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10 QUESTIONS ABOUT ZERO ENERGY BUILDINGS: A STATE-OF-THE-ART REVIEW

10 PREGUNTAS DE LOS EDIFICIOS ENERGÍA CERO: REVISIÓN DEL ESTADO DEL ARTE

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RESUMEN

Los Edificios Energía Cero o ZEB (*Zero Energy Buildings*) promueven una mirada integral de la arquitectura sustentable y un cambio profundo en la manera de construir. La investigación y el desarrollo en transición energética deben necesariamente enfrentarse a problemas tecnológicos y socioeconómicos. En esa línea, la meta aquí es ofrecer una respuesta para minimizar el impacto energético y ambiental del sector edilicio. Se realizó, para ello, una revisión del estado del arte de la temática, donde se seleccionaron 97 artículos científicos considerados de mayor relevancia, en el período de 2006 a 2020. La metodología consistió en un análisis de esos textos a partir de diez preguntas formuladas para abordar la temática: sus orígenes, estado actual y proyecciones futuras en relación a la eficiencia energética y la sustentabilidad. Las preguntas hacen referencia a definiciones (P1), sustentabilidad (P2), tecnologías involucradas (P3), emisiones (P5), energía (P4) (P6) (P7), normativas (P8), cambio climático (P9) y proyecciones futuras (P10). El trabajo permite concluir que los ZEB se integran de manera holística en la transformación hacia un futuro renovable y sustentable en materia de soluciones energéticas y, a su vez, tienen potencialidad para ser implementados en diferentes posiciones geográficas y climáticas.

Palabras clave
edificios, ZEB, sustentabilidad, eficiencia energética

ABSTRACT

Zero Energy Buildings (ZEB) promote a comprehensive view of sustainable architecture and a profound change in the way to build. Research and development in energy transition must necessarily face technological and socio-economic issues. In that line, the goal here is to offer a response to minimize the building sector's energy and environmental impact. To this end, a review of the state of the art of the subject was carried out, where 97 scientific articles from a period comprising 2006 to 2020, considered the most pertinent, were selected. The methodology consisted of analyzing these texts based on ten questions formulated to address the subject: their origins, current status and future projections regarding energy efficiency and sustainability. The questions refer to definitions (Q1), sustainability (Q2), technologies involved (Q3), emissions (Q5), energy (Q4) (Q6) (Q7), regulations (Q8), climate change (Q9), and future projections (Q10). The work allows concluding that ZEB are integrated in a holistic way in the transformation towards a renewable and sustainable future in terms of energy solutions and, in turn, they have the potential to be implemented in different geographical and climatic positions.

Keywords
buildings, ZEB, sustainability, energy efficiency

INTRODUCTION

The International Panel for Climate Change or IPCC, together with the International Energy Agency or IEA, state that buildings consume 40% of international end energy and produce 33% of greenhouse gas emissions, directly or indirectly (IEA, 2008; IPCC, 2018). Likewise, it has been estimated that between 1971 and 2004, carbon emissions have increased around 2.5% per year in commercial buildings and 1.7% per year in residential buildings; a trend that continues until today (Ürge-Vorsatz, Harvey, Mirasgedis & Levine, 2007; Lausten, 2008; Zhiqiang, Zhai & Helman, 2019).

Over the last decade, Zero Energy Buildings or ZEB, also known as positive energy buildings, low energy buildings or ecological buildings, appeared, with the intention of promoting a comprehensive view of sustainable architecture and a profound change in the way to build (Marszal & Heiselberg, 2015).

The European Union in 2010, established that:

> All EU member states must ensure that by 31st December, 2020, that all new buildings are nearly Zero Energy Buildings (nZEB); and after 31st December, 2018, all new buildings occupied and owned by public authorities are nearly Zero Energy Buildings (European Commission, 2010, Art. 9 p. L 153/21)

Currently, the goal continues being reaching the global target set by the IPCC, which consists of limiting global warming to 1.5°C compared to preindustrial levels (IPCC, 2018; Kylili & Fokaides, 2015).

ZEBs promise to be an essential tool to achieve the decarbonation of the building sector (Kosai & Tan, 2017; Xing, Hanaoka, Kanamori & Masui, 2018). Their operation is based on that, through high building energy efficiency, with the use of energy production technologies with renewable sources, this is capable of equaling or, even, exceeding the consumption the building requires in an annual period (Berardi, 2018; Lung, Alberg, Connolly & Vad, 2017). This differentiates them from other buildings conceived in the framework of sustainability, as they respond to the neutral energy balance between generation and demand, limiting primary energy use (Sartori, Napolitano & Voss, 2012).

The following stand out among the most important variables to understand a ZEB: the measurement unit; the period and all types of energy included in the energy balance, along with renewable energy supply options; the connection with energy efficiency and energy efficiency infrastructure; indoor environment; and building-grid interaction (Marszal *et al.*, 2011).

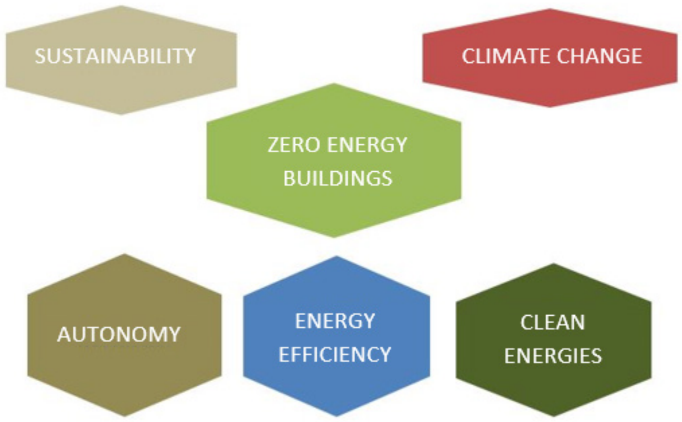


Figure 1. Topics chosen to formulate the 10 questions about ZEBs.
Source: Preparation by the authors.

The goal of minimizing the building's environmental impact and carbon footprint during its life cycle demonstrates that it is important to comprehensively evaluate the building's design, since RE generation technologies also generate impacts, associated in part to their manufacturing and then, to their operation (Vares, Häkkinen, Ketomäki, Shemeikka & Jung, 2019).

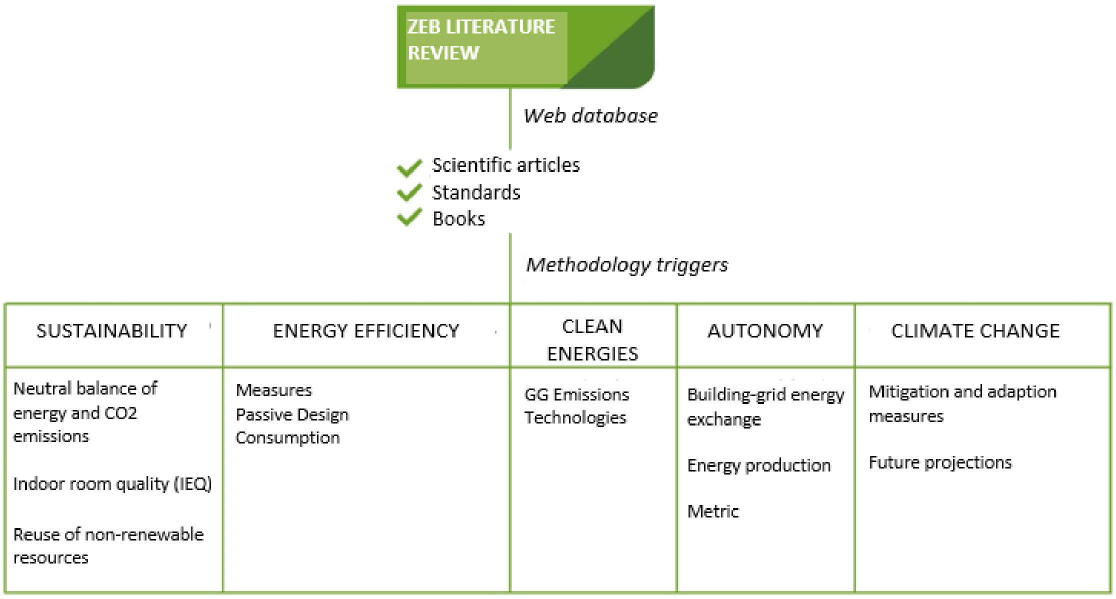
As a forecast, they are presented as a growing reality towards the mitigation of emissions generated by the building sector, being key in the formation of smart cities.

The objective of this study was to make a revision of the state-of-the-art on the topic, organized starting from a format of 10 questions which were the result of 5 issues behind the literature selection: sustainability, energy efficiency, clean energies, autonomy and climate change. Starting from the answers extracted from this analytical review, we hope to make a contribution to the scientific and academic world in the debate about ZEBs.

METHODOLOGY

A revision of the specialized scientific literature published between 2006 and the present day was made, as this is the year where the issue addressed as the focus of different research appears. Two search engines were used for this: Science Direct and Google Academic. The search strategy consisted of using keywords related to the study: nZEB, ZEB, NZEB, Zero Energy Buildings, nearly zero energy buildings. In this way, more than 200 hits were obtained from the scientific and academic area, while, the references of the articles found, were also considered.

The analysis of the literature demonstrated the relationship of the topic with the following concepts: sustainability, energy efficiency, clean energies, autonomy and climate change. These guided the work



SUSTAINABILITY	ENERGY EFFICIENCY	CLEAN ENERGIES	AUTONOMY	CLIMATE CHANGE
Neutral balance of energy and CO2 emissions Indoor room quality (IEQ) Reuse of non-renewable resources	Measures Passive Design Consumption	GG Emissions Technologies	Building-grid energy exchange Energy production Metric	Mitigation and adaption measures Future projections

Figure 2. Study of the conceptual framework. Source: Preparation by the authors.

and, from there, created the respective conceptual framework (Figure 2). Based on these concepts, identified as intrinsic reference of the origin of the study's topic, the field of study was limited to 75 academic articles, books and book chapters. The focus of this review was answering 10 key questions, fundamental when beginning the study of Zero Energy Buildings. As a result, the literature was classified by the question it would answer (Table 1 – Appendix) and with its source: journal article, book chapter, conference article or entity document (Figure 3).

The questions (Q) were organized starting from particular topics related to ZEB to, later address more global issues such as climate change. They were organized in the following way: Q1: concept and definitions; Q2: sustainability; Q3: technologies involved in the design; Q4: building-grid relationship; Q5: greenhouse gas emissions; Q6: impact on the energy matrix; Q7: consumption of the building sector; Q8: assessment methodologies; Q9: impact on climate change; and Q10: forecasting. In this way, the conceptual framework of 10 questions for the proposed analysis appears as follows.

RESULTS AND DISCUSSION

WHAT IS UNDERSTOOD BY ZERO ENERGY BUILDINGS (ZEBS)?

There are different interpretations or guidelines about what ZEBs are, which depend on the climatic, economic or political conditions of the country that describes them, but that share a common objective: reducing or neutralizing the environmental impact of buildings (Attia, 2018).

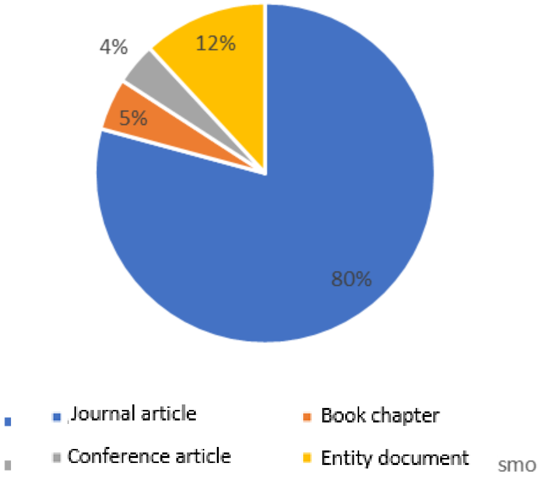


Figure 3. Origin of the sources reviewed. Source: Preparation by the authors.

The literature shows three main names: Zero Energy Buildings (ZEB), Net Zero Energy Buildings (NZEB) and nearly Zero Energy Buildings (nZEB) (D'Amanzo, Mercado & Ganem Karlen, 2019).

The nomenclature ZEB refers to a broad notion: highly technological buildings with a very low or zero energy consumption from the external distribution grid. The energy needed for their operation comes from renewable sources, in some cases exclusively, since autonomous buildings are included within this typology (Marszal & Heiselberg, 2015). They have a large proportion of this internal energy distributed, for its use in electrical appliances, heating and cooling (Carlucci, Causone, Pagliano & Pietrobon, 2017). On occasions where excess energy is produced, this can be returned to the external distribution grid or stored in batteries, in the case of autonomous buildings.

NZEB have the same characteristics as ZEB, very low energy demand and higher onsite renewable energy production (Brambilla, Salvalai, Imperadoir & Sesana, 2018). They have connection to an energy infrastructure and are characterized by their neutral energy balance, measured in a given period, normally one year, using kWh/m^2/year as a numerical indicator (Booth, Barnett, Burman, Hambrick & Westby, 2010).

nZEB also have a high performance in respect to energy efficiency, since the annual primary energy consumption is very significantly covered by energy from renewable sources, either produced onsite or nearby. The primary energy value varies from 20 kWh/m^2/year to 180 kWh/m^2/year in residential buildings (Piderit, Vivanco, Van Moeseke & Attia, 2019). It is worth mentioning that this is the most named and mentioned denomination in the literature consulted (D'Agostino, 2016; Marszal & Heiselberg, 2015, Sartori *et al.*, 2012).

The first research on the topic emerged in the United States, in the Department of Energy (DOE), where ZEBs were defined as "buildings where you obtain enough renewable energy onsite to equal or exceed the annual energy consumption" (Crawley, Pless & Torcellini, 2009; Deru, Griffith & Torcellini, 2006). Initially, it was suggested to foster building energy efficiency through residential ZEB by 2020, and through commercial ZEB by 2025.

Meanwhile, Torcellini, Pless & Deru (2006) suggest four conceptualizations that are considered in different research projects (Congedo, Baglivo, Zacà & D'Agostino, 2015; Good, Andresen & Hestnes, 2015; Harkouss, Fardoun & Biwole, 2019; Moschetti, Brattebø & Sparrevik, 2019):

- Net zero site energy: "Building that produces the energy needed for its annual operation onsite or on the land where it is located" (Torcellini *et al.*, (2006, p.5);
- Net zero source energy: "Building that produces the energy needed for its annual operation through renewable energies, minimizing the use of external primary energy" Torcellini *et al.*, (2006, p.5);
- Net zero energy costs: "Building where energy costs for annual consumption are zero, due to the energy surplus exchange with the distribution company" Torcellini *et al.*, (2006, p.5);
- Net zero energy emissions: "Building that produces as much emission free renewable energy as it uses from energy sources that produce emissions" Torcellini *et al.*, (2006, p.5);

Figure 4. Design principles of an EEC. Source: Preparation by the authors, based on Attia (2018).

Alongside this, Kilkis (2007) highlights that it is necessary to count incorporated energy (exergy) in each stage of the building's life cycle, to establish a complete energy balance between generation and demand. Thus, he develops a new conceptual expression: Net Zero Exergy Building (ZEXB). These are buildings that have a zero total annual energy transfer, whereby the calculation counts all energy transfers that take place during a given period. Years later, Hernandez and Kenny (2010) will present a similar proposal through the term "Life Cycle Zero Energy Building" (LC-ZEB).

Directive 2010/31/EU of the European Parliament and Council of the European Union define nZEB as those in which a "nearly zero or very small amount of energy required must be covered by a significant amount of energy from renewable sources, produced onsite or nearby" (European Commission, 2010); freeing each member country to assess the amount of energy for consumption in cooling, heating, sanitary hot water and equipment, measured in kWh/m^2/year.

Meanwhile, in Nordic countries, the literature presents concepts that look to holistically integrate aspects of sustainability, like the "Energy trias" (Mlecnik, 2012). Figure 4 defines ZEB through a conjunction of variables, EE with energy conservation measures, indoor environment quality (IEQ), the reduction of CO2 emissions caused by the building and the generation of renewable energies

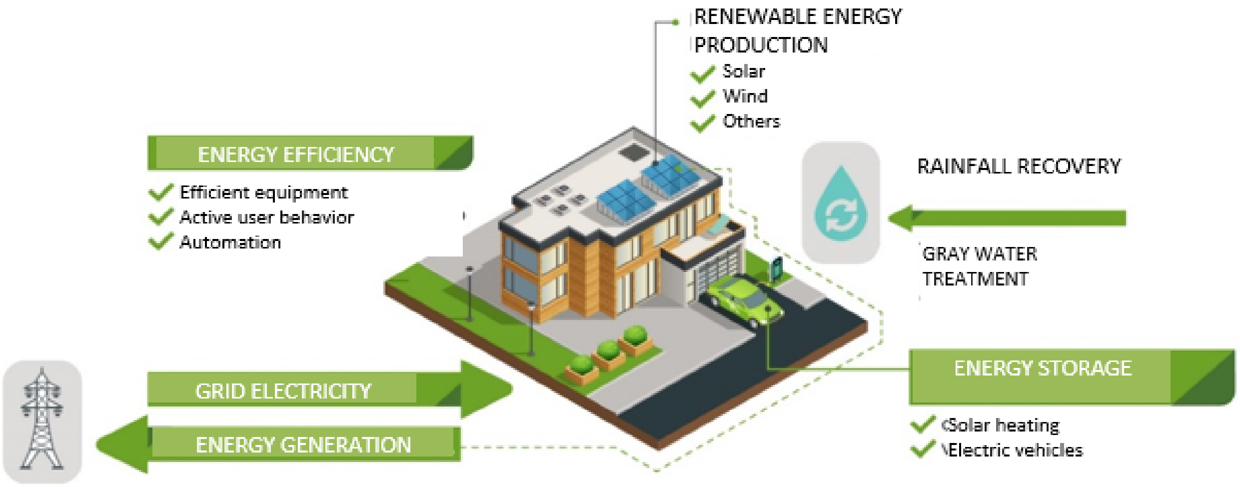


Figure 5. Integrated water and energy optimized consumption model. Source: Preparation by the authors, using Javanmard et al., 2020

(RES). According to Attia (2018), the union of these variables could determine architectonic design principles adaptable to the interests of investors.

ZEB, starting from the concepts presented, are conceived as buildings that seek energy self-supply on an annual basis and the comprehensive reduction of the environmental impact throughout their entire life cycle. Said objective could only be achieved through the incorporation of better RE technology. For this reason, nZEB are considered the first step in sites where the technology necessary for this has still not been installed. The different interpretations of the aforementioned authors establish guidelines for new research on the matter.

WHAT MAKES ZEB DIFFERENT FROM OTHER BUILDINGS CONCEIVED IN SUSTAINABILITY?

Sustainable design in architecture is a creation process where sustainable development criteria are established, such as: reduction of expenses in the natural resources used; reduction of soil, air and water contamination; improvement of comfort and quality inside the building; economic and financial savings in construction projects; and reduction of waste generated in the construction process, maintenance and end of the building's life cycle, as well as in the manufacturing of construction materials and equipment for buildings (Hernández-Moreno, 2008).

ZEB are buildings conceived from a sustainable perspective that, in addition, seek to achieve a neutral energy balance between generation and demand on an annual basis, reduce water consumption and waste, and with this, reduce the building's carbon footprint throughout its life cycle (Mertz, Raffio & Kissock, 2007; Lausten, 2008; Ibn-Mohammed, 2017; Chastas, Theodosiou, Kontoleon & Bikas, 2018; Attia, 2018).

Energy consumption is linked to comfort standards, considering sustainability in the determination of the indoor climate of buildings and preferring, as a result, available low energy solutions (Nicol & Humphreys, 2002). This statement is clear in the ZEB, where indoor thermal and visual comfort is sought, by means of energy free resources, like solar gains and natural ventilation (Kalbasi, Ruhani & Rostami, 2019; Wei, Wargocki, Zirngibl, Bendžalová & Mandin, 2020).

Several studies also present them as a solution for water consumption and the waste produced around the world by the building sector, -14% and -60% respectively, according to Petersdorff, Boermans and Harnish (2006); and the reuse of waste for new purposes and recycling (Belausteguigoitia Garaizar, Laurenz Senosiain & Gómez Telletxea, 2010; De Gisi, Casella, Notarnicola & Farina, 2016). For this reason, they are considered as a comprehensive solution to face the issue of energy consumption and environmental deterioration (Guillén-Lambea, Rodríguez-Soria & Marín, 2017; Chastas *et al.*, 2018; Piderit *et al.*, 2019; Deng, Wang & Dai, 2014). Figure 5 shows the optimal operation of a ZEB, according to Javanmard, Ghaderi & Sangari (2020).

In order to validate the behavior of a ZEB or nZEB, there must be a neutral or near zero energy balance, on an annual basis. The units for energy balance may be distributed energy, primary energy, CO_2 equivalent and exergy (D'Agostino, Marino, Minichello & Russo, 2017). Other parameters, like the metric of the balance and the balance period are defined by the regulations (Marszal *et al.*, 2011).

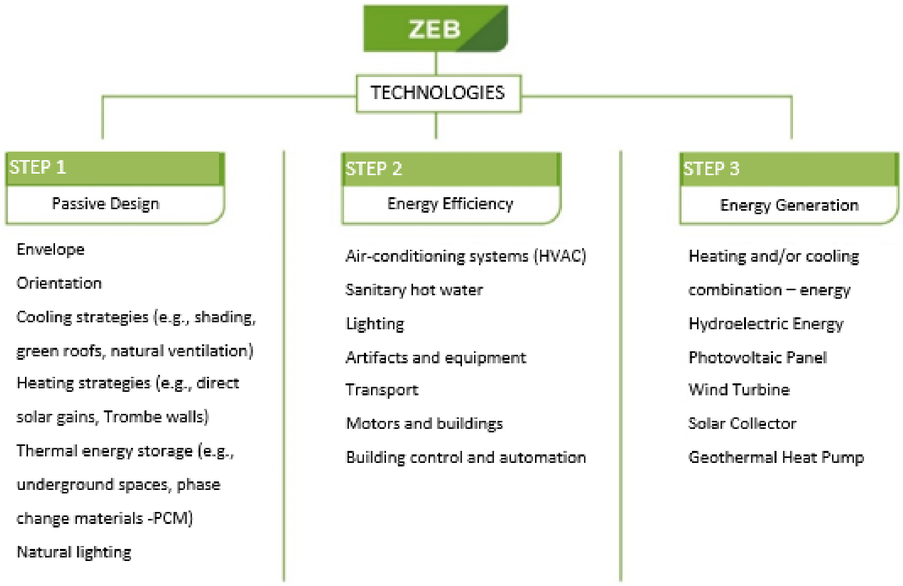


Figure 6. Technologies by categories integrated in ZEBs. Source: Preparation by the authors, using Deng et al. (2014).

Sartori *et al.* (2012) distinguish three types of balance – annual import-export (Equation 1); annual demand-generation (Equation 2), and monthly demand-generation (Equation 3).

$$\sum e \times f_e - \sum i \times f_i = E - I \geq 0 \qquad (1)$$

Where *E* and *I* correspond to exported and imported and *f* to the metric factor (kWh, kWh/m^2, CO$_2$, exergy, etc.)

$$\sum g \times f_g - \sum d \times f_d = G - D \geq 0 \qquad (2)$$

Where *G* and *D* correspond to generation and demand and *f* to the metric factor (kWh, kWh/m^2, CO$_2$, exergy, etc.)

$$g_{m,e} = \sum_m \max[0 \cdot g_e(m) - d_e(m)]$$

$$d_{m,e} = \sum_m \max[0 \cdot d_e(m) - g_e(m)]$$

$$\sum gm,e \times f_{gm,e} - \sum dm,e \times f_{dm,e} = Gm - Dm \geq 0 \quad (3)$$

Where *Gm* and *Dm* correspond to monthly generation and demand and *f* to the metric factor (kWh, kWh/m^2, CO$_2$, exergy, etc.)

The choice between the three balance types will depend on the scope that is established. Generally, the annual demand and generation balance is used (Equation 2), since, according to the authors, it allows obtaining a greater number of results to analyze.

On the other hand, if one needs to know the emissions produced directly or indirectly during the processes related to the building's construction, its maintenance and end of life, the Neutral Carbon Balance can be made (Moschetti *et al.*, 2019; Seo, Passer, Zelezna & Hajek, 2016). Through the building's Life Cycle Analysis tool (Fjola *et al.*, 2018; Hernandez & Kenny, 2010; Jusselme, Rey & Andersen, 2018; Moschetti *et al.*, 2019) or through calculation formulas of tons of carbon accumulated in the building's materials and amount of emissions, as indicated by equation 4 (Rodríguez Manrique, Kobiski & Fassi Casagrande Jr, 2014).

$$E_{kg}CO_2 = \sum_{i=1}^{n} a_i \cdot b_i \cdot c_i \qquad (4)$$

Where *a* means the amount of energy accumulated by type of material (MJ.m^{-3}); *b*, the percentage energy consumption by source; *c*, the CO$_2$ emission by source (kgCO$_2$.MJ^{-1}); *i*, the typology of the material, and *n*, the amount of material.

It can be said that the road towards a carbon neutral ZEB must focus greatly on the energy incorporated in the materials and the emissions, given that the low demand of operational energy is already a priority regulated in most countries (Moschetti *et al*, 2019).

WHAT ARE THE TECHNOLOGIES INVOLVED TO ACHIEVE ZEBS?

The technologies involved to achieve ZEBs are: Passive and energy conservation technologies; Energy Efficiency in the building's operation; and technologies to produce energy from Renewable Energies (Cao, Dai & Liu, 2016).

In step 1 (Figure 6), numerous studies are seen that deal with the envelope, promote the use of low carbon emission materials and natural ventilation to reduce the possibility of overheating inside buildings (Li, Yang & Lam, 2013; Volf *et al.,* 2018). Moga and Bucur (2018) propose the integration of nanomaterials, as these possess 3 to 5 times less conductivity, along with a reduced thickness, and they state that this could be an interesting variant in building rehabilitation cases, where the option of adding thickness to the envelope is difficult.

Regarding step 2 (Figure 6), about EE technologies, several authors encourage reusing indoor air through air exchangers for cooling and heating (Bordoloi, Sharma, Nautiyal & Goel, 2018; Justo Alonso, Liu, Mathisen, Ge & Simonson, 2015; Liu, Li, Chen, Luo & Zhang, 2019), and automation and control systems for an optimal operation (Buso, Becchio & Corgnati, 2017; Hamdy, Nguyen & Hensen, 2016).

As for step 3 (Figure 6), literature presents that the most used RE source in these buildings is solar energy, through the integration of Photovoltaic Panels for electricity, for SHW systems and thermal solar conditioning, combined with heat pump systems (Jovanovic, Sun, Stevovic & Chen, 2017; Li *et al.*, 2013; Osseweijer, Hurk, Teunissen & Van Sark, 2018). In terms of cooling systems, new technologies with desiccants and membranes are incorporated, to foster energy saving and low environmental impact (Chen & Norford, 2020).

DOES A ZEB PRODUCE ENERGY CONNECTED OR ISOLATED FROM THE GRID?

A ZEB produces renewable energy onsite for its supply and the surplus is exchanged with the external grid. When the energy generation is not enough to cover consumption needs, energy is taken from the external grid (Berardi, 2018). In cases which have energy storage batteries, the electricity for the building's operation is taken from three sources: intermittent renewables (for example, Photovoltaic Solar); energy storage battery; and external infrastructure. The sum of the energy among them is consumed by the demand sought (Kosai & Tan, 2017).

For the U.S. Department of Energy and The National Institute of Building Sciences (2015), the designation of ZEB must be used only in buildings that have demonstrated, through their current annual measurements, that the distributed energy is less than or equal to the renewable energy exported from the site.

Meanwhile, Debbarma, Sudhakar and Baredar (2017) explain that the electricity generated by integrated photovoltaic panels can satisfy approximately between 20% and 75% of electricity requirements, depending on the city and its location. The difference between the time of use and time of generation of onsite or "nearby" electricity, complicates the possibility of using all the electricity for self-consumption. The connection to the grid tends to be necessary to allow a true zero energy physical balance. Therefore, it is assumed that excess electricity generated onsite is sent back to the grid, using this as unlimited storage (Hermelink *et al*, 2013). Given what has just been said, the variant of autonomous buildings is not recommended as the generation system is oversized to reach self-consumption and a very high cost electrical and thermal energy storage system is required (Lausten, 2008).

As an example of interaction with the grid, studies made in Latin American countries show important progress in their legislation on "Distributed generation", which contributes to reaching higher ZEB integration possibilities. In this context, Vargas Gil *et al.* (2020) state that the largest photovoltaic solar plants of South America are located in Brazil and Chile, and they also highlight the renewable energies plan of Argentina (renovAR), whose objective is awarding electricity contracts using renewable sources.

Likewise, regarding distributed generation for self-consumption, Costa Rica has a recording system through the Energy Direction of the Ministry of Environment and Energy (MINAE), where an installed total of 54,504.92 kW is seen, in the framework of Decree 39220 – MINAE, to April 2020, which represents more than 1,924 registered systems (MINAE, 2015; Strategic Energy, 2020). Chile, in turn, has Law 21.118 from 2019, where the right is given to the distributer's clients to generate their own energy, self-consume it and inject their surplus to the grid under the Net Billing modality (Ministry of Energy, 2018). And Argentina has Law N°27.424, with similar conditions (Honorable Congress of the Argentine Nation, 2017).

WHAT IS THE IMPACT OF GG EMISSIONS INVOLVED IN THE GENERATION OF ENERGY USING RE, FOR THE OPERATION OF ZEBS?

Energy generation using Renewable Energies is recognized for its contribution towards the reduction of GG in the atmosphere. According to IPCC, the quick integration of EE and RE technologies in buildings will lead to a drastic reduction of CO_2 emissions (Rogelj *et al.,* 2018).

From this perspective, several works have proven that clean energy generation produces environmental impact. Hammond and Jones (2008) indicate that, on photovoltaic panels, CO_2 emissions on fine plates are 67 kg CO_2/m^2 and monocrystalline of 242 kg CO_2/m^2. According to Finnegan, Jones and Sharples (2018), the study of the life cycle analysis of new and existing technologies is essential to choose the appropriate system.

The amount of GG accumulated in ZEBs is associated to the materials and technologies installed in the building. As an example of this, the graph of Figure 7 summarizes the results of the research of Vares *et al*. (2019, where three building cases with an nZEB, without integration of RE, were compared. There, EEC1 corresponds to a building connected to the external electricity grid with the integration of thermal solar energy for SHW, PV fine plate panels and plate type thermal solar collectors; EEC2, to one that has no connection with the electricity grid and has equal RE generators with the addition of batteries to store solar energy; and, EEC3, to another that is connected to the electricity grid and generates all the energy for heating and SHW thermal solar energy using parabolic plate type collectors.

Ultimately, it is seen that, during the estimated 25-year life cycle for the systems, the greater the building's autonomy is, the accumulated emissions increase. However, when the RE technology chosen produces electricity (EEC-1 case), it generates 40% less GG emissions, in comparison to an NZEB without RE integration (Vares *et al.*, 2019).

The EEC1 variant shows that, under conditions that consider an active user in energy efficiency matters, energy conservation strategies could be combined and thus reduce the percentage of emissions during the system's operation, mainly for heating and cooling.

It can be said that the GG impact involved in ZEBs can be regulated by the decisions of the investors regarding technologies being integrated in the buildings (Attia, 2016; Azzouz, Borchers, Moreira & Mavrogianni, 2017; Hernandez & Kenny, 2010; Lamnatou, Motte, Notton, Chemisana & Cristofari, 2018).

WHAT IS OR WHAT WOULD BE THE IMPACT ON THE ENERGY MATRIX?

ZEB are integrated holistically in Smart Energy Systems, in the electricity, heating, cooling, industry, buildings and transportation sectors, to address solutions for a transformation towards a renewable and sustainable future in energy solutions (Lund *et al.*, 2017).

Along this line, Seljom, Byskov, Tomasgard, Doorman & Sartori (2017) made an analysis about the impact of these buildings on the reduction of energy consumption with projections to 2030 and 2050 for the Scandinavian system. The results revealed a reduction of electricity consumption for heating of 8% and 18%, respectively. Bearing in mind that a 25% renewal of all building stock in ZEB is expected by 2030, and 50% by 2050, this would change the operation of flexible electricity generation.

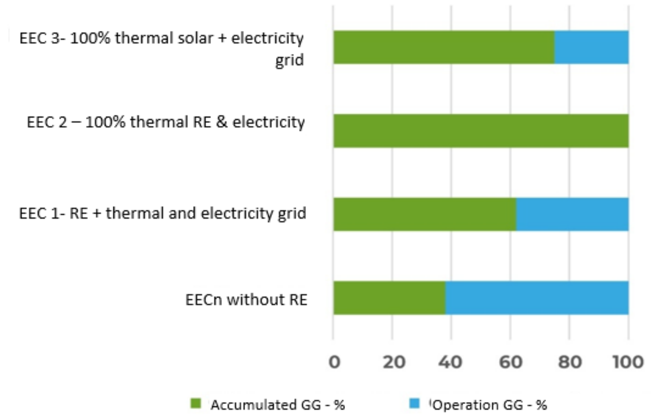


Figure 7. Comparative graph of the percentage of GG emissions for 25 years of operation for each case. Source: Preparation by the authors, using Vares et al. (2019).

District Heating and Cooling Systems (DHC) are based on the use of local sources of heat, cooling and fuels which, under normal circumstances, would be lost. On the DHC platform (2012)[1], three scenarios 2020-2030-2050 are suggested for the EU, in which it is foreseen to extend existing urban heat production plants and increase solar-thermal plants.

In Latin America, progress is being made in energy efficiency policies. In Argentina, for example, they have moved forward in building energy certification projects in the standard, IRAM 11900-2017 "Energy supply in dwellings. Calculation method and energy efficiency labeling" (IRAM, 2017), which seeks to evaluate the end use of conventional energy that contributes to the energy demand of the dwelling through heating, cooling, indoor artificial lighting and sanitary hot water services. The design bioenvironmental strategies are mentioned as an effective way to contribute towards EE (Fernández, Garzón & Elsinger, 2020).

In terms of RE generation, law N°27.424 is ratified in Decree 1075/2017 "System to encourage the distributed generation of Renewable Energy integrated to the public electricity grid" (Honorable Congress of the Argentine Nation, 2017), where the legal and contractual conditions are established for the generation of electricity of a renewable origin

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[1] See https://www.euroheat.org/publications/brochures/district-heating-cooling-vision-towards-2020-2030-2050/

by users of the distribution grid. An important step is considered in the Argentine national legislation that starts ZEB integration. Specifically, article 7 indicates that:

> starting from the ratification of this decree, all domestic public building construction projects must consider the use of a distributed generation system from renewable sources, consistent with taking advantage of the zone it is located in, prior study of its environmental impact where this applies, pursuant to the applicable regulations in the respective jurisdiction. (Honorable Congress of the Argentine Nation, 2017, p. 4).

WHAT IMPACT DO ZEBS HAVE ON THE CONSUMPTION OF THE BUILDING SECTOR?

ZEB could make important savings in the sector's consumption. In fact, an energy demand of 25% to 50% lower than that generated by conventional buildings is estimated (Häkämies *et al.*, 2015). For this, it is worth highlighting that it is necessary to underline an efficient user behavior in the use of passive systems and active technologies (Carpino, Mora, Arcuri & De Simone, 2017; Causone, Tatti, Pietrobon, Zanghirella & Pagliano, 2019).

In Figure 8, the different sectors included in balance calculations are illustrated, and it is seen that the highest potential in energy savings is found in the reduction of the heating and cooling demand (Garde *et al.*, 2014). A building in template climates, with a suitable insulation, could reduce heating demand by between 20% and 50% (Taleghani, Tenpierik, Kurvers & Van den Dobbelsteen, 2013). To achieve an optimal design, the consumption should be 30 kWh/m^2/year (Hermelink *et al.*, 2013). D'Agostino and Parker (2020) also consider that it is important to reduce the impact of the energy consumption coming from lighting and household appliances.

In Figure 9, an example of the operation and calculation of the energy flows within a ZEB is seen, where concentric scales show, from outside in, the building's interaction with the external grid. First of all, the net primary energy enters to cover thermal and electrical demand until reaching the limit with the external grid system. The building takes the energy needed for different sectors' consumption and covers the whole demand with energy generated from RE systems. Finally, the surplus is exported to the distribution system, generating a positive balance between generation and demand.

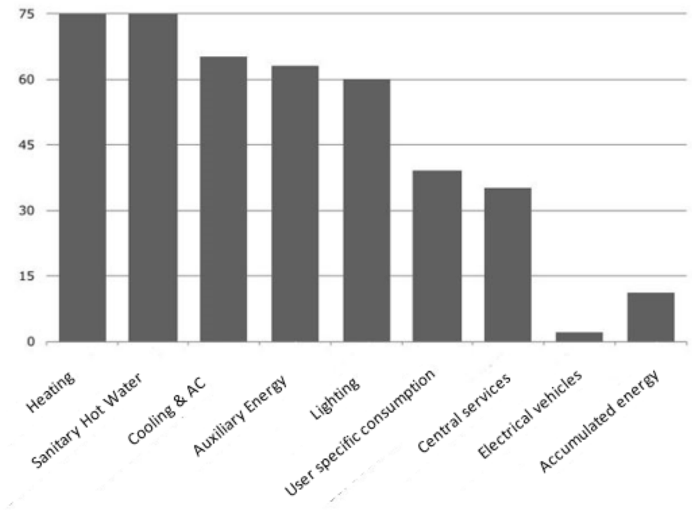

Figure 8. Demand by sectors included in the calculation of the balance for a ZEB. Source. Hermelink et al. (2013).

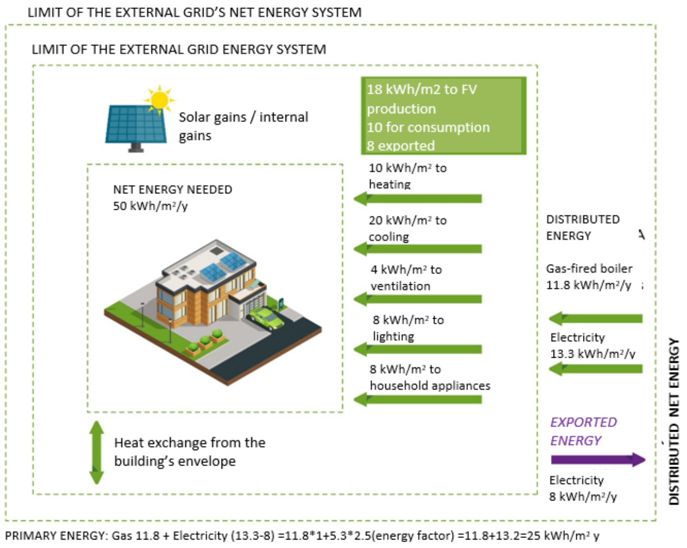

Figure 9. Example of the calculation of energy flows in a ZEB. Source: Preparation by the authors, using Berardi (2018).

ARE THERE METHODOLOGIES TO EVALUATE A ZEB?

The concept of ZEB requires a clear and consistent methodology for energy calculations. Initially, the most important unknowns in this sense were about the measurement of the balance, the period of the balance, the type of energy included in the balance, the type of energy balance, accepting renewable energy sources, the connection with the energy infrastructure and the requirements to achieve energy efficiency, indoor climate and, in the case of

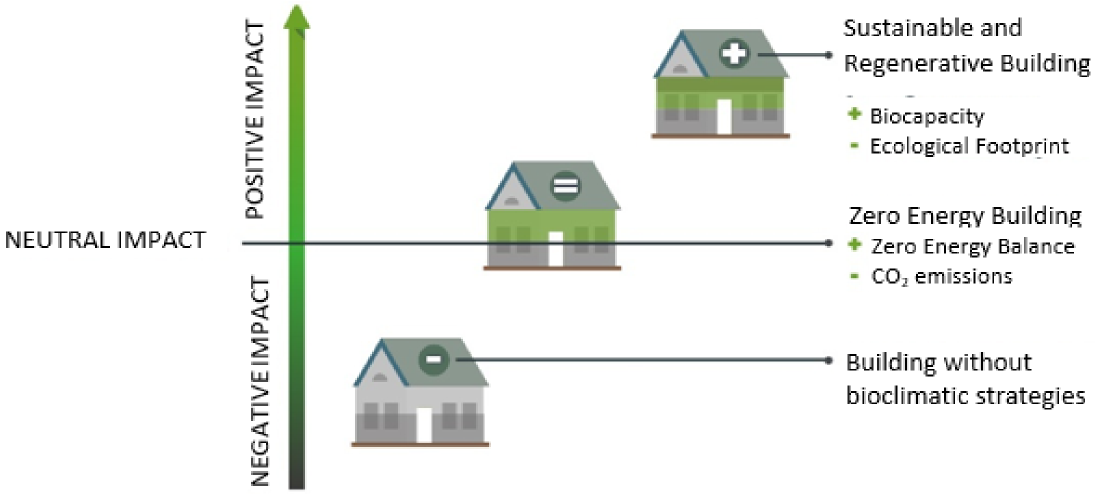

Figure 10. Vision of EEC as regenerative and sustainable buildings. Source: Preparation by the authors, using Attia (2016).

buildings with a connection to the grid, interaction of the building with it (Marszal *et al.* 2011).

As a reference to determine a regulatory framework, the literature highlights two main legislations: that passed by the Directive of the European Parliament and Council (EPBD), in regulation 2010/31/EU from 2010 and that established by the Department of Energy of the United States (US DOE) *"A Common Definition for Zero Energy Buildings"* from 2015. In the first, it is indicated that public buildings built until 31/12/18 must be nZEB and, consequently, all buildings being built to 31/12/2020 will be (European Commission, 2010; D'Agostino, 2016; Pacheco-Torgal, 2014). The second defines as a main strategy, reaching sellable ZEB dwellings by 2020 and commercial buildings by 2025.

Years later, the contribution of IEA along with SHC (Solar Heating and Cooling) through the Task 40 program – Energy conservation in community buildings and systems (ECBCS) - Towards Zero Energy Solar Buildings – will present that there are three key steps to develop a ZEB, providing greater flexibility in the decision making for building design: optimizing the passive building design, maximizing energy efficiency to minimize the building's energy demand, and exploring the generation of onsite renewable energy to cover existing needs (IEA, 2015).

Currently, the technical and economic feasibility of ZEBs is analyzed using parametric simulation (Ferrara *et al.*, 2020). This tool is valuable for the designer, as it allows making low energy suggestions and optimizing the model in the design process at an early stage and in a holistic manner (Lobaccaro *et al.*, 2018).

WHAT IS THE IMPACT OF ZEB TO FACE CLIMATE CHANGE?

Climate change (CC) presents challenges in making adaptation and mitigation measures in buildings. Studies show that it is possible to reduce the sector's emissions by 40% with the technologies available in the market (United Nations Environment Programme – Sustainable Buildings & Climate Initiative, 2009). The mitigation strategies are focused on energy balance, thermal comfort and the interaction with grids (Chai, Huang & Sun, 2019).

The integration of EEC into the built environment, whether through new buildings or the rehabilitation of existing ones, will achieve a greater energy and environmental quality in the constructions, as a response to the need of creating resilient cities that CC brings with it, as this demands more self-sufficient behaviors in the use of resources (Calvente, 2007). It has been shown, in this context, that due to the increase of land temperature, in the future it will be necessary to improve passive solar protection measures and to progress with cooling technologies for the summer period (Flores-Larsen, Filippin & Barea, 2019).

The neutral impact achieved by limiting the consumption of fossil fuels and the neutral energy development during the building's life cycle, can become greater and more positive. The search for the highest efficiency in the administration of non-renewable resources and the maximum generation of those renewable ones, contributes to reaching a superior scale in sustainable building matters (Attia, 2016). In Figure 10, it is seen that the positive development through ZEBs can increase the

Figure 11. nZEB community, Zero carbon homes, United Kingdom. Source: Photograph taken from the Bioregional Development Group (https://www.bioregional.com/).

biocapacity and reverse the ecological footprint of the building, which can become regenerative buildings.

WHAT ARE THE PROJECTIONS FOR THE IMPLEMENTATION OF ZEBS?

The growth of the ZEB mass has transcended the world in recent years and its continuity is expected. From this point of view, the European Parliament and Council (2018) has declared that

> each member state will set out a long-term strategy to support the renewable of their residential and non-residential building stock, both public and private, transforming them into properties with high energy efficiency and decarbonized before 2050, facilitating the economically profitable transformation of existing buildings into nearly zero energy consumption buildings (European Parliament and Council, 2018, Art. 2 p. L 156/81).

To this, it has to be added that, China recently generated a version of the Technical Regulation for ZEB (*Technical Standard for Nearly Zero Energy Buildings* – GB/T 51350-2019), where it is proposed to reach the objective "three 30% in the future: 30% of new ultra-low energy buildings; 30% of renewable energy for buildings; and 30% of old buildings restored as ultra-low energy buildings" (Luo *et al.*, p. 2, 2020).

In brief, it is expected that the ZEB contribute significantly in smart cities (Kylili & Fokaides, 2015). Facing this challenge, the idea of "nZEB community" is suggested, based on a collaborative concept, where the buildings that belong to them, can freely share RE generation, energy storage and information (Huang & Sun, 2019). Rehman, Reda, Paiho and Hasan (2019) suggest the need of seeking technically efficient and economically affordable energy storage methods. Another example along this line, is the multi-family dwelling program implemented by government policies in the United Kingdom, *Zero Carbon Homes* (Figure 10), which represents a contribution in the transition towards low carbon buildings (Heffernan, Pan, Liang & de Wilde, 2015).

CONCLUSION

In this work, ten questions about ZEB were answered, from a revision of existing literature, with the objective of identifying, developing and understanding their main characteristics.

The state-of-the-art indicates that ZEB are distinguished from other buildings conceived in the framework of sustainability, mainly because of their achievement of a neutral energy balance between energy generation and demand; balance in which it is also possible to consider the amount of CO_2 emissions generated during the building's entire life cycle. This condition can be reached along two lines. The first of these is related better to the holistic parameters of sustainability and is based on energy efficiency, in passive conditioning and, in the restriction of their energy consumption to achieve the neutral balance starting from a very reduced generation of renewable energy. The risk lies in that said neutral balance can also be obtained based on a second line, depending of a great own renewable energy production, that represents an impact itself on climate change. It is proven that, in the RE systems at 100% in autonomous buildings, accumulated GG emissions are generated during the system's entire life cycle; a condition that cannot be solved, reason why it constitutes a great limitation.

Therefore, it is considered essential that, to reach the neutral balance, the greenhouse gas emissions, especially CO_2, are counted throughout the building's entire life cycle.

Energy consumption for heating and cooling tends to be the most compromised in buildings, which is why the literature reviewed proposes achieving savings in the ZEBs of between 25% and 50% respectively, limiting both to 30 kWh/m^2/year.

In some cases, the ZEBs use an energy storage system that tends to be oversized, as the batteries still represent a very inefficient technology, generating a high level of inefficiency and a high investment cost.

In the cases of ZEBs with connection to the grid, the energy generation is aided by the building-grid exchange, so that the user can satisfy their energy needs using RE and return surplus energy to the grid, so that other users can use it. The grid energy remains available only at the times when RE generation is insufficient. Therefore, the possibility of balancing emissions generated by RE during the system's operation is established through an active behavior in energy efficiency matters by the users.

Worldwide, the growth of the ZEB mass has transcended boundaries and it is projected this trend will continue, promoting notions of community and circular economy, which is backed by the support received from regulations of the main developed countries. It is expected that ZEBs, in their path towards high energy efficiency, form part of the paradigm of Regenerative Sustainable Buildings, that seek to contribute to the biocapacity of Earth and to the reduction of the ecological footprint caused by the building sector.

Notwithstanding what has been said, the definitions and diversifications suggested, since their beginnings, in the specialist literature, essentially constitute a theoretical basis over empirical experiences, especially when looking at developing countries. Given that the metric indices can vary depending on their geographical, technological, economical limitations, among others, it can be expected that Latin America generates its own holistic approach adapted to the different conditions and realities that characterize it.

ACKNOWLEDGMENTS

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APPENDIX

TABLE 1 (PART 1)

EJE TEMÁTICO	UBICACIÓN	AUTOR / AÑO PUBLICACIÓN	FUENTE
DEFINICIONES DIVERSIFICACIONES AUTONOMÍA	PREGUNTA 1	Attia, 2018	Net Zero Energy Buildings
		Torcellini, Pless y Deru , 2006	Conference for ACEEE
		Brambilla, Salvalai, Imperadori, & Sesana, 2018	Energy and Buildings
		Booth, Barnett, Burman, Hambrick, & Westby, 2010	NREL Technical Report
		Congedo, Baglivo, Zacà y D'Agostino, 2015	Data in Brief
		Good, Andresen y Hestnes, 2015	Solar Energy
		Harkouss, Fardoun y Biwole, 2019	Energy
		Moschetti, Brattebø y Sparrevik, 2019	Energy and Buildings
		Kilkis, 2007	Proceedings of Energy Sustainability
		Hernandez & Kenny, 2010	Energy and Buildings
		Comisión Europea, 2010	EU Directive
		Piderit, Vivanco, van Moeseke, & Attia, 2019	Sustainability
		Delia D'Agostino, 2016	Publicaciones de l UE.
		A. Marszal y Heiselberg, 2015	AALBORG University
		Sartori, Napolitano y Voss, 2012	Energy and Buildings
		Mlecnik, 2012	Energy Efficiency
SUSTENTABILIDAD	PREGUNTA 2	Hernández Moreno, 2008	Acta Universitaria
		Kristinsson, 2012	Libro
		Laustsen,2008	Códigos EE
		Chastas et al., 2018	Building and Environment
		Attia et al., 2018	Net Zero Energy Buildings
		Guillén-lambea, Rodríguez-soria, & Marín, 2017	Revista Hábitat Sustentable
		Chastas et al., 2018	Building and Environment
		Piderit, Vivanco, van Moeseke, & Attia, 2019	Sustainability
		Deng et al., 2020	Energy
		Diana D'Agostino, Marino, Minichiello, & Russo, 2017	Energy Procedia
		A. J. Marszal et al., 2011	Energy and Buildings
		Sartori, Napolitano, & Voss, 2012	Energy and Buildings
		Moschetti et al., 2019	Energy and Buildings
		Seo, Passer, Zelezna, & Hajek, 2016	International Energy Agency
		Fjola et al., 2018	Energy and Buildings
		Hernandez & Kenny, 2010a	Energy and Buildings
		Jusselme, Rey & Andersen, 2018	Energy Reviews
		Moschetti, Brattebø & Sparrevik, 2019	Energy and Buildings,
		Rodríguez Manrique, Kobiski, & Fassi Casagrande Jr, 2014	Revista Hábitat Sustentable
		Kalbasi, Ruhani, & Rostami, 2019	Journal of Thermal Analysis and Calorimetry
		Wargocki, Zirngibl, Bendžalová, & Mandin, 2020	Energy and Buildings,
		Petersdorff, Boermans, & Harnisch, 2006	EU Directive
		Belausteguigoitia Garaizar, Laurenz Senosiain, & Gómez Telletxea, 2010	Sustainable Building Conference
		De Gisi, Casella, Notarnicola, & Farina, 2016	Civil Engineering and Environmental Systems
		Javanmard, Ghaderi, & Sangari, 2020	Sustainable Cities and Society
TECNOLOGÍAS PASIVAS EFICIENCIA ENERGÉTICA ENERGÍAS RENOVABLES	PREGUNTA 3	Javanmard, Ghaderi, & Sangari, 2020	Sustainable Cities and Society
		Li, Yang, & Lam, 2013	Energy
		Volf et al., 2018	Energy and Buildings
		Moga & Bucur, 2018	International Conference Interdisciplinarity in Engineering
		Bordoloi, Sharma, Nautiyal, & Goel, 2018	Renewable and Sustainable Energy Reviews
		Justo Alonso, Liu, Mathisen, Ge, & Simonson, 2015	Building and Environment
		Liu, Li, Chen, Luo, & Zhang, 2019	Applied Thermal Engineerin
		Buso, Becchio, & Corgnati, 2017	Energy Procedia
		Hamdy, Nguyen, & Hensen, 2016	Energy and Buildings
		Jovanovic, Sun, Stevovic, & Chen, 2017	Energy and Buildings
		Osseweijer, Hurk, & Teunissen, 2018	Renewable and Sustainable Energy Reviews
		Chen & Norford, 2020	Energy and Buildings
DEMANDA Y GENERACIÓN DE ENERGÍA	PREGUNTA 4	Berardi, 2018	Handbook of Energy Efficiency in Buildings
		Kosai & Tan, 2017	Sustainable Cities and Society
		U.S.Department of Energy & The National Institute of Building Sciences, 2015	Reporte organismo
		Debbarma, Sudhakar, & Baredar, 2017	Resource-Efficient Technologies
		Hermelink et al., 2013	European Commission
		Lausten, 2008	Report International Energy Agency

TABLE 1 (PART 2)

ENERGÍAS LIMPIAS	PREGUNTA 5	Rogelj et al., 2018 Hammond & Jones, 2008 Finnegan, Jones, & Sharples, 2018 Vares, Häkkinen, Ketomäki, Shemeikka, & Jung, 2019 Attia, 2016 Azzouz, Borchers, Moreira, & Mavrogianni, 2017 Hernandez & Kenny, 2010a Lamnatou, Motte, Notton, Chemisana, & Cristofari, 2018	IPCC Inventory of Carbon & Energy Energy and Buildings Journal of Building Engineering Sustainable Cities and Society Energy and Buildings Energy and Buildings Journal of Cleaner Production
IMPACTO EN MATRIZ ENERGÉTICA POLÍTICAS PÚBLICAS	PREGUNTA 6	Lund, Alberg, Connolly, & Vad, 2017 Seljom, Byskov, Tomasgard, Doorman, & Sartori, 2017 DHC, 2012	Energy Energy Euroheat & Power
CONSUMO DE ENERGÍA	PREGUNTA 7	Häkämies et al., 2015 Carpino, Mora, Arcuri, & De Simone, 2017 Causone, Tatti, Pietrobon, Zanghirella, & Pagliano, 2019 Garde et al., 2014 Taleghani, Tenpierik, Kurvers, & Dobbelsteen, 2013 Hermelink et al., 2013 Agostino & Parker, 2020	VTT Technical Research Centre of Finland Building Simulation Energy and Buildings Energy Procedia Renewable and Sustainable Energy Reviews
METODOLOGÍA DE EVALUACIÓN CERTIFICACIÓN	PREGUNTA 8	A. J. Marszal et al., 2011 Comisión Europea, 2010 Delia D'Agostino, 2016 Pacheco-Torgal, 2014 U.S.Department of Energy & The National Institute of Building Sciences, 2015 IEA, 2015	Energy and Buildings DirectivaUE Energy Construction and Building Materials reporte organismo International Energy Agency.
CAMBIO CLIMÁTICO	PREGUNTA 9	UNEP,2009 Chai, Huang, & Sun, 2019 Calvente M., 2007 Flores-Larsen, Filippín, & Barea, 2019 Attia, 2016	Reporte organismo Energy Resiliencia : un concepto clave para la sustentabilidad Energy and Buildings Sustainable Cities and Society
PROYECCIONES FUTURAS COMUNIDAD ZEB	PREGUNTA 10	Parlamento Europeo y del Consejo, 2018 Luo et al., 2020 Kylili & Fokaides, 2015 Huang & Sun, 2019 Rehman, Reda, Paiho, & Hasan, 2019 Heffernan, Pan, Liang, & de Wilde, 2015	DirectivaUE Applied Energy Sustainable Cities and Society Applied Energy Energy Conversion and Management Energy Policy

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