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Author: Juan Collado

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ZERO ENERGY BUILDINGS AND ZERO ENERGY DISTRICTS, MOVING TOWARDS A NET ZERO EMISSION SOCIETY

Juan Collado

Master Thesis

Urban Planning and Renewable Energy Solutions

Supervisor

Harald Nils Røstvik

University of
Stavanger

Preface

The presented thesis is the result of a five years' master program and the finalization of my academic career in urban planning and renewable energy solutions at the University of Stavanger. In this master programme I have very much enjoyed my studies and I am more than grateful for the opportunities that the University of Stavanger offered me during my academic development. During the study time, I have learned and expand my knowledge as to what are the main issues that our world is facing. Furthermore, I developed valuable academic skills and have greatly expanded my knowledge throughout planning and environmental issues. Knowledge, Which I wish to use in my future endeavours, and be able to contribute in making this planet a better place.

Moving towards a Net Zero Emission Society is highly challenging, however, with the current transformation in the energy context, there is still many possibilities in which our society have the opportunity to achieve sustainable cities. Therefore, to contribute with this challenge, this study proposes a conceptual framework for successful planning process development of Zero Energy Districts (ZEDs). In that regard, I believe that the implementation of ZEDs can play an important role in achieving the sustainable future that all wish for.

Acknowledgements

First of all, I am very grateful to my thesis supervisor Prof. Harald Nils Røstvik, who throughout his lectures about the energy issues has been an important factor in the selection of my thesis topic. Moreover, his constructive feedback, great scientific knowledge and by supplying the correct literature has been extremely valuable to me. I would also like to thank the group of supervisors that delivered valuable contributions to my research.

Finally, on a personal note, I would like to thank my family for their patience and moral support. and especial thanks to my parents for their emotional support during my studies, especially through the long days and nights of working on this thesis.

Juan Collado

Stavanger, 15th of June 2022.

Abstract

Within the ongoing issues of global warming and the recent global energy crisis, our society is currently facing environmental challenges regarding fossil fuels depletion, energy consumption and pollution. If these environmental issues keep increasing without any rapid solution, the consequences of this, will eventually lead to a point where we will not be able to solve it. The United Nations International Panel on Climate Change's (IPCC) latest report stated that there are 11 years left to save the planet before an irreversible climate catastrophe is triggered (United Nations, 2019). With this statement and the increasing evidence of other environmental studies, it is clear that strong actions against global warming are of major importance. In this regard, energy consumption and Green House Gasses (GHG) emissions are key elements in order to address in an effective way the anthropogenic global warming.

One particular area to address this issue, is the building sector, which yearly and gradually is generating more waste, consumes more than one third of all energy and is responsible for nearly one third of the greenhouse gas emissions (GlobalABC, 2021). Technological development such as the application of the Zero Energy (ZE) concept in the building sector is important for the correct choice of energy systems. Local energy systems in Zero Energy Buildings (ZEB) can contribute to increase the renewable energy (RE) production and provide alternatives for the distribution of energy.

How buildings and cities should be developed in order to contribute to this, is still being researched. In that sense, districts play an important role, since they are considered as the "optimal scale to accelerate sustainability, small enough to innovate quickly and big enough to have a meaningful impact." (EcoDistricts, 2014) Therefore, the application of integrated district approaches such as, the Zero Energy Districts (ZED) could positively affect the future of energy policies.

This report aims to understand how to improve the energy performance in the building sector, by moving beyond the ZEBs concept towards a larger scale such as ZEDs, which is relatively a new concept in both scientific research and real projects. The approach means that a district scales, the optimisation of the energy performance of a set of buildings is much better than the individual building approach.

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List of abbreviations

COP	**Conference of the Parties**
CUS	**Centre for Urban Sustainability**
DH	**District Heating**
EC	**European Commission**
ECS	**Energy Conservation Systems**
ED	**Energy Demand**
IEA	**International Energy Agency**
IECC	**International Energy Conservation Code**
IPCC	**International Panel on Climate Change**
nZEB	**nearly Zero Energy buildings**
PE	**Plus Energy**
PEBs	**Plus Energy Buildings**
PEDs	**Plus Energy Districts**
PV	**Photovoltaics**
RQ	**Research Question**
RE	**Renewable Energy**
REP	**Renewable Energy Penetration**
RES	**Renewable Energy Systems**
UN	**United Nations**
UNFCCC	**United Nations Framework Convention on Climate Change**
ZE	**Zero Energy**
ZEB	**Zero Energy Building**
ZECs	**Zero Energy Communities**
ZED	**Zero Energy District**

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Chapter 1 Introduction

1.1 Context

Global warming has been increasing drastically at a high rate since the 1950s, and based on the climate change synthesis report from the IPCC in 2014, human activities such as fossil fuel depletion and GHG emissions have been identified as one of the main causes (Allen et al., 2014). Moreover, according to the International Energy Agency (IEA), fossil fuels are still the dominant source of energy, accounting for almost 80% of GHG emissions that comes from burning fossil fuels to produce energy (IEA, 2020). If the share of fossil fuels in the energy mix remain the same while the world population continues to grow, emissions would reach levels that would have severe repercussions for the planet (Foster & Elzinga, 2013).

The global awareness over the consumption of non-renewable energy sources and the impacts of emissions in climate change has evolved from an issue of interest primarily to natural scientists into one of the top priorities on the global policy agenda (Bernauer, 2012). Subsequently, the creation of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 was the beginning of global politics that addressed the issue of climate change. Currently with 197 parties, the UNFCCC aims to stabilize the atmospheric concentration of GHGs to prevent "dangerous anthropogenic interference with the climate system" (UNFCCC, 2021). In order to constantly update the politics in how to achieve this objective, members of the UNFCCC have to meet yearly at the Conference of the Parties (COP). A s a result, in 1997 (COP3) the Kyoto Protocol was created, obliging industrialized countries and economies in transition to reduce emissions over a commitment period (Lewis et al., 2018). More notably in 2015 (COP21) was the creation of the of the Paris Agreement, which was the first international environmental treaty to legally bind all Parties to undertake bold efforts to limit global warming to below 2 degrees compared to pre-industrial levels (Jepsen et al., 2021).

Along with the Paris Agreement, the rise of renewable resources together with Energy Efficiency (EE) technologies became key in the new strategies to reach the targets. Consequently, in the 2030 climate & energy framework, big green actors such as the European Commission (EC) have agreed to increased its share of renewable energy to at least 32%, and at least 32.5% improvement in its energy efficiency by 2030 in the main sectors (EC, 2021a). As one of the important sectors in the energy consumption, the building sector became one main target. In this regard, Building codes and laws such as the International Energy Conservation Code (IECC) in the USA and the Energy Performance of Buildings Directive

(EPBD) in Europe, became the main instruments to improve the energy efficiency of buildings (Jha, 2015). One key strategy to achieve these targets was the development of the Zero Energy Building (ZEB) concept. On the one hand, the 2021 IECC includes a Zero Energy building appendix which provides cities and states an opportunity to reach the Zero Energy targets by 2050 (IECC, 2021). The EPBD on the other hand, outlines specific measures to achieve this, including a mandate that proposed that all new buildings must be nearly Zero Energy buildings (nZEBs) from the 31st of December 2020, and ZEBs by 2030. (EPBD, 2021). However, at the current level, this strategy is found to be insufficient to keep up with its long term goals of becoming climate-neutral by 2050.

While efforts continue in increasing the uptake on ZEBs, interests in extending the ZE concept to a District scale have also begun to emerge (Sougkakis et al., 2020). Extending the zero-energy concept to a larger territorial scale allows the exploitation of the building stock diversity within the District and considers the contribution from different energy performances and production capabilities (Amaral et al., 2018). This facilitates the share of not only the energy demand (ED) but costs, and resources, which cannot be done in individual ZEBs. Additionally, adopting the zero-energy concept to larger scales includes the issues regarding Transport, urban form, location, etc. that are often neglected in singular ZEBs. Furthermore, economic benefits may also be achieved through the design, acquisition, operation, and maintenance of energy systems across many buildings (Polly et al., 2016). Thus, transitioning to ZEDs does not only pave the way towards Zero emissions societies, but it can play an important role on the economic competitiveness of energy efficient solutions (Pless et al., 2018).

1.2 Relevance of the study

The application of the zero-energy concept to larger areas is recently being an important part of the city planning process, Nevertheless, much of the academic research is still focused on the building level, consequently, the majority of districts have been and are still planed without consideration for energy performance as a whole. Furthermore, few studies have focused in the steps needed to achieve the transition to ZEDs, none of them, however, have offered a comprehensive conceptual framework that can be applied to different districts as an integrated planning process. In this regard, in order to overcome the current energy crisis by reducing the energy consumption and fossil fuel dependency, as well as reaching the emission targets, this study is relevant by developing an integrated energy conceptual framework for ZEDs that not only planners and designers, but policymakers and stakeholders can use for further development.

1.3 Purpose of the study

This study aims to find the main challenges and successes in the design and strategies principles of the ZE concept in the building sector, and how this can be applied to a larger scale such as ZED. Advancing in the scale from ZEBs to ZEDs encourage the development of an integrated conceptual framework that can potentially be adopted in the development of ZEDs in different contexts. Although there is an increased awareness on the importance of the ZE concept, much of the current literature is still focused at the building level. Having only few studies dedicated to larger scales such as ZED, and showing some gaps on the application of the ZE concept to larger territorial scales. In that sense, this master thesis seeks to fill this gap by proposing an integrated conceptual framework for the design and planning strategies of ZED that can be used for future development.

The development of an Integrated Conceptual Framework for ZED provides universal guidelines that can be applied into different contexts, regardless of political, socio-cultural and economic conditions. The end-results of this study therefore offers a universally applicable framework for successful ZEDs development.

1.4 Research questions

To develop a comprehensive conceptual framework, and to design and transform districts to ZEDs, the following research question must be addressed: **What are the most effective planning principles and strategies within the Zero Energy concept that can be used for a more integrated development of ZEDs?** In order to answer the main Research Question (RQ), the following sub questions will be discussed as support to any proposed recommendations or conclusions derived from the literature and the case study findings;

(Q1) What are the main factors influencing the energy system of a ZED?
(Q2) What are the main challenges and opportunities of ZED?
(Q3) What factors led to the successful development of current ZED?

1.5 Objectives

This master thesis ultimately seeks to investigate the principles and the most effective strategies of the ZE concept in order to enhance successfully the transition from ZEBs to ZEDs by:

- Conducting a state-of-the-art analysis of the current literature.
- Using real projects on the application of the ZE concept on larger scales.
- Developing a conceptual framework for the development of ZEDs.

1.6 Limitations

With the focus on energy within the building sector, this thesis has limited the scope of the analysis towards the energy infrastructure of the building stock, therefore, areas such as, ED, EE and the share of RE within the building stock are of particular interest, meanwhile, areas such as transport and public spaces which can include other challenges and opportunities are not considered for this study, since they are not related to the focus of the study. Furthermore, this thesis focus on the planning development aspects that are involved in ZEDs, which are those related to political, financial and technological strategies. These technical strategies, however, are complex in its entirety and therefore, cannot be fully covered within the timeframe for this thesis. Finally, given the complexity of achieving a zero energy balance in terms of energy calculations and methodologies, this thesis is limited to provided and recommend calculations for the energy consumed and produced in a more theoretical way. Furthermore, while considering calculations, the embodied emissions of the life cycle of ZEDs was mentioned but not fully addressed as it deserves a better evaluation of its environmental impact in achieving the Zero Energy balance.

1.7 Structure

First the **Chapter 1** introduces the research problem within a context to support the relevance of this master thesis. Moreover, presents the research questions this study aims to answer and provides an overview of the structure of the study. **Chapter 2** describes the methods used in order to answer the research question. **Chapter 3** Presents the topic and context of the Zero Energy concept is explored with a conceptual approach to the literature review. This chapter clarifies definitions of ZE concepts, defines the scale of the intervention, describing the energy principles and challenges of the concept and finally contextualizes the topic in different contexts. Offering a theoretical information for a conceptual framework. **Chapter 4** Explores different examples and the major contributions of the Zero Energy concept in real life. Offering the practical information for the development of a conceptual framework. **Chapter 5** Aims to develop a conceptual framework that can be used for future development of ZEDs. **Chapter 6** Discusses and summarizes the main findings of the study and proposes recommendations for future work.

Chapter 2 Methodology

In order to address scientifically the research question, the main method for this master thesis is a qualitative research method

2.1 Qualitative research method

Qualitative research, broadly defined, is a type of social science research that collects and works with non-numerical data. According to Patton 2001, "Qualitative research is the kind of research that produces findings arrived from real-world settings, using a naturalistic approach that seeks to understand phenomena in context-specific settings, such as real world setting where the researcher does not attempt to manipulate the phenomenon of interest, but rather the phenomenon of interest unfolds naturally"(Patton, 2001)

This kind of social phenomena structure that this method provide is very applicable towards issues of energy consumption in communities, as it allowed the study to gain a thorough knowledge of the concept itself with the use of literature review, combined with insight into social phenomena related to the concept through the particular case studies presented in this master thesis.

Based on Neuman's framework 2009, There are 7 steps in the Qualitative Research Process

1. "*Acknowledge self and context.* Qualitative researchers rely on personal beliefs, biography, or specific current issues to identify a topic of interest or importance." (Neuman, 2009). As being part of this Master Program, I have a deep interest for cities and environment. Throughout the program, the main issues that cities face were in a way well documented, and possible solutions were as well discussed. In this regard, one of the main issues that cities face is related to energy and CO2 emissions, being the concept of ZE one of a particular interest in the reduction of energy consumption and the path towards sustainability.

2. "*Adopt a perspective*. qualitative researchers may consider the theoretical-philosophical paradigm or place their inquiry in the context of ongoing discussions with other researchers. Rather than narrowing down a topic, this means choosing a direction that may contain many potential questions." (Neuman, 2009). The concept of ZED is recently new in the academic literature, and there are many questions that are still unanswered, the development of a conceptual framework, creates the opportunity to develop different approaches towards specific areas. For this master thesis, the aim is to gain advanced knowledge of all factors and perspectives regarding the ZE concept.

3–6. "*Design a study and collect, analyse, and interpret data*. This is a fluid process with much going back and forth among the steps multiple times. Often the researcher not only uses or tests a past theory, but also builds new theory. At the interpret data stage, the qualitative researcher creates new concepts and theoretical interpretations." (Neuman, 2009).Through the literature review and the proposed case studies, the information collected should be adequate in order to conduct a proper analysis, enabling the possibilities for further assumptions regarding the conceptual framework for principles and strategies for ZEDs, as well as the main supportive data towards any conclusions and recommendations for future studies.

7. ***Inform others***. This is similar for both approaches, but here again, the style of a report varies according to the approach used." (Neuman, 2009). The style of communication for this study is the master thesis itself, and the conceptual framework for ZED, which will be available for any interested parties.

2.2 Application of the methodology

In order to answer the research questions proposed and be able to provide a proposal regarding the conceptual framework for ZEDs, this chapter describes the methodology that has been applied to identify core practices in the development of both ZEBs and ZEDs. To fulfil this aim, this research is divided in different qualitative research methods.

First, a literature review has been performed to answer the (Q1) and (Q2). here, a variety of scientific articles, books, and other literary texts on ZEBs and ZEDs have been consulted and analysed to identify the key elements in the ZE concept. Therefore, it identifies factors, principles, strategies, successes and challenges involved in the development of ZEBs and ZEDs. The goal for the literature review is then, to provide a broad knowledge within the contextualization of the Zero Energy topic as well as to serve as input to the conceptual framework.

This literature review is then complemented by an exploration of different case studies, that will serve to answer (Q3). Analysing four important ZEDs this chapter investigate the main drivers of barriers of real projects, moreover, it compares the results of the literature review with the case studies, the goal for this part is then, to identify the existing correlation between the literature and the application in real projects.

Finally, in accordance with the results from the previous chapters, this part, provides valid information to design a holistic, multidimensional framework considering all elements that can be positive for the further development of ZEDs

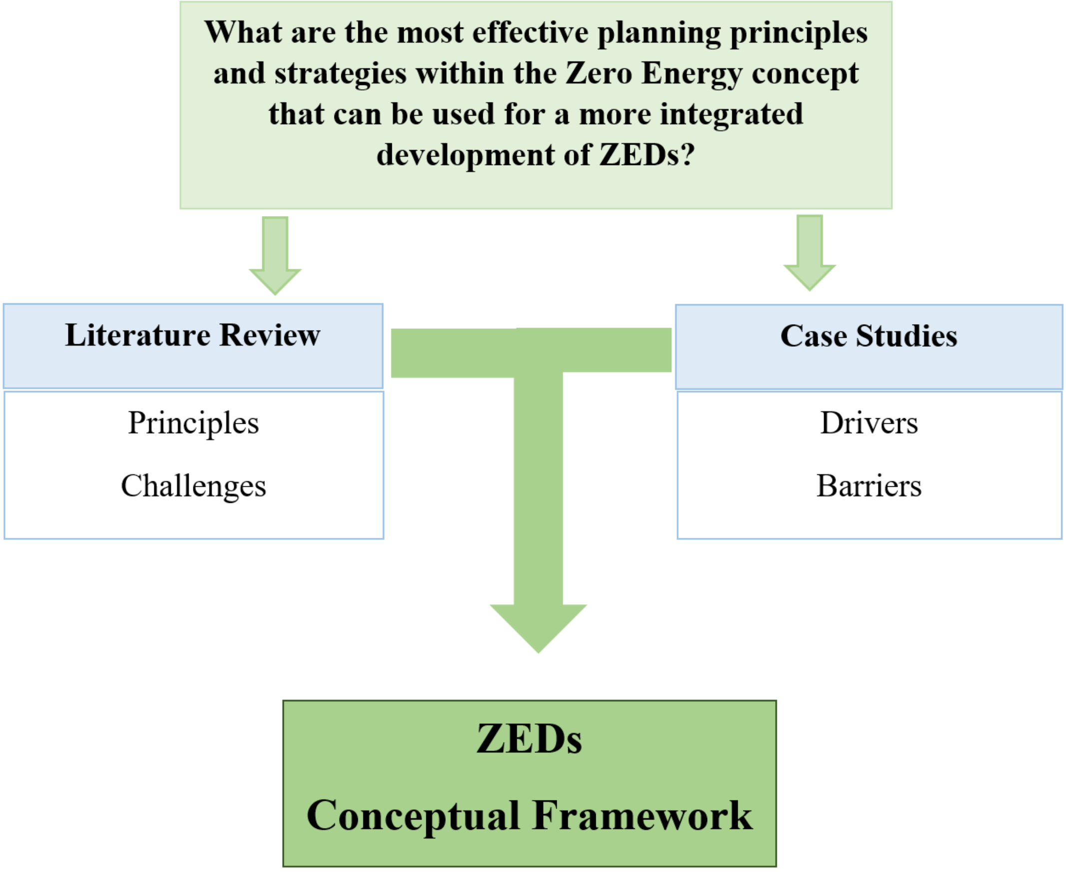

Figure 1. Qualitative research method for ZEDs conceptual framework. Author's elaboration

Chapter 3 Literature Review

This chapter surveys, analyses, and synthesizes scholarly sources and the concepts related to both ZEBs and ZEDs in order to situate this master thesis within existing knowledge and to identify the gaps therein.

3.1 Building sector

Represented broadly by a vast variety of man-made structures which are predominantly build to be shelter for people, these buildings are located in all type of environments around the world, and depending of the type of context, these constructions are made out of different materials, ranging from traditional building materials such as concrete and wood to high-tech building materials such as new insulation materials and photovoltaic (PV) Systems (Valence, 2018). According to the global status report for buildings and construction of 2021 by the UN, the building sector is mainly divided in three categories : Residential, Non-residential and industrial sector(United Nations, 2021).

Residential. Residential sector may be considered as the main area of the industry as it represents the majority of the buildings. These buildings normally are in the form of single family residences and multifamily buildings. Being undertaken by private and public developers. These buildings have a more traditional approach when it comes to building materials.

Non-residential. Depending upon the type of building, non-residential building construction can be procured by a wide range of private and public organisations, including local authorities, educational and religious bodies, retailers, hoteliers, property developers, financial institutions and other private companies. The majority of these buildings tend to use a more modern approach when it comes to use new building materials.

Industrial. Industrial construction includes a range of industrial buildings dedicated to the production and manufacturing process such as power stations and processing plants (United Nations, 2021).

In the UN Sustainable Development Goals (SDGs) 7, 11 and 13, (Clean energy, Sustainable cities and communities, and climate action). The building sector plays an important role in achieving these goals, especially those Within the context of climate change and sustainable energy consumption (United Nations, 2016). Along with industry and transport, according to the IEA, the building sector is one of the largest sectors, accounting for almost 36% of the world's energy consumption (IEA, 2021). When considering the environmental impacts of the energy consumption in the building sector in combination with the growing threats due to urban growth and fossil fuel depletion, the urgency of ambitious and rapid measures to achieve sustainable environments is evident.

This is Particularly important for cities, where the share of build-up area accounts for more than the 50 % of the cities and is even worse for metropolitan cities (Clos J, 2013). Furthermore, more than half of the world's population currently lives in urban settlements and this number is expected to increase to 68% by 2050 (United Nations, 2018). According to the European commission (EC) the rapid grow of cities comes with a great number of challenges, especially those related to a higher demand for energy consumption and emissions (EC, 2021b).

In that context. Districts, which are regarded as a "community within a city, generally with a strong social component, with considerable interaction between members" (Amaral et al., 2018), and considered as "smaller cities" (Barbano & Egusquiza, 2015) have the possibility to provide valid information to make possible the analysis of a complex structure such as of the city. Therefore, the district scale can be considered as an "optimal scale to accelerate sustainability, small enough to innovate quickly and big enough to have a meaningful impact." (EcoDistricts, 2014). In which, the application of integrated district approaches such as, the Zero Energy Districts (ZED) could have positive implications for the future of energy policies.

3.1.1 Energy and emissions

The development of human society is highly dependent upon the use of energy. However, the inappropriate use and production of energy has led to our current environmental problems. Therefore, the proper use of energy is an essential component of sustainable development, which is only possible if our society strive for environmentally friendly, socially acceptable and feasible solutions (Salehabadi et al., 2020). The Building sector in that sense play an important role as part of those solutions, amongst other factors, mainly because energy consumption and CO2 emissions are becoming the main issue to address within the sector (Binicki et al., 2020).

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According to the C40 Cities Climate-Leadership Group, large cities consume two thirds of the world's energy and are responsible for 70% of global CO2 emissions (C40 Cities, 2022). As the number in population growth continue to increase, these emissions are expected to reach levels where an irreversible climate catastrophe would have severe repercussions for the planet (United Nations, 2019). Yet, even with all the measurements and policies applied to prevent further damage to the climate. In the latest report from the Gobal ABC In 2021, it was found that, since 2010 the percentage growth rate of Energy consumption and emissions in the buildings sector are still increasing and until 2019 the CO2 emissions reached their highest level ever (GlobalABC, 2021), as shown in figure 2.

In the period of 2020 and 2021, due to the Covid pandemic and the slowing of growth in building construction, emissions decreased significantly, however, according to the IEA, this reduction is only temporary, meaning that once activities come back to normal, energy consumption and emissions will regain the normal growth rate (IEA, 2021).

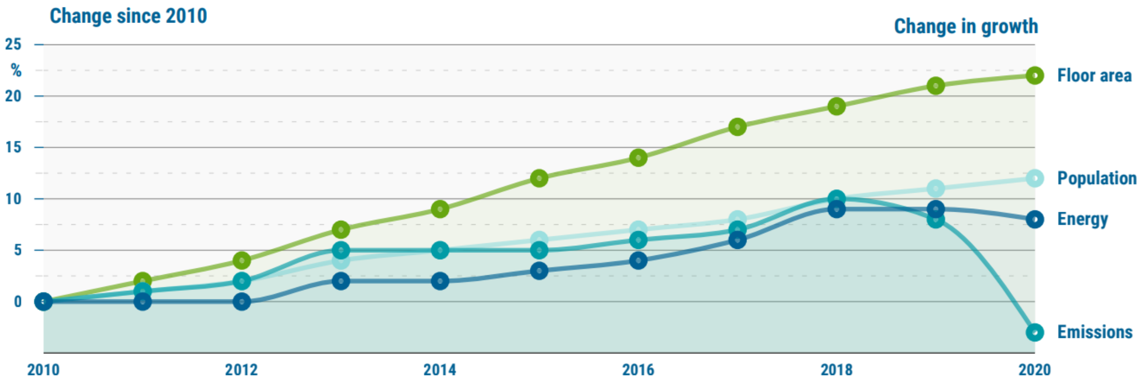


Figure 2 : Change in global drivers of trends in buildings energy and emissions 2010-2020 (IEA, 2021)

Within the current context, energy and CO2 emissions from the building sector are the highest ever recorded (GlobalABC, 2021). Having a Global energy demand of about 127 EJ, which represents a total share of 36 per cent of the global energy consumption. And CO2 emissions from the sector reach levels of almost 10 Gt, which accounted for 37 per cent of the world's total CO2 emissions (GlobalABC, 2021). Additionally, as Urban areas continue to increase, and are expected to host more than two thirds of the world's population by 2050 (United Nations, 2018), the share of emissions has the potential to be higher than other sectors.

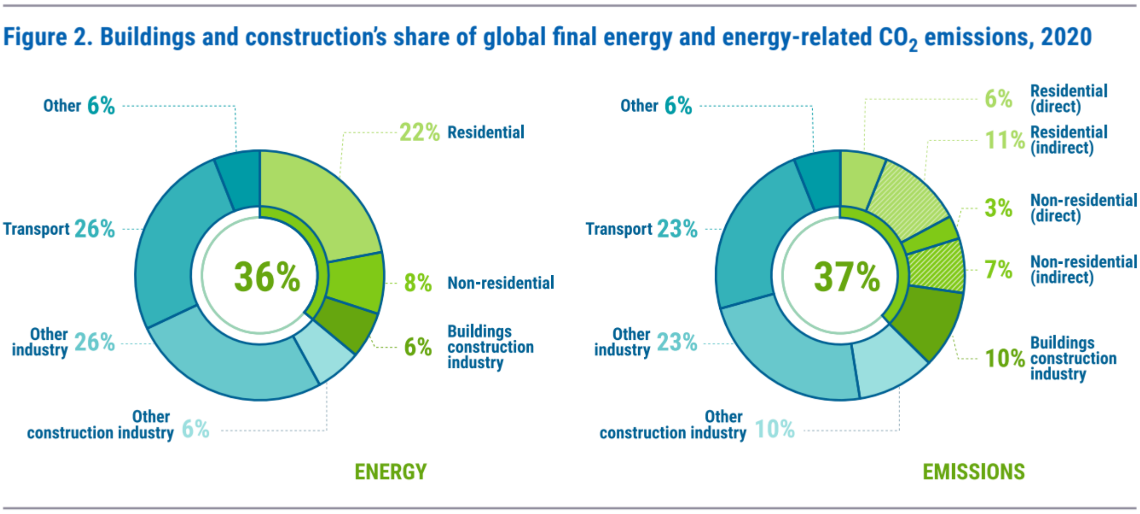


Figure 3. Share of global final energy and related CO2 emissions in the building sector 2020 (GlobalABC, 2021)

The world's climate is changing rapidly due to energy consumption and man-made greenhouse gas (GHG) emissions (IPCC, 2021), Growing concern over the long-term impacts of climate change has incited an active participation among nations on how they manage and consume their resources. Numerous, multiscale efforts to mitigate these impacts are currently in place worldwide, more rigorously in the form of climate policies and regulations (United Nations, 2021). In line with its commitment to the Paris Agreement, the EC has developed an exhaustive framework to make Europe the first climate-neutral continent by 2050 (EC, 2021b). To realize this ambitious goal, the EU shall have cut its GHG emissions to at least 40% of the levels recorded in 1990, have increased its share of renewable energy to at least 32%, and have improved its energy efficiency to at least 32.5% by 2030 (EC, 2021a).

Since the building sector alone accounts for 40% of the world's energy consumption and 36% of its CO2 emissions (GlobalABC, 2021), and if their share in the energy mix is maintained and world population continues to grow, the level of emissions that would be reached would have severe repercussions for the planet (United Nations, 2019). In that regard, the building sector developed a range of measures and strategies that were designed for the short and long term. Many of those which includes significantly the reduction in Energy consumption, GHG emissions reduction and energy efficiency (EC, 2021a). The EPBD, for instance, specific measures to achieve this, includes a mandate that all new buildings must be nearly ZEBs from the 31st of December 2020 (EPBD, 2021). The sector, therefore, plays a crucial role in the combat against climate change and the road towards a Zero emission society.

3.1.2 Renewables and Energy efficiency

The energy transition of the building sector from fossil based to zero-carbon has been considered as one of the main pathway towards a Zero Energy society (GlobalABC, 2021). However, decarbonisation of the energy sector with new technologies such as Carbon capture storage (CCS), may not be a viable solution in the present time due to the economic challenges (Lamberts-Van Assche & Compernolle, 2022). Therefore, while promising new solutions are still in development, more viable and rapid actions are needed to reduce carbon emissions and mitigate the effects of climate change. In that context, renewable energy and energy efficiency measures has been considered as the main solutions towards the decarbonisation of the sectors, as they can potentially achieve 90% of the required carbon reductions (IRENA, 2018). Furthermore, according to the UNFCC 2021, renewable energy generation and energy efficiency improvement are the most frequently referred policy within both, the energy and the building sector (UNFCC, 2021), see figure below.

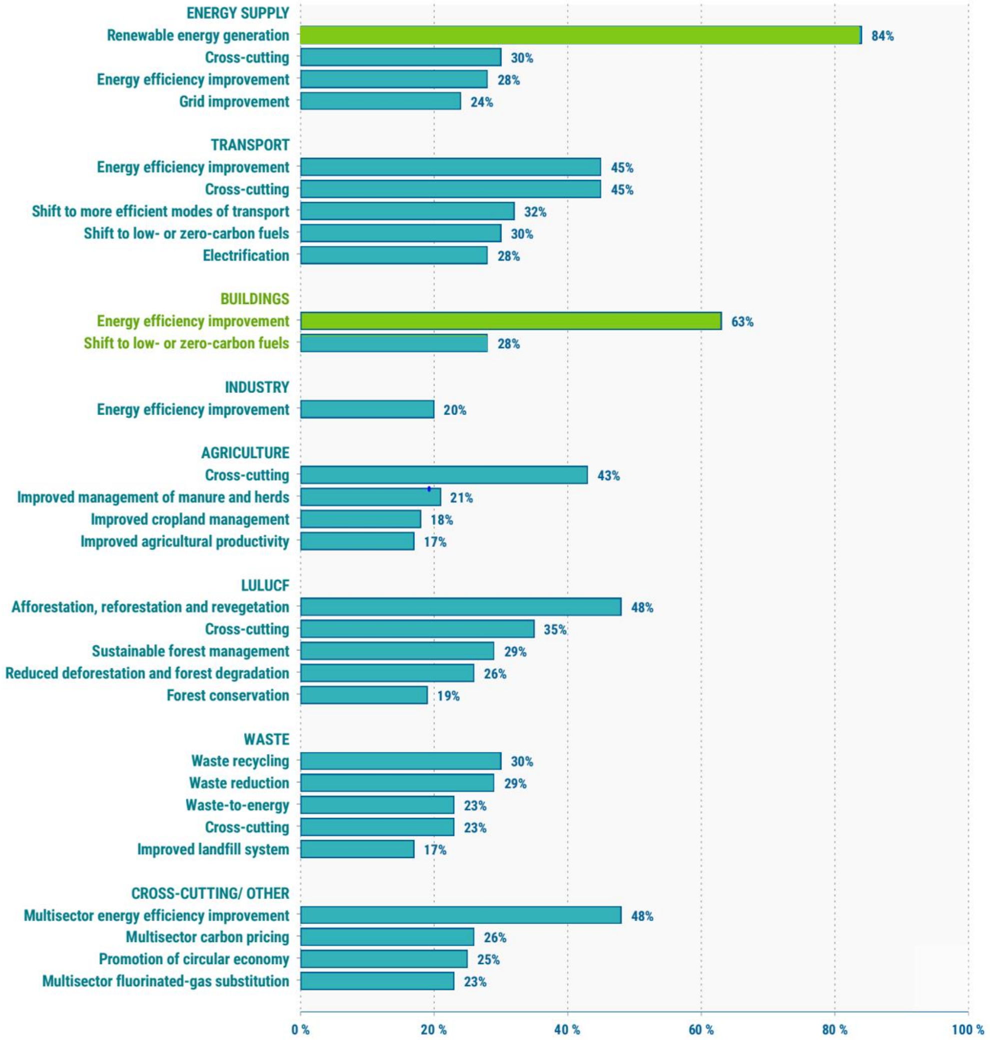


Figure 4. Share of Parties referring to the frequency indicated mitigation options in Nationally Determined Contributions (UNFCC, 2021)

In the IEA's latest report on renewables 2021, it states that, "the growth of renewable capacity is forecast to accelerate in the next five years, accounting for almost 95% of the increase in global power capacity through 2026" (IEA, 2021)**.** According to this report, with the development of new policies and technological improvements, the capacity to produce electricity from solar panels, wind turbines and other renewables is going to drastically accelerate over the coming years, being Solar PV the main contributor of growth in renewable electricity, with its capacity additions forecast to increase by 17% and wind additions are set to be more than triple by 2026 (IEA, 2021).

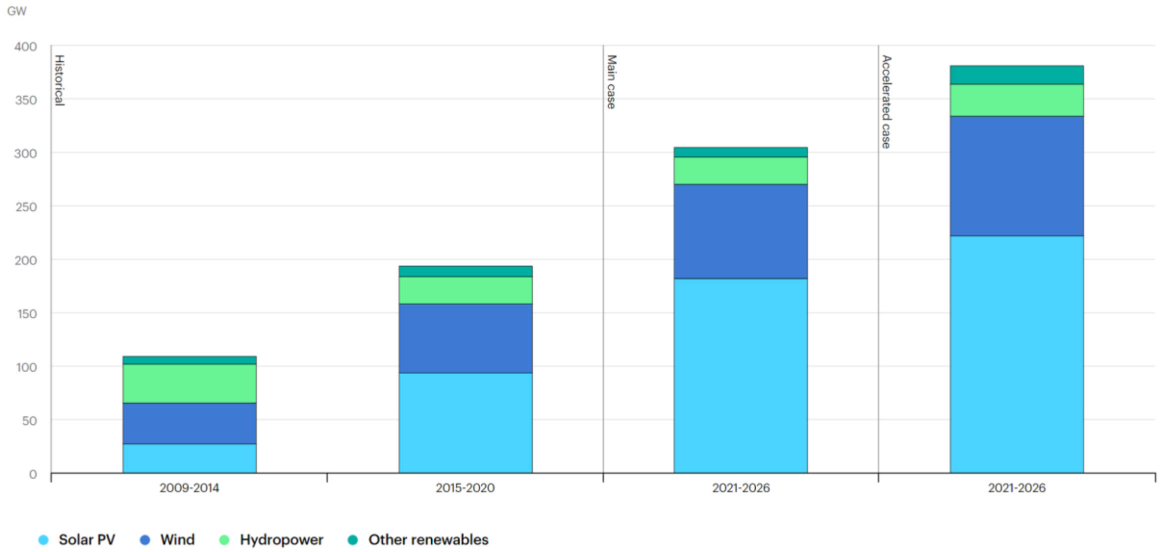


Figure 5. RE capacity growth by technology, main and accelerated cases, 2021-2026 (IEA, 2021)

In the process of transforming the energy systems, energy security is high on the agenda. These developments, however, are part of an even-larger transition towards a low-carbon society, and consequently, Introduction of more variable renewables, such as wind and solar power, must be complemented by solutions that ensure flexibility and energy security (Vitošević et al., 2021). Therefore, in order to achieve a significant reduction in energy consumption and consequently CO2 emissions, the main sectors need to focus on challenges such as, increasing EE and decarbonizing the power system (Jägemann et al., 2013).

Energy efficiency, is broadly defined as "**the minimization of the amount of energy consumed without reducing the product and life quality and performance by preventing existing energy losses. It also covers the use of wastes and aims to use energy resources more** efficiently with advanced technologies and takes various energy recovery measures" (Kaya et al., 2021). In other words, this means the control of energy losses in the different energy sources such as, gas, steam, heat, air, and electricity use without reducing the overall performance of the buildings. According to the EU Energy Efficiency Directive (EED), “EE is the most cost effective way to reduce emissions, improving energy security, enhancing competitiveness and making energy consumption more affordable for all consumers” (Malinauskaite et al., 2020). Therefore, among the main strategies towards low-carbon sustainable buildings, effective energy management (EE) was identified as the central element in achieving the overall goal of reducing energy consumption (Jiang & Tovey, 2009). In that regard, one of the main strategies to increase the energy efficiency in the building sector was made by Ruparathna in 2016, which simplified the approach by broadly defining the improvement of EE under organizational or managerial changes, RE technologies and offsetting methods under technical changes, and awareness under behavioural changes (Ruparathna et al., 2016)

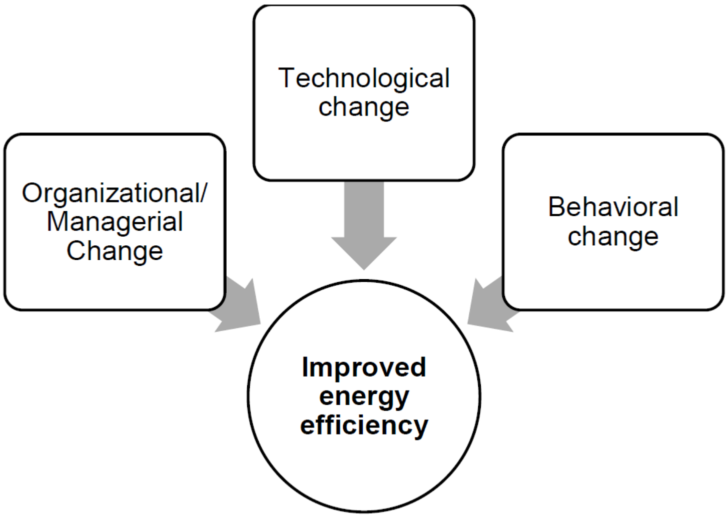


Figure 6. Approaches toward energy efficiency in the building sector. (Ruparathna et al., 2016)

A push towards changing energy systems to approach a zero-emission future is already present in Political goals such as “The Clean Energy for All Europeans legislative proposals” or “The Winter Package” (2016). Within the Goals, the topic of green energy and energy reduction are included and revised by several directives, of which the most relevant are the Renewable Energy Directive (RED) Council (2009) and the Energy Performance in Buildings Directive (EPBD) (2010). The RED requires an increased share of renewable energy. This implies that the **renewable energy production in the sector must increase**. On the other hand, the EPBD is regulating the energy performance of buildings through measures such as energy requirements for buildings, building elements and technical systems. This implies that the **energy consumption in the sector must be reduced**.

As buildings are becoming progressively EE and energy self-sufficient, commitments to develop zero energy and zero carbon emissions buildings are gaining traction. Consequently, certification organizations and Green Building Councils across the world are developing Strategies and goals in order to deliver both, zero Energy buildings and zero energy Districts (GlobalABC, 2021).

3.2 Zero Energy concept

The origin of the ZE concept may have started in 1977, when Esbensen and Korsgaard at the technical university of Denmark studied the solar heating of an experimental residential building in winter, where the main term to describe the project was the "Zero Energy House" (Esbensen & Korsgaard, 1977) .However, the term did not have much attention back then, and it was not until the 2000s that the concept started to be relevant in both research and policymaking due to its demonstrated success in reducing the energy consumption and the CO2 emissions of the building sector (Omrany et al., 2022). A review of the Zero Energy concept within the building sector in the past literature made by Aghamolaei in 2018, confirmed the rise of the concept and further reveals that, the application of the concept is still more prominent at the building level than at the district scale, nevertheless, the study proved that the ZE concept within the building sector is an area of study that is rapidly gaining prominence in both the building and the district scales (Aghamolaei et al., 2018).

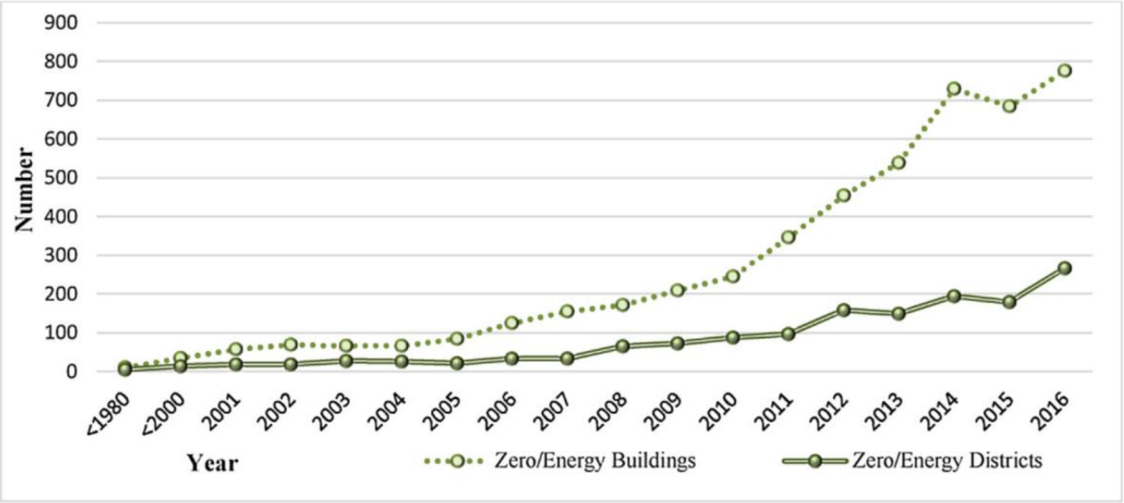


Figure 7. Studies published on the zero energy concept for buildings and districts. (Aghamolaei et al., 2018).

Currently, the concept of zero-energy in the building sector it is still in development and do not have a widely recognised standard definition (IPEEC, 2019). However, as part of the global decarbonisation strategy, the ZE concept must become the primary goal for buildings and districts across all economies. Therefore, Organizations around the world are working with developers, financing organizations, and building users to promote and accelerate the uptake of the zero Energy concept (GlobalABC, 2021).

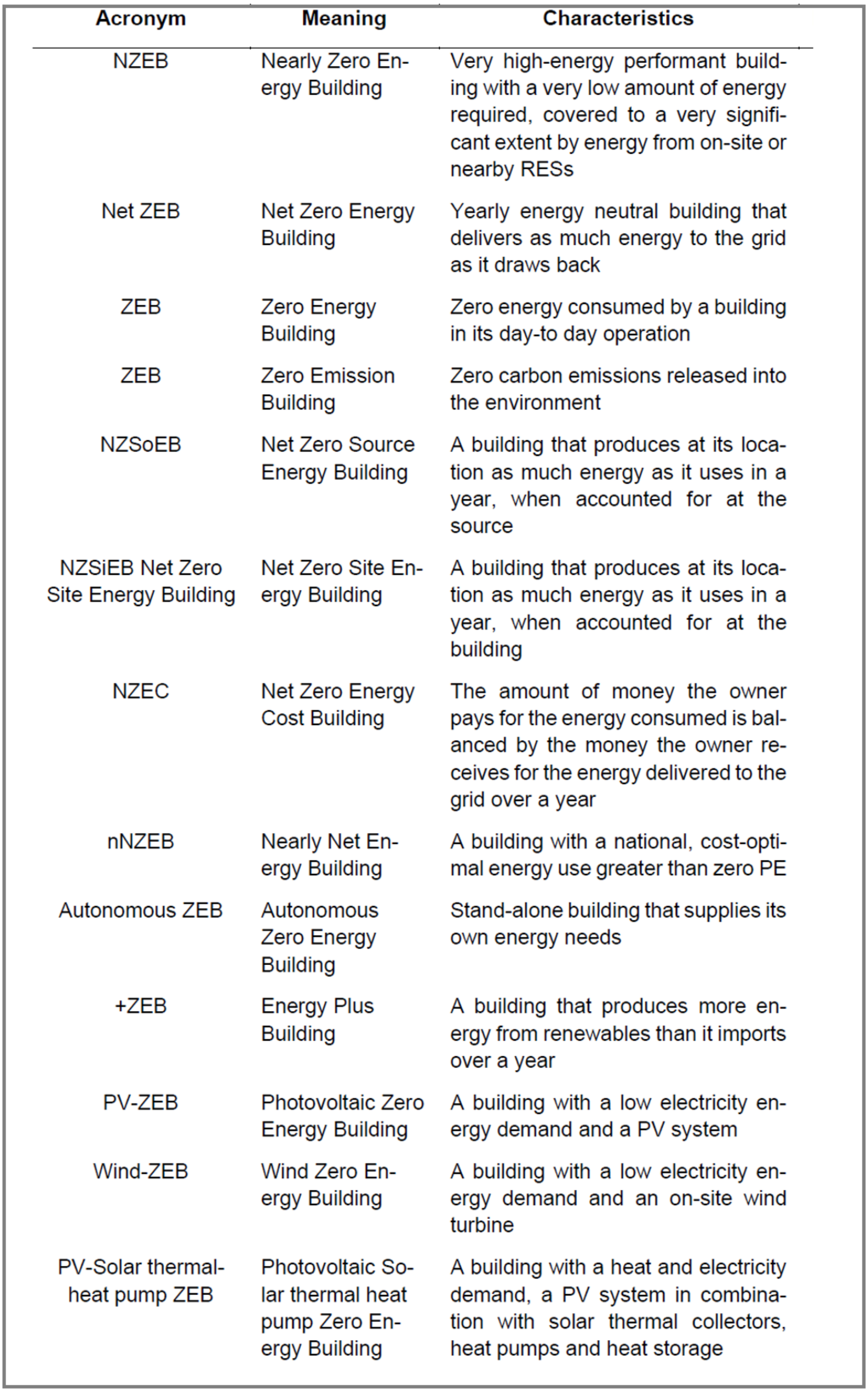
3.2.1 ZE Definitions

Literature on zero energy definitions is currently large with different terms and concepts, as well as attempts from several authors, in that regard, Paul Torcellini 2006, which is one of the most important contributors to the ZE literature, in his definition on ZEBs, he based the definition of ZE concept on four Parameters:

1- **Net Zero Site Energy**: Defined by the amount of consumed and generated energy at a site, regardless of where or how that energy is sourced. the overall summation of the energy consumed must equal zero, which means the energy generated is the same as the energy consumed.
2- **Net Zero Source Energy**: Source Energy is defined by primary energy needed to extract and deliver energy to a site, including the lost energy or wasted energy in the process of generation, delivering and distribution. Which means that it produces at least as much energy as it uses in a year.

3- **Net Zero Energy Cost**: Net Zero Energy Cost is the simplest metric to use. It means that the whole building has a total energy cost of zero during in the period of a year.
4- **Net Zero Energy Emissions**: Net Zero Energy Emissions District is the district that uses no energy that results in emissions or offsets any emissions by exporting emissions free energy; this exported emission free energy should be at least equal to the consumed energy. (Torcellini et al., 2006)

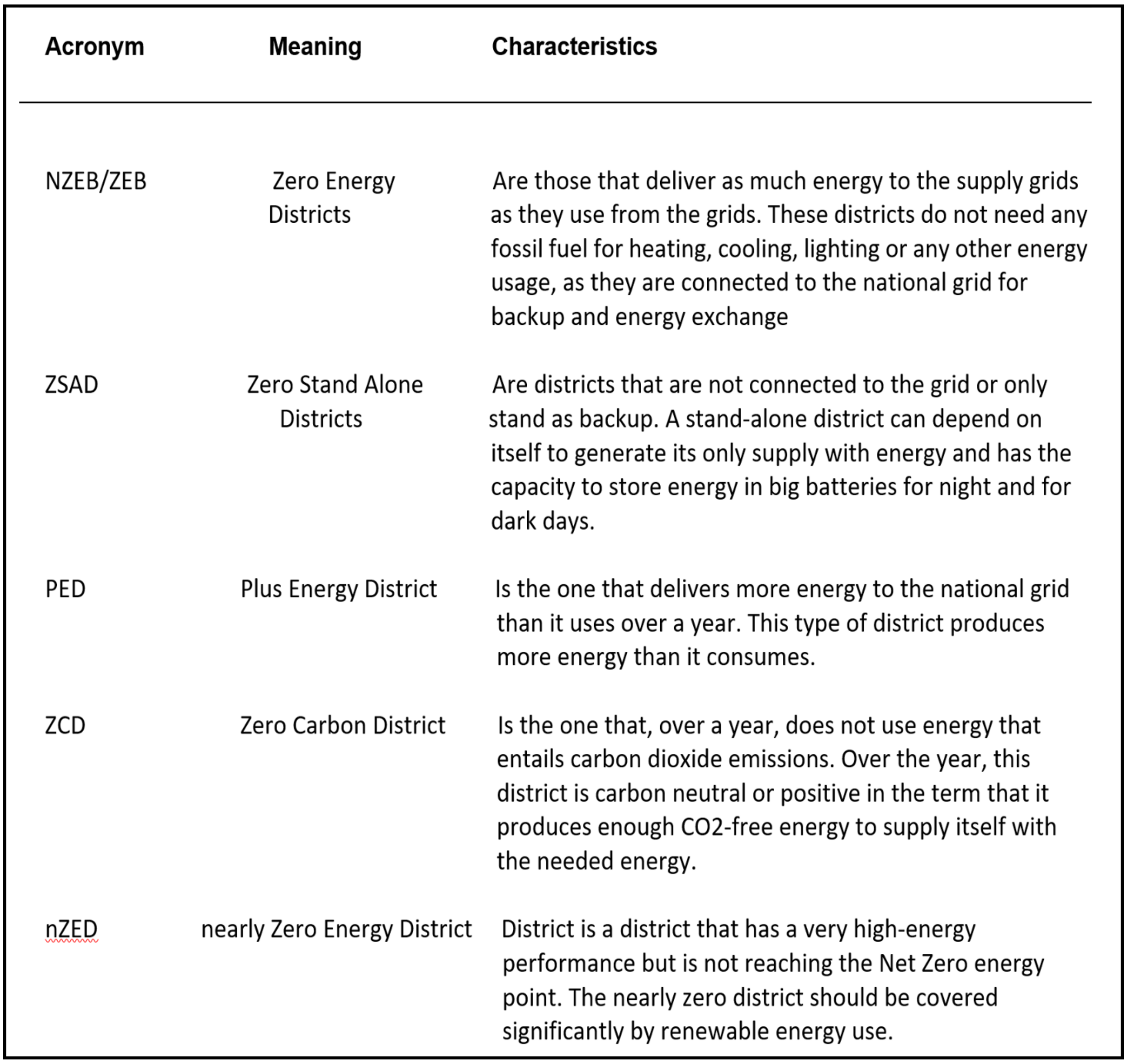
Based on those parameters, there were different types and scales in the definitions, that result with several ZEBs and ZEDs definitions that exist today. D'Agostino and Mazzarella 2018, provides an overview of the main terms that have been launched around ZEBs (D'Agostino & Mazzarella, 2018), as listed in table below.



Acronym	Meaning	Characteristics
NZEB	Nearly Zero Energy Building	Very high-energy performant building with a very low amount of energy required, covered to a very significant extent by energy from on-site or nearby RESs
Net ZEB	Net Zero Energy Building	Yearly energy neutral building that delivers as much energy to the grid as it draws back
ZEB	Zero Energy Building	Zero energy consumed by a building in its day-to day operation
ZEB	Zero Emission Building	Zero carbon emissions released into the environment
NZSoEB	Net Zero Source Energy Building	A building that produces at its location as much energy as it uses in a year, when accounted for at the source
NZSiEB Net Zero Site Energy Building	Net Zero Site Energy Building	A building that produces at its location as much energy as it uses in a year, when accounted for at the building
NZEC	Net Zero Energy Cost Building	The amount of money the owner pays for the energy consumed is balanced by the money the owner receives for the energy delivered to the grid over a year
nNZEB	Nearly Net Energy Building	A building with a national, cost-optimal energy use greater than zero PE
Autonomous ZEB	Autonomous Zero Energy Building	Stand-alone building that supplies its own energy needs
+ZEB	Energy Plus Building	A building that produces more energy from renewables than it imports over a year
PV-ZEB	Photovoltaic Zero Energy Building	A building with a low electricity energy demand and a PV system
Wind-ZEB	Wind Zero Energy Building	A building with a low electricity energy demand and an on-site wind turbine
PV-Solar thermal-heat pump ZEB	Photovoltaic Solar thermal heat pump Zero Energy Building	A building with a heat and electricity demand, a PV system in combination with solar thermal collectors, heat pumps and heat storage

Table 1. The main ZEBs definitions, adapted from (D’Agostino & Mazzarella, 2018)

This definitions could include the same concepts when applied to a district scale, therefore, in order to define ZEDs based on the above mentioned, Lausten suggested the presence of five main definitions (Laustsen, 2008)



Acronym	Meaning	Characteristics
NZEB/ZEB	Zero Energy Districts	Are those that deliver as much energy to the supply grids as they use from the grids. These districts do not need any fossil fuel for heating, cooling, lighting or any other energy usage, as they are connected to the national grid for backup and energy exchange
ZSAD	Zero Stand Alone Districts	Are districts that are not connected to the grid or only stand as backup. A stand-alone district can depend on itself to generate its only supply with energy and has the capacity to store energy in big batteries for night and for dark days.
PED	Plus Energy District	Is the one that delivers more energy to the national grid than it uses over a year. This type of district produces more energy than it consumes.
ZCD	Zero Carbon District	Is the one that, over a year, does not use energy that entails carbon dioxide emissions. Over the year, this district is carbon neutral or positive in the term that it produces enough CO2-free energy to supply itself with the needed energy.
nZED	nearly Zero Energy District	District is a district that has a very high-energy performance but is not reaching the Net Zero energy point. The nearly zero district should be covered significantly by renewable energy use.

Table 2. The main ZEDs definitions adapted from (Laustsen, 2008)

Since the main goal of the different definitions is to obtain a zero balance of the different components, and although, there is not a widely recognised standard definition of the ZE concept, what most definitions have in common are the following elements: **very low energy consumption that aim to achieve zero-energy or zero emissions over the course of a year, where any energy consumed or carbon emitted is offset by using renewable sources, usually at the site, but it can also be done offsite.** Furthermore, within the definitions mentioned, there is the presence the novel concept of Plus Energy (PE), which is the ultimate goal for both ZEBs and ZEDs, however, due to the current and incomplete energy solutions within the sector, the full potential of PEBs and PEDs cannot be exploited (Tuerk, 2021). With that on mind, this research focuses mainly on the concept of ZEBs and ZEDs as the general definitions for the ZE concept in the building sector.

3.3 The scale of the Zero Energy concept

As mentioned before, there are two main areas where the concept has had major impacts on literature, namely, ZEBs and ZEDs.

3.3.1 Zero Energy Buildings

At the building level, the "Zero Energy House" developed by Esbensen and Korsgaard may be perceived as some of the earliest attempts to applied the ZE concept at a building scale. Here, the idea was to meet entirely the heating needs with solar heating systems by reducing the energy consumption during winter through energy conservation arrangements (e.g., highly insulated constructions, heat recovery in the ventilating system, etc.) (Esbensen & Korsgaard, 1977). In that sense, the Zero Energy House was essentially a Zero Energy Building. Since then, what a zero-energy building is and how much have the term been expanded with each and every study, is still uncertain. However, based on the definitions mentioned before, the ZEB is usually presented as the general term that refers to any energy-efficient building capable of generating energy from renewable sources to offset its energy demand (Sartori et al., 2012).

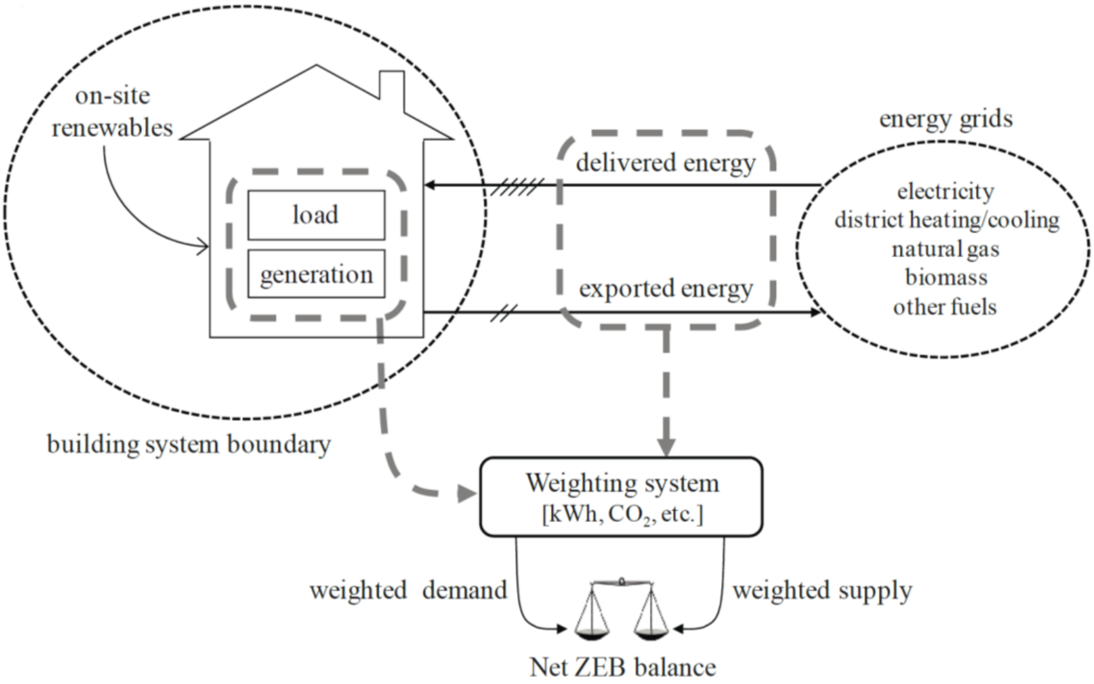


Figure 8. NZEB relevant terminology. (Sartori et al., 2012)

Depending on their connection (or not) with an energy infrastructure. ZEBs may be broadly classified into Off-grid and On-grid ZEBs:

On the one hand, Off-grid ZEBs (also called self-sufficient ZEBs) are buildings that do not require connection to any utility grid, since their capacity to store energy for night time or wintertime use facilitates their autonomous self-supplication (Laustsen, 2008). On the other hand, on-grid ZEBs (also known as grid-connected ZEBs) are connected to at least one energy infrastructure such as electricity grid or pipe networks. In which they have the possibility to purchase energy from and to feed excess energy onto, avoiding in that sense the need for on-site storage (Marszal et al., 2011). Going Off Grid means that the building is completely disconnected from the electric grid or any other network, and must be able to independently produce all the energy they need to power the building during the whole year. On the other hand, On-grid ZEBs are more dynamic in terms of energy distribution. For instance, a net ZEB is essentially an on-grid ZEB, since the word "net", according to Sartori 2012, indicates "a balance between energy taken from and supplied back to the energy grids over a period of time, nominally a year" (Sartori et al., 2012).

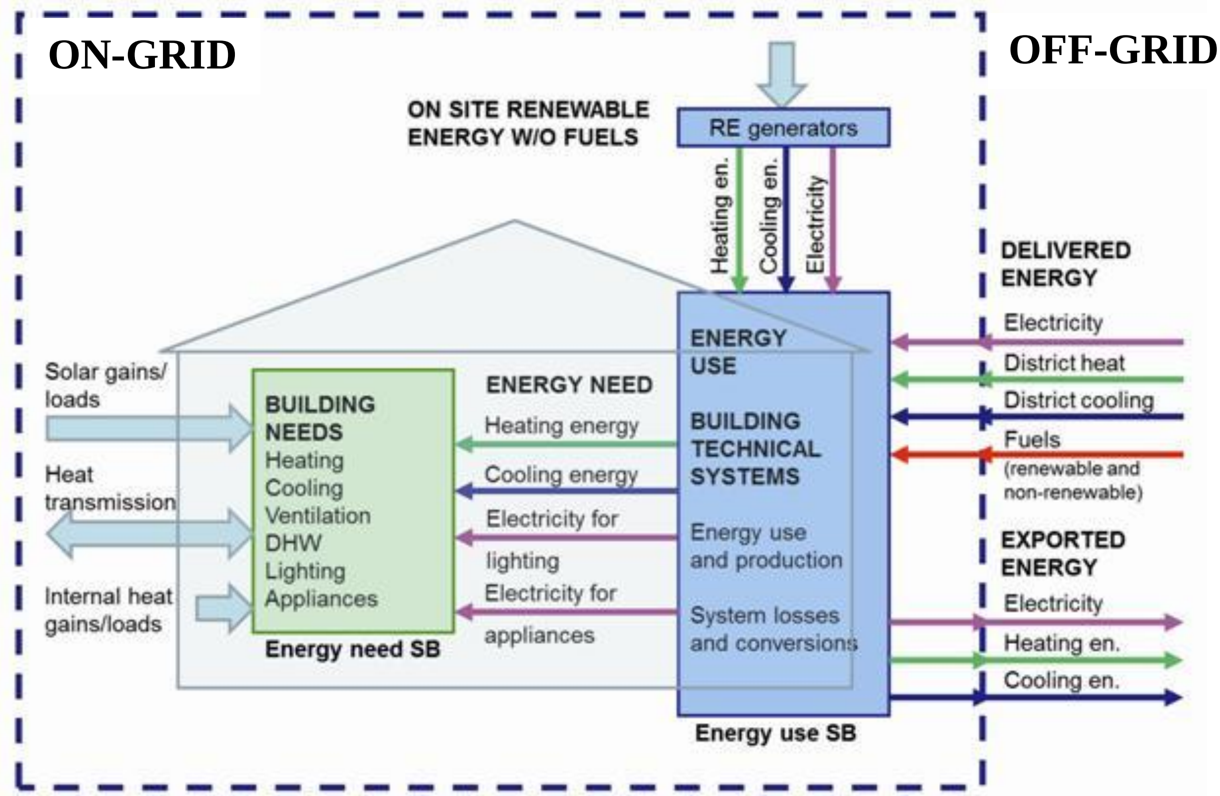


Figure 9. Building site boundary. Off-grid and On-grid energy systems. (REHVA, 2013)

While the goal for an ZEB is simply a neutral result for energy balance over a given period of time, an energy plus or positive energy building (+ZEB/PEB) aims for a net positive balance, where the energy delivered to the grid exceeds the energy imported from it (Salom et al., 2021). The "positive" target, however, requires more clarification on the minimum limits to be considered as PEB. Furthermore, it faces some challenges such as, network regulations and technological constraints, that might affect its extensive realization (Shandiz et al., 2020). The "net zero" target, on the other hand, provides a narrower focus that enables the measurement and verification of actual building performance, but also lessens the achievability of the zero-energy goal (Shandiz et al., 2020). To make this objective more flexible and attainable, a "nearly zero" target is introduced by the EPBD, which somehow takes into account the uncertainties involved in the planning and operational processes. In this sense, The EPBD defines a nearly zero-energy building (nZEB) as "a building that has a very high performance" and whose "nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby." (EPBD, 2021). However, how high the performance should be and how much of the energy demand must be covered by on-site ZEBs are left to the discretion of each context (Pacho, 2021).

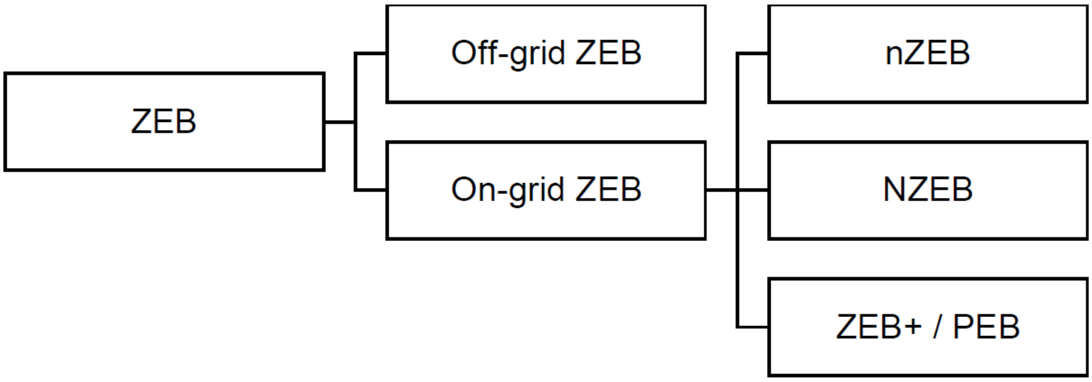
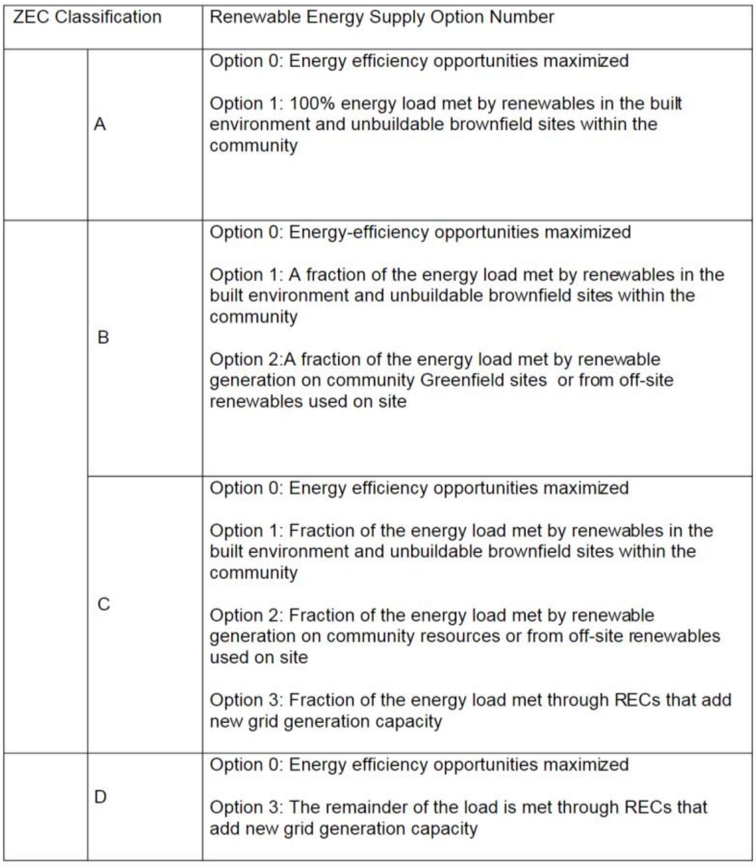


Figure 10. Classification of ZEBs based on grid connection and net balance.(Pacho, 2021)

3.3.2 Zero Energy Districts

While efforts to investigate the applicability of the zero-energy concept at the district level remain significantly less than those at the building scale, attempts toward ZEDs have increased at a rapid rate since 2009 (Aghamolaei et al., 2018). Carlisle 2009, made the first documented attempt to extend the ZE concept to a larger territorial scale in 2009, when they adapted (Torcellini et al., 2006) hierarchy of renewable energy supply options for ZEBs to the community level (Carlisle et al., 2009). The resulting hierarchy became the basis for the classification of Zero Energy Communities (ZECs), which they defined as those with “greatly reduced energy needs through efficiency gains such that the balance of energy vehicles, thermal, and electrical energy within the community is met by renewable energy” (Carlisle et al., 2009). Furthermore, Marique and Reiter in 2014, described three main energy uses at the district level: building energy consumption, the production of on-site renewable energy and transportation energy (Marique & Reiter, 2014). Based on this classification system (Table 4), ZECs that offset their entire energy demand from RE systems available within the built environment and district sites are ranked as the highest (ZEC A), while those that only purchase the energy from Renewable Energy Certificates (REC) to meet their needs are ranked as the lowest (ZEC D) (Carlisle et al., 2009).



ZEC Classification		Renewable Energy Supply Option Number
	A	Option 0: Energy efficiency opportunities maximized Option 1: 100% energy load met by renewables in the built environment and unbuildable brownfield sites within the community
	B	Option 0: Energy-efficiency opportunities maximized Option 1: A fraction of the energy load met by renewables in the built environment and unbuildable brownfield sites within the community Option 2:A fraction of the energy load met by renewable generation on community Greenfield sites or from off-site renewables used on site
	C	Option 0: Energy efficiency opportunities maximized Option 1: Fraction of the energy load met by renewables in the built environment and unbuildable brownfield sites within the community Option 2: Fraction of the energy load met by renewable generation on community resources or from off-site renewables used on site Option 3: Fraction of the energy load met through RECs that add new grid generation capacity
	D	Option 0: Energy efficiency opportunities maximized Option 3: The remainder of the load is met through RECs that add new grid generation capacity

Table 3. ZEC Classification System. Source: (Carlisle et al., 2009).

As an extension of the ZEB concept, a ZED is a group of buildings such as a city district, community, village, cluster of buildings or campus, with a stated goal of achieving zero or positive energy, producing at least the same amount of energy as they demand, and whose reduced energy demand is produced by on-site or nearby renewable energy (Shnapp et al., 2020). Furthermore, as in the case of ZEBs, ZEDs may also be defined and classified based on their grid connection and net balance targets. An off grid ZED requires no connection to any utility grid, while On-grid ZEDs such as, nearly zero-energy district (nZED), a net zero-energy district (NZED), and a plus or positive energy district (+ZEDs/PEDs) are all connected to an energy infrastructure in order to import or export energy when necessary (Shnapp et al., 2020).

As previously discussed in the definition section, the ZED target is a more flexible, realistic, and attainable objective than those targets for PED. This is mainly, because within the current literature, ZEDs can hardly reach a plus balance, since high value energy is dissipated to the environment at a lower value, in accordance with the energy conservation principle (D’Agostino & Mazzarella, 2018). Therefore, the deployment of 100 PEDs in the EU by 2025 (Urban Europe, 2021), remains an ambitious goal given that not all the members can accommodate the drastic changes in energy systems to address the challenges associated with achieving local energy surplus (Brozovsky et al., 2021). Based on these arguments, this master thesis directs its attention towards the ongoing and more mature initiatives on ZEDs. Nevertheless, the development of strategies and principles for ZEDs could serve as a starting point and a prerequisite for the realization of PEDs (Derkenbaeva et al., 2022)

3.2.3 Transition from ZEBs to ZEDs

When it comes to the implementation of sustainable development in the building sector, the focus has started shifting from individual buildings (micro-scale) to districts and cities (meso- and macro-scale) (Askeland et al., 2019). According to Salom 2014, The idea of extending the scale of the concept is based on the belief that sustainable cities are more than just buildings, it includes open spaces, infrastructure and transport (Salom et al., 2014).

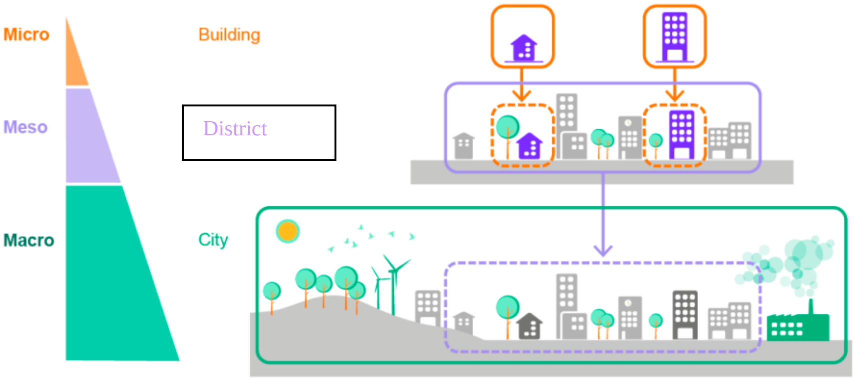


Figure 11. Transition of the ZE concept, from a micro to a macro level, adapted from (Askeland et al., 2019)

By extending the system boundary to several buildings, it is possible to obtain additional benefits as compared to considering individual buildings separately, especially those related to energy sharing (Askeland et al., 2019). When placing a zero or positive-energy objective on a district, the diversity of the energy interplay of the building's different energy performances and production capabilities provides an opportunity to share the neighbourhood's energy needs, costs and resources (Amaral et al., 2018). From an economic perspective, moving from ZEBs to ZEDs allows costs to be reduced through high-energy efficiency and renewable energy technologies. This setup, however, requires holistic and smart planning. Where, EE combined with technologies, such as RE systems, local energy networks and energy storage systems, can offer overall cost-effective solutions (Shnapp et al., 2020).

Furthermore, the ZED approach is able to address concerns raised by individual ZEBs allowing for higher accuracy when measuring energy performance, better managed demand and generation flexibility (Salom et al., 2021). As an example, districts being able to use different energy resources and having more elements to play with, than an individual building. Nevertheless, enlarging the scale of intervention from building to district increases the complexity of the energy performance assessment and design factors (Eržen, 2017). Therefore, a ZED requires that "all stakeholders, including citizens, come together and collaborate in order to develop the best-fit solution for and by the citizens and municipalities in order to play their role in the global climate crisis. With the support of an enabling policy framework, the citizens of the communities should be able to develop their district concepts themselves" (Askeland et al., 2019).

3.4 Zero Energy Principles

Developed by Andresen in 2008, the Kyoto pyramid is one of the most used principles in order to save energy. According to the Pyramid there are 5 general steps (from the bottom of the pyramid to the top), that should follow:

1. Reduce the heat losses by minimize the heating demand: super insulated- and air tight building envelope, minimized the thermal bridge and use effective heat recovery ventilation.
2. Reduce the electricity consumption to avoid energy waste by exploitation of sunlight to take advantage of solar heat and -light, use energy efficient electric devices: lights, pumps or fans, and low pressure drops in the pipes or ventilation air paths.
3. Utilize the “free” solar heat and -light by optimum the window and building orientation, proper use of thermal mass, solar collectors and PV cells.
4. Show and control the energy usage by using use-and-control devices, “smart” technologies: energy watch to show the correlation between the electricity usage and the resident living style, different profile schedule to control heating demand, ventilation system, lightning and electrical equipment when it is needed.
5. Choose local energy source and carrier: E.g. district heating (DH), natural gas, biomass and geothermal heat pump. (Andresen et al., 2008)

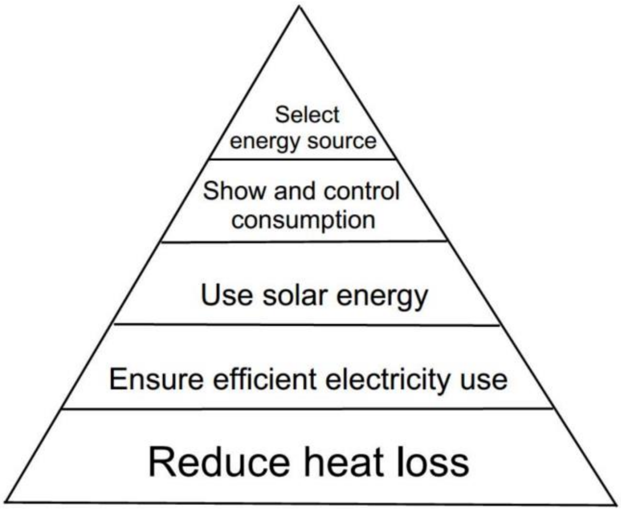


Figure 12. Kyoto pyramid steps to save energy in buildings. (Andresen et al., 2008)

The IEA, on the other hand, on its report on Modernising Building Energy Codes to Secure our Global Energy Future, makes a distinction between energy *sufficiency* and energy *efficiency* measures, with the former designed to reduce the need for energy services and the latter to reduce the amount of energy needed to generate these services (IEA, 2013).

Buildings, however, are just only of the factors upon which these principles or measures may be applied. According to Ratti (2005), energy building performance depends on (1) the climate, (2) urban geometry, (3) building design, (4) systems efficiency, and (5) occupant behaviour, being the last four factors, the only ones that can be designed and manipulated by humans (Ratti et al., 2005). In that regard, Bourdic and Salat suggested that these "four fundamental scales" could be leveraged to improve urban energy efficiency by following the order specified in their diagram (Bourdic & Salat, 2012), ideally.

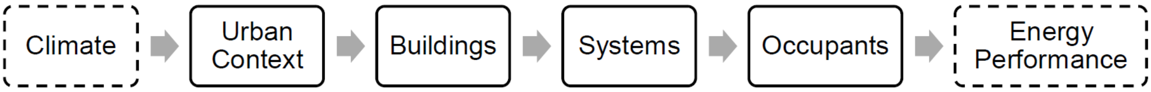


Figure 13. Four fundamental scales affecting energy performance. Source: (Bourdic & Salat, 2012)

Based on the literature presented, the following sections elaborate on the central energy principles of ZEDs**: Energy conservation (passive and active), renewable energy systems (RES) and grid connection.**

3.4.1 Energy Conservation (Passive) and Energy Efficiency (Active)

As presented in this thesis, the conservation of energy is an essential component for the success of ZEDs. Furthermore, saving energy is almost always easier and cheaper than producing energy (Torcellini et al., 2006). Based on the literature on the Zero energy concept, There are two main ways to reduce the energy consumption**: maximize energy conservation through passive systems, and energy conservation through the EE of active systems** (Brozovsky et al., 2021; D'Agostino & Mazzarella, 2018; Ferrara et al., 2019; Sartori et al., 2012; Torcellini et al., 2006). In most literature on ZEBs, passive energy conservation measures are often incorporated under energy efficiency. However, Passive energy conservation methods such as, ventilation, orientation and building insulation means that less energy is required in the first place. Energy efficiency, on the other hand, means that active systems (all systems that require energy to operate, e.g. artificial lighting) are designed to operate with the least amount of energy possible.

To minimize a building's energy demand and carbon impact, passive systems are the most effective way of saving energy (Brozovsky et al., 2021; D'Agostino & Mazzarella, 2018;

Torcellini et al., 2006). Passive control measures focus mainly in the utilization and optimization of the free energy coming from nature, and although, the energy demand of these systems is unlikely to be covered entirely by passive design, the optimization of passive solutions can substantially lower the energy demand of active systems (Brown, P., 2010).

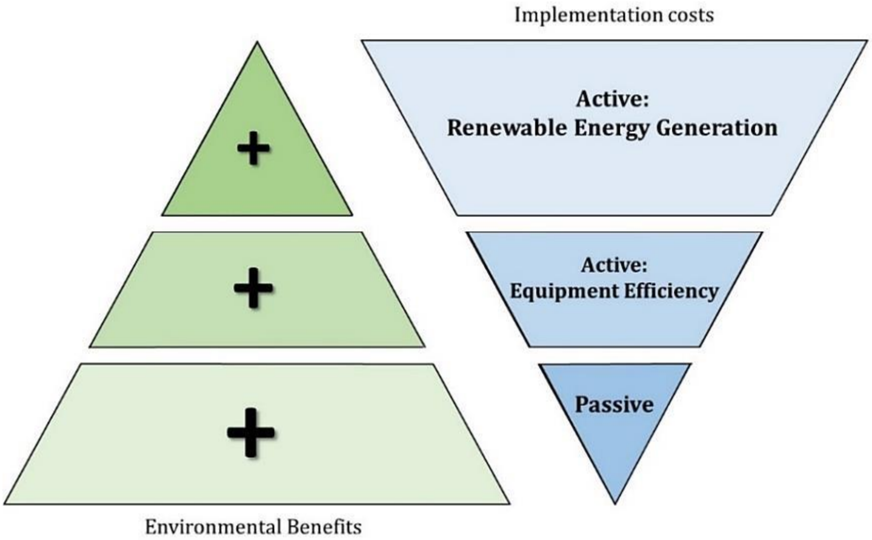


Figure 14. Relation between the environmental benefits and the implementation costs of the ZE principles (Brown, P., 2010)

Passive energy conservation

According to the IEA 2020. Space heating and cooling requires the most energy of all other energy end-uses in buildings (IEA, 2020). Therefore, In order to reduce the energy consumption coming from heating and cooling, Passive energy conservation systems are the first step to reduce the energy usage coming from heating and cooling (Zhang, 2011).

In this regard, the insulation of the building's envelope is the first step to reduce the heating and cooling demands of buildings. Furthermore, passive solar heating systems such as, orientation and solar protection are as well passive solution to reduce heating-related energy demands (Anderson & Michal, 2003). Passive ventilation measures include wind-driven ventilation, buoyancy-driven ventilation (driven by forces from temperature differences) and night cooling ventilation. An example of passive air-conditioning is the humidification of the air in a building through building integrated vegetation and water bodies in the building (Mandala & Das, 2020). The energy demand for lighting can be as well be passively reduced by the optimization of daylight. Choosing the orientation, form and size of the building's windows to optimize daylight can reduce positively the energy demand for lighting (Robbins, 1980).

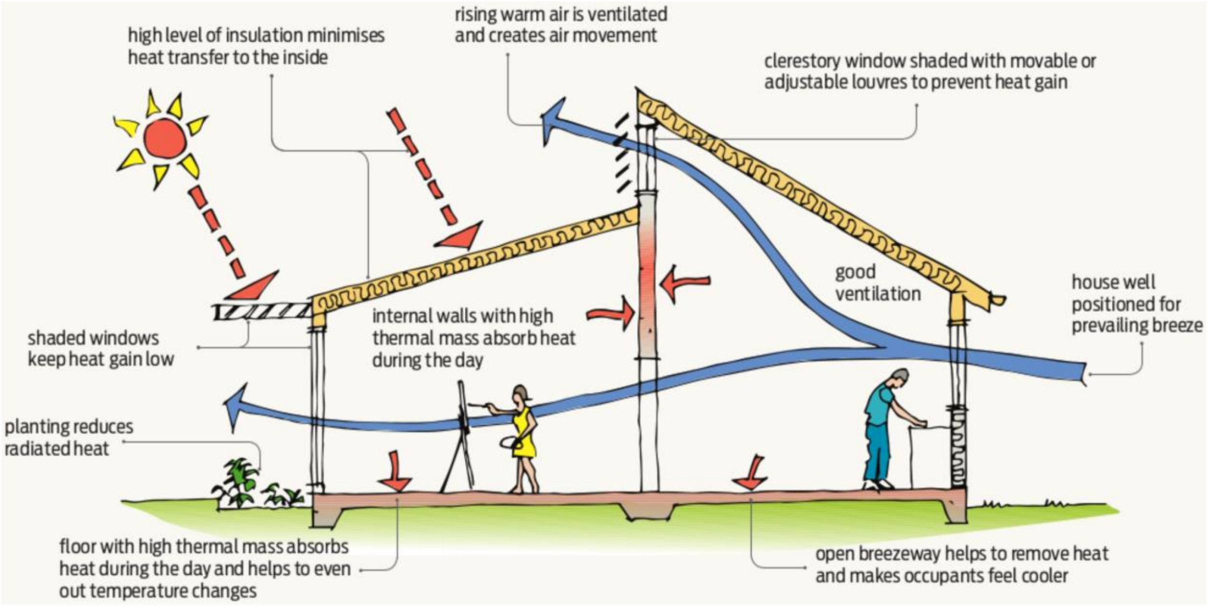


Figure 15. Passive design strategies (Lewis & Barrow, 2018)

These are only a few examples of passive measures that require little energy and little investment to generate substantial energy savings and environmental benefits. The definition below developed by Ansems in 2018 provides a general definition for passive energy conservation. **“Passive energy conservation entails the utilization of natural forces (e.g. sunlight and airflow) and optimization of the building’s design (predominantly insulation of the envelope) to not require any energy besides ‘free’ natural energy to operate. Integration of passive systems diminish the energy demand of active systems, therefore leading to energy conservation**” (Ansems, 2018).

Active energy conservation

Active systems are all systems that require energy to operate. Active systems therefore also entail systems and appliances that are aimed at energy conservation, but require energy to do so. Solar power generation systems, storage batteries and geothermal air-conditioning systems are therefore included in active systems (Xin & Rao, 2013). Lighting, plug loads, computer systems and other equipment and installations are also part of the active energy conservation system. Therefore, increasing the energy efficiency of these systems is the key for smart Districts (Abdullah et al., 2019).

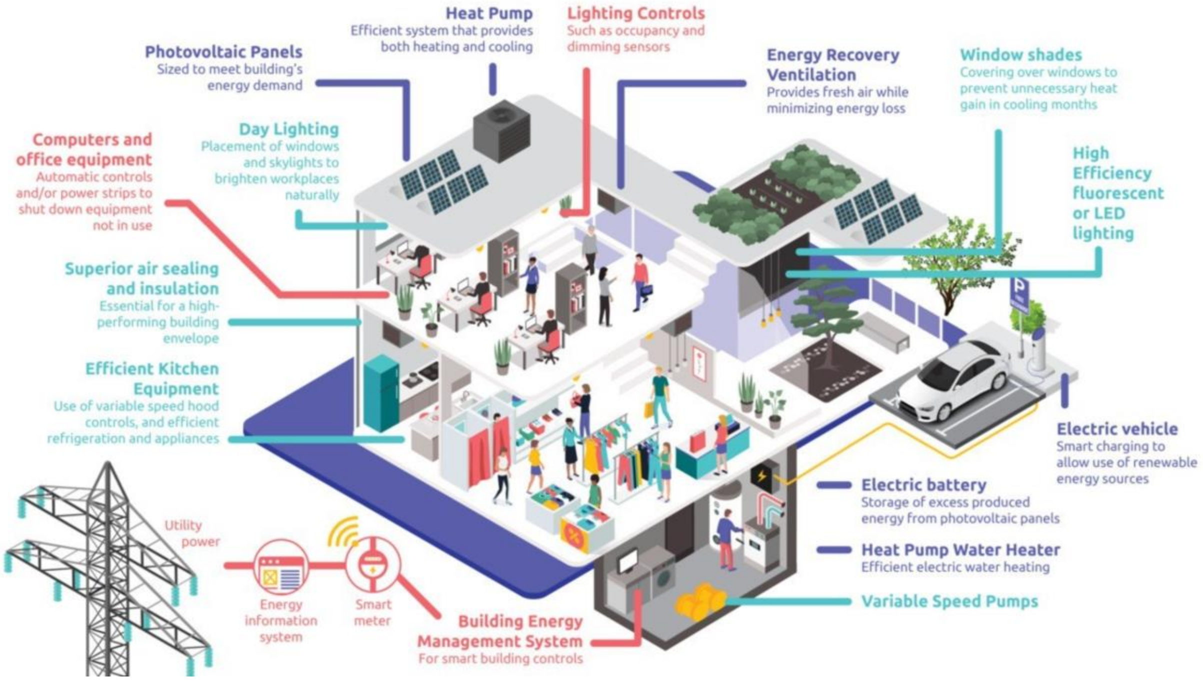


Figure 16. Active Energy conservation systems (Sustainable buildings and cities, n.d.)

As often referred by literature, active energy conservation systems are part of the energy efficiency. In this regard, there are various definitions of energy efficiency.
Simpler and more general definitions of energy efficiency as found online are:

- Energy efficiency means using less energy to provide the same service (Wikipedia, 2022).

-From the building perspective, according to Meier 2002. A building can only be defined as being energy efficient if it contains the following elements: EE technologies that effectively reduce energy use. When operating as designed; the building must supply features appropriate for that kind of building; and the building must be operated in such a manner as to be efficient (evidence of this is low energy use relative to other similar buildings) (Meier Alan, 2002).

-From the urban perspective, Olughu 2021, defines Energy efficiency as the ability to capitalize on new technologies and equipment to do same work with less energy (Olughu, 2021).

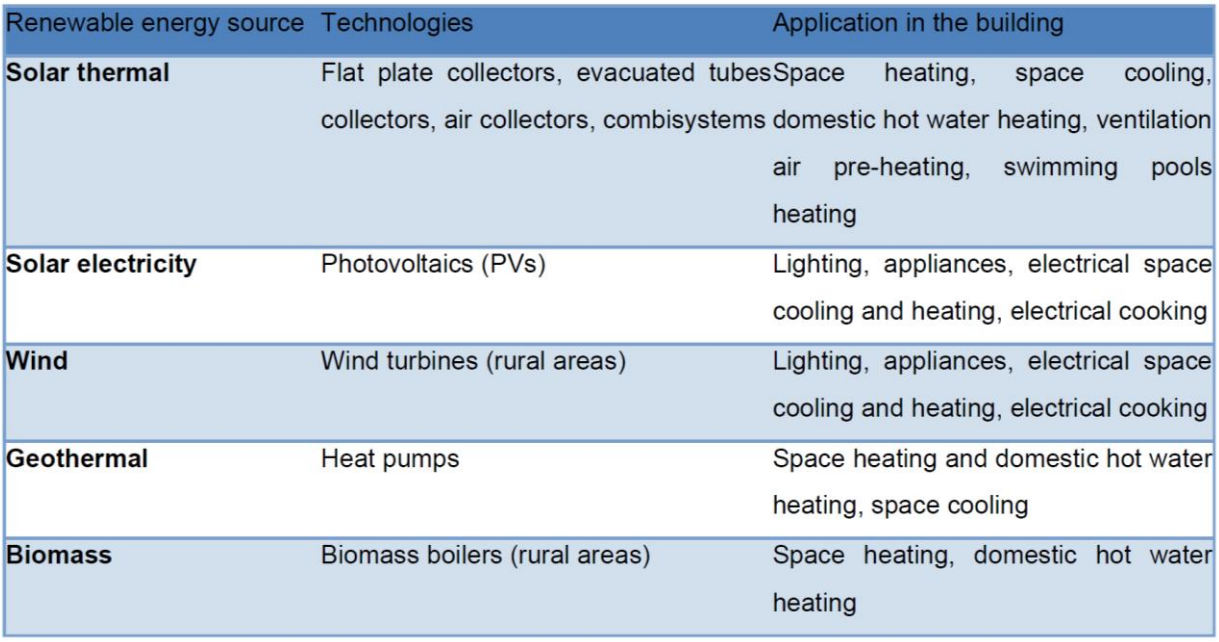
Although there are more definitions regarding energy efficiency, a more general definition provided bellow described, Energy efficiency as "**the minimization of the amount of energy consumed without reducing the product and life quality and performance by preventing existing energy losses. It also covers the use of wastes and aims to use energy resources more efficiently with advanced technologies and takes various energy recovery measures**" (Kaya et al., 2021).

To emphasize the difference between energy efficiency (active energy conservation systems) and passive conservation systems. It is important to point out that passive conservation systems are designed strategies that comes before the application of any energy efficiency measures. Furthermore, maximizing energy efficiency measures before the installation of renewable energy generation systems has been identified as the fundamental strategy toward ZEBs given that On-site renewable energy supply options are often limited (i.e. due to the limited surface area for solar systems), especially in high-rise buildings and in the refurbishment of existing ones (Sartori et al., 2012). This limitation, however, can be effectively reduced by adopting a district approach to zero-energy (D'Agostino, 2015), where the aggregation of resources, costs, and requirements permits the flexible utilization of different levels of energy performance and energy production capacity (Sougkakis et al., 2020).

3.4.2 Renewable Energy Penetration (REP)

Once the energy demand has been minimized through the application of the energy conservation methods from above. The remaining energy demand needs to be covered by the production of RE.

RE can be generated on the district site, in public areas such as, parking lots, or renewable energy systems can be also integrated into the building structure. The most common on-site renewable energy generation systems include photovoltaic (PV) panels, solar water heating, ground source heat pumps and wind turbines (Torcellini et al., 2006). Wind turbines, however, need specific planning permission and can only be established if the site is large enough and noise and visual complications have been taken into consideration (Mohammed, 2012). On the other hand, solar energy is one of the most important renewable energy sources in ZEB (Attia, 2018). Design considerations related to PV-panels are the building's orientation (large southern exposure in the Northern Hemisphere and northern exposure in the Southern Hemisphere), Urban morphology, shading (e.g. from other structures, especially in the urban context) and the inclination of the PV system (Attia et al., 2017).



Renewable energy source	Technologies	Application in the building
Solar thermal	Flat plate collectors, evacuated tubes collectors, air collectors, combisystems	Space heating, space cooling, domestic hot water heating, ventilation air pre-heating, swimming pools heating
Solar electricity	Photovoltaics (PVs)	Lighting, appliances, electrical space cooling and heating, electrical cooking
Wind	Wind turbines (rural areas)	Lighting, appliances, electrical space cooling and heating, electrical cooking
Geothermal	Heat pumps	Space heating and domestic hot water heating, space cooling
Biomass	Biomass boilers (rural areas)	Space heating, domestic hot water heating

Table 4. Main RE systems in the building sector (Chanchpara, 2019)

For the case of the on-site RE production, this means that, the RE needs to be generated within the District site. Additionally, this definition also allows for the import of off-site renewable energy sources, as long as they are used to generate energy within the building site (Hermelink et al., 2013). Off-site RE sources include wood pellets, ethanol and biofuels. These are imported to the ZED from off-site locations, yet, they are used to produce energy on-site (Marszal et al., 2011). This energy is mainly used to provide space heating and water heating. The final option for renewable energy is to purchase green energy that comes from renewable sources such as wind power or utility PV systems that are available on the electrical grid. Torcellini (Torcellini et al., 2006) provide a ranking for renewable energy sources according to the level of application option.

Option Number	NZEB Supply-Side Options	Examples
0	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
	On-Site Supply Options	
1	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
2	Use renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building.
	Off-Site Supply Options	
3	Use renewable energy sources available off-site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off-site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
4	Purchase off-site renewable energy sources.	Utility-based wind, PV, emissions credits, or other "green" purchasing options. Hydroelectric is sometimes considered.

Table 5. Ranking of preferred application options of renewable energy sources (Torcellini et al., 2006).

3.4.3 Grid Connection

In the case of ZEDs not being able to meet their energy demand with the On-site RE, they are supposed to meet this requirement from non-polluting and renewable resources from outside the district area. Therefore, achieving a ZED status without using the energy grid is complicated. For instance, Most PEBs are connected energy grid. Mainly because when the building's (renewable) energy production exceeds the building's energy demand, the excess energy is exported to the utility grid (Torcellini et al., 2006). In that sense, the excess in energy production delivered to the grid compensates for the periods of excess demand; hence resulting in an energy balance.

Without grid connection, excessively generated renewable energy can therefore not be used to offset later energy use. Rather, it would be wasted due to lack of storage technologies of renewable energy. Grid connection is therefore inevitable for ZEBs (Goch et al., 2017) at least until technology advances and allows for better energy storage systems. According to Gabbar 2017. The energy grid usually consists of electricity, district heating and cooling, natural gas, biomass and other fuels (Gabbar, 2017). Therefore, based on the origin of the local grid, energy grid supply can be both beneficial or detrimental to the ZEDs.

3.5 Main challenges

3.5.1 The political context

Despite the vast efforts of legal instruments supporting the implementation and consolidation of both ZEBs and ZEDs, the lack of a commonly agreed framework for the definition and calculation methodology of the ZE concept is still one of the main challenges that inhibits the progress towards ZEBs (Marszal et al., 2011). To address this first issue, Sartori 2012, proposed a consistent framework for setting ZEBs definitions, which they claimed as suitable to serve as a basis for regulations and national policies (Sartori et al., 2012). This framework took into account the seven parameters that Marszal 2011, identified as necessary in order to establish a general ZEB definition, these parameters include: (1) the metric of balance, (2) the balancing period, (3) the type of energy use included in the balance, (4) the type of energy balance, (5) the acceptable RE supply options, (6) the connection to energy infrastructure, and (7) the requirements for energy efficiency, indoor climate, and building grid interaction(Marszal et al., 2011). Together they reflect the main arguments around ZEB definitions (Sartori et al., 2012). Furthermore, in D’Agostino’s assessment of the progress toward the establishment of ZEBs definitions, it was found that a coherent definition was still lacking, thereby making the nZEB concept difficult to implement in construction practices and routines, especially in the refurbishment of existing buildings (D’Agostino, 2015).

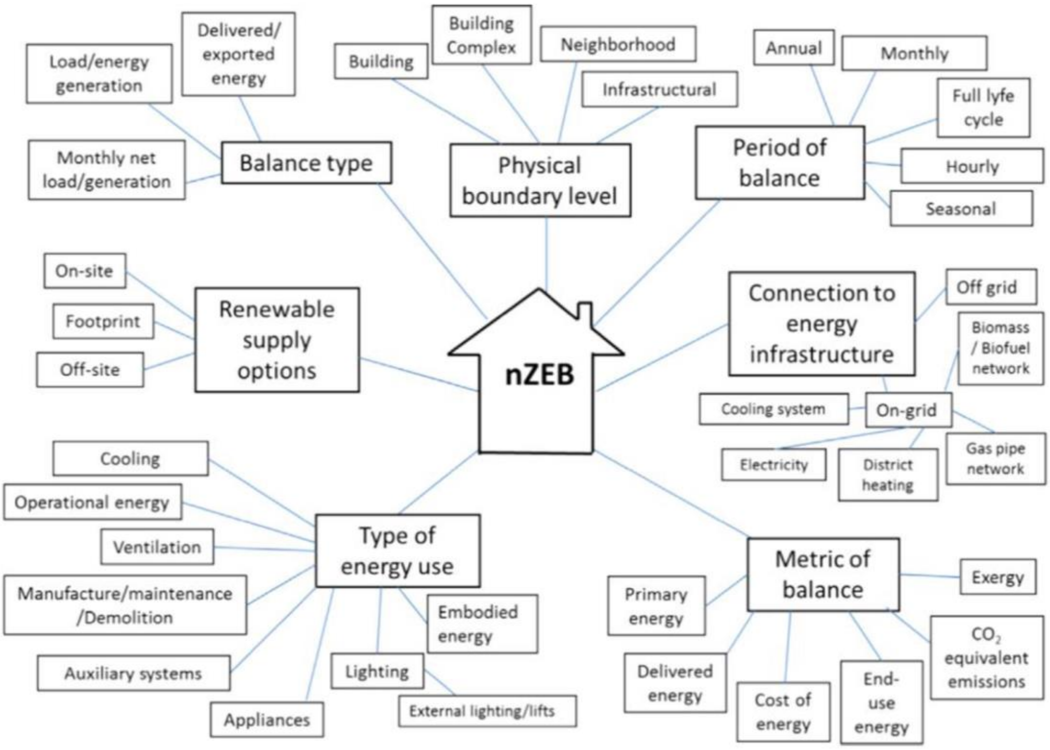
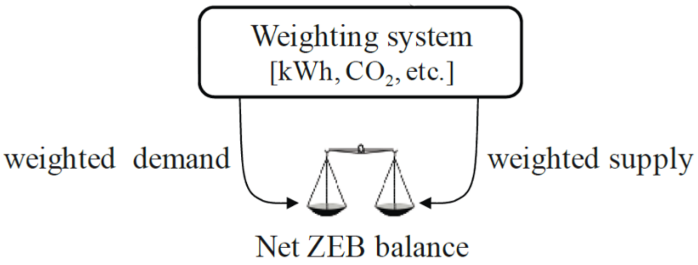


Figure 17: Main arguments around nZEBs that must be settled before establishing a common and consistent definition. (D'Agostino, 2015)

On top of the adaptation of a common and general definition, the full integration of the ZEB concept in national building codes and international standards represent the challenge of a standardized procedure to compute the energy balance (Marszal et al., 2011). Sartori 2012, attempted to address this issue by proposing a calculation based in the balancing off of the weighted demand by the weighted supply over a period of time (Sartori et al., 2012), described in the Diagram bellow.



$$|weighted\ supply| - |weighted\ demand| = 0$$

Figure 18. Energy balanced diagram. (Sartori et al., 2012)

The weighted demand refers to the sum of all delivered energy (or load), while the weighted supply pertains to the sum of all exported energy (or generation), both of which are obtained by adding the weighted values of energy for each carrier (Sartori et al., 2012). National and regional policies for NZEB would therefore be the most effective legal instruments. However, as Attia 2017 notes, national authorities lack strategies and local authorities lack governmental support to create an infrastructure for the implementation of NZEDs (Attia et al., 2017).

To further complicate the challenges in policy implementations and ZEB market uptake on a global scale, the EU and U.S. differ in their approach to NZEB. These differences complicate the evaluation of global progress towards NZEB and create confusion for other countries that are considering to set similar goals (Zhang, J, 2015). The EU pursues ‘nearly ZEBs’ (nZEBs) and most commonly uses the zero source energy approach. The US on the other hand pursues ‘Net ZEBs’ (NZEBs) and predominantly applies the site-energy metric (Zhang, J, 2015).

3.5.2 The economical aspect

Due to the novelty and high performance of this new technology, the initial economical cost of ZEBs are often seen as the main obstacle hindering the uptake of the concept (Hu, 2019), therefore the economic incentives are a key issue in addressing the development of ZEDs (Krangsås et al., 2021). . In this regard, governments already have a variety of options for creating incentives in order to support or subsidize the installation of renewable energy equipment, including discounts on purchasing equipment, tax incentives, expedited permitting and others (Cox, 2016). Incentives can also be used by the private sector to encourage cities, housing associations, households and companies to implement ZEDs. At the same time creating additional local jobs in energy business, improving air quality, benefitting public health and preventing energy poverty (Lelieveld et al., 2015).

Generally ZEDs are more expensive than traditional projects and the main barrier for this development is the access to adequate funding and business models (Bossi et al., 2020). Yet, ZEDs also hold the potential for fostering economic sustainability by being cost efficient and self-sufficient. In that regard, Salom 2021, proposed the following categories of indicators in order to track and reflect the savings from the building level to a neighbourhood scale: capital costs, operational costs and overall performance.(Salom et al., 2021)

In Norway, for instance The establishment of research centres on zero emission buildings and neighbourhoods (the ZEB and ZEN research centres) is financed by the Ministry of Petroleum and Energy. This is initiated to spur the development of technologies and solutions through research in close collaboration with business as well as public partners (Backe & Kvellheim, 2020) . Through the administration of the Energy Fund, Enova is responsible for incentives addressing increased energy efficiency/-production, reduced emissions and reduction in peak load. Enova has support schemes that offer support to private and professionals and is organized as a public enterprise under the Ministry of Climate and Environment (ENOVA, 2022).

3.5.3 The Technological aspect

One of the main challenge in this area is the one cornering the efficiency of renewable energy systems. Currently, the conversion energy efficiency for PV systems and Wind turbines are between 20% and 40% respectively (Fowsiya et al., 2022). Nevertheless, most of the technologies at these stage are still in development in an upward trajectory as far as improving the efficiency is considered, if this continuous, the conversion efficiency for all renewable technologies have the potential to provide over 90% of the mitigation needed in the energy system by 2050 (IRENA, 2017).

Another important challenge associated with high-performance buildings is the performance gap which is represented by the difference between the intended performance of the building and the actual performance of the building (Attia et al., 2017). Furthermore Attia 2018, summarizes challenging factors that result in the performance gap as being the “source of our greatest difficulties and stresses to design high-performance buildings”, based on the complication that exist by combining energy efficiency, cost, construction quality, performance validation and assessment through building design, construction and operation to achieve a robust performance (Attia, 2018).

3.5.4 Social the Transition issues

The shift from ZEBs to ZEDs, comes with its fair share of challenges. Working in larger scales involves looking at a wide variety of parameters, complicating in that sense the analysis of the entire system (Aghamolaei et al., 2018). In that regard, Koutra 2017, provides a more holistic approach by adding people, services, and currency to the instruments being exchanged within and outside the district. In this systemic approach, the district is not considered as an autonomous urban unit but as a portion of a city with different interrelated elements (Koutra et al., 2017). In a review of seven exemplary case studies of nZEDs in Europe, it was reveal that ZE initiatives are also driven by sustainability goals such as social equity and improved quality of life rather than only the classical energy and emissions goals, implying that successful attempts toward ZEDs are those that are framed within the overarching goal of achieving sustainability (Saheb et al., 2019). Social surveys for instance, regularly indicate huge public support for solar power and energy reduction measures, however, the issue of installing potentially unsightly panels on historic structures is a different history (Lingfors et al., 2019). In a study made by the Uppsala University on installation of PV systems on heritage buildings, it was found that the installation of PV systems on the roof of historical buildings may be acceptable, as long as they remain unnoticeable (Lingfors et al., 2019).

Based on Carlisle 2009, definition of a ZEC, the energy used for transportation and on public infrastructure must also be considered in the energy balance, on top of the energy required from the buildings alone (Carlisle et al., 2009). Amaral 2018, further identify (1) climate, (2) morphology, and (3) public spaces as the key urban elements affecting district energy performance, in addition to those that are observable from the building level (Amaral et al., 2018). In this regard, the ZE balance is only achieved by considering the whole system, rather than the buildings alone

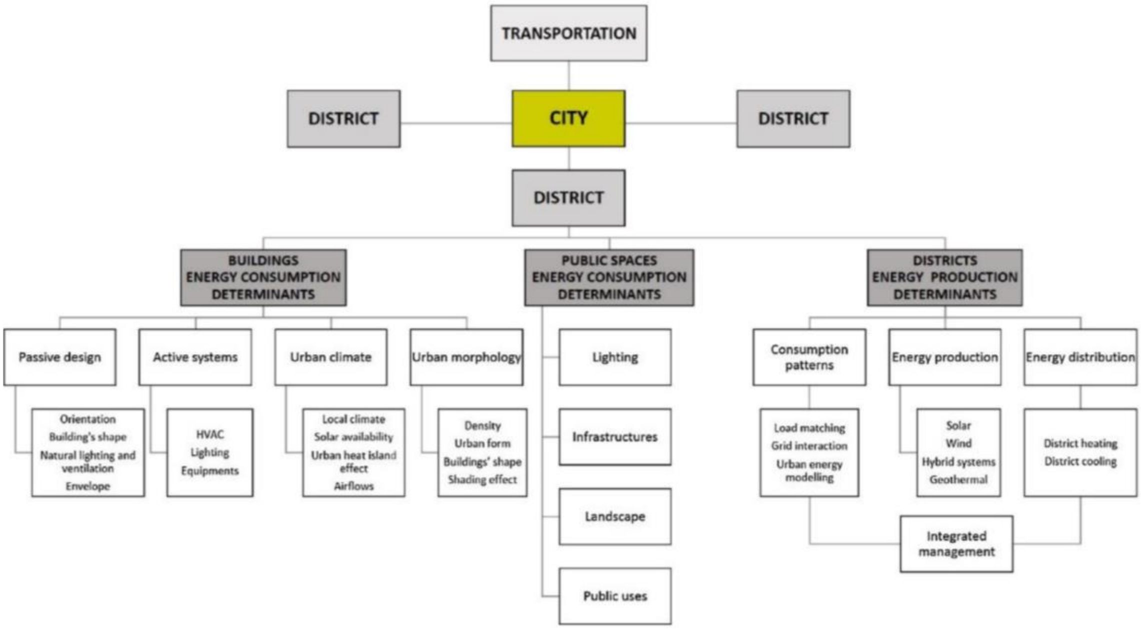


Figure 19: Factors affecting the energy balance in the district scale. (Amaral et al., 2018).

Chapter 4 Case Studies

This section presents and explores four case studies of districts that underwent the energy transition process to determine if the principles mentioned in the literature review do work in practice. For this purpose, a wide varied range of projects with from different climate zones were selected. The idea behind selecting different projects is to provide a more general and holistic approach towards the development of a conceptual framework that could potentially be applied in the development of ZEDs regardless of the type of project. Therefore, these four case studies have been selected following the criteria of retrofitting, redevelopment and new projects.

Moreover, following Bourdic and Salat 2012, assessment systems to determine the energy models at the district scale (Bourdic & Salat, 2012). This chapter divides the analysis of the case studies in 4 steps: (1) Context, (2) Strategic plan and structure, (3) Objectives, (4) Best practices and (5) Results.

4.1 Lehen, Salzburg, Austria (Retrofit)

With the highest number of citizens, Lehen is the largest district in Salzburg situated close to the city centre. With buildings that were constructed in the 1950's, this district was facing an imminent decay, however, it was not until the financial contribution from the EU-funding programme of CONCERTO that the district regain attention among citizens. This programme was aimed to demonstrate that the optimization of the building sector of whole communities was more efficient and more economical than doing so for individual buildings (Turégano et al., 2012). The urban renewal of the district, along with its consequent social upgrading, was intended to demonstrate its feasibility to become a model district for sustainable development primarily through energy-efficient constructions that restored central functions of public life and whose heating demand was supplied by a centralized solar heating sys-tem (Strasser et al., 2011) .

Figure20. Location of the city of Lehen in the city of Salzburg. (Google maps, nd)

4.1.1 Context

The highly populated district of Lehen started to decay after the demolition of the old football stadium and the consequently closing down of many small business, moving to better places. These events together with the poor condition of the existing building infrastructure, which was mainly residential buildings that were built between the 1950s and the 1970s (Table 14). Given the conditions of the old infrastructure, many of the buildings lacked proper thermal performance and adequate indoor conditions. Furthermore, the energy used for heating was equipped with heating systems powered by oil or gas (Saheb et al., 2019).

	Existing Buildings	**New Buildings**
Number of buildings	13	12
Number of dwellings	623	550
Average age of buildings	60-70 years	-
Type of buildings	85% residential 15% commercial	80% residential 20% commercial
Area	50,000 m^2	105,000 m^2

Table 6: The Building Stock of the Lehen Revitalization Project adapted from (Saheb et al., 2019)

4.1.2 Strategic Plan and structure

Prior to the revitalization of Lehen by the CONCERTO initiative, it is important to mention that there was already initiatives towards a “Smart City 2050” developed by the local authorities of Salzburg, which included concrete sustainability targets for building energy efficiency and the use of renewables, particularly Solar systems (Strasser et al., 2011). As part of the European Green Cities Network, Salzburg had been actively promoting sustainable development through its local strategy of optimizing building eco-logical footprint while providing high levels of comfort (Saheb et al., 2019). In that sense, the urban renewal of the district of Lehen is the clear example of how increased energy efficiency and the use of renewables could in fact improve the attractiveness and the quality of life of the district.

The realization of the plan was organized by a steering group together with a group of technical team composed of both public and private organizations. These groups were mainly focused on renovation and implementation of renewables. Although the Participants of these groups had already a stipulated “high-quality agreement” to guarantee the thermal standards and energy requirements, the funding of the project directed by the CONCERTO was the one in charge providing the final energy efficiency standards (Saheb et al., 2019).

Given the strategic location of the district, the plan started with a new train station, which was the perfect opportunity for new developments in the area (Immendoerfer et al., 2014). Figure below provides the key plan of the developments within the Lehen renewal project, while Table 15 contains the legend explaining the key plan.

	Development	N/R	GFA [m^2]	Description / Composition
1	Stadtwerk Lehen residential part	N	36,117	Residential complex composed of 287 subsidized apartments, a kindergarten, and a student dormitory with 97 units
2	Stadtwerk Lehen commercial part (Neue Mitte Lehen)	N	-	Building complex with 48 flats, a library, a center for the elderly, a café, and a bar
3	Stadtwerk Office Prisma	R	7,975	A high-rise office building built in the late 1960s
4	Esshaver Straße	N	1,072	A four-storey building comprised of 12 rented and owner-occupied flats designed to the Passivhaus standard
5	Neue Mitte Lehen solar plant	N	144	Solar thermal plant integrated within the Neue Mitte Lehen
6	Parklife senior residence	N	7,145	Senior daycare center comprised of 90 beds, a kitchen, common rooms, and rehabilitation
6a	Parklife apartments	N	5,975	56 apartments for rent
7	Kuenburggasse	R	4,568	45-apartment building
8	Strubergasse	R	16,660	285-apartment building
9	PV hospital	N	-	New hospital with 30-kWp PV plant on its roof

Notes. N = New.
R = Retrofit.

Table 7. Development areas in the Revitalization Project. (Saheb et al., 2019; Strasser et al., 2011)

Figure 21: Distribution of the developments areas in the district of Leheb. (Saheb et al., 2019).

4.1.3 Objectives

As part of its “Smart City 2050” plan and climate-neutral vision for 2050, the objective for Salzburg is to lower its energy consumption per capita by 30% between 2010 and 2050 and to increase its local RE production from 8.8% in 2010 to 32.3% in 2050 (“Smart City Salzburg,” n.d.). As part of this objective, the renewal project in Lehen aimed to contribute to the attainment of these targets by reducing the energy demand for both new and existing buildings to 75% below the national standard and by increasing the share of RE in its DHS (Pacho, 2021).

4.1.4 Best Practices

The strategies implemented to reduce the energy consumption in both new and old buildings were primarily based on passive systems such as, the installation of high thermal insulation and heat recovery in ventilation systems. Furthermore, all new buildings were obligated to fulfil the (Passivhouse) standard while the old ones were renovated to specific low energy building standards. When it comes to renewables, solar thermal collectors were installed across developments and were coupled with solar tanks and heat pumps to increase system flexibility and efficiency, respectively. This solar tanks (Figure 24) distributed heat to both new and existing buildings via micro-network grid and supplied 30% of the district heating demand. The remaining 70% was covered by the existing district heating system, which operated on biomass and industrial waste heat (Saheb et al., 2019). Part of the electricity demand, on the other hand, was covered by the 50 KW PV installations scattered across buildings. Lastly, an inter-active “Energy Traffic Light System” was set up to keep residents involved and supportive of the project. This monitoring scheme provides a visualization of their relationship with their energy demand and the share of RE in their supply (Saheb et al., 2019).

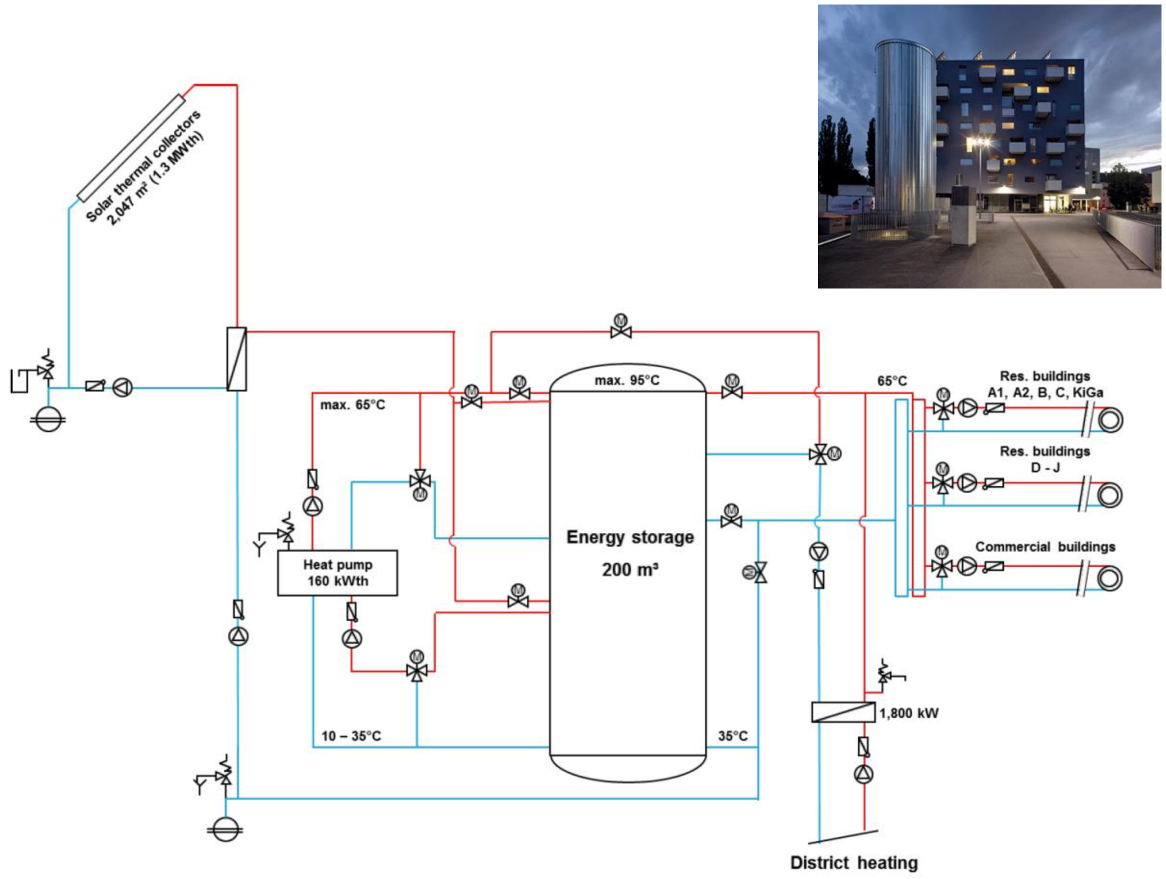
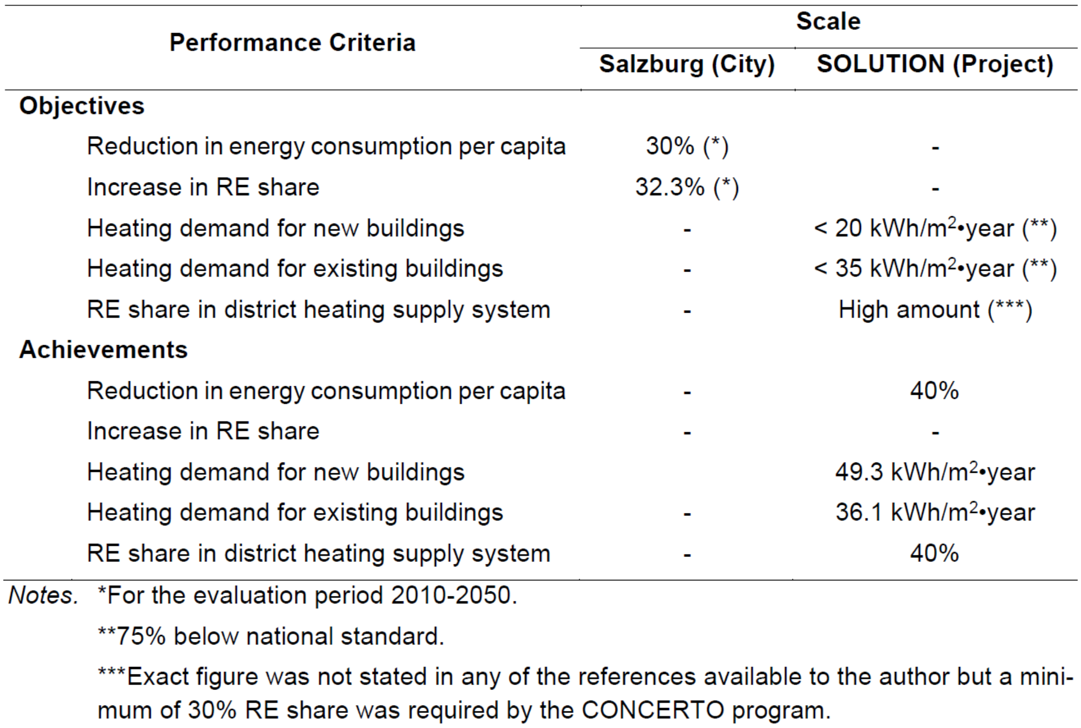


Figure 22. Solar tank and hydraulic scheme of the heat supply system Stadwerk Lehen (Mauthner & Joly, 2018)

4.1.5 Results

Based on the actual results after the implementation, the project's objectives for heat demand reduction in both new and existing buildings were not met. Nevertheless, it is important to mention that the achievements for the reduction of energy consumption per capita and for the increase in the share in renewables, the targets set by the City of Salzburg (for the consumption reduction) and by the CONCERTO program (for the RE share)for the district heating system were successfully met (Saheb et al., 2019). Therefore, by regulating and setting high requirements for the energy consumption reduction of the project. The district of Lehen was able to contribute significantly to achieve the City's results shown on the table below.



Performance Criteria	Scale	
	Salzburg (City)	SOLUTION (Project)
Objectives		
Reduction in energy consumption per capita	30% (*)	-
Increase in RE share	32.3% (*)	-
Heating demand for new buildings	-	< 20 kWh/m^2•year (**)
Heating demand for existing buildings	-	< 35 kWh/m^2•year (**)
RE share in district heating supply system	-	High amount (***)
Achievements		
Reduction in energy consumption per capita	-	40%
Increase in RE share	-	-
Heating demand for new buildings		49.3 kWh/m^2•year
Heating demand for existing buildings	-	36.1 kWh/m^2•year
RE share in district heating supply system	-	40%

Notes. *For the evaluation period 2010-2050.

**75% below national standard.

***Exact figure was not stated in any of the references available to the author but a minimum of 30% RE share was required by the CONCERTO program.

Table 8: Objectives vs. Achievements of the Lehen Revitalization Project. (Saheb et al., 2019)

4.2 Valdespartera and Picarral, Zaragoza, Spain (Redevelopment-Retrofit)

Valdespartera and Picarral are two separate districts in Zaragoza, which were used as key examples for the RENAISSANCE project, which was an urban generation program from a integrated energy approach. In response to the call of the CONCERTO program, the RENAISSANCE project conducted urban regeneration operations in select districts in Lyon (France) and Zaragoza (Spain) from 2005 to 2012. These districts were then planned to be consider as pioneers for community level sustainability (Turégano et al., 2012) through the adoption of high energy performance criteria in new and existing buildings and through the increased use of renewables (Saheb et al., 2019).

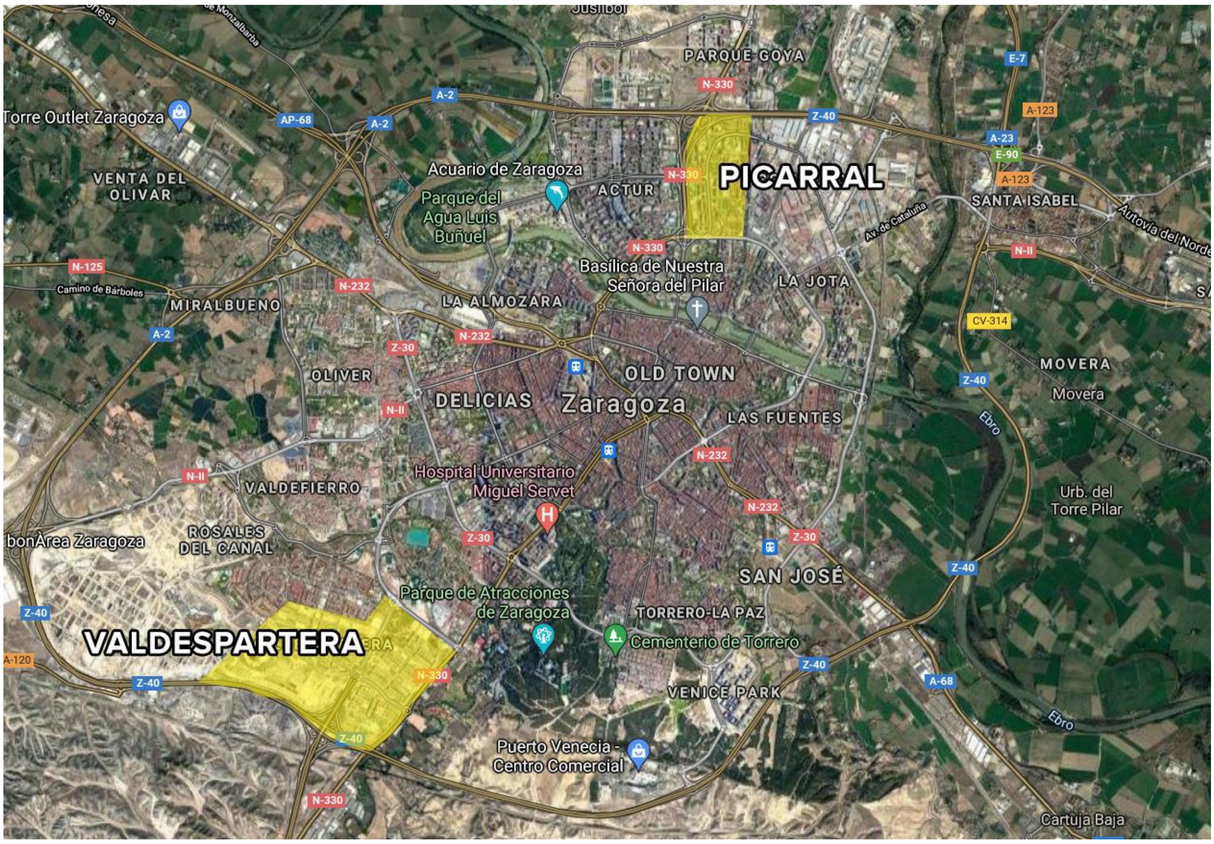


Figure 23. Location of Picarral and Valdespartera districts in Zaragosa Spain. (Google maps, nd)

4.2.1 Context

As part of the RENAISSANCE project the two districts were planned with two different but complementary approaches toward replicable and affordable energy transition in the social housing sector (Saheb et al., 2019). The first area of intervention was Valdespartera, a former ancient military precinct located in the suburbs, and the second was Picarral, an aging working-class residential district built between the 1940s and 1960s (Turégano et al., 2012). Valdespartera was transformed into a social housing district through the construction of 616 new bioclimatic apartments (with a total of 9,650 social housing units) and an exhibition center on urban sustainability (CUS). Picarral, on the other hand, due to the economical constrains had only 70 (out of the planned 196) of its social housing apartments and one of its public schools (Cándido Domingo) renovated to bioclimatic design principles (Turégano et al., 2012). Table 10 provides a breakdown of the area composition for Valdespartera and Picarral.

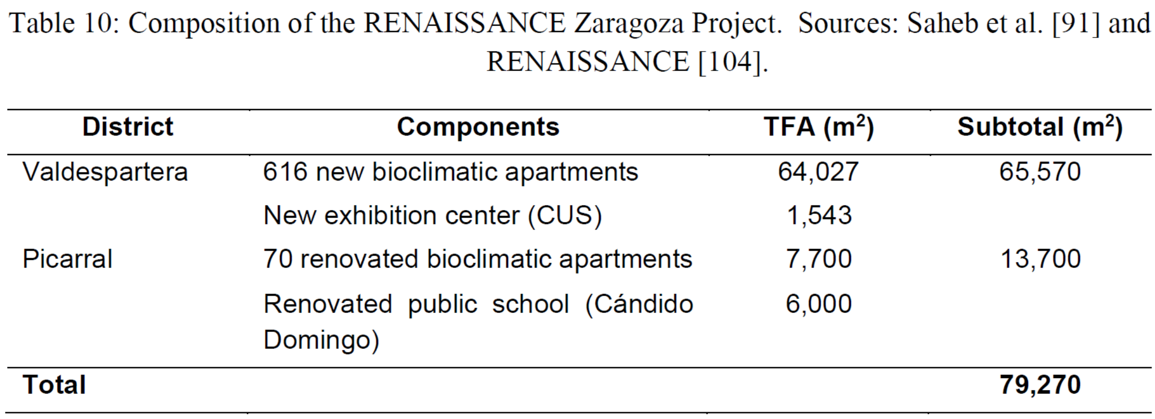


Table 10: Composition of the RENAISSANCE Zaragoza Project. Sources: Saheb et al. [91] and RENAISSANCE [104].

District	Components	TFA (m^2)	Subtotal (m^2)
Valdespartera	616 new bioclimatic apartments	64,027	65,570
	New exhibition center (CUS)	1,543	
Picarral	70 renovated bioclimatic apartments	7,700	13,700
	Renovated public school (Cándido Domingo)	6,000	
Total			**79,270**

Table 9. Building Components in the renovation project. (Saheb et al., 2019)

Figure 24. Valdespartera (Redevelopment) on the left and Picarral (retrofit) on the right (RENAISSANCE, n.d.)

4.2.2 Strategic Plan and structure

The municipality of Zaragoza before the implementation of the RENAISSANCE project, had already set a 2010-2020 target to save 24% of CO2 emissions through a 24% reduction in energy consumption and a 35% increase in the share of renewables (Saheb et al., 2019). However, due to the restrictions set by Zaragoza and the governing old town district regulations, the development of new energy efficient buildings were to some degree prohibited, thus, affecting the municipality’s goal in achieving the emissions targets. In the end, with persistence and a strong commitment the municipality eventually manage to reform the outdated old town regulations which, in turn, secured the districts in the RENAISSANCE project.

The realization of the RENAISSANCE project in Zaragoza was made possible by the strong collaboration between public and private stakeholders. In that regard, with the influence of the political position, the municipality organized and mobilized all stakeholders involved in the process, thus, leading the whole project. Table 11 lists all the actors involved in the RENAISSANCE Zaragoza project with their corresponding roles.

Actor	Domain	Role / Contribution
Ayuntamiento de Zaragoza	Public	Political leadership; overall project management
SMZV	Public	Management of the design and construction of the bioclimatic apartments and the CUS in Valdespartera
Universidad de Zaragoza	Public	Local coordination with residents; monitoring campaign and social work
CENER	Public	Evaluation of refurbishment plans for Picarral apartments
URBIC	Private	Innovative design of a collective energy-efficient gas heat pump for cooling and heating integrated in an ESCo model
Endesa	Private	Technical expertise on the management of gas and electricity consumption at the district scale

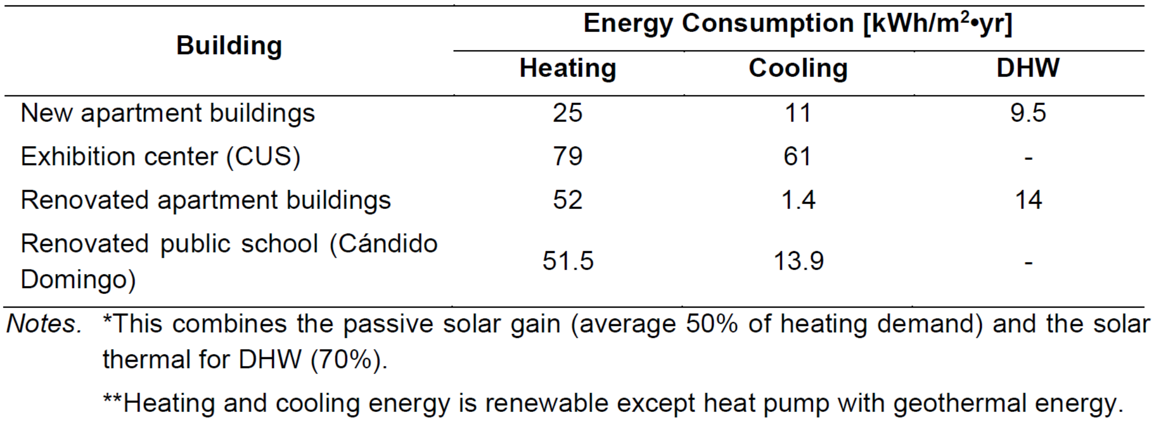
Table 10. Actors involved in the RENAISSANCE project. (Saheb et al., 2019)

4.2.3 Objectives

One of the main objectives for The municipality of Zaragoza was the adaptation of the building structure to the strong difference in temperature that went between hot summers and cold winters. In that regard, the RENAISSANCE project was intended to demonstrate the sustainability and the technical and economic feasibility of adopting bioclimatic principles in building design and construction to ultimately accelerate their standardization in practice (Turégano et al., 2012). In line with this goal, Valdespartera and Picarral must collectively achieve (1) a minimum of 39% to a maximum of 71% reduction in energy consumption and (2) a minimum of 40% to a maximum of 60% increase in RE supply (Saheb et al., 2019).

4.2.4 Best practices

To realize these targets, the RENAISSANCE project applied all the energy zero principles that affect the energy performance at all scales of intervention (Bourdic & Salat, 2012). Given that the Zaragoza program was divided between a retrofitting and redevelopment project, passive design strategies at the Urban level such as, the orientation of buildings to promote solar gain and the location of buildings to create sufficient distances to avoid shading was only possible in the District of Valdespartera, Nevertheless, High-performance in building materials and insulation were applied on the building requirement for both districts.



Building	Energy Consumption [kWh/m²•yr]		
	Heating	Cooling	DHW
New apartment buildings	25	11	9.5
Exhibition center (CUS)	79	61	-
Renovated apartment buildings	52	1.4	14
Renovated public school (Cándido Domingo)	51.5	13.9	-

Notes. *This combines the passive solar gain (average 50% of heating demand) and the solar thermal for DHW (70%).

**Heating and cooling energy is renewable except heat pump with geothermal energy.

Table 11. Energy consumption in main buildings (Saheb et al., 2019)

The share of renewables increased in the form of solar, geothermal and bioenergy, and it was used to partially cover the demand for electricity, heating and hot water in both districts (Turégano et al., 2012). Furthermore, in order to improve the efficiency of the whole system, DH networks were installed in the case of Valdespartera and upgraded in the case of Picarral. Lastly, the creation of an online system by the university of Zaragoza and the CUS building, was used to inform users about the energy consumption issues and provided specific recommendations to improve them.

Figure 25. CUS building for the energy control and management (*Valdespartera Ecodistrict, Zaragoza*, n.d.)

4.2.5 Results

The monitoring campaign led by the University of Zaragoza helped to identify the energy issues that had caused deviations from the expected performance of the energy system. In that regard, the RENAISSANCE Zaragoza project manage to successfully secure the majority of its targets presented in the table. However, since the data found only account for the residential buildings, excluding public buildings such as the exhibition center and the public school, it is hard to determine with accuracy if the reduction targets were met. Nevertheless, the thermal energy consumption of the buildings presented on the table below can support a positive claim since both values are still less than the standard.

Performance Criteria	**Scale**	
	Zaragoza (City)	**RENAISSANCE (Project)**
Objectives		
CO_2 savings	24% (*)	-
Reduction in energy consumption	24% (*)	39% to 71% (**)
Increase in RE share	35% (*)	40% to 60% (**)
Achievements		
CO_2 savings	-	-
Reduction in energy consumption***	-	49% for new apartments 37% for renovated apartments
Increase in RE share	-	40%

Notes. *For the evaluation period 2010-2020.
**Must be *collectively* achieved by Valdespartera and Picarral.
***Based on final average energy consumption.

Table 12. Results of the renovation project in Zaragoza (Saheb et al., 2019)

4.3 Bo01 city of tomorrow, Sweden (Redevelopment)

Bo01 is a developing urban area in Västra Hamnen (the western harbour) of Malmo Sweden. A new modern city district, with housing, offices, shops and local services. The aim was to change the industrial site to a new sustainable city district, making in that sense Västra Hamnen a high priority development area in the city and an important part of the plans to improve Malmö as an attractive city, and an international leading example for sustainable districts. A city district that inspires creativity, develops further knowledge and stimulates economic growth.

Figure 26. Location of the Bo01district in the city of Malmo (Google maps, nd)

4.3.1 Context

The district was a former industrial area dedicated to the ship building economy. After the collapse of the shipbuilding industry, the area was sold to the city in 1996. In addition to being land claimed from the sea, the decades of industrial use left a legacy of contaminated soil. Approximately $33.4 million from the Swedish government and $2.1 million from the European Union subsidized the cost of site remediation and energy efficient infrastructure and building elements (Austin, 2013) . With the construction of the University of Malmö in 1998, the city initiated the redevelopment of the area as the main indicator of the city government’s strategy. An environmental component was added to this program, due to the impact of the Paris agreement, which encouraged local governments to engage in climate change mitigation and sustainable development. The result of these two impulses was the redevelopment of the Bo01 district as a sustainable extension of Malmö that host 4000 resident in an area of 100 000 m2 (Austin, 2013).

4.3.2 Strategic Plan and structure

Due to the engagement of the local government in climate change and sustainability, the city’s strategies were exerted through ownership, goal formulation, and planning. In that regard, the city hired Klas Tham, a well-known architect and planner, who balanced the technological goals of the project with an overarching concern for the social environment and elevating the aesthetic quality of the development (Austin, 2013). Through a series of meetings, his approach was transmitted to the stakeholders in order to developed the “Quality Program,” which established performance requirements for material, technological, environmental, and architectural quality measures (Austin, 2013). This led to a clear understanding of the requirements and enhanced coordination and agreement between the different stakeholders (Contreras, 2020).Since the city owned the property, the city was responsible for the master plan and sold small parcels to developers for site design, in coordination with the master plan and the Quality Program (Austin, 2013).

Figure 27. Master plan of the Bo01 district in the Västra Hamnen area.(Västra Hamnen, n.d.)

4.3.3 Objectives

As part of the climate change initiative, one of the main objectives of the city was to be able to create a district powered 100% by renewable resources. In general, the largest energy demand in buildings was space heating and cooling. Therefore, an average energy maximum of 105 kWh per m2 was set as the energy target which at that time was a 40% reduction of the Swedish average (City of Malmö, 2006). Another important objective in Bo01's climate-neutrality in order to reduce pollution, is the waste management which is used for heating and biogas production.

4.3.4 Best Practices

The energy emphasis at the Bo01 district was primarily the development of renewable energy resources rather than highly energy efficient buildings. Nevertheless, in order to provided energy efficient buildings, the buildings needed to be constructed under Passivhus standards and some of them included heat recovery systems (Urban green, 2008). Bo01 in that sense, has the distinction of being a ZED, mainly because, 100% of its energy comes from renewable sources such as: A 2MW wind turbine located about 1½ miles away in the northern part of the Western Harbor, a 120 m2 integrated PV systems and 1400 m2 of solar collectors for additional electricity and district heating, and a heat pump system connected to the district for district heating in the winter and district cooling in the summer. Additionally, a waste management plan was set for the production of biogas and heat to contribute to the district heating system. (City of Malmö, 2006).

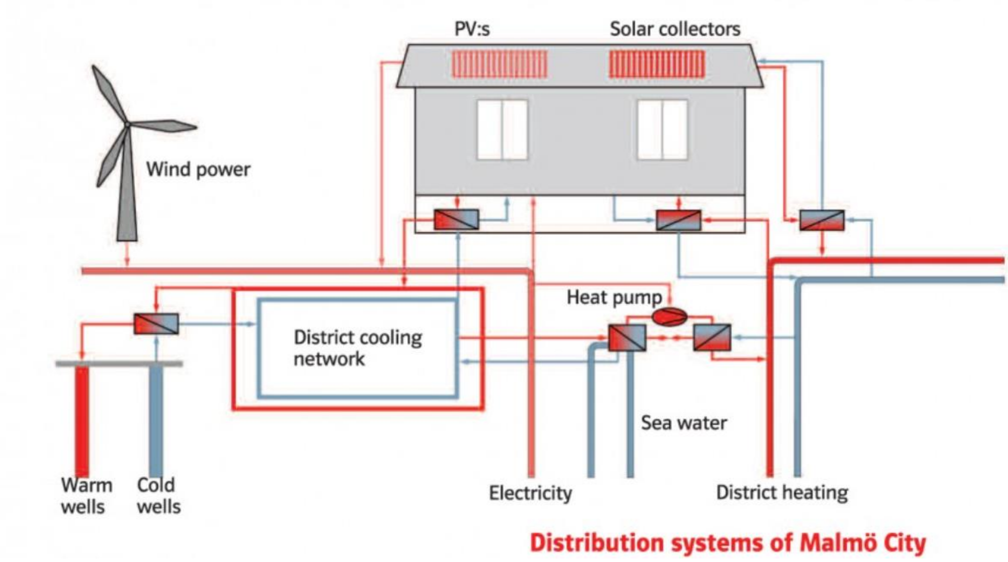


Figure 28. The Bo01 distribution system of renewables. (E.ON. Varme sverige, 2008)

4.3.5 Results

Since the buildings were constructed under the Passivhus Norden standards, it was assumed that several of the buildings within Bo01 have met this target, achieving an energy use of 63 kWh per m2 (Koch & Kersting, 2011). However, in a study made by the Lund University in 2003, it was found that the average use for buildings with heat recovery was 126 kWh per m2, while for buildings without heat recovery the average use was 186 kWh per m2 (Nilsson, 2003). Failing in that regard with the initial target of 105 kWh per m2. However, given the distribution of renewable energy produced by the project, which is is 6,300 MWh/year for heating, 4,459 MWh/year for electricity, and 1,000 MWh/year for cooling, it is arguable to claim that the district of BO01 is one of the first ZED (Koutra et al., 2017)

4.4 Masdar city, Abu Dhabi, UAE (New development)

Masdar city is a new city project in the city of Abu Dhabi of the United Arab Emirates (UAE), with the purpouse of being the “world’s first zero carbon emission city”. Acting as the cornerstone of the country when it comes to sustainability, the goals and plans for this Eco city are based on the use of renewable energy technologies, massive information systems, and self-driving cars, making this city everything the UAE hopes to become (D’Eramo, 2021).

Figure 29 location of Masdar city in Abu Dhabi. (Google maps, nd)

4.4.1 Context

Criticized by being one of the leaders in CO2 emissions, the UAE started to act as the leaders in clean energy solutions by developing sustainable developments and clean energy solutions (D'Eramo, 2021). In that sense, the company Masdar, which is owned by the country, began to work in 2006 on Masdar City, an ambitious project that aimed to be the "world's first zero-carbon emission city". As any other new city in the UEA, Masdar city was located on a desert area near the city of Abu Dhabi. Initially the city was planned to host about 50 000 people in an area of 6 000 000 m2 (D'Eramo, 2021), however, due to the global financial crisis, the city current status is of an area of 300 0000 m2 with a population of 2000 people (Kadi, 2021).

4.4.2 Strategic plans and structure

In order to develop a well structure and highly energy efficient design in both, building and urban scale, the initial design of the city was delivered to the firm Foster and partners, which is an architecture firm that take the principles of sustainable architecture and energy efficiency as their priority (Foster & Partners, n.d.). Furthermore, given the challenges in incorporating efficient energy and water systems, the city partnered with other stakeholders that solely worked in the use of renewables and efficient systems such as IRENA (Masdar city, n.d.).

Figure 30. Masdar city master plan (Masdar city, n.d.)

4.4.3 Objectives

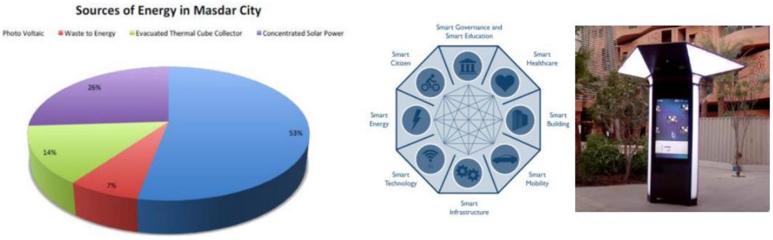
On top of the objectives of building a Zero Carbon Emission city and a 100% use of renewables in the energy production, Masdar's specific objective, was "to make a city where citizens expend the least amount of energy while maintaining a high quality of life" (D'Eramo, 2021). Moreover, in addition to the waste management objective as in the previous case of BO01, one of Masdar's main concern was the reduction of water usage through a water management system (Kadi, 2021). In that regard, Masdar's main objective is not just inventing new technologies and infrastructures; but is also about encouraging consumption's behaviour in its citizen (Randeree, 2018) .

4.4.4 Best practices

Most of the energy needs of the city are met by photovoltaic solar power and concentrated solar power alone, with innovative projects, such as the construction of a solar thermal power plant, underway. Some of the most interesting aspects of Masdar, however, come from its innovations not in energy production, but in decreasing water and energy consumption. Additionally, the city had strict regulations regarding the recycling of waste (Kadi, 2021) .

With the help of smart energy management systems, the citizens are able to see if there is any overuse of energy from their houses, making the citizen's energy consumption monitoring, one of the best practices to achieve the desired amount of energy without affecting the quality of life (D'Eramo, 2021). Furthermore, in addition to the energy conservation systems such as, passive design and insulated wall systems. In order to improve the thermal efficiency of both, the city and the buildings, the city focused as well on the use of new technologies such as, the wind tower to cool down the environment, and the use of Reinforced Vitrified Concrete, which effectively insulates against heat and does not require cleaning (D'Eramo, 2021).

Solar tower and 10MW Solar Photovoltaic Plan



Energy production and smart management

Ancient principles with new Architecture

Figure 31. Masdar city’s Best practices in energy consumption. Adapted from (Masdar city, n.d.)

4.4.5 Results.

Given the challenges that building a new city undertake, the results in Masdar city were not as initially expected. Firstly, because the city was Initially designed to be finished by 2009, however, the current analysis indicates that city is still in the initial phase with only a 5 % of the final the area in use (Kadi, 2021). Furthermore, In order to become the first “Zero Carbon emission city” Masdar was intended to be One hundred percent fueled by sustainable power source, however in recent studies the use of renewables covers only the 50 % of the energy demand (D’Eramo, 2021). Finally, in regards of the smart integration system that stores and control the energy consumption of the district, it was found that this systems could as well lead to the manipulation of data for control over populations (Kadi, 2021).

4.5 Evaluation

By reviewing the state of the art of the zero energy concept in literature and in practice, this chapter provides an overview over the literature and the case studies. Furthermore, this part of the thesis will serve to discuss the answer to the sub questions mentioned in the Research question part.

(Q1) What are the main factors influencing the energy system of a ZED?
(Q2) What are the main challenges and opportunities of ZED?
(Q3) What factors led to the successful development of current ZED?

Firstly, the district approach towards the zero energy objective has recently gained the attention of researchers and policymakers, mainly due to the technical, economic, and social advantages that ZEDs have over ZEBs. ZED provides a more accurate analysis of a district and its system and facilitates the application of optimal technological solutions. The solutions implemented at this scale offers as well the opportunity to interplay between the difference in energy demand to achieve the desired ZE balance. By reaching the ZE balance, Districts will not only improve the environmental sustainability of the building sector, yet, it provides the opportunity to create sustainable business models. This models opens opportunities for collaborative work among stakeholders (especially between project leaders and end users), which may increase social acceptance of district renovations and, thus, accelerate the energy transition.

Secondly and as the answer for the (Q1), the main factors affecting the energy system of the districts are:
(1) The climate: Regarded as the only factor that is not human dependant, the climatic conditions in which districts are situated play an important role in the ED. Depending on the type of climate, the energy needed could be in the form of heating or cooling, moreover, the potential for RE production is as well affected by aspects such as solar radiation and wind speed.

(2) The Urban context (location, urban form): As the first factor that is influenced by humans, the form in which the district is design, affects directly the ED, mainly due to aspects such as, wind and heat island effect, morphology, Density, Orientation, etc.

(3) The energy consumed by its buildings: As mentioned in the ZE principles, buildings have an immense effect on the ED. In that regard, the ED can be reduced considerably with passive design, active systems, and a good occupant behaviour.

(4) Local energy production: Regarded as the factor that balance the ED, the final energy production of the ZED is Determined by the potential of the share in REs, energy distribution networks, smart Energy management, and consumption patterns.

Thirdly and as the answer for the (Q2), The main challenges that ZEDs face are those related to, political, technological and economical aspects, additionally the challenge bound to the transition from ZEBs to ZEDs is as well present. Furthermore, by following the principles used in the ZE concept, the opportunities to achieve the zero energy targets at the district level are: (1) Energy conservation measures (passive and active), (2) maximization of RE supply, and (3) the optimization of the grid systems through flexibility and autonomy. These are also known as “three pillars of action”, where, the first and second fundamental strategies focus separately on the demand and supply side, respectively, while the third involves the interaction between them (Koutra et al., 2017).

Finally answering the (Q3). In the case studies, it was found that ZEDs are primarily driven by climate and energy policies that support and incentivize their uptake in order to combat climate change. This political influence has ultimately led to the creation of funding and supportive schemes that enabled the realization of ZEDs. Nevertheless, ZEDs are still challenged by the lack of adequate financial support, especially for complicated projects such as, Masdar city and in low-income areas such as Lehen and Picarral. Moreover, through these case studies, it was possible to notice the establishment of energy standards as crucial factors in achieving the energy goals, however, the performance gap represented an important issue. Here, it was observed that the actual energy performance of the districts is lower than the designed performance. Consequently, these complications prevented stakeholders from achieving the initial goals of the project. In the distribution and sharing aspects, DH systems was used as the main energy carrier, and user’s involvement and energy awareness was possible through the interaction with Energy Management Systems.

Chapter 5 Conceptual framework

The approaches toward strategies, frameworks, methods, and tools are mainly developed within the ZEBs level, on the other hand, within the novelty of ZEDs Conceptual frameworks as a research domain are still simplified and in development stages (Koutra et al., 2017), nonetheless, the significant amount of publications found in ZEBs literature (Attia, 2018; Saheb et al., 2019; Sartori et al., 2012; Zhang, J, 2015), has made possible the theoretical foundation for the transition to ZEDs, therefore in order to improve the analysis of complex and interrelated systems such as districts, the performance of each element and its impact on other members should be addressed with an integrated approach (Aghamolaei et al., 2018). As such, the integration of energy systems from the start of the planning process are essential in the success of ZEDs (Koutra et al., 2017). In the figure below, Shandiz 2020, describes the level of performance that can be achieved by integrating energy systems from the initial stage, rather than the last stages (Shandiz et al., 2020)

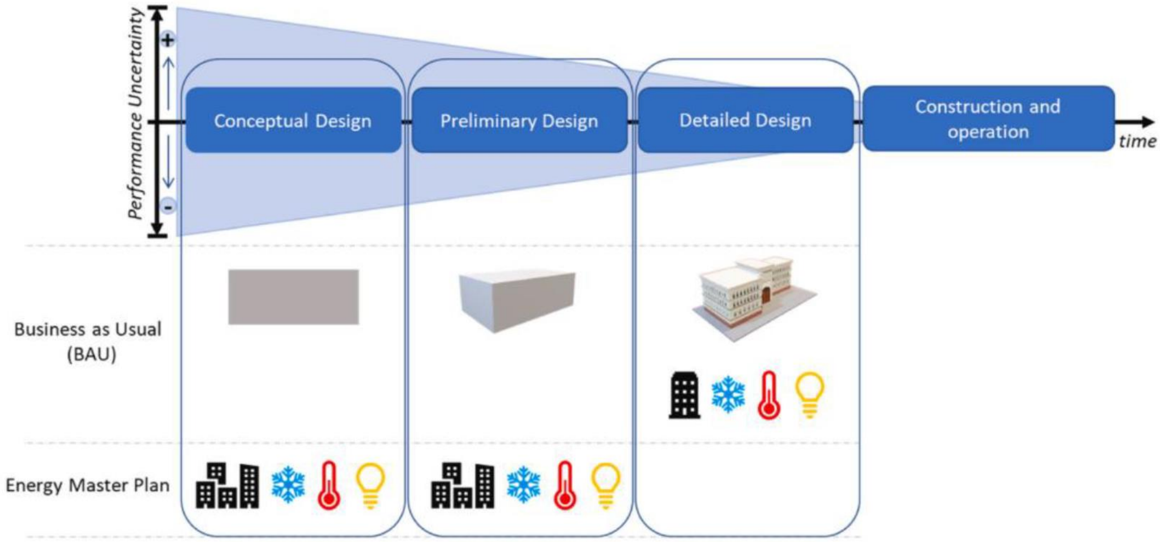


Figure 32. Energy performance of an energy integrated vs BAU model (Shandiz et al., 2020)

More important for this master thesis, in order to answer the main RQ "**What are the most effective planning principles and strategies within the Zero Energy concept that can be used for a more integrated development of ZEDs?**". This chapter presents a conceptual framework which is mainly based on the literature review and the case studies that were presented during the analysis of this thesis. The key success principles that were identified in the literature together with the strategies and best practices in the case studies have been synthesized into an Integrated Recommendation Framework. In that respect, there are many different frameworks and methodologies for strategic planning and planning process, and although there is no fixed rules regarding the right steps, generally, the strategic planning process has 5 common phases: Initial Assessment, Situation Analysis, Strategy Formulation, Implementation, and Monitoring and evaluation.(Ali et al., 2011; Maleka, 2014; Thompson et al., 2019). Following this principle and given the limitations of the analysis, the presented master thesis focuses mainly in the 3 initial steps for the development of the conceptual framework.

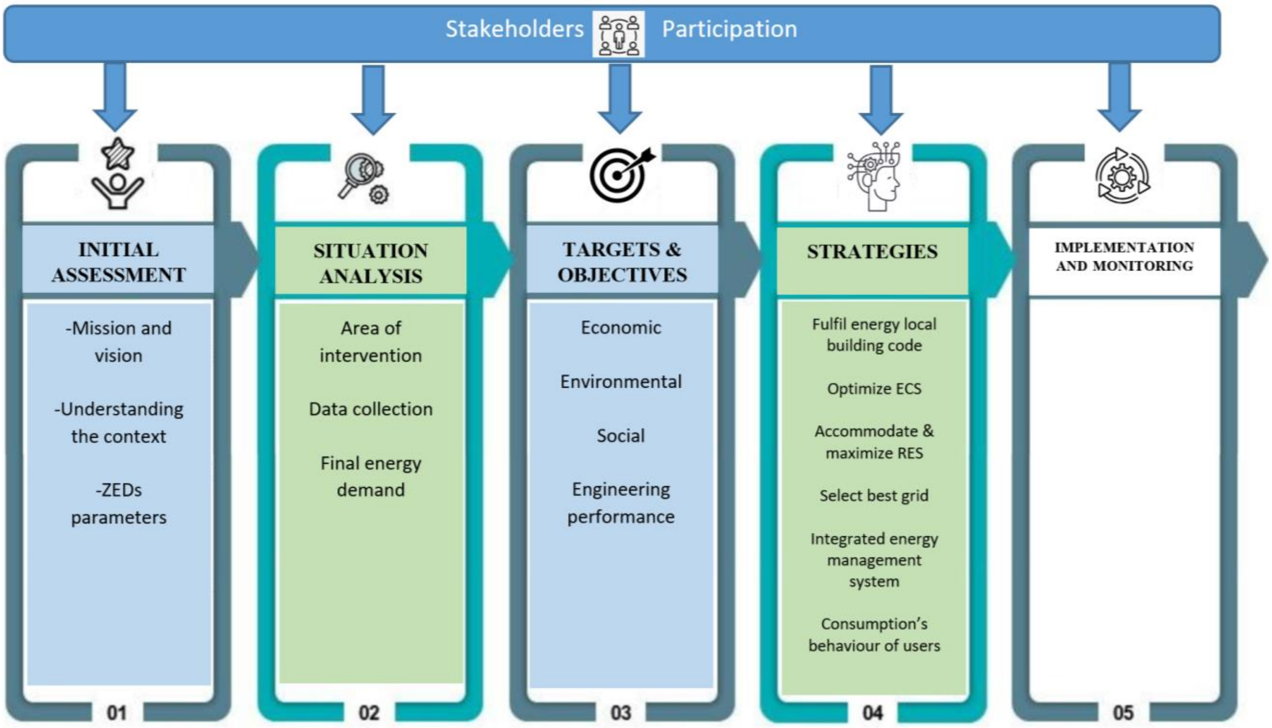


Figure 33. Conceptual framework for planning process of ZEDs. Author's elaboration

5.1 Initial assessment

The starting point of the process is the initial assessment, at this stage of the process, stakeholders must identify the ZED's mission and vision

5.1.1 Alignment of stakeholders with mission and vision statements

One of the first aspects to consider when developing ZEDs is the establishment of goals, targets and strategies (Attia, 2018; Koutra et al., 2019; Shandiz et al., 2020; Sikder et al., 2016). However, this can only be achieved when stakeholders share a common mission and vision. As showed in the case studies chapter, the success of ZEDs was based upon establishing an agreement between stakeholders around their common goals, intended outcomes, and the strategies to reach them. Consequently, the development of a ZED is not only dependent upon technical developments, but also how concepts and solutions are received and supported by stakeholders at the different levels of the planning process (Backe & Kvellheim, 2020)

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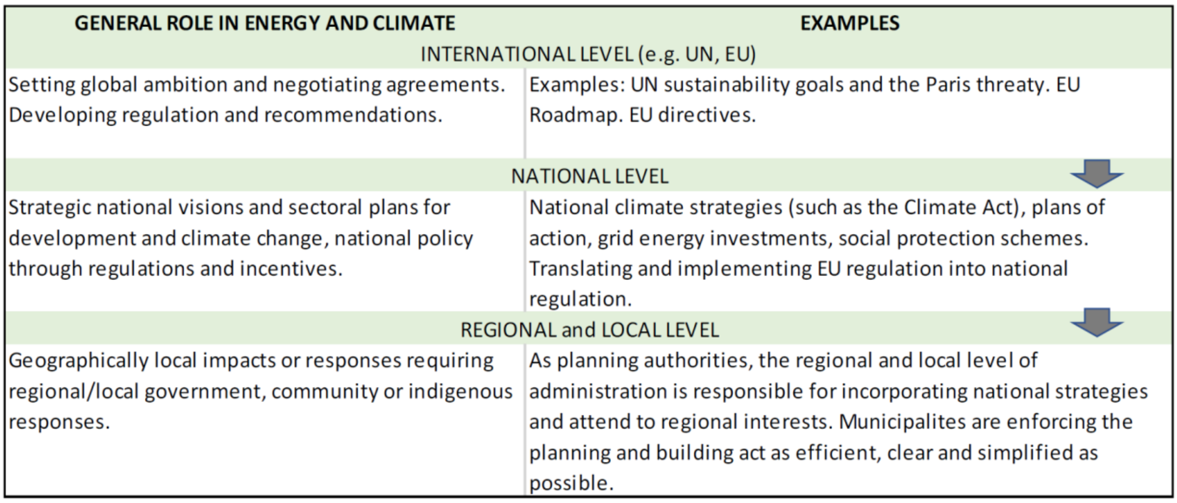


GENERAL ROLE IN ENERGY AND CLIMATE	EXAMPLES
INTERNATIONAL LEVEL (e.g. UN, EU)	
Setting global ambition and negotiating agreements. Developing regulation and recommendations.	Examples: UN sustainability goals and the Paris threaty. EU Roadmap. EU directives.
NATIONAL LEVEL	
Strategic national visions and sectoral plans for development and climate change, national policy through regulations and incentives.	National climate strategies (such as the Climate Act), plans of action, grid energy investments, social protection schemes. Translating and implementing EU regulation into national regulation.
REGIONAL and LOCAL LEVEL	
Geographically local impacts or responses requiring regional/local government, community or indigenous responses.	As planning authorities, the regional and local level of administration is responsible for incorporating national strategies and attend to regional interests. Municipalites are enforcing the planning and building act as efficient, clear and simplified as possible.

Table 13. Stakeholders Levels in the planning process towards ZEDs (Backe & Kvellheim, 2020)

By involving stakeholders from the beginning of the process, the goals and targets tend to be more realistic and can be maintained during the whole process such as the case of the Lehen, Valdespartera and Picarral. In Sikder's 2016 "EnUp conceptual model" for energy optimized urban planning, the participation of stakeholders is crucial not only at the beginning but in every stage of the planning process (Sikder et al., 2016).

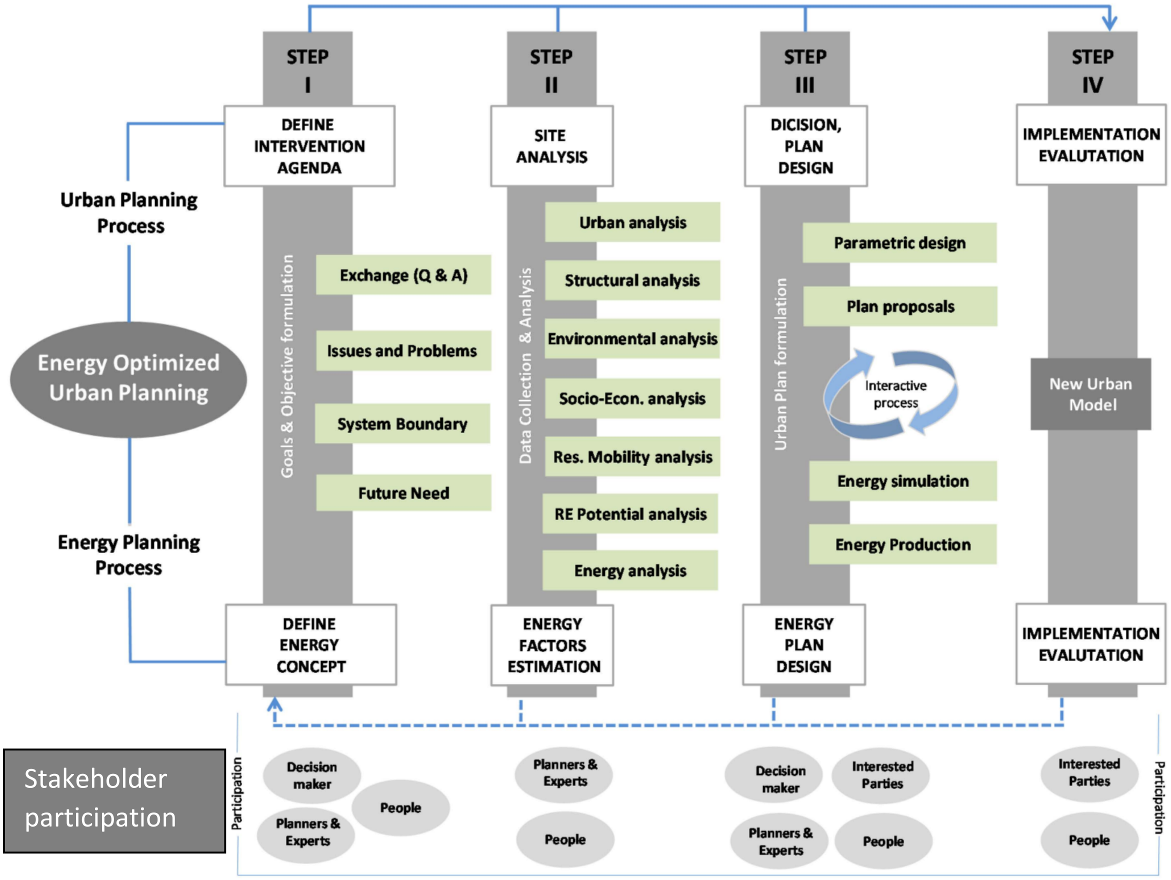


Figure 34. Participation in the "EnUp conceptual model" adapted from (Sikder et al., 2016)

Maintaining a high level of stakeholder involvement throughout the entire project must be done rigorously to prevent misunderstandings and deviations as in the BO01 district. Otherwise, failing to do so can jeopardize not only the project timeline, but in the worst cases, the completion of the project such as the case of Masdar city.

According to Backe and Kvellheim 2020, it is important to give developers realistic feedback on the potential of the development of an area through: "•Early dialogue with the developer about plans for development• Being predictable and consistent when giving permissions. No one should be able to have their way simply by renegotiating and being persistent. • Create arenas where actors could meet, as well as creating possibilities for new knowledge competencies. •In some cases, municipalities can also use exceptions from the Planning and Building Act to spur a preferred development" (Backe & Kvellheim, 2020).

5.1.2 Understanding the context

Understanding the context in which the development of a ZED takes place is essential for the success of the project. As showed in the cases studies, whether the district is a new development area that have only new buildings (Masdar) or a renovation/retrofit project with all old (Vadespartera and Picarral) or some old and some new builds (Lehen and BO01). The approaches and goals were different, in that sense, understanding these premises can highlight the intervention points, allowing different goals and strategies of the design parameters (Shnapp et al., 2020). Moreover, in the literature review, it was found that the main challenges that ZEDs face are within the political, social and economic context, regarded as important factors in the initial phases of any ZEDs project.

Firstly, given that international and national policies are the major drivers for ZEDs, both the literature review and the case studies has demonstrated that the political context played a major role in establishing ZEDs. Regulations and standards for the building sector shape the energy performance of buildings, and different regulations apply within different countries to reach political goals (Backe & Kvellheim, 2020). According to Koutra 2019, understanding these policies is an essential step for stakeholders in order to have a holistic vision of the ZEDs project (Koutra et al., 2019). Moreover, defining projects within the political context helps stakeholders to determine and modified the goals and targets of the project (Shandiz et al., 2020).

Secondly, Economic incentives are necessary in order to engage stakeholders, in the case of Valdespartera and Picarral, and Lehen, these district successes in achieving the final completion of the project mainly because they were part of funding programs such as CONCERTO and RENAISSANCE, while, in the case of Masdar city the economic aspect was the main barrier to complete the project.

Finally, given the environmental benefits of the project, social surveys regularly indicate huge public support for solar power and energy reduction, however, the issue of installing potentially unsightly panels on historic structures is a different history (Lingfors et al., 2019). The district of Picarral, for instance, given the historical importance of the area, they were initially against any kind of alteration, but finally agree to proceed with the project, when good solutions were presented, therefore, it is critical to retrofit or install PV systems on historic buildings with minimum visual impact (Lingfors et al., 2019).

5.1.3 Definition of ZEDs parameters in the current context.

The achievability of the initial goals and targets depend highly on a clear definition of the project. By clearly defining and describing the type of project, stakeholders can have a better understanding of the initial concepts and can strengthen a common vision of the project (Pless et al., 2018). In that regard, one of the main aspects in this stage is the universal definition of a ZED, which is still not very clear on the literature. For instance, in 2013, the Norwegian Building Authority in cooperation with the consulting firm Rambøll developed a report that offered a coherent definition of nZEB. Although extensive debate took place on this report, a consensus was not reached on a definition (Backe & Kvellheim, 2020). Nevertheless, as it was mentioned in the definition chapter, the aim is to "**consume less and to produce equal or more energy"**, therefore, the projects may need to establish their own parameters based on this principle. Another important aspect when defining ZEDs parameters is to establish whether the district is considering the Life cycle assessment in their calculations, according to Burohapold 2019, no current official framework of highly energy efficient constructions considers embodied energy and the full life cycle in their calculation methods (burohapold, 2019). . Only the ZEB research centre had a life-cycle focus on emissions and introduced a CO2 factor on electricity (Backe & Kvellheim, 2020). Especially because for technologically advanced constructions, production, transportation and recycling of materials can reduce large proportions energy and emissions in the production phase, compared to the reduction that can be achieved in operation phase. For instance, In Germany, the full life cycle of most new buildings material are set for around 50 years. Such materials require large amounts of primary energy demand in their production. Therefore, Short distances in transportation can further lower the amount of embodied energy(burohapold, 2019).

5.2 Situation analysis

According to Shnapp 2020, diagnosing the situation analysis of a district requires an accurate representation of its entire system (built and non-built environment, energy system, on-site resources, etc.) to identify its current demand and the available offer within the district (Shnapp et al., 2020). Therefore, in order to provide as much information as possible, at this stage of the process the main focus lies on: The analysis of the Area of intervention, Data collection and the determination of the final ED.

5.2.1 Area of intervention

In order to understand the role and interplay of the district's characteristics, the building stock needs to be understood as a whole rather than individual buildings (Saheb et al., 2019). As part of the district's profile, the urban characteristics of the district must be clearly understood by the stakeholders. Therefore, according to (Shnapp et al., 2020), the following list of parameters should be taken into account in order to enable an overall assessment of the area of intervention in ZEDs:

District boundaries: By defining the district boundary, we ensure the data collected is accurate and can be used to estimate the flow of energy within buildings.

Climate and weather conditions: the project should consider as an important factor the climate and weather conditions, since they represent the RES potentials for buildings and the districts within the area.

Density and building locations: The density of the district determines directly the district's morphology and the compactness of the district, affecting the heat island effect and the wind patterns. Moreover, the location of buildings affecting the orientation and the shading patterns within spatial urban design.

Type and number of buildings: A district is a community, therefore, there will likely be a range of building typologies, ages and sizes within the building stock. These differences within the building stock need to be considered as they have different energy performance and requirements (Shnapp et al., 2020) .

5.2.3 Data collection (energy consumption and energy production).

According to Koutra 2017, the collection and analysis of data are the most important part in diagnosing the situation analysis of a district, since it facilitates the identification of site opportunities and constraints (Koutra et al., 2017). However, The accuracy of the analysis depend on the quantity and quality of the data collected and the methods and tools used to gather and process them (Shnapp et al., 2020). In that context, Aghamolaei 2018, defined three important steps in the data processing stages: Input data mining, as the initial part of the process defining concepts approaches and system interactions; Data transformation processing, as a form to classify the initial metrics; and a standardized output in order to set data objectives (Aghamolaei et al., 2018). In the figure below, a recommended framework to process data at the initial stages of the data gathering process in energy performance assessments was as well suggested by (Aghamolaei et al., 2018).

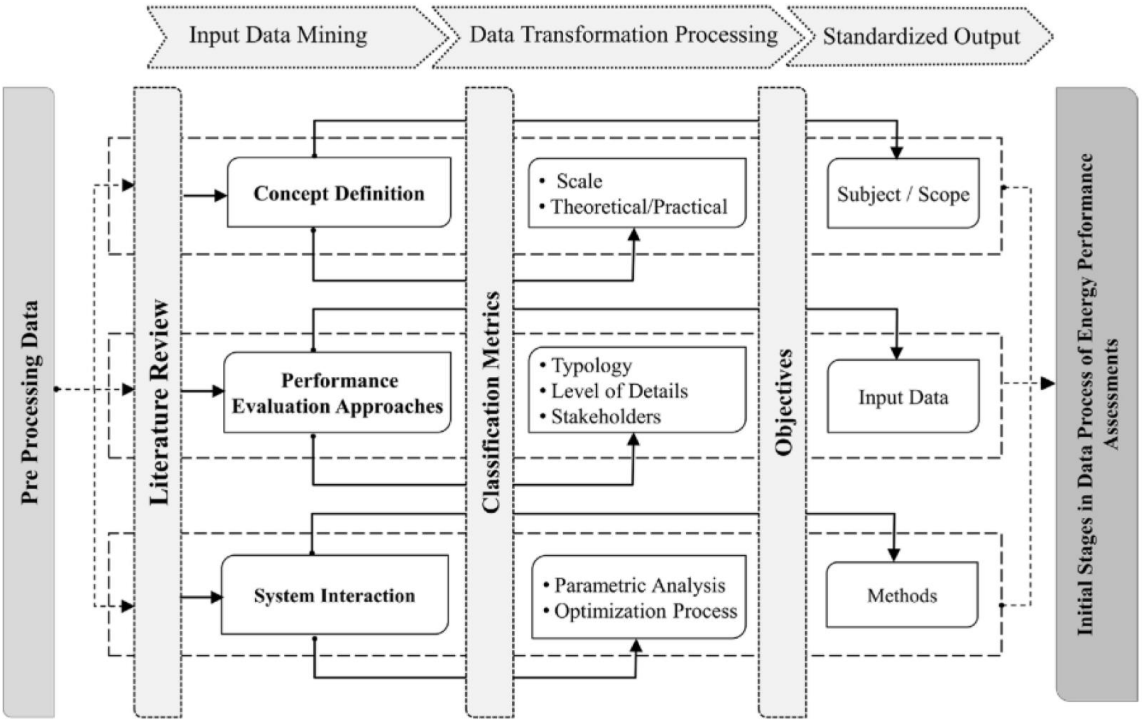


Figure 35: A framework to process data in energy performance assessments. (Aghamolaei et al., 2018).

Once the data is collected and the related objectives are in place, it is important to define the reference point of the energy consumption of each building in the district. In that sense, Shnapp 2020, suggested that Reference buildings can represent each building type and the geometry of the real buildings in the district can be used and designed according to minimum requirements of the standards related to the building envelope and the energy systems (Shnapp et al., 2020).

5.2.3 Determination of the final Energy demand (ED)

Once the data is collected and processed, the next step is to determine the district's energy demand, which is an estimation of the energy saving potential of the district and its final on site energy production. Since districts are a group of buildings, the methods to determine the energy demand should be based on **from general to particular and from particular to general methods** (Ferrari et al., 2019), as per the suggestions from literature and the case studies presented in this thesis, the focus for this stage is on from particular to general methossa , in which, the energy demand of each building within the district is calculated and then added with the other buildings to reach the total district energy demand. For example, by simply adding all individual buildings in the district together and then dividing them by the floor area to give a whole district building energy demand. According to Shnapp 2020, a minimum performance calculation should be applied for each individual building and aggregated in order to find the kWh/m² for the whole group of different buildings, where the buildings that cannot achieve the desire results should be identified, and then compensated by other buildings that have the potential to contribute with more energy(Shnapp et al., 2020). Furthermore, both the literature review and case studies provided specific ideas into how an individual district target could be defined and in as much or little detail depending on stakeholder's ambitions. The Stakeholders would then have an understanding of the district's demand before setting any target

5.3 Defining Targets, objectives and strategies

As mentioned in the initial phase of the framework, one of the most important aspects to consider when developing ZEDs is the establishment of goals, targets and strategies (Attia, 2018; Koutra et al., 2019; Shandiz et al., 2020; Sikder et al., 2016). In that regard, the data collected together with the initial mission and vision provided the necessary information in order to establish concrete and specific goals and objectives.

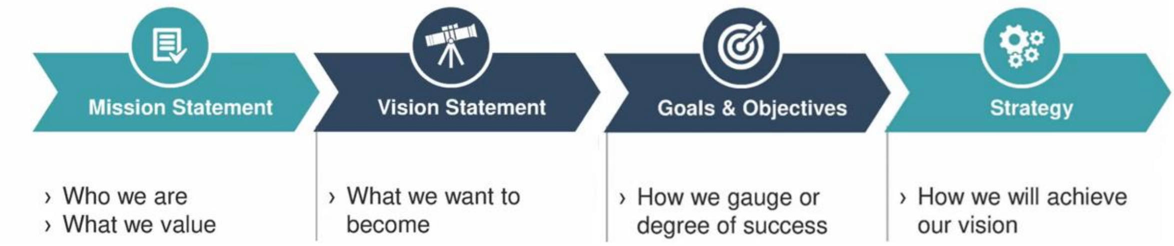
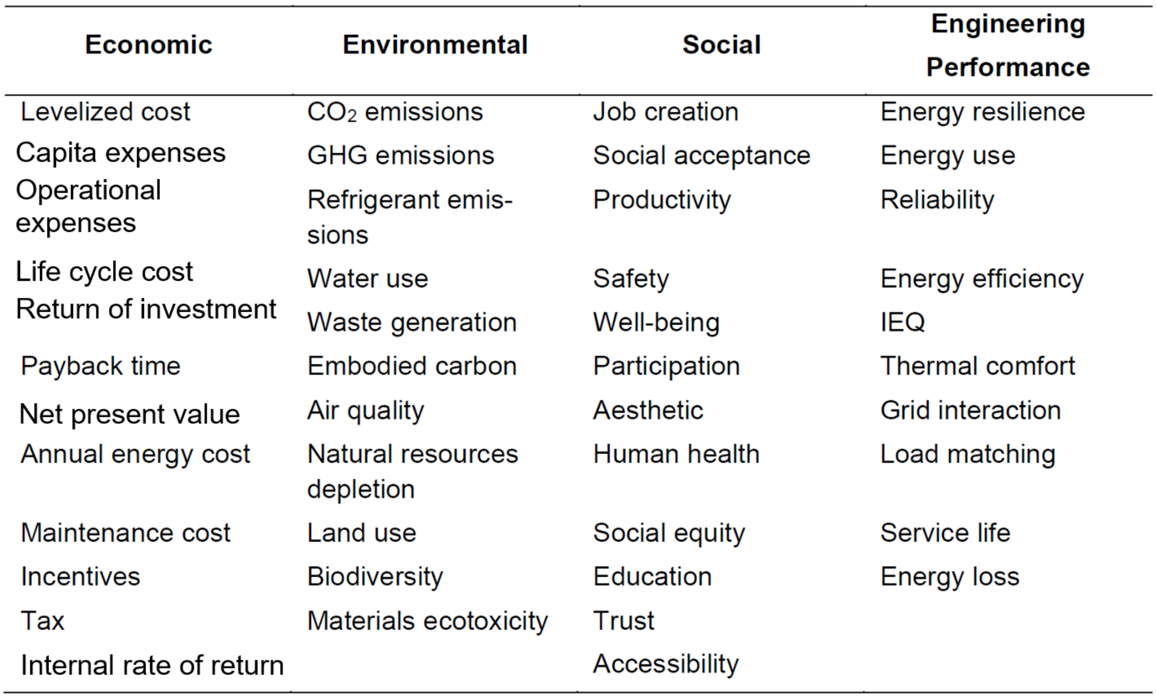


Figure 36: From mission establishment to setting objectives, adapted from (Overgaag, 2020).

During the analysis of this thesis, it was found that targets and objectives may differ depending on the constrains within the context. In that regard, Shandiz 2020, suggested that the main objectives should be based on environmental, economic, social and technical aspects. Furthermore, these objectives need to fulfil the minimum requirements established by regulatory entities (Shandiz et al., 2020). This methodology summarizes the main aspects that stakeholders need to consider when implementing a ZED. In the table below, a broad description of the objectives is listed according to the different aspects (Shandiz et al., 2020).



Economic	Environmental	Social	Engineering Performance
Levelized cost	CO_2 emissions	Job creation	Energy resilience
Capita expenses	GHG emissions	Social acceptance	Energy use
Operational expenses	Refrigerant emissions	Productivity	Reliability
Life cycle cost	Water use	Safety	Energy efficiency
Return of investment	Waste generation	Well-being	IEQ
Payback time	Embodied carbon	Participation	Thermal comfort
Net present value	Air quality	Aesthetic	Grid interaction
Annual energy cost	Natural resources depletion	Human health	Load matching
Maintenance cost	Land use	Social equity	Service life
Incentives	Biodiversity	Education	Energy loss
Tax	Materials ecotoxicity	Trust	
Internal rate of return		Accessibility	

Table 14. Main objectives within the four aspects of ZEDs. (Shandiz et al., 2020)

Based on the Zero Energy principle, the approach allows the development of objectives that not only satisfied the energy and environmental requirements but also finds how important is the social acceptance and the cost-optimal production in order to meet the sustainability of ZEDs.

5.4 Strategic design

The strategies to be implemented should be based on the results of the ED calculations. Moreover, understanding the energy demands in terms of heating, cooling and electricity, the strategies should focus on energy systems that can meet these demands. There are a variety of options available, however, the solutions chosen by stakeholders and the level of implementation will depend on different factors such as, context, district demands, technical capacity, etc. Therefore, in order to meet the objectives and goals, this part reviews the methodologies and technologies that can successfully be part of the district's energy solution combining local requirements, ECS, RES, connections to energy networks and grid, smart and shared systems, smart control, and user’s behaviour.

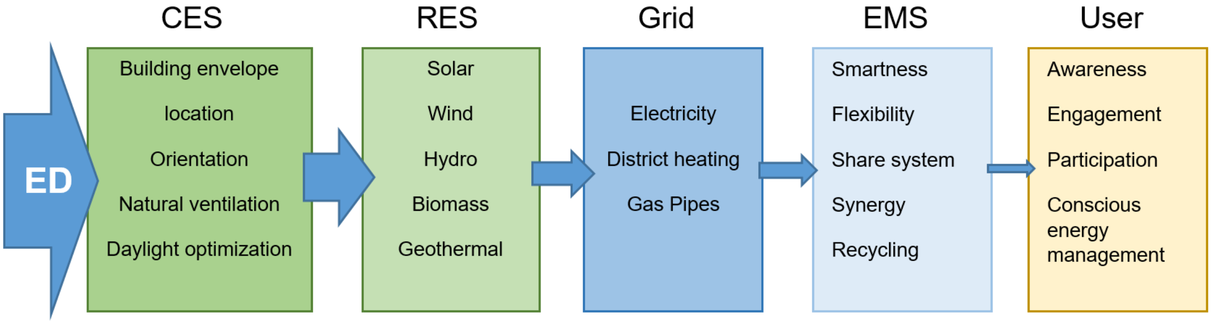


Figure 37. Representation of the ED throughout the implementation of the strategies. Author’s elaboration

5.4.1 Fulfil the Energy requirements of the local building code

Before the development of any ZE measurement, the initial step when implementing strategies for ZEDs is the compliance with the local building code. Given that, regulations and standards for the building sector shape the energy performance of buildings (Backe & Kvellheim, 2020). According to Shnapp 2020, strategies should follow the same approach as the EPBD outlines and hence follow the rules in the local building code, therefore, each building should adhere to the local building code’s minimum energy requirements, thus meeting the initial energy requirements (Shnapp et al., 2020).

5.4.2 Optimise Energy Conservation Systems (ECS) versus Renewable Energy Sysstem (RES)

Both the literature and the case studies has shown that when it comes to reduce the energy consumption, the first and most important strategy in any ZED development is to minimize the building stock’s energy demand through the optimization of ECS. As showed in both the ZE principles chapter and the best practices of the case studies, this can be done by both passive and active conservation system. Both for new and retrofitting projects, Passive energy conservation starts with the building design envelope in order to reduce the energy losses to the minimum and ensure the thermal performance of the buildings; meanwhile, location, orientation and form can be mainly applied to new projects in order to ensure passive solar heating, natural ventilation and daylight optimization.

Once the energy efficiency reaches its maximum potential, it is then, that the remaining energy demand can be supply with RES, which can be done onsite or off site.

5.4.3 Accommodate and maximize RES.

Unlike ZEBs, The ZED concept includes new perspectives in terms of energy supply from RES. Especially because, when RES are implemented on large areas and with different building typologies, the natural resources within the district will offer a range of alternative measures, which provide with a great opportunity in terms of maximizing the energy production. In that sense, Shnapp 2020, suggested that “an entire area can be supplied with decentralised forms of energy, with individual buildings supporting each other with excess energy” (Shnapp et al., 2020). Currently, there is a wide range of renewable energy technologies that exist at the moment, some of which can be done on-site or off-site, and can be used together to complement each other. Consequently, the possibilities to combine different elements are magnified at the district scale.

On-site RES level generation including heat pump systems, PV, wind, solar electric, photovoltaic (PV), solar thermal, solar hot water (domestic water heating and space heating), solar ventilation air preheating and geothermal heat pumps. Heating and cooling including district heating and or cooling plants, biomass, geothermal; solar thermal, heat pumps, etc.

Off-site RES level generation is mainly supplied by large electricity farms including wind, solar, hydropower and other renewables.

5.4.4 Selection of the best grid energy alternatives.

As mentioned at the beginning of the implementation of the strategies, the energy supply within the district can be done throughout systems of heating, cooling and electricity grids. In terms of thermal systems, district heating and cooling, has been considered one of the best alternatives for large areas, given that, it offers a wide variety of options and technical solutions that already exist (Cruz & Ugalde-Loo, 2021). On the other hand, when it comes to electricity, one of the predominant characteristics of electric grids is based on its flexibility, since it can be used for many purposes such as; Heath, cooling, light, etc. Moreover, it provides the opportunity to export the excess energy when is not needed, feeding back energy into the energy grid also entails economic benefits for stakeholders (burohapold, 2019).

5.4.5 Integration of the systems through an integrated Energy Management System (EMS).

Smartness and flexibility refers to the ability of the district to manage its energy demand and local generation according to the climate conditions, grid requirements and user needs and preferences (Salom et al., 2021).Therefore, by combining the ECS, RES and the best grid systems through an integrated EMS, there is the possibility to create the synergistic effect, which "is the result of two or more processes interacting together to produce an effect that is greater than the cumulative effect that those processes produce when used individually" (Safeopedia, n.d.), moreover, the district overall energy performance can be maximised to give an overall energy and carbon target of zero or positive energy for the district (Shnapp et al., 2020).

The District EMS also allows for energy to be shared and recycled throughout the community. As mentioned in the energy demand chapter, the buildings that are not capable of achieving a nearly zero energy target can be detected and compensated with excess energy from other buildings. For instance, excess heat energy can be removed from one building and put back into the system to be used in another building that needs that heat. Moreover, as in the case of the "Energy Traffic Light System" in Lehen, the "CUS" in Zaragoza and the "information screen" in Masdar city, Smart systems are not only meant to improve the energy performance of the district but also can be used as a vessel to educate consumers behaviour to improve the resident's awareness of energy consumption

5.4.6 Encourage consumption's behaviour of users

As the last step in this framework, achieving a well performing district does not only require the use of technical solutions, it requires the user's awareness and engagement in their consumption's behaviour. Energy consciousness describes the behavioural determinants of energy use, which according to Buzovski 2020, is a crucial factor in order to eliminate occupant's inadequacies in their energy consumption, encouraging at the same time, environmentally conscious energy management (Bukovszki et al., 2020). Moreover, as Backe 2020 points out, "a neighbourhood design and development process that does not involve citizens, risks slowing down the transition to a low carbon society, causing disaffection because users do not understand the changes being made or associate themselves with the aims being set "(Backe & Kvellheim, 2020). In that sense, Innovation or technology driven by citizen initiatives is often better accepted than those impose by authorities (Akcakaya Waite, 2022).

6 Discussion and Conclusions

6.1 Discussion

The presented thesis has elaborated upon Zero Energy Districts as one of the main solutions for the energy and related GHG emissions within the Building sector. Identifying central drivers and barriers, the three main parts of this study are related to the theoretical analysis, practical information from the case studies and the application of a conceptual framework to the further development of ZEDs.

The first part, elaborates firstly on the ZE context, and how policies and road maps are leading towards the reduction of energy and related GHG emissions, and the effects on climate change. Secondly, the ZE concept and principles are discussed together with the implementation of ZEDs and the possibilities therein. Lastly, the challenges will provide the opportunity to discuss how ZEDs can be addressed from different perspectives.
The second part, elaborates on the main drivers and barriers that real ZED projects faced during the implementation of the strategies and its development.

Context

As one of the main concerns among political leaders, current policies are leading to the development of a series of important energy technologies in order to mitigate the effects of climate change. Consequently, these roadmaps are mainly focused on low-carbon technologies in the main sectors. As such, the building sector is seeking to contribute with this goals with the development of the ZE concept. Due to its potential to contribute to the decarbonisation of the building sector, this concept can be applied at different scales (ZEBs and ZEDs) and at different levels of performance (nZEDs, ZEDs and PEDs). Therefore, regardless of the type of intervention (ZEBs or ZEDs), the most important aspect of these strategies is to accelerate the energy transition in order to mitigate the effects of climate change.

ZE concept

Within the novelty of the ZE concept, this thesis presented a set of different technologies used for the optimization of EE and the share of RE, which are regarded as the most important low carbon technologies for the success of ZEDs, however, in order to keep improving the development of the concept there should be no limitations on specific solutions. Openness for different technologies will provided more alternatives for better solutions in the future. In that sense, all kind of solutions should be considered as long as they are sustainable. On the one hand, regardless of how good the solution is, EE solutions should at all times be the first priority, since as for today, EE technologies are regarded as the most cost-effective alternatives and are the main contributors in the energy reduction within the building stock. On the other hand, although, RE can enable major contributions to the reduction of GHG by replacing fossil fuels, the On-site production capacity of RE is to a great extent determined by the local and regional natural conditions, moreover, the space needed for the generation of RE is as well limited by both the area of the district and the urban environment. Furthermore, the implementation of waste management can contribute with the overall performance of the district, however, this implies certain level of user's engagement towards

In relation to the implementation of ZEDs vs ZEBs, the flexibility and sharing function of the energy infrastructures at the district level are one of the most important aspects when it comes to ZEDs. Until now, energy infrastructures, such as electricity networks and heating systems, have typically been operated and optimized separately. In that regard, ZEDs offers a lot of technical and economic benefits by taking advantage of the synergistic effect between the different systems and networks. In fact, political discussions are already investigating the use of cross-energy carrier synergies in order to improve distribution grid constraints in an efficient and cost-effective way, enabling the possibility of energy sharing not only at district levels but at larger scales such as cities, thus, improving in that sense that sustainability of local and global resources.

In a final quote, it is important to mention that the initiatives regarding ZEDs can further consolidate the development of PEDs which is the ultimate goal of sustainability. In that regard, the realization of the PED concept could be seen as the next step towards an even higher ambition, regarding both, the energy reduction performance, and the further minimization of CO2 emissions.

Challenges

By studying the ZE concept in depth as part of this master thesis, it is clear that a ZEDs has a lot more to it than only being an environmentally friendly solution. ZEDs are very challenging from a political, economic and technical level. In the political context, regardless of the efforts and ambitious set by the relevant authorities. There is still an unclear definition of what a ZED is, leaving the definition for open interpretation among stakeholders. Thus, rather than being the guidance towards the implementation of the concept, this could lead to miss interpretation and confusion that could discourage stakeholders to the further development of ZEDs.

As in all business as usual models, the ZE concept appear to be new and complex, which for some investors this can be perceived as expensive. However, ZEDs present unique opportunities to cost-effectively achieve the desired expectations from investors, since most of the cost for this technologies occurs at the moment of investment, whereas the the operational cost is minimal and on top of that, it also provides the opportunity to produce its own energy as in the case of PEDs, this surplus in terms of energy can be used as a commodity that can be used to increase the value of the properties. However, the integration of ZEN assets, such as local production of energy, will challenge current market structures and require higher integration of markets related to building design, thermal energy and electricity. Furthermore, challenges and opportunities related to value distribution and capture within different business models are elaborated upon.

From a technological perspective it is evident that there is a lot of room for ZEDs to improve in the future. These improvements will be decisive in the uptake of the ZE concept as they will be beneficial for both, the efficiency and the economy of the systems. As presented in this thesis, the energy conversion efficiency of new technologies is improving drastically with new developments, at the same time, the prices will keep decreasing as they become more prevalent in the marked.

From these perspectives, ZEDs present unique opportunities to cost-effectively achieve high levels of energy efficiency and renewable energy penetration across a collection of buildings that may be infeasible at the individual building scale.

Case studies

The case studies presented in this thesis, provided the empirical information needed in order to gather real information as to what are most drivers and barriers in the implementation of ZEDs. The success of the projects in achieving its energy targets was mainly due to the political influence. Through this political organizations, it was possible to maintain the contribution among stakeholders across the different stages. Good political initiatives, however, must be able to provided not only good leadership but the necessary funding and new business models in order to ensure the completion of the project, especially when it comes to deal with big investments projects (Masdar) and social housing developments (Picarral). Moreover, awareness raising campaigns and a continuous participation from different actors throughout the duration of the project had further strengthened stakeholder engagement and cooperation. This includes the importance of citizen participation, in that regard, the case studies demonstrated that engagement proved to be crucial in the successful execution of the entire project since it created mutual trust and, thus, enabled public acceptance of the project. Finally, through these case studies, it was possible to notice the performance gap as one important issue. Here, it was observed that the actual energy performance of the districts is lower than the designed performance. Therefore, it is imperative for stakeholders to consider these differences in order to prevent miscalculations in achieving the initial goals of the project.

Framework

Ultimately, the aim of this thesis was to identify best practices and barriers in order to propose a conceptual framework for ZEDs. As it became evident in the analysis, given the interdisciplinary nature of ZEDs, the development of a conceptual framework is complex and extensive. Moreover, it is possible that the models for energy calculation and strategic tools presented in this framework will not succeed in taking into account all these factors. Nevertheless, in order to answer the main RQ and considering the complexity and broadness of ZEDs, the presented framework do not provide an objective and concrete answer to the RQ, rather it contextualized the planning principles and strategies to provide an answer. Consequently, the proposed framework is not intended to be applied in real ZEDs projects, rather, is something that use all the available intervention opportunities based on existing models and tools that can be used as a generalized methodology for the future development of ZEDs.

6.2 Conclusions

Our society is currently facing challenges with regard to climate change and resource depletion. These challenges include global warming, fossil fuels and related GHG emissions. On top of that, the rapid urbanization growth has resulted in a drastic worsening of the predicted trends. As one of the main energy consuming sectors, the building sector is responsible for more than one third of global primary energy consumption and subsequently GHG emissions. In order to reduce the energy consumption in the building sector, the concept of ZE has been the main driver towards the energy neutrality of the sector.

Climate and energy policies across different levels have been the main drivers for the development of the ZE concept, in that regard, literature on ZE definitions is currently large with different terms and concepts, however, there has been two major areas where the concept had major impact in the building sector, i.e., ZEBs and ZEDs. Regardless of the scale, the main characteristics of these solutions are based on EES and RES, which are both the minimization of energy demand and the maximization of energy production, respectively. Moreover, in the case of ZEDs, grid connections play an important role in the energy performance due to its flexibility and the potential for energy sharing.

The transition from ZEBs to ZEDs has been primarily driven by the joint of technical, economic, and social advantages that ZEDs have over ZEBs. Consequently, ZEDs have received more attention in recent years. The switch to larger scales however, has its own challenges, mainly because at the district level, there is a greater number of factors that affect the energy performance of districts. Moreover, despite the support from energy policies and regulatory frameworks, the uptake of ZEDs it is still affected by financial aspects such as the case of Masdar and social barriers such as the case of Picarral.

This thesis concludes with the development of a conceptual framework for ZEDs, providing the best planning principles and strategies. These Planning principles are based on the importance of integrating the energy aspects from the beginning of the planning process (i.e., initial assessment and situation analysis) rather than the last stages (Strategies and implementation). Among the strategies, a representation of the ED through the strategies was the determining factor to prioritize the different strategies, starting from EE, RE, grid systems, EMS and user's behaviour.

In the end, ZEDs when properly developed and implemented can effectively reduce the energy consumption, decrease greenhouse gas emissions, minimized waste and provided a healthier environment. Moreover, they play an important role in the energy security and combating the effects of climate change. Therefore, I believe that by taking the ZEDs to even larger scales (cities) and even better performances (PEDs) we can rapidly achieve the desired Net Zero Emission society that the world urge for.

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