Full title: Review on performance aspects of Nearly Zero-Energy Districts

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Declarations of interest: None

Acknowledgements

The presented work is framed under the *Energy for Sustainability Initiative* of the University of Coimbra (UC).

Funding: This work was supported by the Portuguese Foundation for Science and Technology (FCT) and European Regional Development Fund (FEDER) through COMPETE 2020 -- Operational Program for Competitiveness and Internationalization (POCI), under the project

Ren4EEnIEQ (PTDC/EMS-ENE/3238/2014 and POCI-01-0145-FEDER-016760 respectively); Ana Rita Amaral and Eugénio Rodrigues acknowledge the support provided by the Portuguese Foundation for Science and Technology (FCT) under Doctoral grant PD/BD/113718/2015 and PostDoc grant SFRH/BPD/99668/2014, respectively.

ABSTRACT

The *nearly zero-energy* concept aims to achieve a significant reduction of energy consumption in the buildings' sector, while promoting the renewable energy dissemination.

In order to move beyond the individual building boundary and to consider the urban context influence, this article presents a critical review on the aspects of applying the *nearly zero-energy* principle to the intermediate urban scale known as *district*, from an architectural and urban planning perspective. A contextualization on the definition of district is proposed, as well as a delimitation of the various urban scales and respective levels of detail, regarding the establishment of the Nearly Zero-Energy District (NZED) concept. Key urban elements as morphology, climate and public spaces are identified in literature, namely the geometric indicators that potentially influence districts' performance. The developed methodologies for calculating districts' energy performance and the respective metrics are explored as well. At the aftermath, challenges for further research opportunities are discussed, namely the need to develop methods to evaluate the real impact of the reviewed urban elements, to appraise the interrelations between climatic and morphological indicators, and especially to accurately include them in the energy performance assessment methodologies of districts.

Keywords: nearly zero-energy district; district scale; urban morphology; urban climate; district energy performance

1. Introduction

The 20/20/20 climate/energy targets proposed at the European growth strategy for the present decade (Europe 2020, 2010) have leveraged the arising of measures and actions, aiming at reducing the energy consumption and at increasing the share of renewable energy sources. In this context, the recast of the Energy Performance of Buildings Directive (EPBD (recast), 2010) brought forward the concept of *nearly zero-energy building* (NZEB).

The deployment of the NZEB model has been attracting the attention of the research community, because of its mandatory character for all European Member States from 2020 onwards, and also due to its inherent principle of decreasing buildings' energy consumption and, thus, associated CO_2 emissions. Significant work has been done on the proposal of definitions for the NZEB concept and possible variations (Crawley, Pless, & Torcellini, 2009; Sartori, Napolitano, & Voss, 2012; Torcellini, Pless, Deru, & Crawley, 2006), on the development of methodologies for design, energy modeling and calculations (Athienitis & O'Brien, 2015; Marszal et al., 2011; Voss, Sartori, & Lollini, 2012), and on the outreach of case studies (Garde & Donn, 2014; Kurnitski, Achermann, Gräslund, Hernandez, & Zeiler, 2013). Even though, the lack of a global and comprehensive framework to characterize NZEB and its requirements, namely regarding performance levels, energy uses or renewables options is still notable (D'Agostino, 2015). This uncertainty may affect how buildings are designed (Sartori, Napolitano, Marszal, Pless, & Torcellini, 2011), considering all the different interpretations that are possible to take into account, such as energy consumption, building cost, thermal comfort, environmental impact or indoor air quality (Athienitis & O'Brien, 2015). This large range of interpretations and the operative technological challenges to achieve the zero-energy objectives at the building level can lead to additional strategies, in which the urban scales are included.

The concept of *nearly zero-energy district* (NZED) arises in this scenario, and it intends to adjust the nearly zero-energy principles to the urban context and to assess its potential impacts and feasibility. By establishing the zero-energy objective to the overall district, the strategy of considering the contributions from different energy performances and different production capabilities allows to take advantage of diversity and the possibility of sharing needs, costs and resources.

Accordingly, the NZED approach intends to address several concerns raised by NZEB at the individual level, which are fundamentally based on energy performance and renewable energy production on site. Regarding the performance aspect, the mutual influence between buildings as well as their surrounding urban context are taken into account, allowing higher energy performance assessment accuracy (Marique & Reiter, 2014).

Regarding the energy production aspect, and due to the current trends on smart energy systems, the existing mismatch between demand and generation that happens at the buildings level can be better managed when an aggregation of buildings is considered (Dai, Hu, Yang, & Chen, 2015; Koch & Girard, 2011). The assessment of the overall energy needs and sharing avoids the oversizing of systems, and the ability of managing locally different energy resources allows enough flexibility to adjust supply to demand, through the help of energy storage, and even to account new consumptions such as the electric mobility. Energy production and distribution can be conceived together, which contributes to minimize losses and, at the same time, can benefit NZED to contribute to a cost-effectiveness that NZEB is still not able to achieve (Kurnitski, 2013; Kurnitski et al., 2011).

One of the main challenges of going beyond the building level to the urban scales is the definition of boundaries for developing properly performance assessment methodologies. Enlarging the scale of intervention enlarges as well the complexity and the design constraints related to urban context that influence the energy performance.

Geometric design parameters play a crucial role in achieving the zero-energy goals, since they are responsible for mitigating buildings' energy consumption for heating, cooling and lighting, and for maximizing the potential of energy production, especially through solar and wind sources. Several studies seek to include urban geometric factors in buildings' performance evaluation, such as aspect ratio or depth ratio (Hachem, Fazio, & Athienitis, 2013), compactness or ground and floor space indexes (Rodríguez-Álvarez, 2016), or floor area ratio, site coverage or shape factor (Mauree, Coccolo, Kaempf, & Scartezzini, 2017). However, even when proposing the methodologies application to neighborhoods, these studies tend to focus on buildings performance, or on a reduced set of indicators, lacking a more holistic approach. When moving to the urban scale to analyze the district as a whole, additional design factors play a significant role on performance evaluation, and literature has evidenced the lack of appropriate methodologies and tools that account for all these parameters, either for researchers as for practitioners (Luederitz, Lang, & Von Wehrden, 2013). When quantifying the factors that influence the energy performance of urban areas, Ratti et al. (2005) argue that generally, even software tools tend to disregard geometry parameters, and default values are assumed when needed to be simulated. This work intends, thus, to contribute to fill this gap, by establishing a knowledge base to support further developments.

In this sense, this article presents a literature review on NZED-related concept, namely through the discussion of the performance aspects that architects and urban planners must take into account when designing or studying it. It aims at understanding the challenges and implications of applying the nearly zero-energy methodological principles to the district scale.

Based especially on published scientific literature since the early 2000's, the main objective of this work is to collect, organize and discuss a set of urban parameters that influence energy demand and production and, consequently, districts' energy performance.

Beginning with *NZEB* surveys and broadening to *district*, *neighborhood* and *community* energy-related studies, this process was developed in two phases that are reflected in the structure of the article. Firstly, a theoretical contextualization on the origin of the key concepts analyzed – the district scale and the nearly zero-energy concept – is presented in Section 2. Afterwards, the understanding of a set of key factors that influence the NZED energy behavior and calculation, regarding the performance perspective, is reflected in Section 3. From this critical review, a summary of methods and tools developed for the study of district-related scale is presented in Section 4. This summary is also helpful in understanding the studies found and the categorization to which they were subjected during the review process. Finally, Section 5 concludes the article with a set of reflections raised by this work and on further research opportunities.

2. Theory

2.1. The scale of the district

Urban planning as a discipline is a relatively recent field of study (Pardo & Echavarren, 2011). So are the district, community or neighborhood (Fulbright-Anderson & Auspos, 2006; Galster, 2001; Sharifi, 2016), which are different terms for the same notion – a "portion" of a city. Even though researchers have not yet come to an agreement regarding the exact definition (Fulbright-Anderson & Auspos, 2006), *neighborhood* appears as a term widely accepted by its original significance, related to a community within a city, generally with a strong social component, with considerable interaction between members (Fulbright-Anderson & Auspos, 2006). More recently, it represents a new interest in urban planning studies, given the intermediation between buildings and the whole urban area. The concept of neighborhood planning is associated as well to the early 20th century, reflected in several urban movements and theories whose aim was to solve the problems brought by industrialization (Sharifi, 2016).

Since Brundtland Report and the establishment of the Sustainable Development concept (Brundtland, 1987), the environmental facet has contributed to a new field within urban studies, driven by the principle that cities have a considerable environmental impact that must be reduced, as a means to improve the citizens' health and their quality of life. It is widely known that buildings are responsible for about 40 % of the total energy consumption (International Energy Agency, 2013); as such, cities represent the highest concentration of energy demand (International Energy Agency, 2015), but also of waste, pollution and greenhouse gas emissions (Huang & Yu, 2014). In order to address these concerns, urban concepts based on sustainability principles such as the *eco-district* have arisen (Flurin, 2017). Luederitz, Lang, & Von Wehrden (2013) brought together several approaches and principles found in literature regarding the various dimensions of sustainable neighborhoods, as the ecological, cultural, economic and social.

To reify these principles, urban environmental assessment methodologies present some narrowing efforts to the neighborhood scale (Ameen, Mourshed, & Li, 2015; Haapio, 2012; Huang, Yu, Peng, & Zhao, 2015; Sharifi & Murayama, 2013). The diversity of methods and tools is wide, comprising lifecycle assessment tools, rating systems, voluntary certification of buildings or communities, of which LEED-ND, BREEAM Communities or CASBEE are the most prominent examples. However, it is noteworthy that their formulation is fairly based on the local realities – the context of the regions where they are developed – and the adaptation to different specificities worldwide can be difficult (Haapio, 2012; Marique & Teller, 2014). Koutra, Ioakimidis, Gallas, & Becue (2018) conducted a review on assessment tools that could support the implementation and development of NZED's, and some of the reviewed tools are abovementioned. Nevertheless, these are dedicated to sustainability, which is a broader approach from energy efficiency, comprising concerns as water, waste or infrastructure.

In what concerns the study of energy in buildings and in cities, the intermediate scale raises the perspective of converging common interests found in both scales. Historically, buildings have been taken as isolated and the influence of urban surroundings on their energy performance has not been properly incorporated (Ratti et al., 2005), as well as the interdependencies that may occur amongst them. By opposition, the city has been considered as a whole, an integrated set of buildings whose attention has been focused on the sustainability-related studies.

Moving from the building scale to the city has an associated increase of complexity by involving more stakeholders and interdependencies, which acts as barriers to the implementation and dissemination of the nearly zero-energy principles. An intermediate scale, such as the district, appears to respond to this intricacy. In accordance to Fonseca & Schlueter (2015), it is an adequate scale to go beyond the limits of the single building without losing its control and, at the same time, capable to address tangible solutions.

The difficulty in defining and delimiting in space an intermediate urban scale is a great obstacle noticed in the literature. This can be assumed as an isolated small settlement, a city neighborhood or even a quarter of a neighborhood. Studies proposing intermediate scale limits have recognized that the values adopted were based on the specific reality of the studied cases. Examples of quantification are given by Rey, Lufkin, Renaud, & Perret (2013) that compared seven Swiss neighborhoods with 100 to 200 inhabitants, or by Huang et al. (2015) that presented the concrete number of 10 km^2 as the desirable maximum size for a unit of the city. Marique & Teller (2014); Jacques Teller, Marique, Loiseau, Godard, & Delbar (2014) considered that a sustainable neighborhood should meet 40 dwellings per hectare in urban poles, 30 dwellings per hectare in city centers and 20 in villages. On the other hand, Koch & Girard (2011) preconceived a neighborhood delimitation as a built area with a size of more than 500 residential units and a high share of residential use. Therefore, no definitive assumption on the ideal boundary or density for a neighborhood has been found. In this perspective, the allocation of the different energy consumption types to each of the three urban scales – building, district, and city – remains unclear.

2.2. The nearly zero-energy concept

The nearly zero-energy concept is, essentially, related to the reduction of the energy demand to almost zero, coupled to the energy supply from renewable sources (EPBD (recast), 2010).

The elements that comprise the design of a NZEB are related to the integration of passive design and active systems (Aksoy & Inalli, 2006; Albatici & Passerini, 2011; Pacheco, Ordóñez, & Martínez, 2012; Sadineni, Madala, & Boehm, 2011), namely: a) passive measures, such as building orientation or an efficient envelope including glazing areas; b) efficient lighting systems used complementary to daylight; c) efficient heating and cooling equipment; d) efficient ventilation; e) renewable technologies; and f) building energy management systems (Kapsalaki & Leal, 2011), within a context of efficient technologies and rational use of energy. Notwithstanding, NZEB has already been widely studied and several variations addressing collateral issues related to energy performance, such as costs and emissions, were proposed (Laustsen, 2008; Torcellini et al., 2006). Also, either the results of Task 40/Annex 52 of the International Energy Agency (IEA) – Solar Heating and Cooling Program (SHC) (Athienitis & O'Brien, 2015), and of REHVA (Kurnitski, 2013; Kurnitski, Achermann, Gräslund, Hernandez, Kosonen, et al., 2013), have become essential publications regarding the state-of-the-art of all the requirements, features and design process.

In urban scenarios, the building performance cannot not be assessed individually. Non-isolated buildings behave as a part of a whole, influencing each other and being influenced by urban context, amongst others as the occupant's behavior or systems' efficiency (Baker & Steemers, 2000). Figure 1 schematizes the main implications of designing a NZEB in urban context where the surroundings are taken into consideration. If a same building is considered individually, different results on the energy performance evaluation would be achieved. An accurate analysis, considering the urban elements that affect the energy requirements, leads to more realistic consumption patterns, which consequently potentiate adequate strategies to reduce energy consumption and an adjusted design of energy systems.

The absence of energy performance indicators such as energy density increases the uncertainty and subjectivity in the definition of reference dimensioning criteria. Nonetheless, Baker & Steemers (2000); Ratti et al. (2005) endeavored to propose a weighted quantification for the factors affecting energy consumption in urban buildings – climate, urban context (not defined), the building (2.5), systems (2) and occupants' behavior (2). Posteriorly, Salat (2009) adapts this principle to the reality of Parisian buildings, considering that the factors and respective weights that affect energy consumption are climate, urban morphology (1.8), building physics (2.5), systems (1.8) and occupant's behavior (2.6).

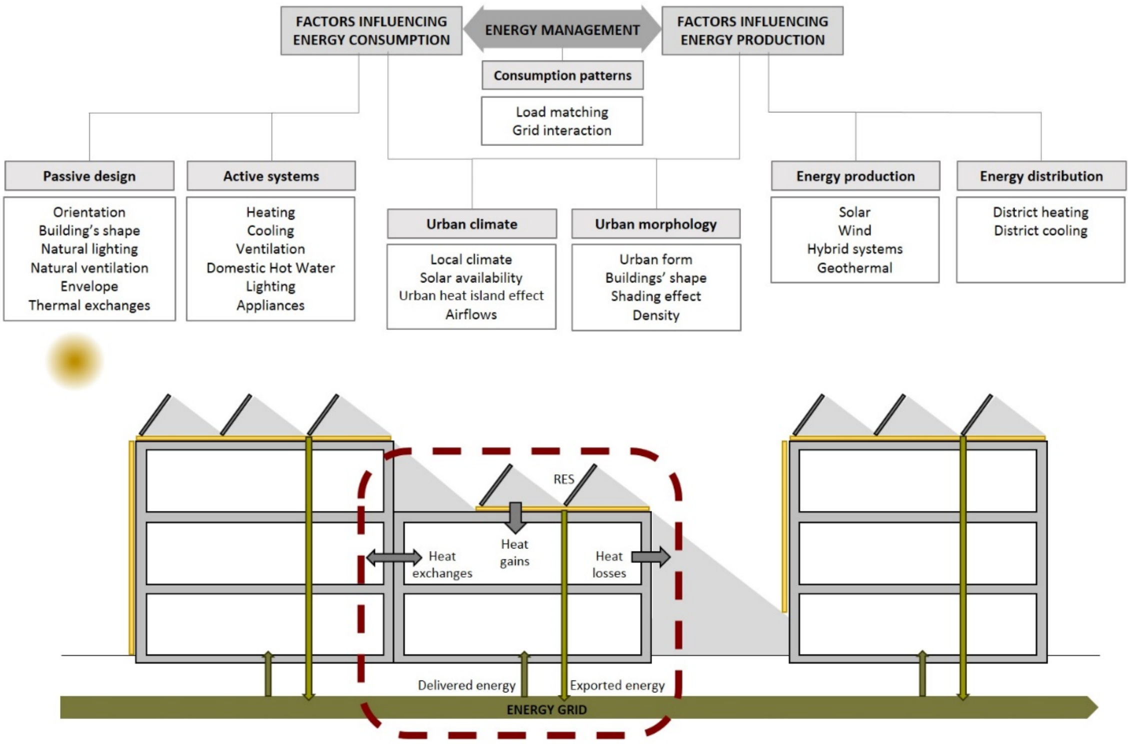


Figure 1: Factors influencing the energy assessment and balance of an NZEB taking into account the urban context.

A first proposal to define a zero-energy community was found in Carlisle, Geet, & Pless (2009), who states that a net-zero energy community is "one that has greatly reduced energy needs through efficiency gains such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy" (Carlisle et al., 2009). It included the energy used for buildings, industry, vehicles, and infrastructure. Later, Marique, Penders, & Reiter (2013); Marique & Reiter (2014) adapted this definition, to consider the energy spent in a neighborhood as the sum of the demand of each building and the transportation of its inhabitants.

Nevertheless, the abovementioned approach raises two questions: a) it is fairly wide, since the definition of "community" is not yet clear – it can be a portion of a city or a small village, and the approaches are invariably different; b) it can become too complex, by not specifying if transportation considers travels within a district, between districts, neighboring districts, or longer distances, which makes a substantial difference and becomes too subjective to be considered at this scale. For Marique & Reiter (2014), the assumptions were based on a very specific reality – home-to-work travels provided by Census data available on Belgian context – and could not be extrapolated to a worldwide basis.

The research project ZenN – Nearly Zero Energy Neighborhoods (Sornes et al., 2014), proposed a definition where the global energy demand of a cluster of residential buildings should be low and partly met by renewable energy sources produced on site. However, this project focused on the renovation of individual buildings without further deepening the level of detail of the districts and considered a neighborhood as a sum of buildings.

In this sense, based on the most general and accepted concept of NZEB concerted in the EPBD (recast), and applying it directly to the district level, it is assumed in this work that a *Nearly Zero-Energy District* (NZED) is a delimited part of a city that "has a very high energy performance (…)", with the "nearly zero or very low amount of energy (…) covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" (EPBD (recast), 2010, p. L 153/18). It is proposed that the energy consumptions to be taken into account in a district performance assessment are the energy needs for buildings and for the district public spaces, such as the public lighting, traffic lights or landscape maintenance.

In this context, an NZED is not a sum of NZEB's of a district; it is considered as a group of buildings with different consumptions and their respective public surroundings, whose overall balance must reach almost zero. Nevertheless, buildings remain the largest consumers of the total amount of energy demand. Thus, the main effort still resides in decreasing individual buildings' loads, and for that, the same energy efficiency strategies proposed for NZEB should be met at the district scale as well. Accordingly, the factors influencing buildings performance at the district scale are those presented in Figure 1. This aggregation of a set of buildings and respective surroundings carries the impact of thermal exchanges between adjacent buildings and of the external environment to the energy performance analysis, enabling to make the most of an integrated resources management including consumption and generation.

A similar exercise of expanding the nearly zero-energy concept can be done to the city scale. However, several authors have already analyzed types and methods for evaluating the energy use in urban structures, such as the creation of urban energy modeling systems or the evaluation of the embodied energy (Davila & Reinhart, 2013; Huang et al., 2015; C. F. Reinhart & Cerezo Davila, 2016; Swan & Ugursal, 2009).

Generally, there is a consensus to include the energy spent in transportation in the total energy consumption of urban areas, either in cities or in neighborhoods, by establishing a correlation between urban morphology, traveled distance and energy consumption in transportation (da Silva, Costa, & Brondino, 2007; Doherty, Nakanishi, Bai, & Meyers, 2009; Jia, Peng, Liu, & Zhang, 2009; Rey et al., 2013; Steemers, 2003). The impact of urban form on transportation has been highlighted as well (Marique & Reiter, 2014). Even though, the uncertainty in predicting populations' pathways and in controlling the transport behavior remains high, namely the use of private cars or public transport and the correlation with cultural behaviors. Due to this subjectivity, it is assumed that transportation energy consumption is particular to the whole city assessment and not to the district. This assumption is based on the premise that people make their daily trips mainly within the city, not within the district. Otherwise, short distances can be done by foot or bicycle and should not be considered in energy accounts.

However, if the penetration of renewable energy production and the adoption of electric vehicles continues, the energy supply for transportation may be managed and incorporated at the district or neighborhood level, and possibly in the building design.

Having these notions in mind, Figure 2 schematizes a stratification proposal regarding the energy demand analysis: district involves the buildings' performance and adds the energy spent in public areas; and city encompasses districts' performance and adds the energy spent in transportation. The energy supply and distribution must be considered in each scale as a whole and should face the total needs.

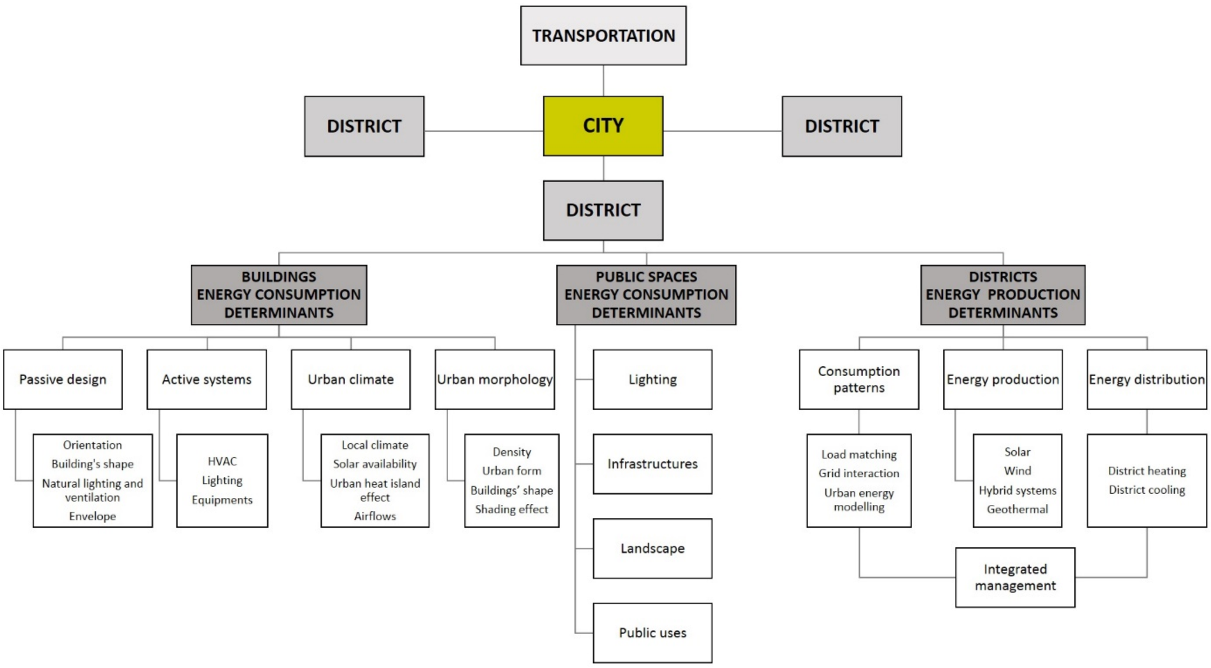


Figure 2: The main energy determinants implied in each scale, focusing on the district balance towards a NZED.

3. Aspects on energy performance

At the urban scale, the buildings' performance has been mainly associated to the availability of solar radiation, either for the passive solar heating and natural lighting within buildings (Compagnon, 2004; Kontoleon, 2015; Nault, Peronato, Rey, & Andersen, 2015; Stevanović, 2013; Vartholomaios, 2015) or for assessing the solar energy capacity of buildings surfaces and public spaces (Freitas, Catita, Redweik, & Brito, 2015; Kanters & Horvat, 2012; Mohajeri et al., 2016; Sarralde, Quinn, Wiesmann, & Steemers, 2015). This has been reflected in several research projects (Aste, Adhikari, & Buzzetti, 2010; Compagnon, 2000; Scartezzini & M., 2003), where solar potential maps, available online for several European cities, gain prominence by helping non-experts to implement solar production solutions (Grauthoff, Janssen, & Fernandes, 2012; Kanters, Wall, & Kjellsson, 2014).

Other factors, such as those related to neighborhood characteristics, as airflow paths, wind speed or even outdoor air and radiant temperature of the Urban Heat Island (UHI) effect (Sanaieian, Tenpierik, Linden, Mehdizadeh Seraj, & Mofidi Shemrani, 2014), will influence not only passive design strategies, but also the sizing and proposal of energy systems.

Assuming that the district's energy consumption goes beyond the individual building, the energy consumed in public spaces should be considered as well in the overall energy balance.

The few approaches to a neighborhood scale found in literature have generally concentrated in specific objectives, without a global perspective. Accordingly, Sanaieian et al. (2014) highlighted the difficulty in studying the impact of the surroundings on the performance of urban blocks precisely because of the difficulty in encompassing all relevant aspects simultaneously.

Nevertheless, for a deep and complete approach of NZED studies, the following subsections gather in a single reckoning the known urban elements that influence buildings performance — urban climate, urban morphology, urban density, and building's form – and add the energy spent in public spaces.

3.1. Urban climate

The growth of urban areas and the complexity of urban morphologies have provided the development of urban microclimates, with special attention to the airflows and wind speed, the outdoor temperature and the solar radiation. These, altogether, contribute to the UHI effect.

This phenomenon is related to the design of urban forms, and a consequence of high urban densities, due to the street canyons that trap long-wave radiation and decrease albedo, combined with heating retaining properties of buildings with high thermal mass (O'Malley, Piroozfar, Farr, & Pomponi, 2015), amongst other factors. The UHI is not an exclusive phenomenon of the great metropolises, and the rise in temperatures can rise significantly when compared to surrounding areas (Madlener & Sunak, 2011). This difference will have a substantial impact on energy consumption associated with the buildings' cooling, as well as on population discomfort, especially in warmer climates. In a recent study, Palme, Inostroza, Villacreses, Lobato-Cordero, & Carrasco (2017) found that incorporating the UHI effect in the buildings' performance simulation can result in an increase of energy need for cooling from 15 % to 200 % in South American coastal cities.

The same urban canyons that provide UHI are related to the variation of airflows and wind velocity as well and, according to Ishugah, Li, Wang, & Kiplagat (2014), this movement and intensity are affected by a combination of building shape, height and distance between buildings. Not only the prediction but also the effects of wind on urban buildings and areas are difficult to quantify (Chronis, Liapi, & Sibetheros, 2012). However, it is known that the building natural ventilation is dependent on urban airflows, as on the temperature difference between the indoor and outdoor environment. On the other side, recent studies recognize that urban wind effect offers good energy production potential (Yang, Su, Wen, Juan, & Wang, 2016). In this sense, districts' design should take into account this twofold effect and assume whether the design options are associated to the increase of wind energy production potential or to the decrease of wind speed related discomfort.

Several studies point to some common measures to mitigate the described urban side effects, namely the reduction of the anthropogenic heat and, especially, the increasing of humidification or effective albedo by foreseeing green urban areas (including location and heterogeneity factors), as vegetation, green roofs and walls, or water surfaces (Rizwan, Dennis, & Liu, 2008;

Srebric, Heidarinejad, & Liu, 2015).

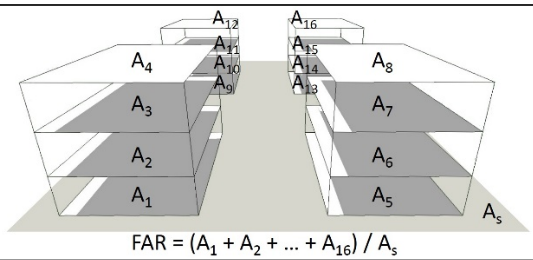
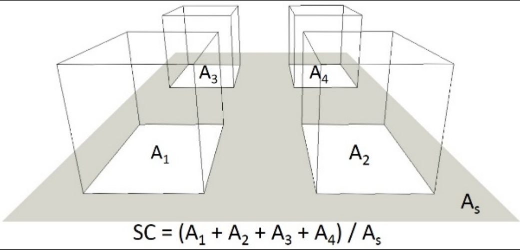
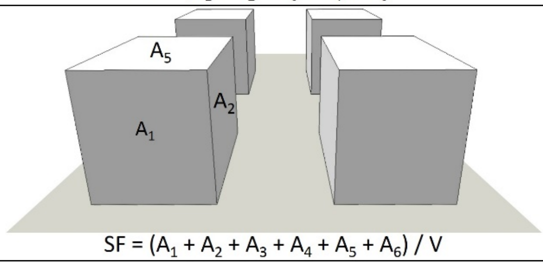
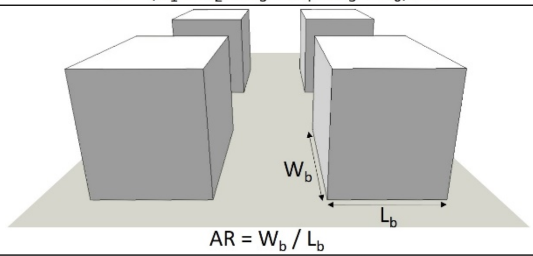
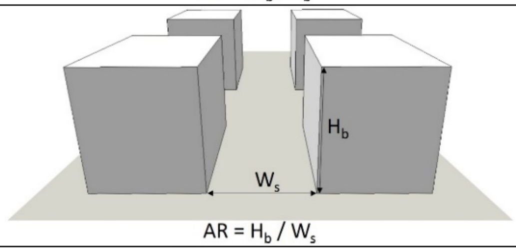
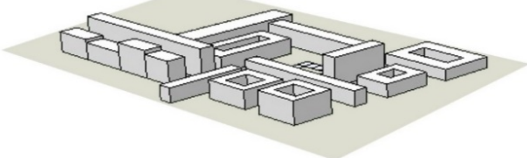
3.2. Urban morphology

Urban morphology is referred to as the form of human settlements, reflected in the various layers of urban fabric or urban texture, which is continuously transforming the cities (Moudon, 1997). Urban morphology and form are still misunderstood according to literature (Doherty et al., 2009). In fact, urban morphology reflects the transformations of the urban form. The latter can be distinguished by focusing on the spatial structure and street patterns, building typologies and the relation between these elements (Rode et al., 2014). As an example, Salat (2009) stated building shape factor and passive volume as functions of urban morphology, and Sarralde, Quinn, Wiesmann, & Steemers (2015) presented five urban morphology classes: building typologies, vertical and horizontal distribution, land use, building geometry, and building density.

Urban configurations will affect energy consumption, both in buildings and in public spaces. Moreover, they will influence the potential for energy generation at urban level as well (Mohajeri, Gudmundsson, Upadhyay, & Assouline, 2015), especially solar, due to different buildings’ forms, heights and densities, and the consequent shading patterns. Those can contribute to an increase of 25 % of the solar potential, when correctly planned (Lobaccaro, Carlucci, Croce, Paparella, & Finocchiaro, 2017).

Table *1* presents the main geometric parameters extracted from literature, able to be applied to districts design and performance evaluation, and explored ahead.

Table 1. Summary of the principal geometric parameters applicable to districts' design

Design Parameter	Unit	Scale	Description	Main impacts	References
Floor-area ratio (FAR)	%	Urban		Energy consumption for transportation	(Rey et al., 2013)
Plot ratio	%	Urban		Solar energy potential	(Sarralde et al., 2015)
Site coverage (SC)	%	Urban		Solar energy potential	(Mohajeri et al., 2016)
Compactness index	%	Building		Buildings energy demand for heating and cooling Natural lighting Shading effect	(Bekkouche et al., 2013)
Shape factor (SF) or Surface-to-volume	%	Building			(Albatici & Passerini, 2011; Ratti, Raydan, & Steemers, 2003)
	%	Building		Natural lighting	(Aksoy & Inalli, 2006)
Aspect ratio	%	Building		Solar energy potential	(Hachem et al., 2013)
Aspect ratio	%	Urban		Solar availability	(Lobaccaro et al., 2017)
Buildings shapes and street patterns	-	District		Overall district energy demand	(Hachem et al., 2013)

3.2.1. Urban density

Density is closely related to buildings' shape, by coupling it to urban forms. Studies show that it is the most influential parameter regarding the solar potential/availability in building blocks (Kanters & Wall, 2014). Several studies state that high densities promote the decrease of energy consumption associated to mobility (Madlener & Sunak, 2011), however other studies argue that denser urban blocks have lesser solar potential (Kanters & Wall, 2014).

Transposing buildings' shape to the urban context, compactness seems to be one of the most commonly used urban form indicators (Mohajeri et al., 2016), even though there is still an unclear association between density and compactness.

Concerning the quantification of density, there have been several attempts to measure the amount of built volume per available land area (Cheng, Steemers, Montavon, & Compagnon, 2006; Depecker, Menezo, Virgone, & Lepers, 2001; Kanters & Wall, 2014; Mohajeri et al., 2016; Parasonis, Keizikas, Endriukaitytė, & Kalibatienė, 2012). The ratio between the total area of all floors per area of the neighborhood is often used to characterize or quantify the density of neighborhoods. It is defined by Rey et al. (2013) as the floor area ratio and by Sarralde et al. (2015) as the plot ratio. Site coverage is also used as an urban density metrics, and introduces the total area occupied by buildings in a given site area (Mohajeri et al., 2016).

The density measurement is also important in NZED analysis due to the influence of the shading effect. Urban forms are subject to limited distances between buildings, which in turn may have varying heights. This intrinsic urban characteristic may result in a shadowing effect between nearby buildings, invalidating some passive design measures, such as orientation or solar availability, both aimed to use natural light inside the buildings, as well as for the integration of solar energy systems. Takebayashi et al. (2015) realized that the solar potential on the rooftops of Osaka is reduced to more than 86 % when shading effect of surrounding buildings is considered. Therefore, buildings' shading effect can affect energy consumption for heating and/or cooling, or even for natural lighting, depending on buildings' properties and climatic location (Martos, Pacheco-Torres, Ordóñez, & Jadraque-Gago, 2016). In warm climates, this effect can decrease the cooling needs, but may block sunlight in colder climates (Nikoofard, Ugursal, & Beausoleil-Morrison, 2011). Given these complex relationships, Han, Taylor, &

Pisello (2015) introduced the concept of inter-building effect, in order to explore the impact of shading and reflection of the building envelope. It was found that shading increases heating and lighting loads and, although with less impact, reflection contributes to cooling needs in nearest buildings, especially in warmer climates. In colder climates, Strømann-Andersen & Sattrup (2011) realized that, depending on envelopes materials' properties, the reflection effect can impact positively on the nearest buildings in dense urban areas, by providing natural light to the lowest buildings' floors.

Contrary to density, no representative index to measure the shading impact was found. However, it is crucial to consider it when assessing buildings' performance in urban contexts. Several studies already comprise it; Rodrigues, Amaral, Gaspar, & Gomes (2015a) used the same building design program and constructive system to determine the thermal performance impact of every building position and orientation in each lot of the urban quarter, considering the effect of surroundings' shadings and reflections. More recently, Rodrigues et al. (2018) correlated several geometry-based indexes with the energy consumption for air conditioning, in order to determine design guidelines for low inertia residential buildings in hot arid climates, taking into account the shading and reflection effects of the surrounding buildings.

3.2.2. Building and urban forms

Buildings' form or shape is one of the most studied passive design aspects. At the district scale, it will influence, along with the abovementioned density, the effect over surrounding buildings, such as the shading effect. In urban areas, shape is often limited by the available space and its configuration.

To quantify the form in terms of energy performance, several indicators are found. These assume importance by being used together with the envelope heat transfer coefficients, in order to evaluate the minimum and the optimal thermal requirements (Pessenlehner & Mahdavi, 2003).

The shape factor is one of the most used; however, it has been showing different interpretations. Usually, it is defined as the ratio between the external surface and the volume of the building (Albatici & Passerini, 2011; Ratti et al., 2003) and, according to this definition, Bekkouche et al. (2013) refer to the surface-to-volume ratio as the compactness index. Although, Aksoy & Inalli (2006) define the shape factor as the ratio of building length to building depth, which means that the building form is here reduced to a two-dimensional shape in the floor plan. This ratio between length and depth is also defined by Hachem et al. (2013) as aspect ratio. At the urban scale, Lobaccaro et al. (2017) uses the aspect ratio as the proportion between the average of buildings height and the average width of the street between buildings. Both studies agree that this is a significantly influential parameter when evaluating the solar potential on buildings' façades and districts (Hachem et al., 2013; Lobaccaro et al., 2017).

Parasonis et al. (2012) present the relative compactness coefficient, which is the ratio between the building shape factor and the minimal shape factor of a rectangular reference building with the same volume. The relative compactness is unidimensional, which is advantageous by allowing to compare buildings with different volumes (Rodrigues, Amaral, Gaspar, & Gomes, 2015b). Globally, it is acknowledged that a high surface-to-volume ratio can increase heat gains in warmer climates or seasons (Ratti et al., 2003). In colder regions, larger external surfaces are more exposed to thermal losses and to the increasing of energy consumption for heating, so the optimal form should be of minimal external surfaces (Aksoy & Inalli, 2006). However, Depecker et al. (2001) found that in mild climates, the shape factor is not relevant to energy demand assessment because of the solar radiation that compensates the heat losses and, therefore, cannot be representative as a building design variable.

The shape factor as surface-to-volume ratio has the ability of assessing the potential of interaction between the building and the climate, namely through natural ventilation and daylighting (Ratti et al., 2003). Despite this, it is also noticed that a too much compact building is not desirable from the architectural and daylight points of view, and may increase energy consumption for artificial lighting (Catalina, Virgone, & Iordache, 2011).

At the urban scale, the complexity in analyzing all buildings' types has led to the creation of archetypes, based on existing statistical data and estimations (Dogan & Reinhart, 2013; Ratti et al., 2003; Sokol, Cerezo, & Reinhart, 2016; Swan & Ugursal, 2009), which can produce an account of the city or district performance by the sum of the archetypes' performances. According to Hachem, Fazio, & Athienitis (2013), the most commonly evaluated are pavilions, courtyard configurations, row houses and street canyons, understanding that this method can limit the probability to generalize findings. Also Ratti et al. (2003) recognize that the simplification of buildings' shapes for pre-determined ones eliminates the complexities found in real urban design. Additionally, the impact of the thermal properties of the building envelope on the building geometry is still unclear.

3.3. Public spaces

The disaggregation of consumptions in urban scales has been mostly focused on buildings and on transportation. There are very few studies analyzing the impact of the energy spent to support urban public spaces in the overall consumption of an urban area, and within these, the accountability is put in public lighting (Fichera, Inturri, La Greca, & Palermo, 2016; Marique & Reiter, 2012). Efficient technologies have already been proposed, such as led lighting or self-sufficient semaphores with photovoltaic cells (Li, Chen, Song, & Chen, 2009), and are gaining an increasingly acceptation from a large part of European municipal authorities. However, other studies show that these energy efficiency policies have created the opposite effect by increasing the use of artificial lighting (Hölker, Moss, Griefahn, Kloas, & Voigt, 2010).

Studies are not consensual; Marique & Reiter (2012) argue that this component plays a residual role in the overall consumption. However, Fichera et al. (2016) consider that lighting corresponds to almost the same as the energy needed for transportation in a given neighborhood.

They present a consumption calculation method consisting in the number of street lamps in an area, multiplied by the power rating of the lamps and the running time in a year, information available in most municipalities.

Considering that "public energy demand" is an integrated part of the overall consumption in a district, energy for traffic lights, advertising systems, infrastructures, landscape maintenance, or support of public activities represent additional requirements of the overall district energy demand.

Moreover, new uses should be accounted for and an analysis of their impacts on the grid is also needed; the main example is the charging systems for electric and hybrid vehicles, which will be responsible for a large increase of the electricity consumption. IEA estimates that these will contribute to a 10 % growth of the overall electricity consumption by 2050 (International Energy Agency, 2011).

3.4. Metrics for districts energy performance calculation

One of the most important aspects of reviewing the influential performance indicators on NZED is to contribute to an accurate evaluation of the overall district energy demand.

In this sense, researchers have been developing methodologies to help architects and planners to calculate or estimate the overall energy consumption or demand of existing or planned districts, respectively. Despite the few studies found, this review allows the comparison between metrics and strategies, shortened in Table 2. It is possible to infer, for each calculation methodology, what are the design parameters considered.

Some other studies seek to develop methodologies for urban scales (Chung & Rhee, 2014; Doherty et al., 2009; Orehounig, Mavromatidis, Evins, Dorer, & Carmeliet, 2014), however they were not considered due to the analyses presented at the building level.

Table 2. Literature on districts energy performance parameters and calculation

Objectives	Method	Metrics/Type of Energy	Units	Parameters considered	Ref.
Study of energy demand for heating and cooling of neighborhoods according to housing units' shape	Dynamic simulations (EnergyPlus)	Total annual energy use	kWh/y	Buildings' shape, density, site layout	(Hachem, Athienitis, & Fazio, 2012)
Analysis of the impact of design parameters on energy performance of neighborhoods	Dynamic simulations (EnergyPlus)	Total annual electrical energy use	GWh	Buildings' energy performance level (local statistics), density, district typology, CBD relative location, streets' design	(Hachem, 2016)
Assessment of the impact of urban form on districts' energy needs	Buildings: sum of energy consumption for heating, cooling, ventilation, appliances, cooking, DHW + Transportation: Energy consumption for daily mobility	Primary energy	kWh/m^2 y	Buildings: heating, cooling, ventilation, appliances, cooking, DHW Transportation: distance, means of transportation, relative consumption rate	(Marique & Reiter, 2014)
Evaluation of overall energy demand of existing neighborhoods	Buildings: Energy Performance Index for each building + Transportation: transport energy indicator + Outdoor lighting: electric energy consumption per unit area of public space	Primary energy for heating	kWhp/m^2 y	Buildings: opaque and transparent envelope surfaces Transportation: distance, means of transportation, number of trips Outdoor lighting: number and type of lamps	(Fichera et al., 2016)
Development of a methodology for evaluating NZED's	Dynamic simulations (URBANopt)	Electricity use for heating and cooling	kWh	Buildings: orientation, window-to-floor ratio, envelope characteristics, airtightness Solar potential: orientation, roofs slopes, avoid building-to-building shading	(Polly, Kutscher, Macumber, & Schott, 2016)
Evaluation of energy consumption of different neighborhood scenarios	Dynamic simulations (ENVI-met)	Electricity use for cooling	kWhp/m^2	Urban layout pattern, street width, street orientation	(Sosa, Correa, & Cantón, 2018)
Development of a methodology for evaluating NZED's	Function of Users, Buildings, Infrastructure, Industrial Activities, Mobility, Other requirements	-	kWh	Buildings: heating, cooling, appliances, DHW	(Koutra et al., 2018)

Hachem, Athienitis, & Fazio (2012) investigated the energy demand for heating and cooling at the neighborhood scale, by considering and comparing different buildings' shapes, densities and site layouts. Residential neighborhoods with similar characteristics are studied – envelope U-values, window types, shading devices, occupants, lighting and appliances loads – but with different configurations and site layouts, providing various districts' plans. The energy performance was analyzed through dynamic simulations at EnergyPlus. Results confirmed the impact of the design parameters on energy consumption for heating and cooling, with a negative impact of non-rectangle buildings' shape or of curved layouts, for example.

Marique & Reiter (2014) propose a methodology for assessing zero-energy neighborhoods, in which the energy consumption is assumed as the sum of districts' buildings (only residential buildings accounted) as a whole, and of transportation for daily mobility.

Regarding buildings, as only residential are considered, the energy consumption is dependent of heating, cooling, ventilation, appliances, cooking and domestic hot water (DHW). It is noticed that design strategies can influence energy consumption for heating, cooling and ventilation (HVAC), but are not specified which and are based on an archetype classification developed in a previous work (Marique & Reiter, 2012).

Regarding transportation, it is considered the total distance travelled by a means of transportation and its relative consumption rate, in a territorial unit and per person. It is also considered the home-to-work and home-to-school commutes.

Fichera et al. (2016) developed a model for calculating and mapping energy consumption in districts based on the sum of the energy consumption of each district's building, of transportation and of lighting of district's public areas. Each of these three elements are analyzed individually and the sub-models developed for each one can be used for autonomous calculations. Regarding buildings, it was considered an Energy Performance Index based on the required primary energy for heating related to the thermo-physical properties of the opaque and transparent surfaces of buildings' envelope, namely the U-values.

Regarding the transportation, it was considered a mathematical equation based on energy consumption by transport mode choice and home-to-work commutes given by land use.

Sosa, Correa, & Cantón (2018) tested different districts configurations in order to evaluate energy consumption and thermal behavior. Buildings characteristics were similar and the streets widths, orientations and layout grids were the variables. Results showed the importance of vegetation and of the albedo of buildings materials in decreasing energy demand by contributing to minimize the UHI effect, and especially the great influence of street patterns and orientation on cooling energy demand.

All the works reviewed use an annual basis for energy balance, with the exception of Sosa, Correa, & Cantón (2018), which is not specified. The main energy type is the electricity, especially for heating and/or cooling, given the need of its on-site production to achieve zero energy goals, from solar or wind sources (Polly et al., 2016).

Despite the diverse methods and metrics developed so far, some common indicators are highlighted: at the buildings' level, the envelope thermal characteristics and the orientation; at the overall district, buildings' shape, density and urban layout are the most found design indicators.

4. Developed tools and methods

The literature review allowed to identify a set of tools and methods that helped to understand the advances on the study of the district scale, even when not necessarily focusing on the NZED topic. They are summarized in Table 3 and Table 4, and are aggregated mainly according to the topic or field of studies. For each study, the objectives, the applied methods, tools and the scales of intervention are described.

Table 3. Methods and tools found in literature to support the study of the district scale (part 1/2).

Topic or Field	Objectives	Methods/tools	Scale	Ref.
NZED	Definition proposal for NZED	Hierarchical and qualitative approach	District	(Carlisle et al., 2009; Sornes et al., 2014)
	Assessment of extending NZEB concept to the neighborhood scale	Dynamic simulations	District	(Marique & Reiter, 2014)
	Development of a methodological approach for evaluating NZED	Simplified energy demand calculation	District	(Koutra et al., 2018)
	Evaluation of alternative strategies for the construction of NZED's	Multicriteria decision analysis (PROMETHEE)	District	(Becchio, Bottero, Corgnati, & Dell'Ana, 2017)
	Optimization of energy systems design towards a NZED	Genetic algorithm (MOBO)	District	(Wang, Kilkis, Tjernström, Nyblom, & Martinac, 2017)
Sustainability assessment tools	Analysis of existing sustainability assessment tools in a community perspective	Comparative analysis of criteria and data	District	(Haapio, 2012; Sharifi & Murayama, 2013)
	Analysis of existing sustainability assessment tools in a community perspective	Comparative analysis of criteria and data	Urban	(Ameen et al., 2015)
	Analysis of existing sustainability assessment tools in a community perspective	Top-down and bottom-up models	District	(Huang et al., 2015)
Solar potential	Development of residential solar blocks with high passive solar potential	Development of solar envelope with dynamic simulation (EnergyPlus)	Urban	(Vartholomaios, 2015)
	Analysis of urban morphology for increasing solar potential in neighborhoods	Statistical data	District	(Sarralde et al., 2015)
	Analysis of compactness indicators related to solar potential in neighborhoods	Dynamic simulations (CitySim)	District	(Mohajeri et al., 2016, 2015)
	Relationships between urban forms, density and solar potential	Dynamic simulations	Building/District	(Cheng et al., 2006; Kanters & Horvat, 2012)
	Analysis of the potential of urban roofs and façades for active and passive solar heating, energy production and daylighting	Numerical simulations	Building/District	(Compagnon, 2004)
	Analysis of solar photovoltaic potential in urban context	Combination of GIS with parametric modeling (Rhinoceros) and simulation (Ecotect)	Urban	(Amado & Poggi, 2012, 2014)
	Investigation of design parameters for increasing solar potential in neighborhoods	Simulation of alternative configurations in EnergyPlus		(Hachem et al., 2013)
	Analysis of urban morphology parameters and buildings' envelopes materials for maximizing solar potential	DIVA-for-Rhino	District	(Lobaccaro et al., 2017)
Urban microclimate	Impact of urban microclimate in buildings' energy performance	Dynamic simulations (EnviBatE, SOLENE-Microclimate)	District	(Gros, Bozonnet, Inard, & Musy, 2016)
	Impact of urban patterns in wind flows at urban level	Computational Fluid Dynamics (CFD)	Urban	(Liu, Xu, Chen, Zhang, & Li, 2015; Mochida & Lun, 2008)
	Inclusion of Urban Heat Island effect on buildings performance simulation	Combination of GIS with simulation (TRNSYS)	Urban	(Palme et al., 2017)

Table 4. Methods and tools found in literature to support the study of the district scale (part 2/2).

Topic or Field	Objectives	Methods/tools	Scale	Ref.
Urban/district design	Analysis of neighborhood properties influencing energy and airflows	CFD	District	(Srebric et al., 2015)
	Analysis of interrelationship between energy use in buildings and in transportation	LT method	Urban	(Steemers, 2003)
	Analysis of the impact of design parameters of neighborhood on environmental performance	Dynamic simulations (EnergyPlus)	District	(Hachem, 2016)
	Analysis of the impact of design parameters of neighborhood on energy demand for heating and cooling	Dynamic simulations (EnergyPlus)	District	(Hachem et al., 2012)
	Analysis of the impact of urban context on buildings thermal performance	Generative design; simulation; optimization algorithms	District	(Rodrigues et al., 2015a)
	Understanding the concept of sustainable neighborhoods	Qualitative analysis	District	(Choguill, 2008; Koch & Girard, 2011; Luederitz, Lang, & Von Wehrden, 2013)
	Analysis of urban form and energy use for transportation	Data analysis	Urban	(da Silva et al., 2007)
	Analysis of the impact of urban form on buildings' energy demand	Urban Energy Index for Buildings (UEIB); LT method	Building/Urban	(Rodríguez-Álvarez, 2016)
	Analysis of urban energy lifecycle	Data analysis; simulation	Urban	(Davila & Reinhart, 2013)
	Assessment of energy demand and supply options in urban planning competitions	Automated procedure; simulation	Urban/District	(Eicker, Monien, Duminil, & Nouvel, 2015)
	Application of parametric design and optimization into urban design	Optimization algorithms (Grasshoper, ANSYS CFX)	Urban	(Taleb & Musleh, 2015)
Energy systems	Analysis of load matching and grid interaction in NZEB's role	Data analysis	Building	(Salom et al., 2011; Salom et al., 2014; Voss et al., 2010)
	Analysis of the lower temperature a district heating can be without losing efficiency and comfort levels	Simulations (IDA-ICE)	District	(Brand & Svendsen, 2013)
	Evaluation of available energy sources to implement a district heating system	Multicriteria decision analysis (PROMETHEE)	District	(Ghafghazi, Sowlati, Sokhansanj, & Melin, 2010)
	Modeling and optimization of energy supply and demand at district scale	Genetic algorithm	District	(Best, Flager, & Lepech, 2015)
	Optimization of urban energy systems	Mixed integer linear program	District	(Morvaj, Evins, & Carmeliet, 2016)
Urban energy modeling	Impact of neighborhood location in energy consumption	Comparative analysis of energy consumption data	District	(Rey et al., 2013)
	Optimization of a district heating system	Linear program (LP) model	District	(Huang & Yu, 2014)
	Impact of urban texture on buildings' energy consumption	LT model; analysis of digital elevation models (DEM)	Urban	(Ratti et al., 2005)
	Characterization of consumption patterns in urban district buildings	Dynamic simulation coupled to a GIS platform	District	(Fonseca & Schlueter, 2015)
	Development of a technical scenario for a 100% renewable energy city	EnergyPLAN analysis model	Urban	(Ostergaard & Lund, 2011)

	Analysis of the impact of district heating systems in renewable energy systems	EnergyPLAN analysis model	District/Urban	(Lund, Möller, Mathiesen, & Dyrelund, 2010)
Computer tools	Solar access support decision processes focusing on sustainable urban design	3D urban information system coupled with solar assessment	Urban	(J. Teller & Azar, 2001)
	Simulation of energy flows for sustainable urban planning	Simulation (CitySim)	Urban/District	(Darren Robinson et al., 2009)
	Urban layout optimization to maximize solar potential	Simulation and optimization	Urban	(Kämpf & Robinson, 2010; Vermeulen, Kämpf, & Beckers, 2013; Vermeulen, Knopf-Lenoir, Villon, & Beckers, 2015)
	Analysis and optimization of energy systems in neighborhoods	City Energy Analyst (CEA)	Urban	(Fonseca, Nguyen, Schlueter, & Marechal, 2016)
	Urban energy simulation and modeling for energy use in neighborhoods	Simulation (OpenStudio)	Building/District	(Polly et al., 2016)
		Simulation (UMI)	Urban/District	(C. Reinhart, Dogan, Jakubiec, Rakha, & Sang, 2013)
	Evaluation of building energy consumption in the district context	Combination of Canopy Interface Model and simulation (CitySim)	Building	(Mauree et al., 2017)
Review of available tools	Evaluation tools for the integration of renewables in diverse energy systems	Review of available tools	Urban/District	(Connolly et al., 2010)
	Tools for modeling solar radiation and assessing solar potential in urban scenarios	Review of available tools	Urban	(Freitas et al., 2015)
	Evaluation tools for electricity grids, microgrids and off-grid energy systems	Review of available tools	Urban/District	(Allegrini et al., 2015; Keirstead, Jennings, & Sivakumar, 2012; Markovic, Cvetkovic, & Masic, 2011; Mendes, Ioakimidis, & Ferrão, 2011)
	Support tools for solar systems design	Review of available tools	Urban/District	(Horvat & Wall, 2012; Kanters, Horvat, & Dubois, 2014)

Regarding methods and tools to approach the study of the district scale, the optimization and simulation techniques used in the various fields of energy related studies are dominant. These act as decision aid tools in early phases of the design process, where changes are still manageable and cost effective.

The performance simulation and design optimization techniques applied to the urban scale can be an efficient way to obtain the best option for each case, according to defined objectives and requirements. Simulation engines as EnergyPlus, Radiance or CFD-based ANSYS CFX are fully disseminated into the processes for estimating buildings future energy needs, lighting distribution or airflows, respectively. To these, specific tools for the urban scale have been coming together, modeling energy flows at the whole city scale and incorporating the complex trade-offs between buildings, transportation, energy systems, among other urban elements. Examples are given by CitySim (Darren Robinson et al., 2009), UMI (C. Reinhart et al., 2013) or CEA (Fonseca et al., 2016), all with different approaches – energy fluxes between buildings, daylighting and outdoor comfort, or integrated energy systems, respectively.

Other modules for these tools have been developed; Vermeulen, Kämpf, & Beckers (2013) coupled a hybrid evolutionary algorithm to the urban energy simulator CitySim focused on radiation and buildings' energy flows, pursuing an evaluation of annual energy needs, defined as the objective function to be minimized in the optimization process. Kämpf & Robinson (2010) used the solar irradiation criterion to apply an evolutionary algorithm coupled to Radiance simulation engine as a building optimization procedure. The main objective was to obtain the best building and urban form according to the urban solar potential for the application of solar thermal collectors or photovoltaic systems. Also US National Renewable Energy Laboratory (Polly et al., 2016) is developing an open source building energy modeling platform. Regarding the conception of NZED and taking advantage of their work on EnergyPlus simulation features, the objective is to develop OpenStudio add-ons that consider urban characteristics; however, the frontiers of the buildings and districts assessment are not clear.

Energy systems are prominent in urban studies and there is a wide range of tools developed for their analysis and modeling, each one focusing on specific objectives within energy planning field. Some applications are the performance assessment of buildings, urban energy modeling, energy network modeling or renewable energy systems dimensioning. Literature has been producing relevant reviews of these tools and methods, as exemplified by Connolly et al. (2010). They selected almost forty tools specifically focused on the integration of renewable sources into energy systems, with the aim of providing information to decision-makers for the most suitable for each objective. Mendes et al. (2011) provided an overview on tools for the optimization and analysis of energy systems at community level, focusing on bottom-up tools, and Markovic et al. (2011) outlined the analysis of different tools according to three aspects: energetic, economic and environmental. Keirstead, Jennings, & Sivakumar (2012) catalogued more than two hundred works in the field of urban energy systems, having categorized them by key areas – technology design, building design, urban climate, systems design and policy assessment. More recently, Allegrini et al. (2015) performed a review on the available technologies and modeling approaches for the prediction and design of energy production systems at the district scale.

Regarding support tools for solar systems design (D. Robinson et al., 2007; J. Teller & Azar, 2001; Vermeulen et al., 2015), it is highlighted the work of the Task 41, Subtask B of the IEA – SHC (Horvat & Wall, 2012; Kanters, Horvat, et al., 2014), which gathered an extensive review on available tools, in order to provide guidance for architects and designers in terms of capabilities of the most used.

Nevertheless and according to Allegrini et al. (2015) there are still no tools that embrace all factors related to energy systems modeling and assessment.

5. Conclusions

This work carried out a review on the relevant aspects that influence energy performance at the district scale from an architectural insight, regarding NZED design process. Several design indicators, namely climatic and morphological, that are proposed and discussed in the literature, are gathered in order to provide a basis for the development of strategies to design NZED.

District as an urban intermediate scale between the individual building and the whole city proposes to better assess the energy performance by accounting the buildings forms, characteristics and urban context, and at the same time, to better integrate the renewable energy generation and distribution systems on site or nearby.

Districts configurations, together with features as surfaces' materials, are responsible for mitigating the negative effects of urban microclimate, such as the UHI effect or the airflows potentiated by urban canyons. In this sense, urban morphology parameters are especially important by contributing to the decrease of buildings energy demand, either for heating, cooling or lighting, but also to solar and wind energy potential of production, which emphasizes their importance on NZED studies and design inclusion.

The variety of morphological parameters found in literature and the differences in significance, shows that there is no standardized or, at least, globally accepted set of indicators for energy efficient urban design, since they have been used individually according to each study purposes. However, it is noted that the geometric parameters influencing districts' performance are related, in their diverse forms, to the representation of density, one of the most prominent and challenging design concerns on urban and neighborhoods design. Density is related to the amount of built-up capacity per land area but also to the amount of citizens per land area. And this latter poses several other questions that go beyond the energetic focused in this work.

Increasing density of urban areas has been a stimulating policy towards sustainability and energy efficiency goals, since it promotes a moderation in the use of available land, and decreases the distances to be traveled, encouraging more sustainable means of transportation. Even though, there is a limit for the benefits of higher dense or compact neighborhoods and this should be determined prior to urban densification and design; on a technical level, it was evidenced in this work that compact urban areas decrease solar potential and natural lighting availability while increase the shading effect; on a social level there is a growing concern with the possibility of overpopulation and livability conditions, either in buildings as in adequate outdoor spaces for all the inhabitants, especially when obscure public environments are shaped. This is a crucial argument to architects, planners and also municipal stakeholders deal with at early stages of design and planning processes.

One of the main challenges of expanding the nearly zero-energy principles to urban scales resides in the growth of complexity. Studies focusing on this subject are still few and this should be understood as an opportunity. For instance, the attempts of calculating the overall districts performance suggest different methodologies, however, the description of the metrics, the forms of calculation and the types of energy involved still need to be deepened.

Thus, further studies are needed in order to understand to what extent the identified parameters affect the energy performance of districts, namely by the correlation between geometric indicators and urban microclimate. If, as seen, urban form affects solar and wind potential, it is expected that geometric indicators have a relative impact, dependent on local climatic conditions.

By gathering the set of urban design indicators that this work proposes, a path is open to evaluate their real impact and to understand the weight of each in districts performance evaluation. In this way it will be possible to achieve a hierarchy within the design indicators, or to correlate them with local contexts. This is especially important for the development of methodological approaches or tools that can embrace the most significant indicators. In an operative perspective, the determination of each indicator’s weight is crucial to achieve more accurate and realistic estimations of energy needs and to correctly dimension the supply energy systems. It is recognized that to be effective, the reviewed performance aspects of NZED should be transformed in countable factors of a calculation whose result is already known – zero, or at least nearly zero**.**

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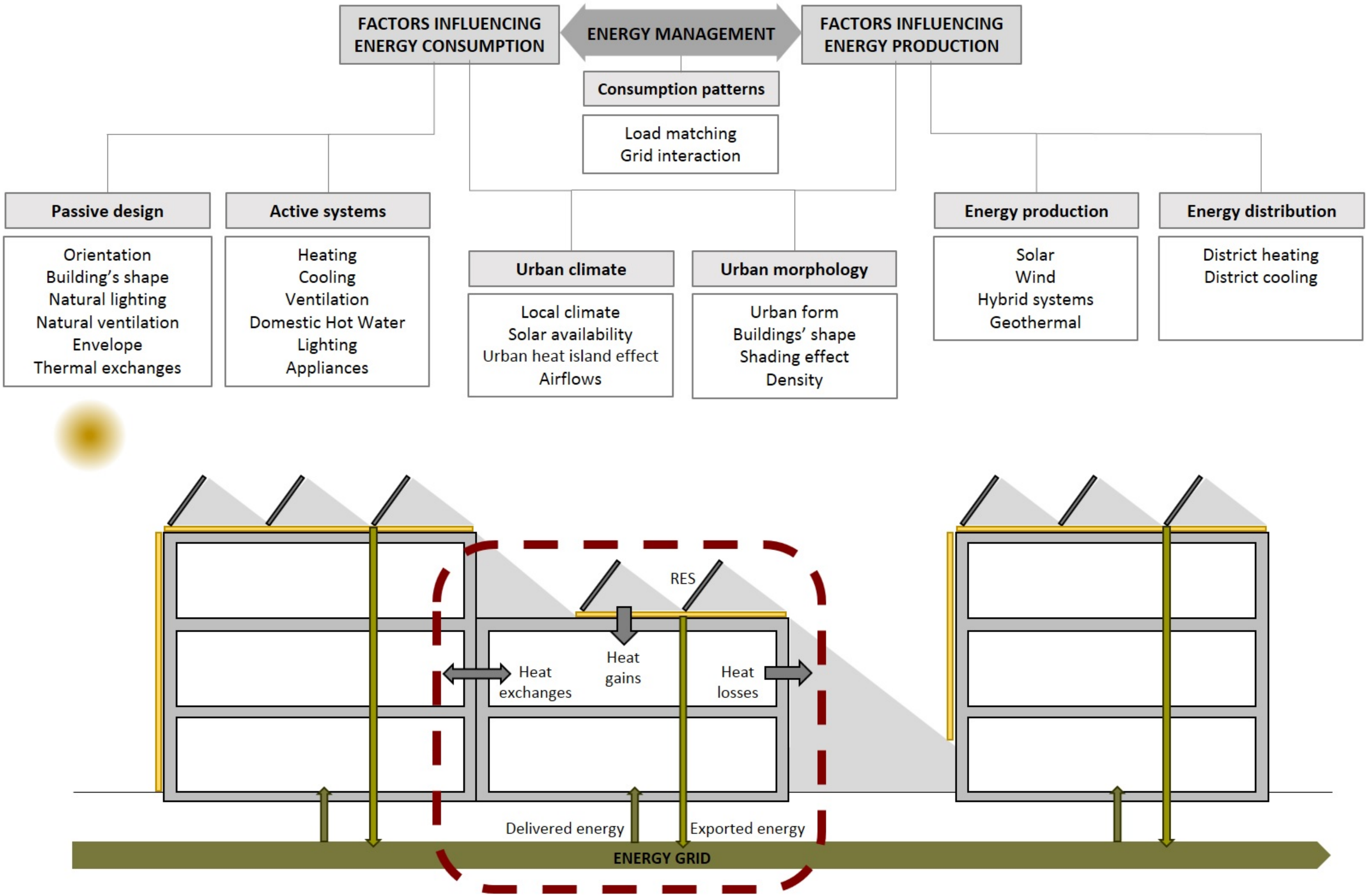
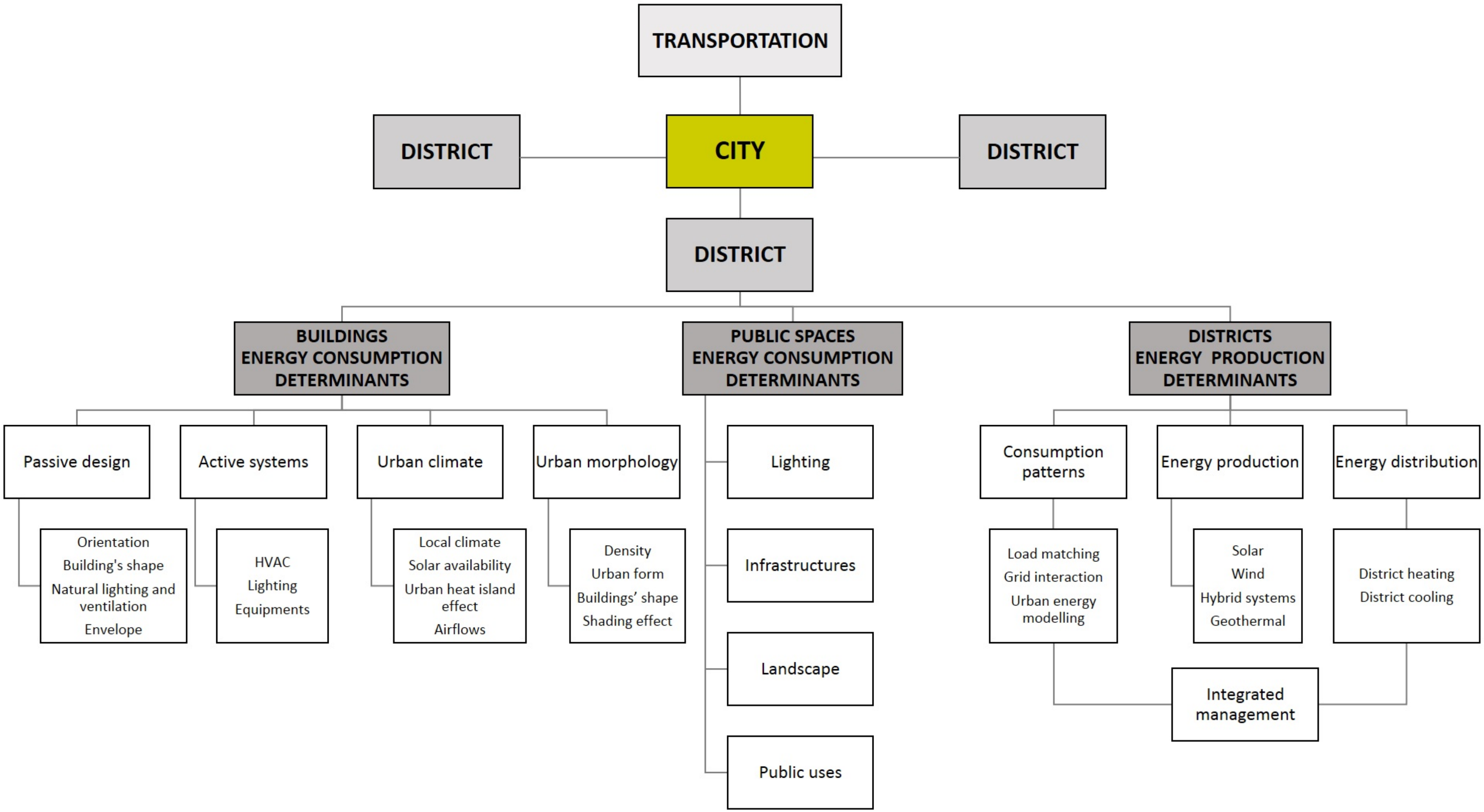


FACTORS INFLUENCING ENERGY CONSUMPTION
ENERGY MANAGEMENT
FACTORS INFLUENCING ENERGY PRODUCTION
Consumption patterns
Load matching
Grid interaction
Passive design
Orientation
Building's shape
Natural lighting
Natural ventilation
Envelope
Thermal exchanges
Active systems
Heating
Cooling
Ventilation
Domestic Hot Water
Lighting
Appliances
Urban climate
Local climate
Solar availability
Urban heat island effect
Airflows
Urban morphology
Urban form
Buildings' shape
Shading effect
Density
Energy production
Solar
Wind
Hybrid systems
Geothermal
Energy distribution
District heating
District cooling
RES
Heat exchanges
Heat gains
Heat losses
Delivered energy
Exported energy
ENERGY GRID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BUILDINGS ENERGY CONSUMPTION DETERMINANTS
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District heating
District cooling
Landscape
Integrated management
Public uses