 103684. [CrossRef]
4. Tokazhanov, G.; Tleuken, A.; Durdyev, S.; Otesh, N.; Guney, M.; Turkyilmaz, A.; Karaca, F. Stakeholder based weights of new sustainability indicators providing pandemic resilience for residential buildings. *Sustain. Cities Soc.* **2021**, *75*, 103300. [CrossRef]
5. Wallemacq, P.; Guha-Sapir, D.; Mcclean, D.; Centre for Research on the Epidemiology of Disaste (CRED); The UN Office for Disaster Risk Reduction (UNISDR). *The Human Cost of Weather Related Disasters: 1995–2015*; CRED: Brussels, Belgium; UNISDR: Cairo, Egypt, 2015. [CrossRef]
6. Lin, J.; He, X.; Lu, S.; Liu, D.; He, P. Investigating the influence of three-dimensional building configuration on urban pluvial flooding using random forest algorithm. *Environ. Res.* **2021**, *196*, 110438. [CrossRef] [PubMed]
7. 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]
8. Santamouris, M.; Vasilakopoulou, K. Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. *e-Prime Adv. Electr. Eng. Electron. Energy* **2021**, *1*, 100002. [CrossRef]
9. Röck, M.; Saade, M.R.M.; Balouktsi, M.; Rasmussen, F.N.; Birgisdottir, H.; Frischknecht, R.; Habert, G.; Lützkendorf, T.; Passer, A. Embodied GHG emissions of buildings—The hidden challenge for effective climate change mitigation. *Appl. Energy* **2020**, *258*, 114107. [CrossRef]
10. Iyer-Raniga, U. Zero energy in the built environment: A holistic understanding. *Appl. Sci.* **2019**, *9*, 3375. [CrossRef]
11. Moghaddasi, H.; Culp, C.; Vanegas, J.; Ehsani, M. Net zero energy buildings: Variations, clarifications, and requirements in response to the paris agreement. *Energies* **2021**, *14*, 3760. [CrossRef]
12. Hafez, F.S.; Sa'di, B.; Safa-Gamal, M.; Taufiq-Yap, Y.H.; Alrifaey, M.; Seyedmahmoudian, M.; Stojcevski, A.; Horan, B.; Mekhilef, S. Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. *Energy Strateg. Rev.* **2023**, *45*, 101013. [CrossRef]
13. GlobalABC; IEA; UNEP. *GlobalABC Roadmap for Buildings and Construction 2020–2050*; IEA: Paris, France, 2020; 110p. Available online: http://globalabc.org/our-work/forging-regional-pathways-global-and-regional-roadmap (accessed on 28 March 2023).
14. Review, A.I. Zero Energy Building Definitions and Policy Activity. 2018. p. 40. Available online: https://www.buildup.eu/sites/default/files/content/766.pdf (accessed on 28 March 2023).
15. APEC Energy Working Group. *APEC nZEB Roadmap*; APEC Energy Working Group: Singapore, 2018.
16. International Energy Agency. Net Zero by 2050: A Roadmap for the Global Energy Sector. *Int. Energy Agency* **2021**. 224p. Available online: https://www.iea.org/reports/net-zero-by-2050 (accessed on 28 March 2023).
17. Taleb, H.M. Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings. *Front. Archit. Res.* **2014**, *3*, 154–165. [CrossRef]
18. Bistline, J.E.T.; Blanford, G.J. The role of the power sector in net-zero energy systems. *Energy Clim. Chang.* **2021**, *2*, 100045. [CrossRef]
19. Iyer, G.; Clarke, L.; Edmonds, J.; Fawcett, A.; Fuhrman, J.; McJeon, H.; Waldhoff, S. The role of carbon dioxide removal in net-zero emissions pledges. *Energy Clim. Chang.* **2021**, *2*, 100043. [CrossRef]
20. Jin, H.; Liu, S.; Kang, J. Thermal comfort range and influence factor of urban pedestrian streets in severe cold regions. *Energy Build.* **2019**, *198*, 197–206. [CrossRef]
21. Subhashini, S.; Thirumaran, K. A passive design solution to enhance thermal comfort in an educational building in the warm humid climatic zone of Madurai. *J. Build. Eng.* **2018**, *18*, 395–407. [CrossRef]
22. Al-Obaidi, K.M.; Ismail, M.; Abdul Rahman, A.M. A study of the impact of environmental loads that penetrate a passive skylight roofing system in Malaysian buildings. *Front. Archit. Res.* **2014**, *3*, 178–191. [CrossRef]
23. Manioğlu, G.; Koçlar Oral, G. Effect of courtyard shape factor on heating and cooling energy loads in hot-dry climatic zone. *Energy Procedia* **2015**, *78*, 2100–2105. [CrossRef]
24. Imessad, K.; Derradji, L.; Messaoudene, N.A.; Mokhtari, F.; Chenak, A.; Kharchi, R. Impact of passive cooling techniques on energy demand for residential buildings in a Mediterranean climate. *Renew. Energy* **2014**, *71*, 589–597. [CrossRef]
25. Torcellini, P.; Pless, S.; Deru, M.; Griffith, B.; Long, N.; Judkoff, R. *Lessons Learned from Case Studies of Six High-Performance Buildings*; National Renewable Energy Lab. (NREL): Golden, CO, USA, 2006.
26. Hu, M. Does zero energy building cost more?—An empirical comparison of the construction costs for zero energy education building in United States. *Sustain. Cities Soc.* **2019**, *45*, 324–334. [CrossRef]
27. 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]
28. Perlaviciute, G.; Steg, L.; Sovacool, B.K. A perspective on the human dimensions of a transition to net-zero energy systems. *Energy Clim. Chang.* **2021**, *2*, 100042. [CrossRef]

29. Baker, E.; Goldstein, A.P.; Azevedo, I.M. A perspective on equity implications of net zero energy systems. *Energy Clim. Chang.* **2021**, *2*, 100047. [CrossRef]
30. Chastas, P.; Theodosiou, T.; Bikas, D. Embodied energy in residential buildings-towards the nearly zero energy building: A literature review. *Build. Environ.* **2016**, *105*, 267–282. [CrossRef]
31. 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]
32. Kneifel, J.; Webb, D. Predicting energy performance of a net-zero energy building: A statistical approach. *Appl. Energy* **2016**, *178*, 468–483. [CrossRef]
33. Chaturvedi, V. A vision for a net-zero energy system for India. *Energy Clim. Chang.* **2021**, *2*, 100056. [CrossRef]
34. van Sluisveld, M.A.E.; de Boer, H.S.; Daioglou, V.; Hof, A.F.; van Vuuren, D.P. A race to zero—Assessing the position of heavy industry in a global net-zero CO_2 emissions context. *Energy Clim. Chang.* **2021**, *2*, 100051. [CrossRef]
35. Sun, Y. Sensitivity analysis of macro-parameters in the system design of net zero energy building. *Energy Build.* **2015**, *86*, 464–477. [CrossRef]
36. Lu, Y.; Wang, S.; Shan, K. Design optimization and optimal control of grid-connected and standalone nearly/net zero energy buildings. *Appl. Energy* **2015**, *155*, 463–477. [CrossRef]
37. Azevedo, I.; Bataille, C.; Bistline, J.; Clarke, L.; Davis, S. Net-zero emissions energy systems: What we know and do not know. *Energy Clim. Chang.* **2021**, *2*, 100049. [CrossRef]
38. Williams, J.H.; Jones, R.A.; Torn, M.S. Observations on the transition to a net-zero energy system in the United States. *Energy Clim. Chang.* **2021**, *2*, 100050. [CrossRef]
39. Panagiotidou, M.; Fuller, R.J. Progress in ZEBs—A review of definitions, policies and construction activity. *Energy Policy* **2013**, *62*, 196–206. [CrossRef]
40. The, M.; Challenge, E. *Meeting the Energy Challenge—A White Paper on Energy*; HM Government: London, UK, 2007.
41. Lien, A.G.; Slagstad, H.; Frosthammer, L.; Andresen, I.; Dokka, T.H.; Hestnes, A.G. 1st Nordic passive house conference Passivhus Norden 2008. pp. 1–344. Available online: https://vbn.aau.dk/ws/portalfiles/portal/16144435/Passivhus_Norden_2008_conference_proceedings.pdf (accessed on 28 March 2023).
42. DCLG. *Zero Carbon for New Non-Domestic Buildings: Consultation on Policy Options*; HM Government: London, UK, 2009; ISBN 9781409820376.
43. Goseberg, N. Reduction of maximum tsunami run-up due to the interaction with beachfront development—Application of single sinusoidal waves. *Nat. Hazards Earth Syst. Sci.* **2013**, *13*, 2991–3010. [CrossRef]
44. Khazaii, J. Buildings of the future. *ASHRAE J.* **2014**, *56*, 68–70. [CrossRef]
45. European Commission. In Focus: Energy Efficiency in Buildings, Today's Challenges in Buildings, 17 February 2020. Available online: https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en (accessed on 28 March 2023).
46. OECD. Nature-based solutions for adapting to water-related climate risks. *OECD Environment Policy Papers*. 29 July 2020, p. 32. Available online: https://www.oecd-ilibrary.org/environment/nature-based-solutions-for-adapting-to-water-related-climate-risks_2257873d-en (accessed on 28 March 2023).
47. Alrashed, F.; Asif, M. Challenges facing the application of zero-energy homes in Saudi Arabia: Construction industry and user perspective. In Proceedings of the ZEMCH 2012 International Conference, Glasgow, UK, 20–22 August 2012; pp. 391–398.
48. Noguchi, M. Japanese Manufacturers' cost-Performance Marketing Strategy for the Delivery of Solar Photovoltaic Homes, Proceedings ISES 2005, Solar World Congress, 6–12 August 2005, Orlando, USA. Available online: https://www.osti.gov/etdeweb/biblio/20638356 (accessed on 28 March 2023).
49. Water Directors of the European Union. Best Practices on Flood Prevention, Protection. *Ec. Europa. Eu* **2003**, 1–29. Available online: http://ec.europa.eu/environment/water/flood_risk/pdf/flooding_bestpractice.pdf (accessed on 28 March 2023).
50. Hebling, C. The Role of Hydrogen in a Renewable Energy Economy. 2013. Available online: https://www.sintef.no/globalassets/project/novel/pdf/0-1_fraunhoferise_hebling_public.pdf (accessed on 28 March 2023).
51. Name, Y. Monitoring and Evaluating the Performance of a Net-Zero-Energy Building in Oman—A Case Study of the GUtech ECOHAUS. In Proceedings of the PLEA 2016 Los Angeles—Cities, Bulidings, People: Towards Regenreative Environments, Los Angeles, CA, USA, 11–13 July 2016.
52. Fraunhofer, I.B.P. *What Makes an Efficiency House Plus?* Bundesministerium für Umwelt, Naturschutz, Bau und Reakt: Bonn, Germany, 2018; Volume 6, p. 59. Available online: http://www.bmi.bund.de/SharedDocs/downloads/EN/publikationen/building/efficiency-houses-plus.pdf?__blob=publicationFile&v=6 (accessed on 28 March 2023).
53. Deng, S.; Dai, Y.; Wang, R. Case Study of Net Zero Energy Apartment. In Proceedings of the 2th International High Performance Buildings Conference, West Lafayette, IN, USA, 16–19 July 2012.
54. Serghides, D.K.; Dimitriou, S.; Katafygiotou, M.C.; Michaelidou, M. Energy efficient refurbishment towards nearly zero energy houses, for the mediterranean region. *Energy Procedia* **2015**, *83*, 533–543. [CrossRef]
55. de Melo, J.; Ugarte, C. *The Arab Republic of Egypt Competitiveness Report 2010 Update*; African Development Bank: Abidjan, Cote d'Ivoire, 2012.
56. Khalfan, M.; Sharples, S. Thermal Comfort Analysis for the First Passivhaus Project in Qatar. In Proceedings of the SBE16 Dubai, Dubai, United Arab Emirates, 17–19 January 2016. Available online: https://www.researchgate.net/publication/266328925_Daylighting_Driven_Design_Optimizing_Kaleidocycle_faade_for_hot_arid_climate (accessed on 28 March 2023).

57. Springs, S.; Laustsen, J.; Adviser, E.P. Examples on Passive and Zero Energy Buildings Strategies in Europe. 2011. 28–29. Available online: https://www.gbpn.org/report-webinar-2-the-role-of-energy-saving-targets-and-regulatory-measures-in-renovation-policy-packages-key-lessons-from-global-best-practices/ (accessed on 28 March 2023).
58. Azevedo, I.; Bataille, C.; Bistline, J.; Clarke, L.; Davis, S. Introduction to the special issue on Net-Zero Energy Systems. *Energy Clim. Chang.* **2021**, *2*, 100066. [CrossRef]
59. Bataille, C.; Nilsson, L.J.; Jotzo, F. Industry in a net-zero emissions world: New mitigation pathways, new supply chains, modelling needs and policy implications. *Energy Clim. Chang.* **2021**, *2*, 100059. [CrossRef]
60. Grubert, E. Beyond carbon in socioenvironmental assessment: Life cycle assessment as a decision support tool for net-zero energy systems. *Energy Clim. Chang.* **2021**, *2*, 100061. [CrossRef]